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MASTER OF SCIENCE IN RENEWABLE ENERGY

TOPIC: COMBUSTION AND EMISSION CHARACTERISTICS OF RWANDAN PEAT

A thesis submitted to the African Center of Excellence in Energy studies for sustainable development (ACE-ESD) in partial fulfillment of the requirement for the degree of MASTERS OF SCIENCE IN RENEWABLE ENERGY

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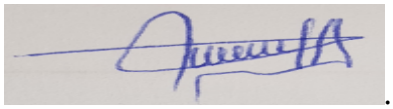
DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature:  ..... Date :..04th November 2021.....

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DEDICATION

This work is dedicated to my wonderful husband, **ZIGIRUMUGABE Emmanuel**, my children, and my mother, who have been my source of inspiration and strength when I've felt like giving up, and who continue to support me morally, spiritually, emotionally, and financially.

To my brothers, sisters, relatives, mentor, friends, and classmates who encouraged me to accomplish this study with their words and encouragement.

Finally, I dedicate this book to the almighty God, thanking him for his guidance, strength, mental power, protection, and skills, as well as for providing me with a healthy life. All of these are available to you.

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ABSTRACT

Peat is being used for power generating more and more over the world, including Rwanda. The Rwandan government is now intending to increase peat generation in the energy sector strategic plan in order to meet the goal of having 100% of households connected to power by 2024. Peat combustion and emission characteristics-based on generation, according to several studies, is required.

TGA analysis with Proximate analyzer and single particle combustion methods in a controlled furnace were used to investigate peat combustion mechanisms. The drying, devolatilization, and burning processes of peat were investigated using weight-loss and particle temperature measurements. The temperature of ash fusion was also analyzed during stationary combustion settings to determine the temperature at which the agglomerates formed. Finally, the ash sintering issues were investigated. The findings revealed that devolatilisation of peat (64–67 % of volatile matter ash free basis) begins at a low temperature of 200–250 °C and proceeds quickly.

An CV (Calorific value) of peat were also studied to analyze whether the amount of heat produced as a result of the complete combustion of a unit volume of the substance and was determined by using Bomb calorimeter. Ash sintering and bed agglomeration were two primary issues encountered during peat combustion. This is owing to the ash's low melting temperature. The usage of peat for electricity generation, according to the findings, will contribute to greenhouse gas emissions in Rwanda's environment. It was suggested that some countermeasures be taken to decrease these emissions. Due to the limited resources available, additional research into the emission characteristics of peat for electrical power generation variables and technology to reduce emissions is recommended, as this study only looked at emissions from combustion.

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LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYM

BFB	Bubble fluidized bed
CO2	Carbon dioxide
NOX	Nitrogen oxide
CO	Carbone monoxide
O2	Oxygen
PAHs	polycyclic aromatic hydrocarbons
SWECO	Swedish consulting company
TGA	Thermogravimetric analysis
PM	Particle matter
MINIFRA	Ministry of infrastructure
REMA	Rwanda environment management authority
REG	Rwanda Energy Group
DMS-41-R-CY1	Daily mixed sample 41
DMS-PR-ST7	Daily mixed Sample-Stockpiles number 7
DMS-41-ST8-21	Daily mixed Sample-Stockpiles number 8, Year 2021
DMS-29-R14-CY2	Daily mixed sample 29

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CHAPTER ONE: INTRODUCTION

1.0. BACKGROUND

The peat potential in Rwanda is 155 million tons of dry peat which covers 50,000 hectares of land. The Ministry of Infrastructure indicated that the Power production capacity from Rwanda peat is roughly estimated at 700 MW (MININFRA, 2015).

Plant biomass and litter in peatlands store carbon. Energy is at the center of every country's economy and development plans around the world. All other industries benefit from the presence of power. Electricity is a crucial component of both industrial and social growth. It powers small appliances like lights and cellphones, as well as industrial processing activities that lead to the creation of high-value products and jobs.

Rwanda generates 218 megawatts of electricity, with 212.5 megawatts connected to the grid and 5.5 megawatts exported. Currently, Gisagara to Peat Power Plant, which is the second peat power plant after Gishoma Rwanda's and Africa's first, will generate 70 MW connected to the grid. Rwanda has a wide range of peat lands that can be used to produce electricity [1].

Water evaporation, oxidative degradation of peat organic matter, and char oxidation are the three steps of peat combustion [2]. Peat is a renewable energy source that generates power to assist Rwanda's national grid in meeting the Energy Sector Strategic Plan's objectives. However, due to carbon monoxide CO, sulfur dioxide SO, and nitrogen oxides NOx emissions, which all contribute to air pollution and greenhouse gas emissions, peat power plants have a negative influence on the environment. Ozone layer destruction result in global warming and climate change.

Thermochemical technologies were used to study peat combustion properties and gas compositions, allowing for a better understanding of how peat combustible products are used. The aim of this study was to investigate peat combustion characteristics and gas emission behaviors at the same time. The distributions of specific gas products were viewed as a function of reaction temperature, and a model was proposed to reveal the possible relationship between the combustion mechanism and evolved gas emission behaviors.

1.1 RWANDA'S PEAT TO POWER PROJECTS

1.1.2 GISHOMA 15 MW PEAT TO POWER PROJECT

Since 2010, the government has been developing a 15MW peat power plant in Gishoma, Rusizi District, to address the country's electricity deficit and to coincide with a significant increase in electricity demand in the region as a result of the local cement factory's expansion and country development. The project was built as a pilot power plant and commissioned in 2016 to show that electricity could be generated using peat energy accessible in the area. As shown on the photos 1, the power plant is currently operational and connected to the grid.

Photo 1:Gishoma Peat Power Plant (REG web site on 31 May 2017

1.1.3. HAKAN 80MW PEAT TO POWER PROJECT

In the Gisagara District's South Akanyaru, an 80 MW peat-fired power plant is being built. This project is being built on a Public-Private-Partnership (PPP) model. The project has been in the construction phase since February 2017, Now the unit-1 has been commissioned, unit 2 is still being commissioned, and by October, 70MW will be on the grid. HAKAN will operate the plant after it is completed, and at the end of the operation time, HAKAN will hand over the power plant to the Rwandan government.

Photo 2:Hakan peat to power Unit-2 under commissioned. (Captured and Edited by Author).

1.3. STATEMENT OF THE PROBLEM

Peat is an alternative energy source that is assisting Rwanda's national grid in achieving its goal of rising electricity generation capacity at a low cost by reducing the usage of costly electricity sources such as heavy fuel oil and diesel power plants. Peat serves as a storage facility for CO2 and other gases emitted into the environment as a result of its use.

However, the combustion and emission characteristics of Rwandan Peat has not been widely investigated. Efficient design of combustion equipment requires data on fuel combustion characteristics and emissions performance. This study provided a comprehensive overview of the combustion and emission characteristics of Rwandan peat used as a fuel to generate electricity.

1.3.1. MAJOR OBJECTIVES

The main objectives of this research was to investigate the combustion and emissions characteristics of Rwandan peat.

1.3.2 THE SPECIFIC OBJECTIVES

The specific objectives of this study are to determine:

1.The quantity of peat available in Rwanda

2.The physical and chemical characteristics of peat

3.Combustion and emission characteristics of peat

1.3. SCOPE OF THE STUDY

Farm and laboratory research were conducted to assess the characteristics of Rwandan peat combustion and emissions.

1.4. EXPECTED OUTCOMES AND SIGNIFICANCE OF THE STUDY

1.4.1. EXPECTED OUTCOME OF THE STUDY

As was to be anticipated, Modeling the initial effect and evolution of emissions, as well as their influence on local to global atmospheric chemistry, involved characterization of emissions resulting from peat combustion of a wide range of Rwandan significant peat. The peat analysis was to provide inputs such as single particle combustion, loss in weight and TGA analysis characteristics for developing environmentally sustainable production technology, in addition to evaluating the peat combustion ability and emission control.

1.4.2. SIGNIFICANT OF THE STUDY

According to the Peat Master Plan 1993, which was updated in 2012, and several minor studies undertaken in the intervening years, Rwanda has 155 million tonnes of dry peat spanning an area of 50 000 hectares.The Akanyaru peatlands contain the majority of the peat, which is why it was chosen for this study.

The study's ultimate goal was to provide information on the combustion and emission characteristics of Rwandan peat, as well as its suitability for electric power generation, as part of Rwanda's Energy Strategic Plan, which aims for a total installed capacity of 560 MW by 2017, with around 200 MW coming from peat. Around 77 % of peat reserves are located near the Akanyaru, Nyabarongo, and Rwabusoro rivers, according to the studies. The capacity for electricity generation from peat in Rwanda was estimated to be 150 MW for sod peat application and 117 MW for milled peat application in a study conducted on peat lands in Rwanda.

1.5. RESEARCH QUESTIONS

1.What is the quantity of peat available in Rwanda?

2.How Rwandan peat are characterized?

3.What are the emissions characteristics from peat combustion?

4.How boilers are performed due to the quality of peat in term of power production?

5.What should be done in the face of climate change in terms of producing power from peat on a continual basis?

1.6. THESIS ORGANIZATION

There are five chapters in the thesis. The thesis is introduced in the opening chapter, which also describes the research's goal. The second chapter is a literature review of other researchers' findings. It goes over the properties of peat combustion as well as the emissions from peat combustion that contribute to global warming potential. It will highlight the difficulties in peat quality analysis and decreasing pollutants during peat combustion for electricity generation. The third chapter discusses the data gathering approach as well as the methods utilized to arrive at the conclusion. The results of the discussions are presented in Chapter 4. The last chapter contains the conclusion and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1. INTRODUCTION

Living matter, also known as biomass, is an organic matter formed by plants as a result of the photosynthetic conversion process. It includes products made from living organisms including tree wood, harvested grasses, plant pieces, stem and leaf residues, as well as the water of living plants. Biomass with a high energy density can be used to generate both heat and electricity.

In order to reduce the use of fossil fuels, bioenergy technologies are being built right now. Biomass and its by-products can meet a variety of energy requirements. The photosynthesis method, which utilizes solar energy, provides the energy value of biomass. It decomposes into its constituent molecules as a result of the release of heat. Biomasses, according to the technology, are a renewable source of energy created in nature through photosynthesis, which is accomplished by solar energy conversion, and they serve as both an energy source and a carbon sink in greenhouse gas mitigation. [3]

Peat can be used instead of biomass as a source of energy. Peat is partly decomposed plant debris that was once believed to be an early stage in the manufacture of coal, according to various scientists. In a number of EU countries, peat is now used to generate electricity; mainly to take advantage of locally available resources and diversify the fuel mix. The downside of peat is that it is flammable.

Due to the issues with peat as a fuel, the Irish government has set a goal of decreasing emissions in Irish peat stations by 30% by co-firing with biomass. Since the 1950s, peat has been utilized to generate power in Ireland. Peat for electricity generation is one of the most polluting fuels in Ireland, according to several studies, as illustrated in Figure 2.[4]

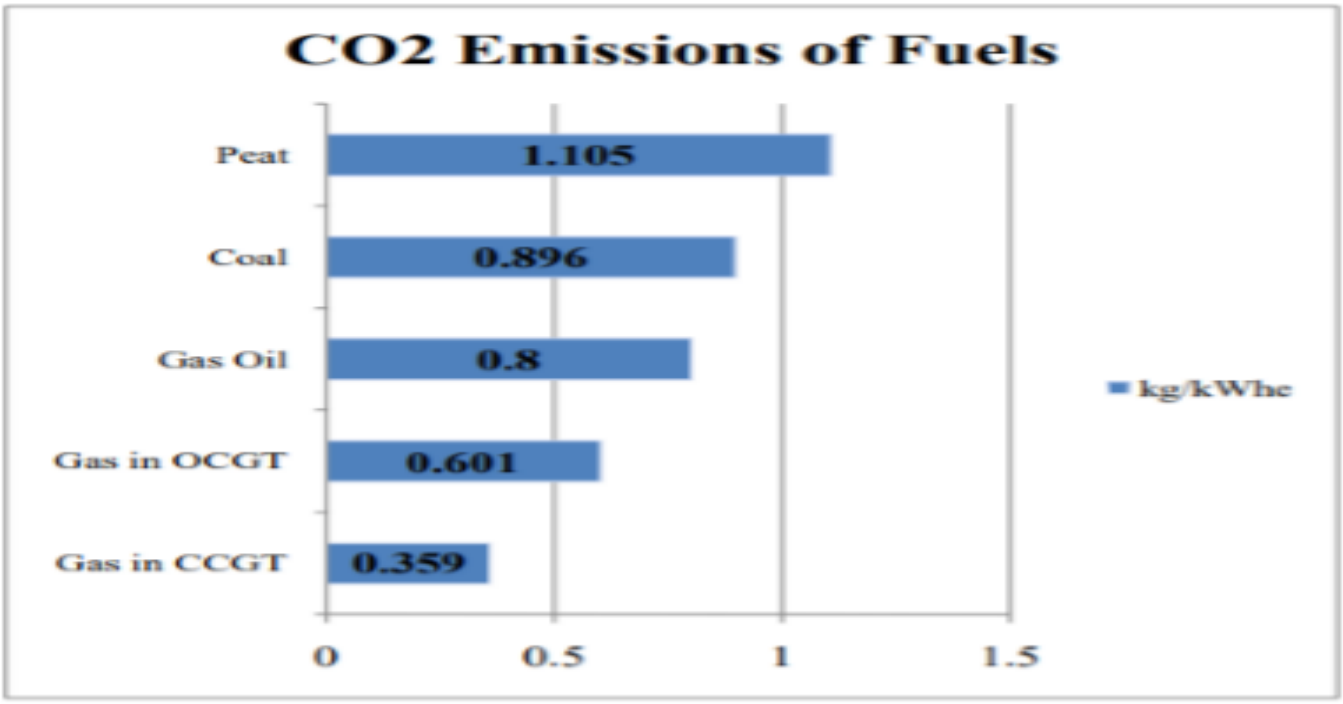


Figure 1:CO2 emissions of fuels in Ireland

In Finland, peat is primarily used for energy generation or horticulture, with 90% being used for energy generation and 7% for horticulture. Finland's total energy is derived from peat, which makes up 6% of the country's total energy. The use of peat has brought Finland's energy imports to a halt, as the country imports two-thirds of its energy.

Peat is now used in a wide range of applications. Peat is a popular source of energy, but it is not environmentally friendly, putting another of the country's goals of pollution reduction in jeopardy. Peat, for example, emits more than 10 million tons of carbon dioxide each year in Finland. [4]

Peat combustion poses a host of different risks in terms of occupational health and safety (OH&S) than petroleum or coal-based fuels. The combustion method, as well as the addition of new occupational activities such as biomass handling, storage, and processing, may be the cause of these variations.

This research will concentrate on characterization of emissions from peat combustion of a broad range of significant peat and where applicable, experiences from these systems will be used.

2.2. CLASSIFICATION OF FUELS

Fuels are classified into (a) Primary or Natural fuels

(b) Secondary or Artificial fuels (derived from primary fuels)

Primary and secondary fuels may also be divided into 3 classes' namely solid, liquid and gaseous fuels

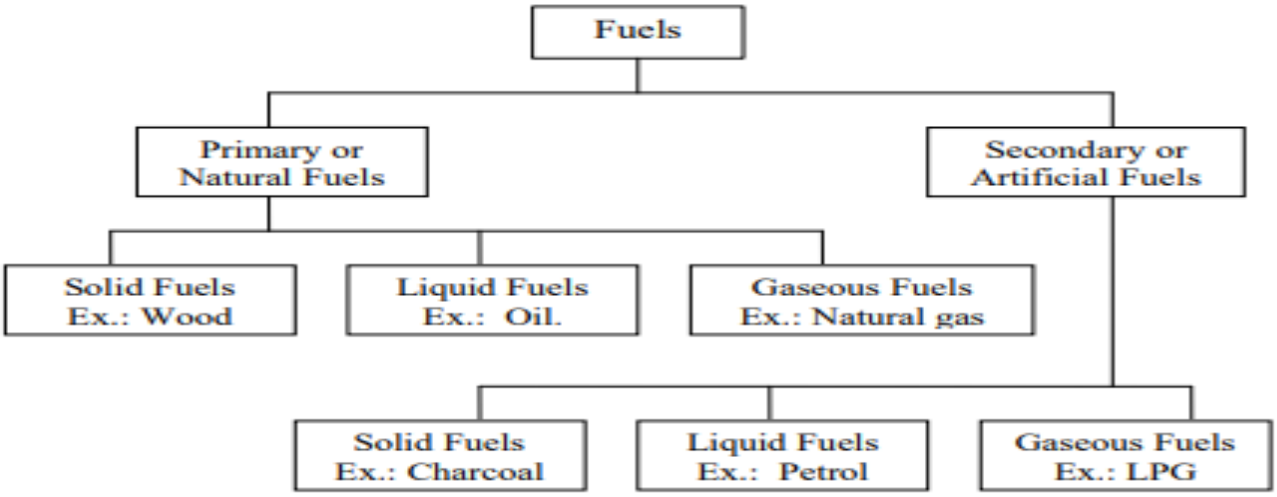


Figure 2:Classification of fuels (A.K.Shaha, 1974)

Fuels make up the bulk of the components used in combustion. Fuels are substances that generate heat and light energy when burned. Wood, coal, cow dung cakes, kerosene, LPG, petrol, and diesel are some of the most widely used fuels. Fuels are used for cooking, heating, driving vehicles, and generating electricity.

2.2.1. SOLID FUELS AND THEIR CHARACTERISTICS

Natural fuels, such as wood and coal, and processed fuels, such as charcoal, coke, and briquettes, are the two primary types of solid fuels. The various advantages and disadvantages of solid fuels are given below:

Advantages

(a) They're simple to handle and transport.

(b) They're easy to store and don't pose a risk of exploding.

(c) They have a low manufacturing cost.

(d) Their ignition temperatures are mild.

Disadvantages

(a) They have a lot of ash in their products.

(b) They waste a considerable amount of heat.

(c) Clinker formation occurs as a result of their burning.

(d) It is difficult to monitor their combustion process.

(e) Their handling costs are excessive.

2.3. PROPERTIES OF COAL

2.3.1. RANKING OF COAL

Coal is a primary solid fuel that is produced by the alteration of vegetable matter under some favorable conditions. Coal is used for a variety of purposes around the world, including power generation, steel production, and cement production. Every year, billions of tons of coal are traded on the domestic and foreign markets. The price of coal is determined by its quality, the desired purpose of usage, and the quantity.

The calorific value, moisture content, volatile matter, sulfur and ash content of coal form the basis of sale agreements, and these properties have a daily impact on burning and environmental efficiency. The main goal of coal sample analysis is to assess the fuel's quality or rank. The most basic and popular method of evaluating fuels is to evaluate moisture content, volatile matter, and ash, as well as to compare fixed carbon with the fuel samples.

2.3.2. Classification of coal

a) Peat

1. Peat is the first stage in the formation of coal.
2. Its calorific value is about 4000-5400 k cal/kg.
3. It is an uneconomical fuel due to its high proportion of (80 -90%) moisture and lower calorific value.
4. It is a brown fibrous mass.

b) Lignite

1. Lignite is an intermediate stage in the process of coal formation.
2. Its calorific value is about 6500-7100 k cal/kg
3. Due to the presence of high volatile content, it burns with long smoky flame

c**) Bituminous coal**

Bituminous coal is further sub-classified on the basis of its carbon content into three types as:

Sub- bituminous coal, Bituminous coal and Semi-bituminous coal.

d) Anthracite

1. Anthracite is the superior grade of coal.
2. Its volatile, moisture and ash contents are very less.
3. Its calorific value is about 8650 Kcal/kg.

Peat is the least matured coal, so it is ranked lowest, while anthracite is the most matured coal, so it is ranked highest. [5]

2.4. PEAT

Peat was previously characterized as partially decomposed organic material primarily derived from plants that accumulated on the surface of a soil in conditions of waterlogging, oxygen deficiency, acidity, and nutrient deficiency. The interaction of water and temperature is the most important factor in peat production and development. Peat formation is influenced by a variety of factors including climate, geology, geomorphology, and hydrology.

Peat characteristics are determined by these factors, which both directly and indirectly affect peat formation and growth. Temperature and humidity are two of the most critical climatic elements that influence organic residue decomposition and transformation.

The rate of decomposition of plant residues is affected by temperature, which affects the activity and reproductive ability of soil microbes. Since soil microbes are scarce in cold environments, plant debris decomposes slowly. The chemicals have a stronger effect at higher temperatures, and soil microbes replicate more quickly, hastening the decomposition of plant debris. The rate at which plant debris decomposes varies depending on the temperature area.

The amount of water available has an effect on peat formation. Plant growth is influenced not only by temperature and water, but also by soil microbes and plant debris. Peat is found in areas where annual average precipitation exceeds annual average evaporation on a global scale. Microbe activity is heavily influenced by soil water. Plant waste is swept away rather than accumulating, which prevents peat formation. [3]

2.4.1. PROPERTIES OF PEAT

2.4.1.1. PHYSICAL PROPERTIES OF PEAT

According to study, peat qualities are affected by the environment, peat production procedures and peat-forming plant kinds. Physical features of peat, according to the researchers, include decomposition degree, water content, relative density, bulk density, and others. Decomposition of peat happens in a variety of degrees. There are three levels of decomposition in peat formation: minimal decomposition, moderate decomposition, and high decomposition. [6]

A. DEGREES OF PEAT DECOMPOSITION

The percentage of materials that have lost their cellular structure owing to decomposition of plant remains is referred to as the degree of peat decomposition. In natural conditions, the degree of peat decomposition varies from 1 to 70%.

Lowly decomposed peat (less than 20 percent), moderately decomposed peat (between 20 and 40 percent), and strongly decomposed peat (more than 40 percent) are the three degrees of peat decomposition. Peat that has been moderately decomposed has a decomposition degree of between 20 and 40%. Two authors, V. Post and J. Post, have cooperated on a book. The first closing procedure was used to determine the decomposition degree of peat, and the decomposition degree of peat was split into ten levels based on the water content.

2.4.1.2. CHEMICAL PROPERTIES OF PEAT

Elemental composition, organic components, and ash are all chemical features of peat. C, H, O, N, and S are the five fundamental elements in peat. Peat's elemental qualities are similar to those of wood and coal. Lowly decomposed peat has an elemental percentage similar to wood, while severely decomposed peat has an elements proportion similar to lignite. In a natural condition, the chemical makeup of peat varies depending on the surrounding circumstances.

There are four types of organic components in peat: The first category is bitumen, which is a natural substance found in peat and may be extracted with organic solvents. Water-soluble stuff like cellulose and easily hydrolyzed matter make up the second group. The contents of water-soluble and easily hydrolyzed materials vary greatly, and these contents decrease as the degree of decomposition increases. Humus, which is made up of humic and fulvic acids, is the third category. Lignin, lignin-like materials, cutin, suberin, and other chemicals comprise the fourth category. Water cannot hydrolyze the components of the fourth type. Si, Al, Fe, Ca, Mg, Na, and P make up over 90% of the total elemental composition of peat ash. The rest of the microelements account for less than 1% of the total.

2.4.2. PEAT HARVESTING PROCESS

The raw peat is first drained to eliminate as much water as possible and to make it easier to prepare the peat collection area, on which the machines will be positioned. Weeds are removed from the peat surface, and water is drained away to create a dry space where the collected peat can dry in the sun and wind. The distance between drains varies depending on the technique of manufacturing, but it is roughly 15-50 meters. Drained bogs typically have a moisture content of 89-91 percent.

Photo 3:Peat harvesting

The milling process is used to obtain normal peat production for energy usage, which is then used to generate electricity or heat. Milled peat can be made into briquettes, which can be used as a household fuel. Belarus, Estonia, Finland, Indonesia, Ireland, Russian Federation, and Sweden are the largest producers and users of fuel peat. [4]

4.3. TYPES OF FUEL PEAT

They are three forms of peat fuel; Milled peat with a moisture content of 40 to 50 percent, air-dried sod peat with a moisture content of 30-40 percent, and artificially dried compressed peat briquettes with a moisture content of 10-20 %. Milled peat is typically extracted on a large scale by mechanized peat extractions, while the others are extracted on a smaller scale by manual, semi-mechanical, or mechanical methods in dry or wet environments.

Milled peat is a mixture of loose peat particles cut from the peat swamp's surface, and the particle size varies depending on the processing process, peat type, and degree of decomposition. The scale ranges from 3 to 8 mm. The peat is cut to a depth of 0.5-2.0 cm and distributed evenly over the surface of the peat bog, where it is dried by the wind and sun.

Depending on the manufacturing procedure, air-dried sod peat that has been compacted manually or mechanically might be cylindrical or brick-shaped. Sod peat that has been mechanically processed measures 10-30 cm in length and 510 cm in diameter, while hand-cut sod peat measures 125 x 125 x 300 mm. The sods are squeezed during manufacturing, and then air-drying causes them to shrink even further. Because air-dried sod peat has a larger calorific content per unit volume than milled peat, it's easier to transport.

Peat briquettes or pellets that have been artificially dried and compressed are uniformly sized and thus simpler to manage than milled or sod peat. Milled peat is mechanically compressed to form briquettes, which are similar in

size to bricks, while pellets range in size from 3 to 30 millimeters depending on the machine used. The moisture content of milled peat raw material ranges from 40 to 55 %, and it must be artificially dried to between 10 and 20 % to create briquettes or pellets. Briquettes and pellets have a high calorific value per unit volume, allowing them to be shipped over longer distances at a lower cost than sod or milled peat.

2.4.4. PEAT TO POWER PLANT

The steam turbine generators, powered by heat engines fueled by combustion or by other sources of turbine turning powers, are commonly used at power plants to produce electricity from various energy sources. One of the energy contributors to Rwanda's production is peat combustion for electricity generation. In Rwanda, there are only two peat power plants: The Gishoma peat power plant, which produces 15 MW, and the Hakan peat power plant, which is nearing completion and will produce 70 MW. The electricity generated was a necessary energy for the country's economic growth and development, but the greenhouse gases emitted are hazardous to the environment. The Figure 4 shows the flow chart of a peat to power plant.

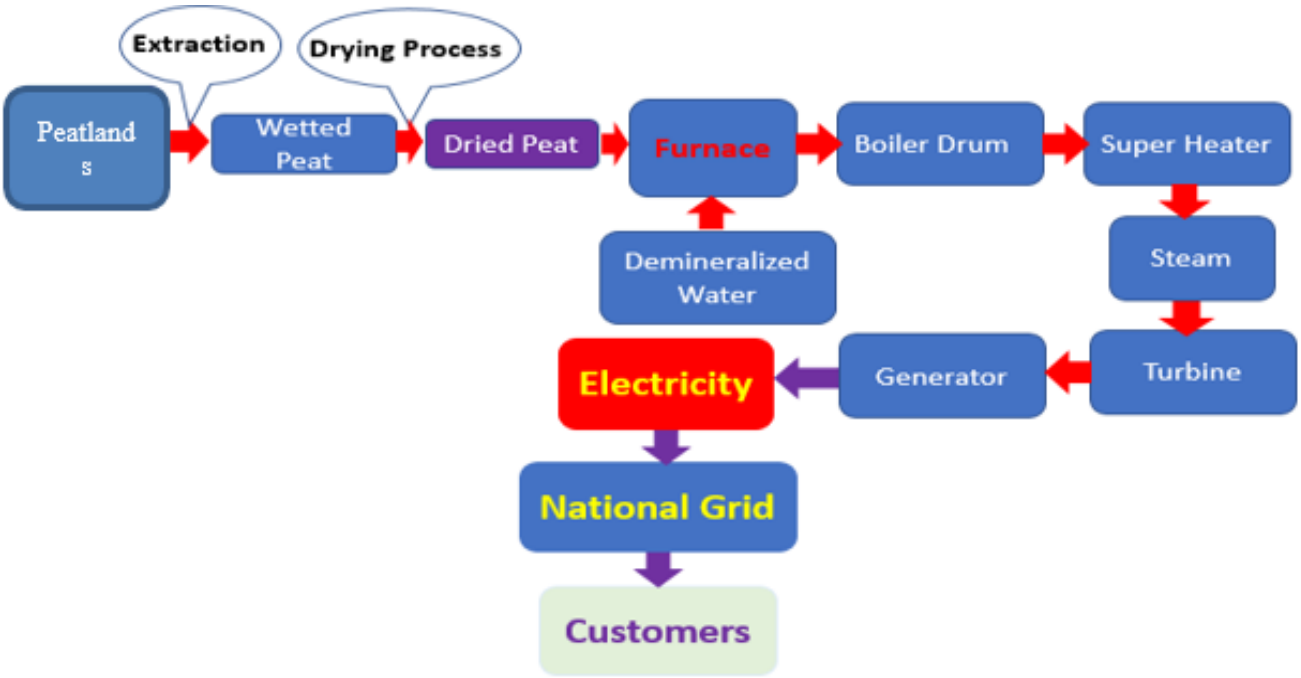


Figure 3:Flow chart of peat to power plant electricity generation

2.5. ANALYSIS OF PEAT

There are two approaches for determining peat quality analysis: ultimate analysis and proximate analysis. The ultimate analysis determines both solid and gaseous peat components, while the proximate analysis only determines the moisture content, volatile matter, the ash content and fixed carbon percentage. The ultimate analysis is conducted by a professional chemist in a fully equipped laboratory, while the proximate analysis can be performed with a simple apparatus.

2.5.1 PROXIMATE ANALYSIS

This peat review offers a clear example of peat's heating and combustion properties. The test determines the moisture, volatile matter, ash, and fixed carbon content of coal. The percentage by weight of Fixed Carbon, Volatiles, Ash, and Moisture Content in coal is determined by proximate analysis. Coal's heating value is directly proportional to the amount of fixed carbon and volatile combustible matter present.

During combustion, fixed carbon serves as the primary heat source. The presence of a lot of volatile matter means that the fuel is easy to ignite. The amount of ash in a furnace affects the design of the grate, combustion volume, emissions control equipment, and ash handling systems. In the following paragraph, various parameters in proximate analysis are explained.

a) Fixed carbon: After the volatile matter has been distilled away, fixed carbon is the solid fuel remaining in the furnace. It's mainly carbon, but there's also some hydrogen, oxygen, sulphur, and nitrogen that didn't get carried away with the gases. Fixed carbon provides a rough approximation of coal's heating value.

b) Volatile Matter: Methane, hydrocarbons, hydrogen, and carbon monoxide are examples of volatile matter, as are incombustible gases like carbon dioxide and nitrogen contained in coal. As a result, volatile matter serves as a proxy for the presence of gaseous fuels. The typical volatile matter range is 20 to 35 %.

Volatile Matter

- Increases the length of the flame proportionally, making coal combustion faster.
- Limits the height and volume of the furnace to a minimum.
- Has an effect on secondary air requirements and distribution.
- Has an effect on secondary oil support

c) Ash Content: Ash is a non-combustible impurity. The typical range is 5 to 40%.

Ash content:

- Reduces the capacity for handling and burning.
- Increases the cost of handling.
- Has an effect on boiler and combustion efficiency.
- Causes slagging and clinkering.

d) Moisture Content: Coal moisture must be moved, treated, and processed. It reduces the heat content per kg of coal since it removes combustible matter. The typical range is 0.5 to 10%.

Moisture content:

• Increases heat loss by evaporation and vapour superheating.

• Assists in the binding of fines to a certain extent.

• Assists in the transfer of heat from radiation.

e) Sulphur Content: Typical range is 0.5 to 0.8% normally.

Sulphur content

• It has an impact on clinkering and sluggishness.

• Corrodes the chimney as well as other appliances such as air heaters and economisers.

• Lowers the temperature of the flue gas exit.

f) Calorific value

The calorific value of coal is a measurement of its heat content (energy value). It's a key metric for coal mining and burning, as well as a benchmark for coal quality and consequently economic value. The calorific value of biomass is the attribute that affects how valuable it is as a fuel. As a result, it determines whether it can be mined in a cost-effective and environmentally friendly manner once it has been examined. It is possible to estimate or establish the ultimate/proximate calorific value. When a unit weight of biomass is completely burned and the combustion products are cooled to a standard temperature of 298 ^{o}K, the CV is defined as the amount of heat emitted. [7]

2.5.2 ULTIMATE ANALYSIS

This method of peat analysis is a more accurate method of determining the chemical composition of coal in terms of elements such as carbon, hydrogen, oxygen, nitrogen, sulphur, and ash. Since the carbon and hydrogen content that has already been combined with oxygen to form carbondioxide and water has no benefit for combustion,

The chemical analysis of coal is insufficient to predict its suitability for use as a source of heat. The chemical composition, on the other hand, is extremely useful in combustion calculations and determining the composition of flue gases.

It can be used to figure out how much air is required for combustion, as well as the volume and composition of the combustion gases. This data is required for flame temperature calculations and flue duct design, among other things.

2.6. COMBUSTION CHARACTERISTICS

2.6.0 INTRODUCTION AND PRINCIPLE OF COMBUSTION

Combustion is the process of converting a material called a fuel into chemical compounds known as combustion products in the presence of an oxidizer. The combustion reaction is an exothermic chemical reaction, which means it releases energy when it takes place.

As a result, combustion can be symbolized as follows:

Fuel + Oxidizer = Y Products of combustion + Energy

The reactants in this case are the fuel and the oxidizer, which are the substances present before the reaction takes place. The reactants produce combustion products and energy, according to this relationship. The amount of energy or heat released per unit mass or per mole during combustion of a fuel is used to measure it in part. The heat of reaction or heating of the fuel is a measure of this quantity value.

A calorimeter, a device that determines chemical energy release by transferring the released heat to a surrounding fluid, may be used to calculate reaction heats. The heat of reaction is the amount of heat transferred to the fluid in returning the combustion products to their initial temperature.

The rapid oxidation of fuel followed by the emission of heat, or heat and light, is referred to as combustion. Only a sufficient supply of oxygen is needed for complete combustion of a fuel. Oxygen (O2) is one of the most abundant elements on the planet, accounting for 20.9 percent of the air we breathe. The rapid oxidation of fuel produces a lot of heat. Before solid or liquid fuels can be burned, they must first be converted to a gas.

Changing liquids or solids into gases usually necessitates the use of heat. If there is enough air present, fuel gases can burn normally. The rapid oxidation of fuel generates a large amount of heat. Strong or liquid fuels must first be converted to a gas before being burned. Heat is typically necessary when converting liquids or solids to gases. Fuel gases will burn normally if there is enough air present.

By absorbing heat from the combustion of fuels and diluting the flue gases, nitrogen decreases combustion efficiency. This decreases the amount of heat that can be transmitted through the heat exchange surfaces. It also raises the amount of combustion by-products, which must move further through the heat exchanger and up the stack to allow more fuel air to be introduced.

Carbon dioxide, water vapour, and sulphur dioxide are formed when carbon, hydrogen, and sulphur in the fuel react with oxygen in the air, releasing 8084, 28922, and 2224 kcals of heat, respectively Carbon can also react with oxygen to form Carbon Monoxide, which produces a smaller amount of heat (2430 kcals/kg of carbon). Carbon burned to CO2 produces more heat per pound of fuel than CO or smoke. [5]

$C + O_2 \rightarrow CO_2 + 8084$ kCals/kg of Carbon

$2C + O_2 \rightarrow 2\,CO + 2430$ kCals/kg of Carbon

$2H_2 + O_2 \rightarrow 2H_2O + 28{,}922$ kCals/kg of Hydrogen

2.6.1 THERMOGRAVIMETRIC ANALYSIS

TGA (thermo gravimetric analysis) is an analytical technique for determining a material's thermal stability and volatile component fraction by measuring the weight shift that occurs when a sample is heated at a constant rate. Thermo gravimetric analysis (TGA) looks at weight variations in a substance as a function of temperature in a controlled environment (or time).

2.6.1.1 Principle of Operation

A TGA analysis is performed by gradually increasing the temperature of a sample in a furnace while weighing the sample on an analytical balance outside of the furnace. TGA detects mass loss when a heat event causes in the loss of a volatile component. Physical changes like melting do not result in mass loss, but chemical reactions like burning do.

The weight of the sample is plotted against temperature or time to show thermal transitions in the substance, such as the loss of solvent and plasticizers in polymers, the loss of water or hydration in inorganic materials, and lastly, the disintegration of the material.

2.6.1.2. Types of TGA

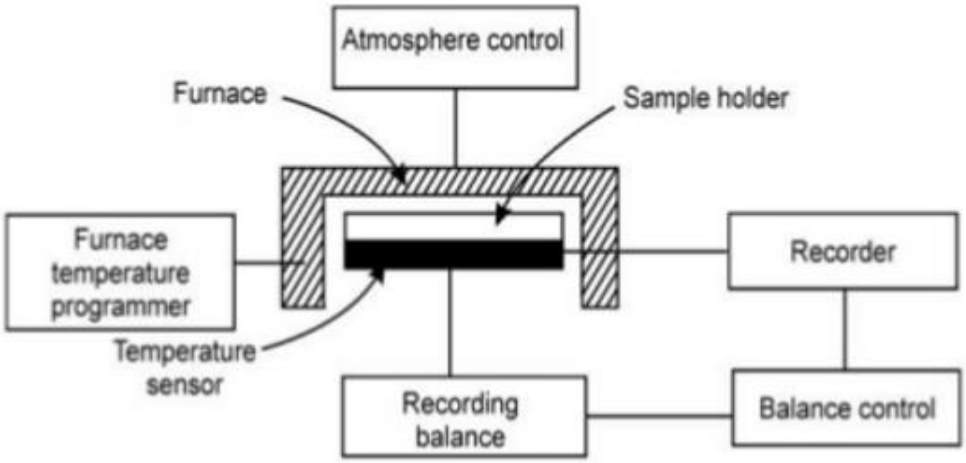
There are three types of thermogravimetry:

Isothermal or static thermogravimetry: The sample weight is recorded as a function of time at a constant temperature.

Quasistatic thermogravimetry: The sample temperature is raised in increments separated by isothermal intervals, with the sample mass stabilizing before the start of the next temperature ramp.

Dynamic thermogravimetry: The sample is heated in an environment where the temperature is changed in a linear manner.

The purity and composition of materials, as well as their drying and ignition temperatures and compound stability temperatures, can all be determined using TGA data.



2.6.2 SINGLE COAL PARTICLE COMBUTION

The combustion of a single coal particle offers valuable insight into the general existence of solid combustion and helps us to better understand pulverized coal combustion. This will demonstrate how many parameters, such as wall temperature, and, of course, particle size and the behavior of particles from various coal forms, affect single coal particle combustion. The coal particle's combustion releases heat until all of the carbon has been burned away, leaving only the non-combustible components of the particle, also known as ash.

The drop tube furnace method has the ability to calculate burning times and temperature histories, as well as obtain data on soot and the period of volatile combustion. This will illustrate the behavior of larger and smaller particles when burning at varying low temperatures, as well as the time of combustion for coal types with high moisture content and coal types with low moisture content.

The behavior of the coal particle during the combustion process has a significant impact on the design of the furnace in which it is burned, such as the necessary residence time, length, and so on. As a result, it's critical to understand which factors, both coal-specific and environmental, affect the particle’s combustion process. This is will achieved by altering the model's parameters and determining the effect on the behavior of the particle's density, diameter, mass of volatiles, and temperature. [8]

2.6.3. AGGLOMERATION BEHAVIOR/ASH TEMPERATURE FUSION

One of the most common operating issues in fluidized bed combustion is bed agglomeration. The formation of agglomerates will alter the hydrodynamics of fluidized bed boilers and affect their stability. Defluidization may result from the extreme agglomeration, resulting in an unplanned power plant shutdown. As a result, comprehending the dynamics of agglomeration and devising effective countermeasures are important.

Fluidized beds are commonly used for biomass combustion due to their ability to burn a wide range of fuels and their economic significance. However, bed agglomeration, which can cause fluidized bed reactors to shut down unexpectedly, has become a serious issue. The alkali content of typical biomass is high, which is released from the fuel during combustion conversion. It can then be carried to the surface of the bed particles, where it forms a sticky layer that promotes agglomeration.

Some studies to examine the formation of bed agglomeration would show that as the combustion temperature rises, the defluidization time decreases. After the inspection, the bed material's minimum fluidization velocity increases. The elements K, Ca, and Si are the most essential in bed defluidization. [9]

2.7. EMISSION FROM PEAT COMBUSTION

Peat-fueled power plants' principal combustion emissions are similar to those of typical fossil-fuel power plants. Depending on parameters such as fuel chemical composition, boiler design, pollution control systems, and combustion circumstances, the levels of these chemicals in the flue gas may vary substantially between facilities. A variety of volatile organic compounds (acrolein, aldehydes) and related persistent semi-volatile compounds (PAHs, dioxins/furans) may be present in addition to criteria contaminants such as PM, carbon monoxide (CO), sulfur oxides (SOx), and nitrogen oxides (NOx), though data on their occurrence and, more importantly, their concentrations in the flue gas are frequently reduced.

The United States Environmental Protection Agency's AP-42 regulation does include emission factors for a number of organic species emerging from wood residue combustion in boilers; these factors were last revised in 2001. The boilers that produced the data for these characteristics are usually industrial-scale systems rather than utility-scale systems, and they mostly utilise waste from wood processing facilities and pulp mills.

CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION

GISAGARA Peat to Power Plant is located in Akanyaru Village, Kirwa Cell, Mamba Sector, Gisagara District in Southern Province of Rwanda approximately 74 kilometers, by road, southwest of the city of Kigali, the capital and largest city in Rwanda. The construction of Gisagara Peat to Power Plant started in 2017. Since March 2021, the plant has been commissioned and is now being tested on the national grid. Two peat-fired units are currently under commissioning and each unit produces 40.2 MW of gross power and 35 MW of net power output.

Photo 4:Gisagara to Peat Power Plant. (Picture taken during site visit)

The main fuel is peat coal and start-up fuel is LDO (Light Diesel Oil), HHV is 10287 Kcal/kg. The calorific value of peat is 4967 Kcal /kg and 11230 Kcal /kg respectively. The pollution control norms are very strict and no deviation is allowed.

The acceptable limit of suspended particle (SPM) and SOX are 50mg/Nm^3 and 200mg/Nm^3 respectively. The raw water drawn from the adjacent Akanyaru river. And the plant is designed in such a way that no water or effluent generated in the plant is returned back to the river. And with DM plant is to check the quantity and the quality of water intake from the river with guaranteed chemical parameters like Conductivity, PH, turbidity, silica….

Peat has been classified as one of the country's strategic energy resources. The HQ Power project manages a 4,200-hectare concession in southern Rwanda, near the Akanyaru River and the Burundi border. In contrast to other foreign peatlands, Rwanda's peat extraction does not necessitate forest clearcutting. The boilers are designed to burn 16 kg of peat per second, and due to the vastness of the peatlands, peat is readily available and will not be prohibitively expensive because it is closer to the site.

The dry harvesting method is used for peat harvesting. Ditches surround the peat bog, which is protected from flooding by high vegetal walls. A special tractor and equipment known as base-machine is used to build the peat production field. Tractors pulling wagons transport peat to the facility (of 25 m3 each). In HQ Power's/HQ Peat's own laboratory, samples of peat and diesel oil are analyzed.

Photo 5:Akanyaru peatlands. (Picture taken during site visit)

The Austrian company AndRitz manufactures the Bubbling Fluidized Bed Boiler, which is one of the world's top suppliers. For steam and power generation, this is the finest technology for burning of a wide range of fuels. The high heat capacity effectively maintains combustion by smoothing out fluctuations caused by fuel quality variations.

The GPPP boiler is designed to have 525 Degree centigrade at furnaces. At boiler start up, usage of sands as bed material and LDO to increase the temperature at the furnaces and later for feeding peat if the requirements are met.

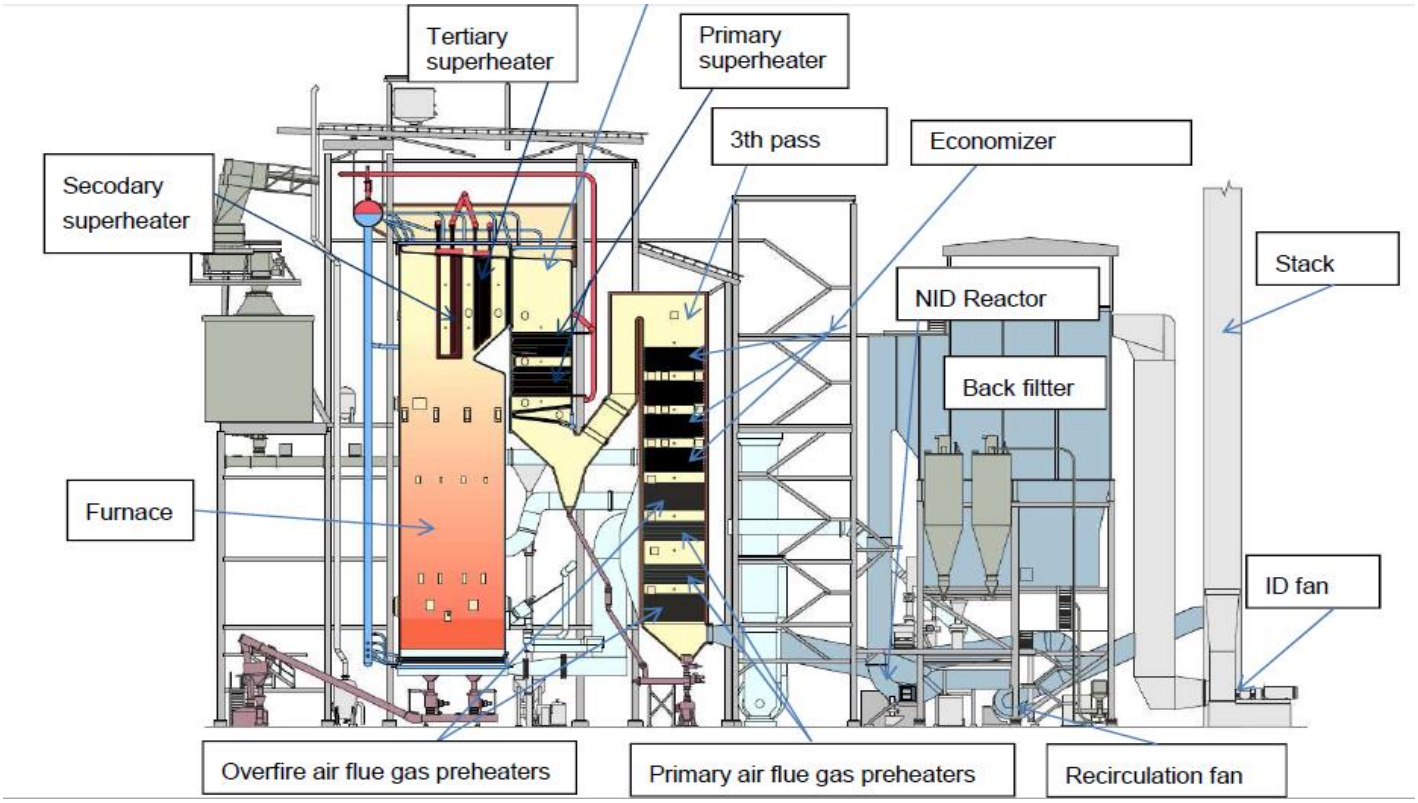


Figure 4:Bubbling Fluidized Bed Boiler

A literature evaluation of research on different peat combustion and emission characteristics was used to gather the necessary information was referred to the laboratory examination of peat combustion and emissions characteristics from Akanyaru peatlands. The site inspections were conducted for the purpose of gathering data and visual observation of the concerns associated to peat properties in terms of energy generation.

The analysis of peat contributed too much to the requested questions employed about boiler performance from peat combustion and utilization, especially during plant operation, according to a literature assessment of institutional and field visits. There are also results from a peat experiment conducted in the laboratory of the HPP plant.

3.2 COLLECTED DATA FROM AKANYARU PEATLAND TO HPP PLANT LABORATORY FOR ANALYSIS

The primary components of the Gisagara Peat to Fired Power Plant are the steam turbine, generator, and boiler, as well as the crusher and transporting system. The facility provides base load power to Rwanda's electrical grid. Specific to the 70MW peat-fired power plant's plans.

Table 1:Plant Capacity summary

Plant capacity	-2x 40MW (Gross output) -2x 35MW (Net output)
Physical characteristics of the peat fired-HQ power plant	
Plant station technology	
Total are of coverage (ha)	4200 ha
Boiler	Bubbling Fluidized Bed Boiler
Turbine	Condensing steam turbine
Pollution abatement Technology	NOx suppression, Particulate –bag filter as dust filter
Cooling technology	Direct cooling water. The cooling water system is closed circuit through cooling towers
Mode of transportation of peat from extraction area	Tractors pulling wagons
Emissions	
Number of chimney	2
Chimney height and inside diameter	80m,
Raw process water requirement	
Demand (m^3/h)	380
Water storage on site	3 tanks operational and 1 stand by
Start up	5MW

3.2.1. SITE VISIT

A site visit was conducted to obtain the necessary information. During my visit, the plant was in the process of commissioning unit-2, which was blowing steam, and was waiting for permission to connect unit-1 to the national grid. There was peat harvesting because it was the dry season. The rain quantity is too low from June to the end of September, therefore harvesting extraction will continue until October.

First, vegetation is removed from the peat surface, and water is drained to allow for run-off. Also, to offer a location where the processed peat can be dried by the sun and wind.

Figure 12: Peatland cleared of vegetation.

3.2.2. OBSERVATIONS

3.2.2.1 AT AKANYARU PEATLAND

Peat piles were waiting to be dried before being gathered at the planned site (peat stockpiles) where it would be shielded from the rain and transported to the peat power plant, as shown in the photos below.

Photo 6:Peat piles at AKANYARU

Photo 7:Dried peat and stationery stockpiles collection area at AKANYARU

3.3. PEAT SAMPLING

Peat sampling was done using stationery stockpiles, which visually split the heap into three horizontal strata. Following sampling procedure, all increments are transferred immediately into one container to make a combined sample, which is then taken to the laboratory (*Appendix 1. Peat sampling procedure*)

3.4. PEAT SAMPLING PREPARATION

After Receiving the combined sample into the laboratory and record the sample details into the laboratory log book, the combined peat sample is mixed and initial sample division of the laboratory sample is carried out to obtain sub-samples for the determination bulk density, Pre-drying and/or equilibration of the peat sample was done. Sequentially, a sub-sample for particle size distribution is obtained. Particle size-reduction using a jaw crusher was then done for those peat materials that do not go through 31,5 mm sieve.

Mixing is further carried out and sample division of the <31.5mm peat material is done to obtain a sub-sample for determination of total moisture content or residual moisture content in case of required pre-drying. Particle size-reduction to <1mm peat material is then carried out using the jaw crusher and sieving using the 1mm sieve. During peat sampling preparation, coning and quartering method was used. (*Appendix 2. Peat preparation procedure*)

3.5. PEAT LABORATORY TESTS

As it was targeted, five samples were taken from the Akanyaru stationery stocks (Gisagara District) and used to determine the overall bogs for energy production, which were then tested in surrounding laboratory of Hakan Peat Power Plants (HPPP).

In a closed crucible (controlled furnace), representative received samples of peat were combusted at 0 and 1100 ^{0}C within 1 hours to determine the moisture content and the ash content, and the combustion products (dried peat) was investigated using laboratory instrumental methods. A sample of peat was weighed. The closed crucible was then sealed and heated in a controlled furnace until the required temperature will reached

Photo 8:Controlled furnace

3.5.1. PROXIMATE ANALYSIS BY SD-TGA PROXIMATE ANALYZER

Because HPPP has a well-equipped laboratory; The moisture, ash, and volatile matter of DMS (Daily Mixed Samples), as well as the calculation of fixed carbon, were determined using a Sundy Proximate Analyzer SDTGA. SDTGA PROXIMATE ANALYZER is used to test the moisture, ash, volatile matter and fixed carbon. It can do batch analysis continuously. Meanwhile, the balance is free from high temperature drift. As result, the efficiency is higher the test results are more accurate. For a proximate analyzer, if the internal balance is fixed under high temperature furnace

It can do batch analysis without waiting together with the 18 samples loading carousel test efficiency could be increased by over 15%. Moisture is tested at low temperature furnace while ash and volatile matter are tested in high temperature of furnace. The high temperature furnace just need drop down (count down) to 950ºC to start ash test of the next batch. the time of cooling is less than 30min. Sample can be weighted without waiting for the cooling of the furnace. During the active analysis, the operator can pre-weigh the next batch of sample with external balance .so weighing doesn't occupy extra test time and the operator doesn't need to weight for furnace cooling to weigh the samples. The operator doesn't have to operate under high temperature with unique manipulation design. During the whole tests, there is wait for the furnace to cool down.

Finally, the internal furnace is fixed under the low temperature furnace. Thus, the balance is far away from drift and is able to perform accurately. During the whole tests, weigh the original samples at room temperature and the samples residuals at low temperatures. Therefore, the tests are more reliable and accurate. Why was the Proximate analysis started by weighing the samples in return of 1 to 2 grams (remember that we have 5 different samples) and heating up the furnace to the specified moisture analysis temperature and keeping the temperature constant (107º C) for the scheduled time (1 hour) and then measuring the moisture loss by itself to get the inherent moisture analysis result and cooling down (counting down) to start the next step.

The next step started by heating up the furnace to the specified volatile matter temperature and keep the temperature constant (750º C) to the scheduled time (7minutes) and then measure by its self the volatile matter of samples in turn to get the volatile matter analysis results and cooling down (counting down) to start the next step.

It was started by heating up the furnace to the specified ash temperature and keep the temperature constant (950º C) to the scheduled time (7minutes) and then measure by its self the mass of the residue remaining to get the ash analysis results and cooling down (counting down) to the last next step by measuring the solid fuel remaining in the furnace (Fixed carbon).

Table 2:Arithmetical proximate analysis

N0	Proximate analysis	Formulas
1.	Moisture content%	$\textbf{Moisture in coal} = \frac{\textbf{W}-\textbf{W1}}{\textbf{W}} \times \textbf{100}$ **Where**, W-Initial weight of coal W_1-Weight of coal powder at 107℃ for 1hour **Or** $\textbf{Moisture in coal} = \frac{\textbf{Loss in weight due to moisture content}}{\textbf{Initial weight of coal}} \times \textbf{100}$
2.	Volatile matter (%)	$\textbf{Volatile matter in coal} = \frac{\textbf{W1}-\textbf{W2}}{\textbf{W}} \times \textbf{100}$ Where W2 –Rate of weigh of coal at 950℃ for 7 minutes W1- Weight of coal powder at 105℃ for 1hour W- initial weight of coal **Or** $\textbf{volatile matter in coal} = \frac{\textbf{The loss in weight due to VM+Moisuture content}}{\textbf{Initial weight of coal}} \times \textbf{100}$
3.	Ash content (%)	$\%\ \textbf{of ash in coal} = \frac{weigt\ of\ ash}{\text{initial weight of coal}} \times 100$
4.	Fixed carbon(%)	$\%\ \textbf{of fixed carbon} = \textbf{100} - \%\ \textbf{of}\ [\textbf{moisture} + \textbf{V.M} + \textbf{ash}]$

Photo 9:Proximate analysis by SD-TGA proximate analyzer

3.5.2. CALORIFIC VALUE (BOMB CALORIMETER)

It began with determining the moisture and ash content of DMS from peat stockpiles, with samples being burned to temperatures ranging from 0 to 1100 degrees Celsius using controlled furnaces. The calorific value was determined by measuring and heating approximate 1 gram of dried peat sample. Transfer the sample to pellet maker, turn the fine powder of coal sample to a small pellet, measure the empty crucible and not the value, measure the weight of the pellet which is the amount of fuel testing .Measure 10cm of tungsten fuse wire thread, fasten each end to an electrode, set the tread near pellet, which act as igniter.0.5cl is filled, then tightened the knur led value knob and screw the cap. Attach the oxygen hose to the inlet value and open the control valve until the pressure reaches at 30ATM.

Put the 200ml of distilled water into a calorie bucker, temperature room should be around 24 degrees, place the oxygen bomb and steel container into calorimeter and attach the electrodes with cord for the detonation, cover the calorimeter by click on start. Wait for 300 seconds the record temperature every 15 seconds until the temperature of water will be constant and the graph denote the variation of the temperatures and calorific value.

Photo 10:Calorific value analysis by Bomb calorimeter

3.7. SINGLE COAL PARTICLE COMBUTION CHARACTERISTICS

The experiment was done by Sticking the temperature probe into peat particle (about 5 mm diameter), set the controlled furnace to 950 degrees centigrade and introduce the peat particle into the furnace and measure the variation of temperature with time. Before the experiment, the particle was weighed using a weighing balance.

3.8. TEMPERATURE-WEIGHT LOSS ANALYSIS PROCEDURE

This experiment was carried out by weighing peat sample (3grames) on the electronic balance; by setting the temperature furnace at which the combustion was complete, we introduced the sample into the furnace and with the fuel samples being weighed at the end of each experiment and compared to the initial samples. The experiment was done for different setting temperature to see the variation of temperature with weight. [10]

3.9 AGGLOMERATION BEHAVIOR/ASH FUSION TEMPERATURE

As the bed material was sand, the experiment was started by carried out a 2 grams of mixed flesh sand (as bed material) and ash; by setting the temperature furnace (different temperatures was used) and maintained the temperature at 1 hour and observed whether it has started agglomerates. We did the same experiment for different setting temperatures until we got the temperature at which we observed ash fusion temperature**.** [10]

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. PHYSICAL PROPERTIES

The table 5 shows the proximate analysis results by TGA as well as oven results while drying peat obtained by the current author. Other parameters such as bulk density and calorific values are also given. It is seen that the moisture content is within the range (average 44.26%), which is typical of peats (35-50%). All of the samples have medium volatile matter percent levels (average 27.7%). Gross calorific values for peat samples ranged from 2949.3 to 3735 Kcal/kg, with an average of 3342.35 Kcal/kg. The CV is within the range as the designed boiler dry peat has a calorific value is ranging from 3280,44 to 4597.4 Kcal/kg. The bed material size is 0.4 mm and the bulk density is 184 kg/m.^{3}

Because problems connected with the peat combustion of high moisture content fuels are avoided, the low moisture content of peat is an essential element in its combustion. The effect of moisture on the thermal properties of fuels is one such issue (Table 5). The heating values of DMS-41-R-CY1 and DMS-29-R14-CY2 peat samples, respectively, are 14.38 and 15.6 MJ/kg, which are within the range of the calorific values of the fire diagram based on dry mass.

All of the samples have a slightly high moisture content, ranging from 40.45 to 51.3 percent, which is adequate for electrical power generation. It indicates that as the moisture content rises, so does the amount of net output power generated decrease as the boiler cannot attend complete combustion.

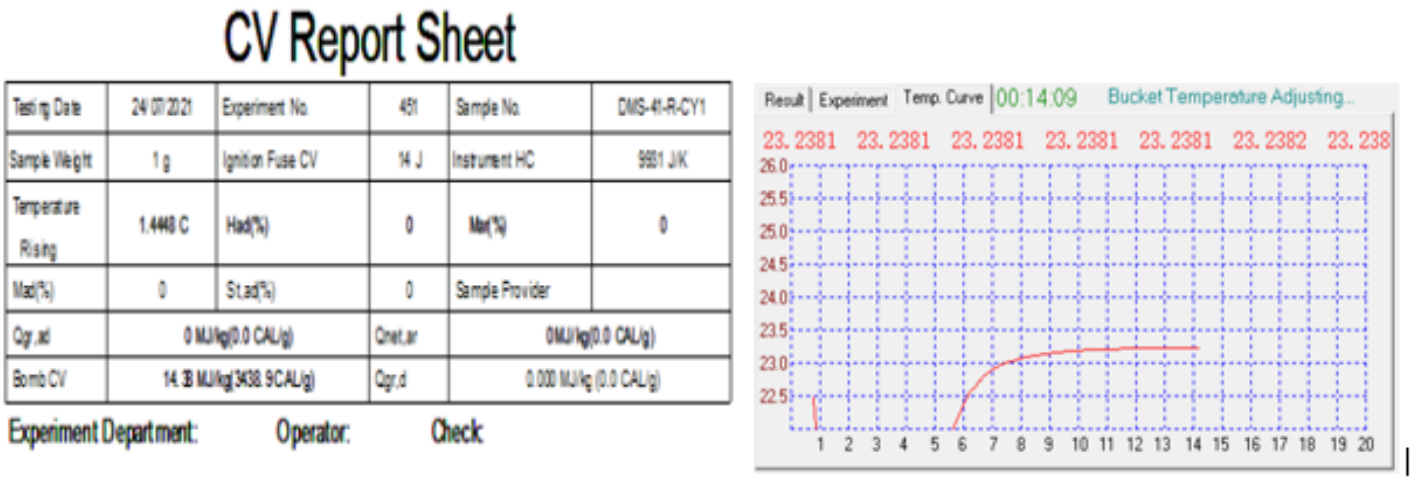
However, the high moisture content of some leftovers reduces their calorific value significantly. Second, high moisture content can cause poor ignition, lower combustion temperatures, and obstruct reaction product combustion. These variables have an impact on combustion quality (T., 1995). The presence of excessive moisture might considerably delay the release of volatiles, according to an analysis of peat drying and devolatilisation processes. Furthermore, high moisture content fuels produce a considerable amount of flue gas, which necessitates the oversizing of flue gas treatment and handling equipments.

Table 3:Peat stockpiles lab results for peat sampled during site visit

PEAT STOCKPILE RESULTS FOR PEAT SAMPLED DURING SITE VISIT									
OVEN RESULTS				TGA ANALYSIS RESULT				BOMB CALORIMETER RESULTS	
Pile Mixed	**SAMPLE ID**	**Wm(%) Moisture content**	**Ash Content (%)**	**Wm(%) Moisture content**	**Ash Content (%)**	**Volatile Matter %**	**Fixed Carbon %**	**CV- HHV (MJ/Kg) 7,2 - 10,5 @40% moisture, 19.4% ash**	**CV- LHV (MJ/Kg)**
Equipment Used		***Drying Oven***	***Muffle Furnace***	***Proximate Analyzer***	***Proximate Analyzer***	***Proximate Analyzer***	***Proximate Analyzer***	***Bomb Calorimeter***	***Calculated Value***
Design Fuel		***45%***	***19.4%***	***45%***	***19.4%***			**13.7 - 19.2**	**8.1**
Boiler Firing Diagram		***35 - 50 %***	***10 - 35%***	***35 - 50 %***	***10 - 35%***				**5.6 - 10.1**
DMS-41-R-CY1		43.8	35.4	40.45	19.80	26.73	13.75	14.38	**7.01**
DMS-41-R-CY1*		49.9	34.8	40.46	18.43	27.10	14.28	12.73	**5.16**
DMS-PR-ST7		43.1	34.1	44.98	13.39	27.04	14.65	12.78	**6.22**
DMS-41-ST8-21		45.8	37.7	44.08	13.92	27.54	14.76	13.85	**6.39**
DMS-29-R14-CY2		45.2	42.4	51.33	11.42	24.18	13.18	15.6	**7.44**

4.2. BOMB CALORIMETER ANALYSIS RESULTS

The figures below depict the temperature curve as a result of the bomb calorimeter experiment of the targeted samples as indicated.



CV Report Sheet

Testing Date	24/07/2021	Experiment No.	451	Sample No.	DMS-41-R-CY1
Sample Weight	1 g	Ignition Fuse CV	14 J	Instrument HC	9881 J/K
Temperature Rising	1.4448 C	Had(%)	0	Mar(%)	0
Mad(%)	0	St.ad(%)	0	Sample Provider	
Qgr,ad	0 MJ/kg(0.0 CAL/g)		Qnet,ar	0MJ/kg(0.0 CAL/g)	
Bomb CV	14.38 MJ/kg(3438.9CAL/g)		Qgr,d	0.000 MJ/kg (0.0 CAL/g)	

Experiment Department: Operator: Check:

Figure 5:CV result report with change in temperature trend of DMS-41-R-CY1 Sample

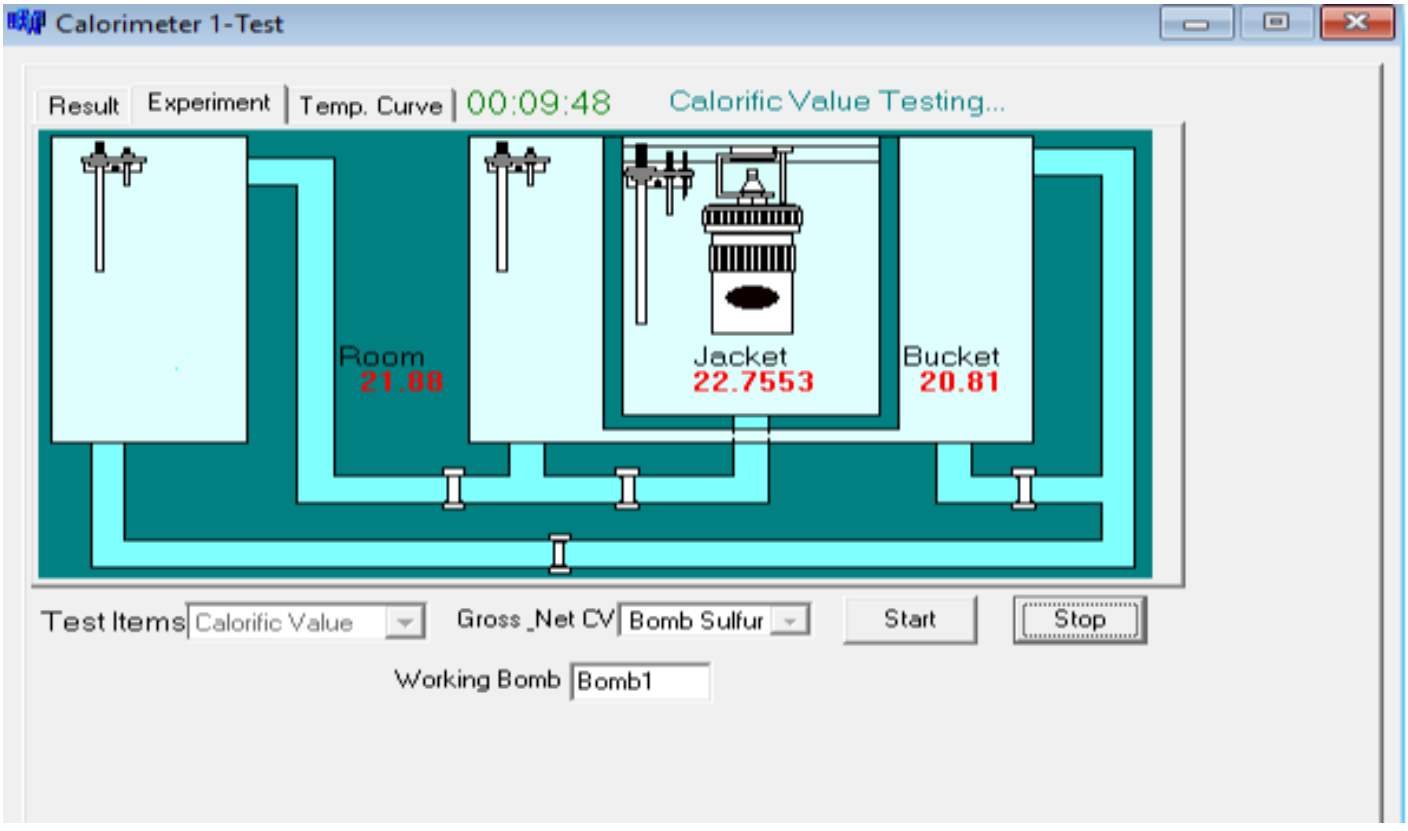


Figure 6:Calorimeter test in progress

After computing the formula for all CV data results (Appendix-3) by calculating the net calorific value (at constant pressure) as received in mega joules per kilogram (MJ/kg) (as shown in table 5), we observed that, as the moisture content increases, the calorific value decreases. This will also have a negative influence on the Gross Electrical or Net Exported at turbine generator terminals. Why is that so? The net calorific values must be within the range, since 98 percent of peat samples must be within it to pass the test.

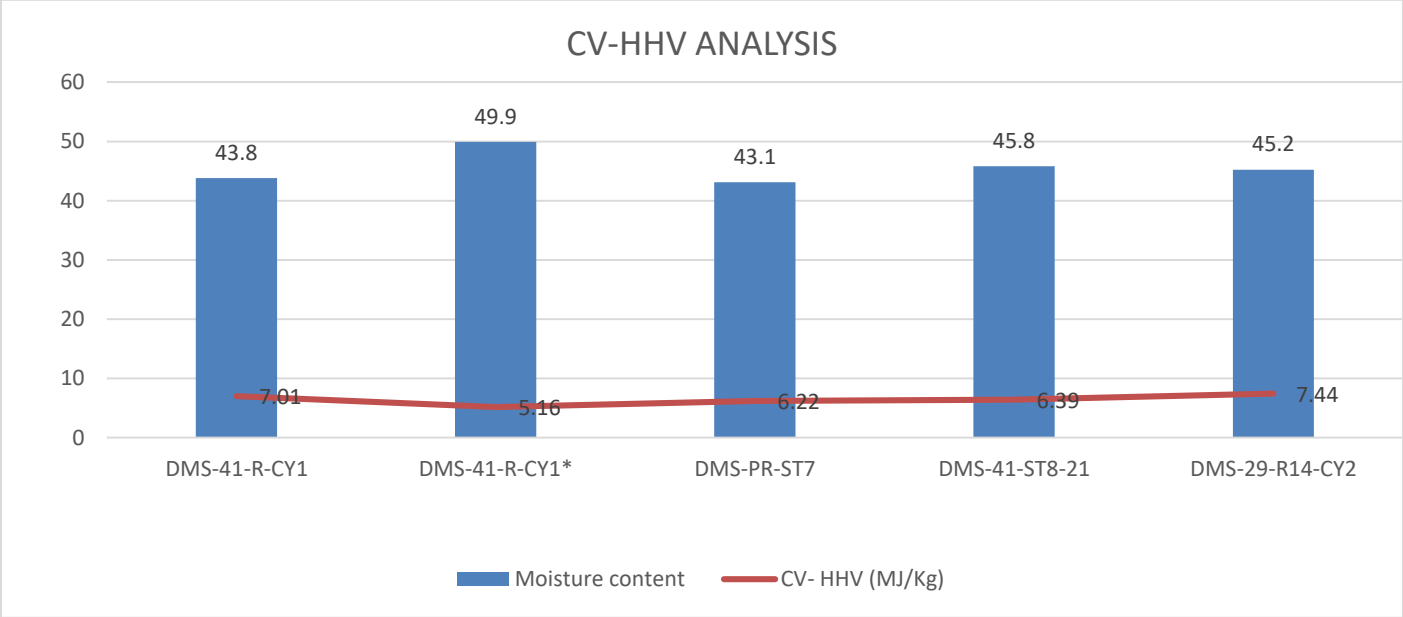


Figure 7:CV –HHV analysis compare to received moisture content

4.3. PROXIMATE ANALYZER RESULTS ANALYSIS

Table 4:Proximate analyzer test results

Report Sheet of Proximate Analyzer Test Results

Print date: 2021/07/24

Sample No.	Mad%	Aad%	Average of Aad(%)	Ad%	Vad%	Average of Vad(%)	Vd%	Vdaf%	FCad%	Average of Fcad(%)	FCd%	), ad(MJ/kg
DMS-41-R-CY1	40.45	19.80	19.80	33.25	26.73	26.73	44.89	67.25	13.02	13.02	21.86	13.75
DMS-41-R-CY1*	40.46	18.43	18.43	30.95	27.10	27.10	45.52	65.92	14.01	14.01	23.53	14.28
DMS-PR-ST7	44.98	13.39	13.39	24.34	27.04	27.04	49.15	64.95	14.59	14.59	26.52	14.65
DMS-41-ST8-21	44.08	13.92	13.92	24.89	27.54	27.54	49.25	65.57	14.46	14.46	25.86	14.76
DMS-29-R14-CY2	51.33	11.42	11.42	23.46	24.18	24.18	49.68	64.91	13.07	13.07	26.85	13.18

Assessor: test2 Tester: test1

The above table shows the SD-TGA analysis results. The results discussion made only on air dry basis (Mad% – Moisture content, Ad%-Ash content, Vd%-Volatile matter and FCd%-Fixed carbon).

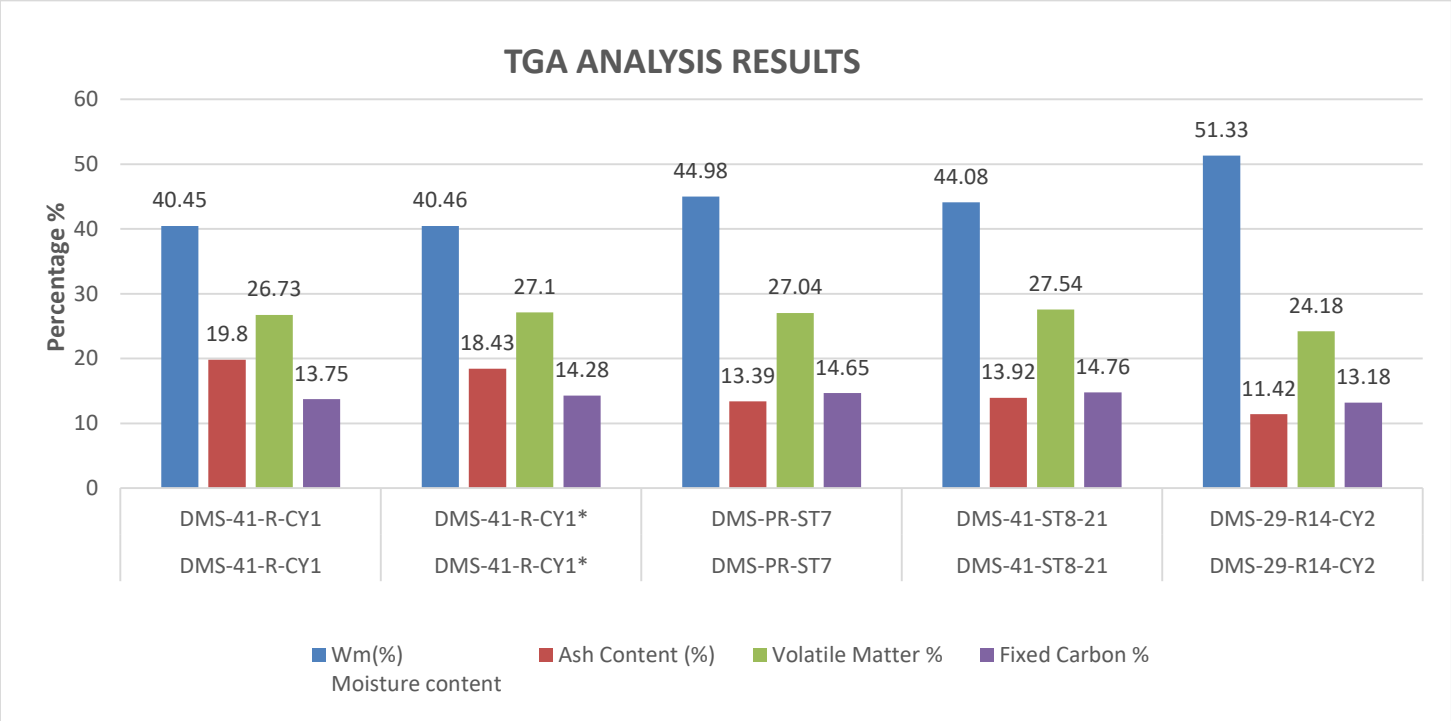


Figure 8:Comparison diagram of field data

According to studies, the country's peat deposits total 155 million tons on a dry basis [11] and and these quantities could be transformed into electricity. The proximate analysis of peat deposited in the Akanyaru Peatlands is shown in Figure15. The amount of potential peat resources varies depending on the sample. The potential peat resources vary from one sample to another.

Total moisture, volatile matter, ash, fixed carbon, and calorific by Bomb calorimeter were determined according to the protocols given by the American Society for Testing and Materials [12] , part of the results shown in Table 6.

4.4. SINGLE COAL PARTICLE COMBUSTION RESULTS ANALYSIS

Fig. 11 shows temperature-time curves for Peat combusted in an oven at different temperatures. The experiment was done by Sticking the temperature probe into peat particle (about 5 mm diameter), set the controlled furnace to 950 degrees centigrade and introduce the peat particle into the furnace and measure the variation of temperature with time.

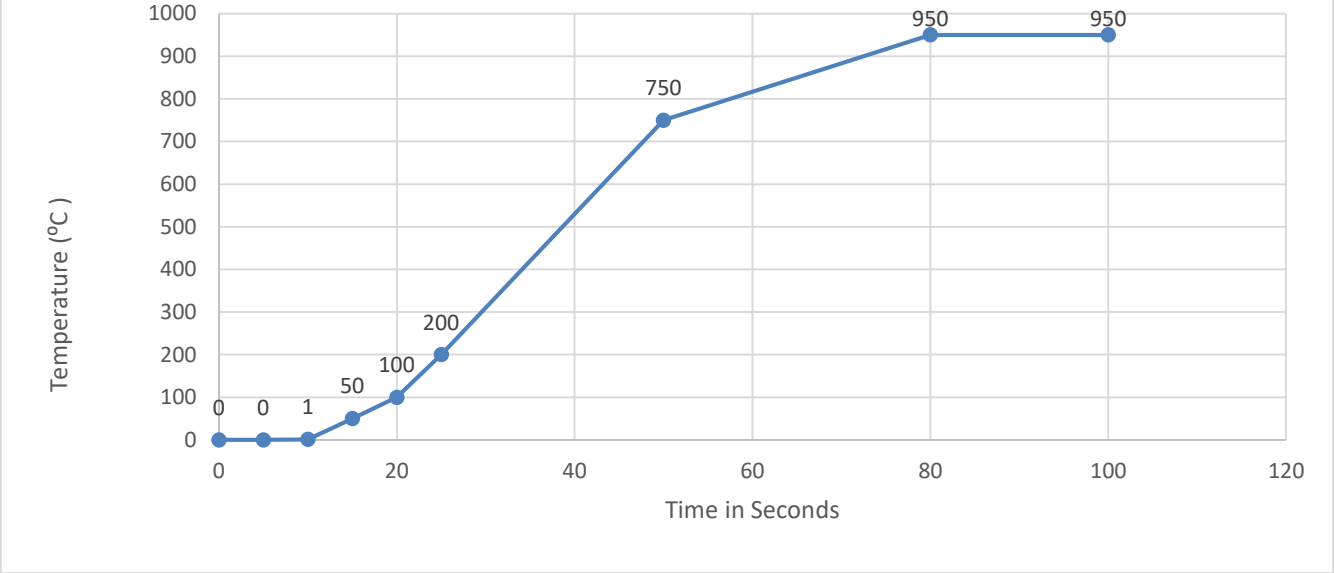


Figure 11: Time–temperature history for peat. Furnace temperature 950°C

The temperature rises rapidly once the drying process is completed, indicating the volatile release and combustion phase. Following then, the temperature remains rather steady during the char combustion phase. The low devolatilisation temperature and high rate of temperature build-up suggest that the peat will devolatilize quickly, ignite easily, and burn out quickly. This is crucial in terms of fuel feeding, heat release, and furnace temperature distribution.

4.5 TEMPERATURE-WEIGHT LOSS TEST TESULTS ANALYSIS

Weight loss curves of peat collected in an oven at various temperatures are shown in Fig. 12. The sample was taken, cooled, and evaluated for weight loss after one hour in the furnace, which was kept at 50°C with 3grams of peat samples. The furnace temperature was then increased, first in 70°C increments up to 200°C, then in 250°C increments up to 950°C, and the analysis technique was repeated each time. The photos below show how the furnace was at 900°C and the ash at the end of experiments.

Photo 11:The furnace was at 900°C and the ash

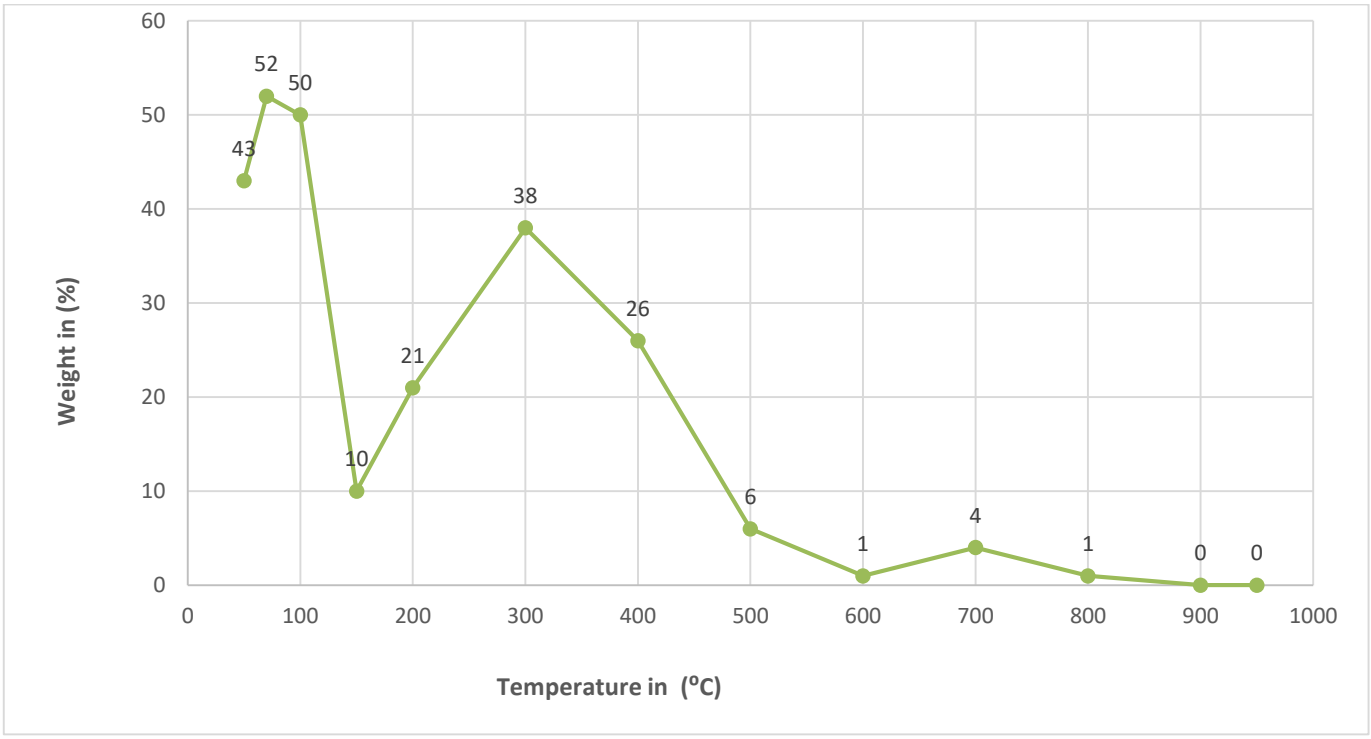


Figure 9:Weight loss analysis of peat combustion at different temperatures.

For the initial weight loss, temperatures between 50°C and 100°C were used, with a weight loss of 52% equivalent to the moisture content of peat obtained by Proximate analyzer. Weight loss continued to grow above 150°C, signaling the onset of devolatilisation, which was more fast around 200–300°C. The burning of the char particles (initial symptoms of ash formation) began at roughly 600–700°C, according to visual inspection. Peat has also been found to have low devolatilisation temperatures.

4.6 ASH FUSION TEMPERATURE RESULTS ANALYSIS

At 950 ºC in 4 hours, bed agglomeration and sintering were detected during continuous combustion studies. The tests were halted, and the furnace was given time to cool. A massive sintered glass structure covering practically the entire cross-section of the furnace was discovered near the feed point. The components from the bed were then collected and analyzed. It was discovered that the bed material included numerous agglomeration particles.

Low sintering ash, according to the literature, can cause slagging, fouling, and corrosion of the heat transfer surfaces in addition to sintering and agglomeration. Corrosion can also affect some steel plant components. There are procedures for raising the melting point of ash to reduce sintering, agglomeration, fouling, slagging, and corrosion concerns. These include the use of additives, alternate bed materials in fluidized bed combustion, and co-firing with other fuels, such as peat and LDO (Case of Hakan peat power plant).

4.7. EMISSION MEASUREMENTS

The flue gas volume flow rate and CO2 content in the stack were measured using the continuous emission monitoring system (CEMS). This measurement was taken after the peat was burned, hence it is a CO2 measurement taken directly.

Table 5: The relationship between the emission observed in the field and the ISO standard emission is recorded in the plant log book and converted at a standard pressure of 1013 Pa and a temperature of 25ºC.

Emission gaz	Average quantities measured(mg/Nm^3)	Percentage emission%	Standard Quantities(mg/Nm^3)
CO	112.0799	15.5804	250
DUST (CH4)	3.2779	1.2	250
NOX	146.5186	93.5	600
SO_2	693.8904	28.225	850

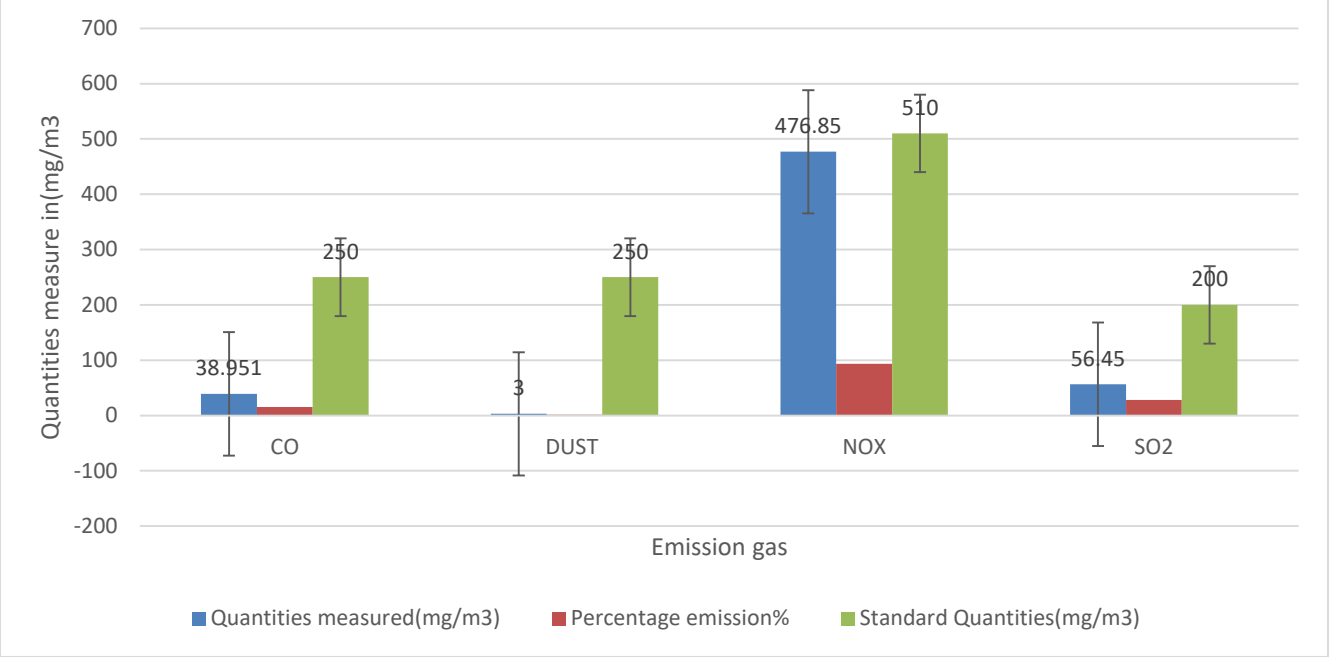


Figure 10: Field data and standard data are compared in this figure.

When compared to other gases such as carbon oxide CO and sulfur dioxide SO2, the nitrogen oxides (NOx) emissions from peat combustion are higher. This demonstrates that reducing the amount of gas generated from combustion peat involves additional effort, despite the fact that the measured values do not exceed those set by ISO.

We're still doing research on the entire peat process cycle, from extraction to end user, because we received results that were standard without taking into account emissions from drainage, extraction, and shipping, and only considering the burning stage at the facility. The quantity of nitrogen oxide is almost equivalent to the quantity defined by standard, as shown by the comparison of gas emissions with standard. This explains why, when other emissions exist in other processes, the level of nitrogen oxide will be higher than the norm, necessitating a thorough investigation.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

The peat to power plant generates electricity to aid the country's economic growth and development. However, they face challenges such as low peat quality, which produces less electricity than the plant was meant to produce, and the production of greenhouse gases, which contributes to the potential for global warming.

According to the boiler design, the quality of peat is still within the range, as determined by laboratory examination and measurement based solely on data from peat during laboratory analysis. However, due to climate change, the quality of peat in the rainy season is significantly lower than in the dry. The inability of peat power plants to produce electricity during the wet season is one of the reasons why they would face challenges. Next researchers are invited to work on a quick solution for maintaining good peat quality during the rainy season by monitoring peat stockpiles and maintaining their condition.

The combustion mechanisms of peat were studied utilizing single particle combustion techniques and TGA analysis in this study. The following conclusions have been reached as a result of the research:

1. Because we need to generate power on a constant basis, Peat stockpiles are required since harvesting peat during the wet season is difficult. Even after a lengthy time has passed since the stockpile was built, a thorough stocking method ensures good quality deliveries from the stockpile to the power plant. Poorly constructed stockpiles, such as the one I witnessed, result in the peat becoming moist and the stockpile self-igniting. During the storage time until the peat is transported to the power plant, the peat stockpiles have to be covered with plastics to decrease the oxygen transport to the stockpile and the temperature of the stock pile should be monitored.
2. Peat has a high volatile matter content as well as a low fixed carbon and ash content. The devolatilization process begins at a low temperature of 200–300°C, with a rapid rate of temperature build-up in the particles. This implies that when heated, peat devolatilizes quickly, necessitating a water-cooled feeding system or a very short residence time in the feeder system to avoid pyrolysis of the peat in the feeding system, which causes blockages and non-uniform fuel flow into the furnace. Because peat has a high tendency to devolatilize quickly, feeding systems should be designed to produce a uniform distribution of peat throughout the furnace's cross-section, preventing excessive temperatures around the feeding point and a more or less even distribution of heat release.

3. Because the emissions from combustion were quantified for the gases measured, the computation and measurement based on the standard (250mg/m^3) data, the CO (38.951mg/m^3) emission is still within permissible limits. We discovered that in the case of the Hakan peat to power plant, numerous gases are emitted from peat combustion but the emission level is still below the Standards maximum values, indicating that the environment is still adequately managed.

4. The low bulk density of peat raises transportation and storage expenses. As a result, peat is better for fire in the producing zone. Peat is a good candidate for co-firing because of its property..

5. Because of the high K2O content in peat, the low melting temperature of ash is a significant issue during combustion. Agglomeration, fouling, slagging, and corrosion issues are all likely to occur. The cost of operating and maintaining the combustion system may rise as a result of these issues. As a result, more research is required in this field in order to develop an appropriate solution for peat ash's low sintering characteristics and how appropriate Techniques including the use of additives, suitable furnace design, and coal co-firing will be as far as improvement is needed.

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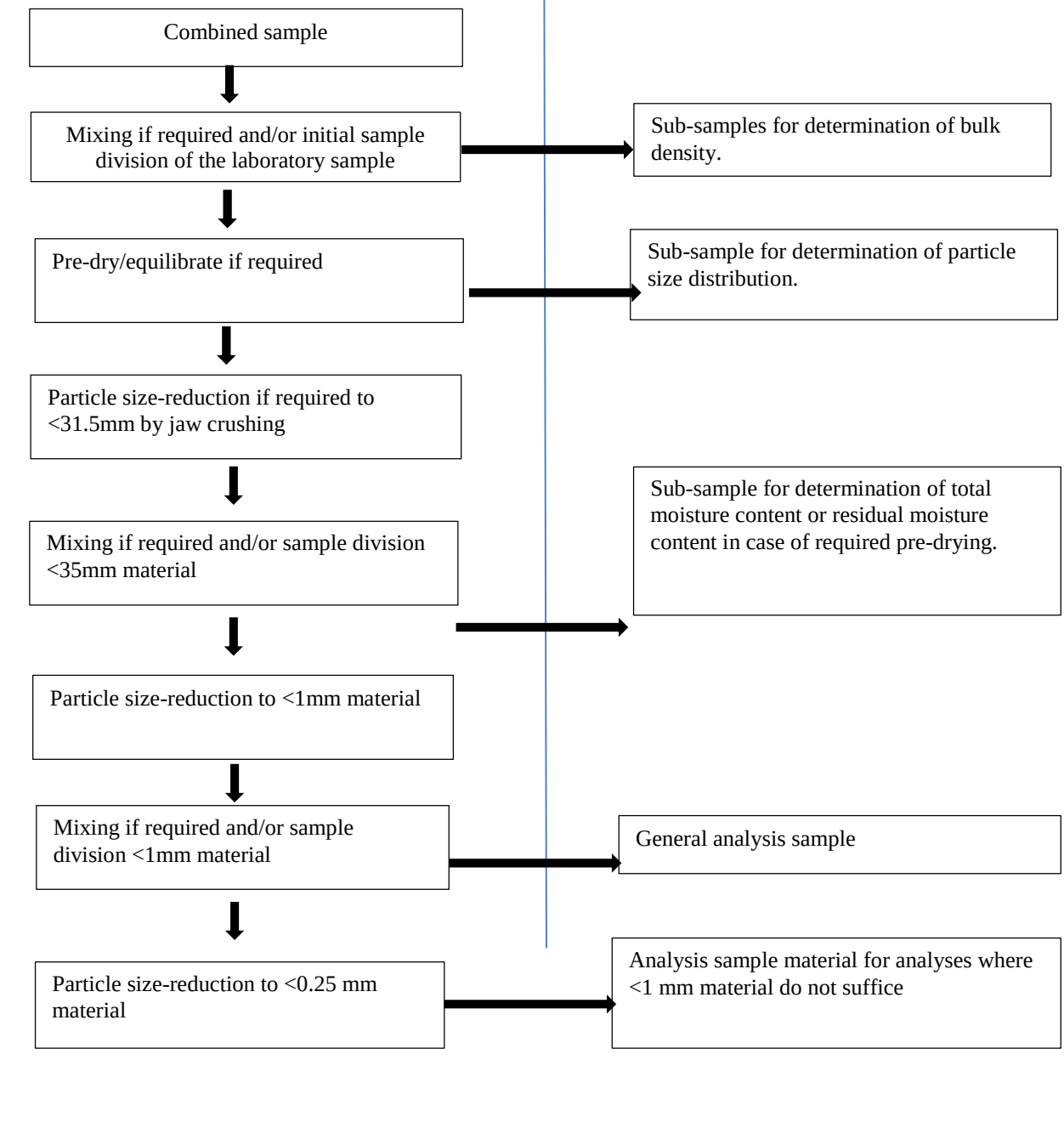
APPENDICES

Appendix 1: Peat sample preparation

Objective:	
This work instruction is to offer guidance on peat sample preparation for laboratory analysis as per SFS-EN ISO 14780:2017 standard.	
Health, Safety and Environmental Precautions:	
Use abrasive-resistant gloves, dust masks-3M(NIOSH/MSHA), safety goggles (ANSI Z81.1-2003) at all times during the activity. Wear a canvas/leather/polystyrene apron during preparation and analysis Dust extractors should be put into service as well as the correct room conditions prior to the sample preparation process commencement.	
Special competence (if applicable):	
Must be trained in proper sample preparation techniques.	
Relevant Documents:	
SFS-EN ISO 14780:2017	
Instruction(s) **Preparation steps**	
1	Receive the combined sample into the laboratory and record the sample details into the laboratory log book as per the sampling certificate filled while sampling as guided by SFS-EN ISO 18135:2017 standard.

2	The combined peat sample is mixed and initial sample division of the laboratory sample is carried out to obtain sub-samples for the determination bulk density as guided by ISO 17828 standard. Pre-drying and/or equilibration of the peat sample is done first if the material is too wet to handle.
3	Pre-drying and/or equilibration of the peat sample is done. Sequentially, a sub-sample for particle size distribution is obtained.
4	Particle size-reduction using a jaw crusher is then done for those peat materials that do not go through 31,5 mm sieve.
5	Mixing is further carried out and sample division of the <31.5mm peat material is done to obtain a sub-sample for determination of total moisture content or residual moisture content in case of required pre-drying.
6	Particle size-reduction to <1mm peat material is then carried out using the jaw crusher and sieving using the 1mm sieve.
7	Further mixing and sample division of the <1mm peat material is carried out as per the general analysis requirements.
8	Particle size-reduction is further carried out using a jaw crusher and/or sieve achieving <0.25mm peat material to obtain analysis sample material foe analyses where <1mm material do not suffice.



Essential Equipment:

Have shovels and scoops as guided by SFS-EN ISO 14780:2017 standard.

Have particle size-reduction; jaw crusher, sieves, weighing balance to an accuracy of 0,1 % of the sample mass as guided by SFS-EN ISO 14780:2017 standard.

Appendices:

Annex A……Principles of correct sample reduction

Annex B……Apparatus for sample division

Annex C……Apparatus for particle size-reduction

Annex D……Methods for sample division

Annex E……Method for reducing laboratory samples to sub-samples and general analysis samples.

Annex F……Storage and labelling

Annex A **Principles of correct sample reduction**	
1	The main purpose of sample preparation is that a sample is reduced to one or more test portions that are in general smaller than the original sample.
2	The main principle for sample reduction is that the composition of the sample as taken on site shall not be changed during each stage of the sample preparation.
3	The sample reduction shall be carried out by a procedure that does not conflict with the requirements of ISO 18134-1 or ISO 18134-2.
4	Each sub-sample shall be representative of the original sample. To reach this goal, every particle in the sample before sample division shall have an equal probability of being included in the sub-sample following sample division.
Annex B **Apparatus for sample division** **Shovels and scoops**	
	They shall have a flat bottom, with edges raised high enough to prevent particles from rolling off, shall be at least 2,5 times as wide as the nominal top size of the material to be processed, and should be large enough to handle normal oversized material particles.

Annex C **Apparatus for particle size-reduction** **Sieves**	
1	A wire-mesh sieve with an aperture size of 1 mm, in accordance with ISO 3310-1, is recommended to check the nominal top size of general analysis samples.
2	A wire-mesh sieve with an aperture size of 0,25 mm will be recommended if sub-samples with this nominal top size are required.
Balance	
	A balance is required that is capable of determining the mass of samples to an accuracy of 0,1 % of the sample mass, and the mass of sub-samples to an accuracy of 0,1 % of the sub-sample mass.
Jar crusher	
1	Drying of the material during coarse crushing shall be avoided by limiting heat production and air flow through the material. 
2	The equipment shall be designed so that it does not lose dust or contaminate the material with pieces of metal, and shall be easy to clean.
3	To prevent moisture losses during particle size reduction, the jaw crusher with as low a crushing speed as possible is preferred.
Annex D **Methods for sample division** **Strip mixing**	
1	This is the convenient method when a combined sample is to be divided into a small number of laboratory samples.

2	Place the whole combined sample on a clean, hard surface and homogenize it by mixing with a shovel, and form into a strip at least 20 times as long as it is wide.
3	Distribute the sample along the length of the strip as evenly as possible, working randomly from end to end. Building up the strip with several layers will increase the quality of the division.
4	Obtain a laboratory sample by taking at least 20 increments from locations evenly spaced along the length of the strip.
5	Take each increment by inserting two plates vertically into the strip and removing all the material from between the plates. The two plates should be inserted the same distance apart each time so that each increment contains the same quantity of material.
6	The distance between the plates should be at least 2,5 times the nominal top size and at least the length of normal oversized material particles.
Long pile-alternate shovel method	
1	For the reduction of peat samples in excess of approximately 50 kg, this sub-sampling method is recommended.
2	Place the entire combined sample on a clean and even floor and mix it thoroughly by manually moving the material to form a long pile.
3	Carry out this process at least three times to ensure thorough mixing.
4	When forming new piles, deposit each shovelful on the end of the new pile.
5	Divide the last pile into two equal piles by using a shovel. Place alternate shovel loads to either side and form into two piles with at least 10 shovel loads (increments) in each pile.
6	One pile is randomly selected and the process is repeated, using appropriately smaller increments as the piles are getting smaller.
Coning and quartering	
1	This method is suitable for producing sub-samples of peat down to approximately 1 kg.
2	Place the whole combined sample on a clean, hard surface.

	
3	Shovel the sample into a conical pile, placing each shovelful on top of the preceding one in such a way that the peat runs down all sides of the cone and is evenly distributed and different particle sizes become well mixed.
4	Repeat this process three times, forming a new conical pile each time.
	Flatten the third cone by inserting the shovel repeatedly and vertically into the peak of the cone to form a flat heap that has a uniform thickness and diameter and is no higher than the blade of the shovel.
5	Quarter the flat heap along two diagonals at right angles by inserting the shovel vertically into the heap(A sheet-metal cross may be used for this operation if available). 
6	Discard one pair of opposite quarters.
7	Repeat the coning and quartering process until a sub-sample of the required size is obtained.
Annex E **Methods for reducing laboratory sample to sub-sample and general analysis sample** **Mixing**	
1	Mixing is recommended before each step of sample division. It should be noted that the sample division does not ensure that samples are adequately mixed. Additional mixing can be done. Note: Beware that mixing may result in loss or gain of moisture.
2	If the material is too wet to handle, pre-drying should be carried out first.

	NOTE: In theory, thorough mixing of a sample prior to its division reduces errors occurring in sample preparation. In practice, this is not easy to achieve and some methods of hand mixing, e.g. forming and reforming into a conical pile, can have the opposite effect, leading to increased segregation.
Initial sample division	
1	If the initial mass of the laboratory sample exceeds the minimum mass given for analysis of each of the parameter under consideration, the laboratory sample may be divided using one of the methods described in Annexure D above.
2	If the material is too wet to handle, pre-drying should be carried out first.
Pre-drying	
1	Pre-drying of wet samples is in general carried out to minimize moisture loss in the subsequent sample division processes, to facilitate the sample preparation processes, and to minimize biological activity. If it is necessary to dry a sample by heating, it shall be dried in an oven at a temperature not exceeding 40 °C. All samples (including those that have been dried by heating) shall be spread out on a tray no more than a few particles deep and left for at least 24 h in the laboratory until they reach equilibrium with the temperature and humidity in the laboratory.
2	Before the laboratory sample or the divided laboratory sample according to initial sample division as above; is subject to pre-drying, determine the mass of the sample by weighing on a balance accurate to at least 0,1 % of the sample mass. Record this mass as *m*sample,1. After pre-drying and equilibrium with the surroundings, record the mass as *m*sample,2.
3	Calculate the moisture loss during pre-drying as a percentage of the initial mass of the sample as shown below; $$M_{\mathrm{p}} = 100 \times \frac{m_{\mathrm{sample,1}} - m_{\mathrm{sample,2}}}{m_{\mathrm{sample,1}}}$$ where *M*p is the moisture loss in percentage; *m*sample,1 is the initial mass of the sample in g; *m*sample,2 is the mass of the sample after pre-drying in g.

	NOTE; If the moisture content of the original sample is unimportant, e.g. only properties of the dry matter or mechanical properties are to be determined or if a separate "moisture analysis sample" is separated or sampled as well, the calculation of the moisture loss can be omitted. Also in this case, it is not necessary to obtain complete equilibrium with the temperature and humidity in the laboratory.
4	Record the result to the nearest 0,1 %.
5	For coarse materials, for example, 24 h under laboratory conditions is not enough to reach equilibrium moisture content in all particles. Constancy in mass should be monitored by re-weighing at intervals at e.g.4 h. The sample material should be turned around from time to time during the equilibrium process.
Particle size reduction of <1 mm material to <0,25 mm	
1	When a sub-sample is required with a nominal top size of 0,25 mm, use a jaw crusher to reduce one of the <1 mm sub-samples to this size. Feed the jaw crusher with small portions of material from the <1 mm subsample and let each portion pass through the 0,25 mm screen to prevent excess heat generation.
Annex F **Storage and labelling**	
1	Samples shall be placed in air-tight plastic containers or bags.
2	Each sample shall be labelled with a unique identification number of the sample, date and time of sampling and identification number or code of the lot or sub-lot number.

Appendix 2: Peat sampling procedure

Objective:	
This work instruction is to offer guidance on peat sampling as per SFN-EN ISO 18135:2017 standard.	
Health, Safety and Environmental Precautions:	
Use abrasive-resistant gloves, dust masks-3M(NIOSH/MSHA), safety goggles (ANSI Z81.1-2003) at all times during the activity. Wear a canvas/leather/polystyrene apron during preparation and analysis	
Special competence (if applicable):	
Must be trained in proper sampling procedures	
Prerequisites	
Have shovels and scoops as guided by SFS-EN ISO 14780:2017 standard. Have proper air tight package e.g. plastic bucket (with lids), or plastic bags (to be closed) Have identification/labelling as guided by SFS-EN ISO 18135:2017 standard. Have sampling plan represented in a form as guided by SFS-EN ISO 18135:2017 standard, to be filled/completed by the sampler. Once this form is completed, it becomes a sampling certificate.	
Relevant Documents:	
SFS-EN ISO 18135:2017 SFS-EN ISO 14780	
Instruction(s) **Sampling from Peat wagons**	
1	An individual wagon load, may be regarded as the entire lot/sub-lot(Block number) or a part of the lot(block number).
2	If the lot consists of a single wagon, the increments shall be extracted from different parts of the wagon, chosen at random.

3	If the lot consists of more than one wagon, increments shall be extracted from either all, or a fraction of, the number of wagons, dependent on the required number of increments.
4	Increments of 2 litres shall be taken in either of the applicable case as mentioned above to form the combined sample. (Refer to the sampling plan for minimum sample quantities).
5	Record the number of wagons sampled as per the sampling plan.
6	When sampling wagons special care shall be taken to encompass the possible segregation of the material in the wagon, e.g. extract increments that cover the entire direction of segregation (a "drill-core" or selecting increments at different depths).
Sampling from stockpiles. **During build up or reclaiming**	
1	Prepare as appropriate either a scoop, shovel, fork, auger, grab, probe or pipe to extract the increments as per the sampling plan equipment requirement. (To confirm sampling equipment available)
2	Increments shall be extracted either from the working face of the stockpile, or from the bucket of a frontend loader or grab or from a single, discrete load delivered to the stockpile before being pushed into the main stockpile.
3	Insert at the right angle a manual auger/probe or a scoop at the surface and spread evenly over the entire surface of the pile when sampling the working face of the pile to avoid possible rolling(segregation) on the surface.
4	Ensure that no portion of the increment is lost during extraction of the scoop from the surface, a probe or an auger shall be used only for peat on which a full column of peat can be extracted so that a representative increment is taken.

Sampling from stationery stockpiles	
1	Visually divide the heap into three horizontal layers. 
2	Take a number of 2 litre increments from each layer in proportion to the volume contained in each layer
3	Equally space the position around the circumference of the heap from which the increments are taken.
4	For increments at the lowest part of the heap, use a bucket loader to dig into the heap to reach the sampling points. Avoid impurities and segregation when extracting the increments
Sample generation for combined samples and laboratory samples	
	After sampling, use either one of the following options as guided by SFS-EN ISO 18135:2017 standard.
1	All the increments are placed directly into one container to form a combined sample, which is sent to the laboratory. In this case the combined sample is also the laboratory sample.
2	The increments are mixed together to form a combined sample, which is then divided and prepared as described in ISO 14780.
3	Each increment is placed in a separate container, and sent to the laboratory. The laboratory combines the increments to form the laboratory sample.

Essential Equipment:

Sampling scoops, sampling box for falling stream, shovel, fork, grab, probes, pipes(spears), sampling frame, hooks, drills(augers). (To be updated as per sampling equipment availability)

Appendices:

Sampling plan

Table A.1 Example of sampling plan

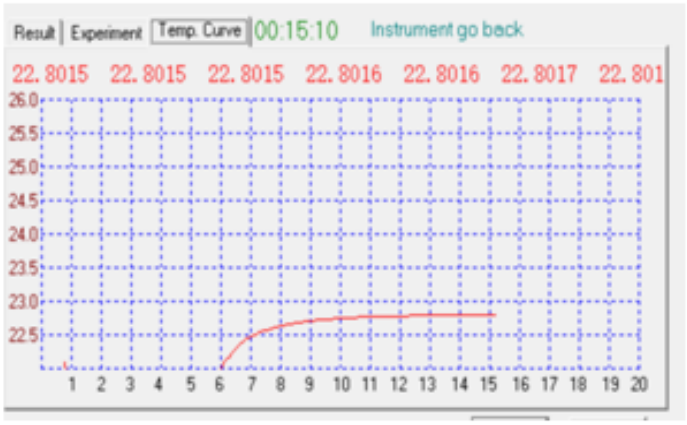
Sampling plan reference number				
Unique sample identification number			Date	
Aim of sampling				
Property	Standard	Mass required	Sampling equipment	
Moisture		kg	Manual	Automatic
Particle size distribution		kg	Scoop ☐	
Bulk density		kg	Shovel ☐	
Mechanical durability		kg	Fork ☐	
Ash		kg	Grab ☐	
Calorific value		kg	Other:	
Sulfur		kg		
Nitrogen		kg	Location of sampling point:	
Chlorine		kg		
Others:				
		kg	Procedure for selecting sub-lots from lots for sampling	
		kg		
		kg	Requirements according to standard:	
Total mass required for tests		kg	Min. number of increments (n_{min})	
Bulk density		kg/m^3	Min. volume, one increment (V_{incr})	litre
Total volume required for tests (V_{req})		litre	Volume of combined sample ($V_{Combined\ Sample}$)	litre
If total volume required (V_{req}) exceeds the calculated volume of combined sample ($V_{Combined\ Sample}$), then increase the number or the volume of increments:			Method of preparing the laboratory sample from the combined sample:	
Actual number of increments (n_{act}), larger than V_{req}/V_{incr}				
Actual volume of increments ($V_{incr,\ act}$), larger than V_{req}/n_{act}				
Actual volume of the combined sample ($n_{act} \times V_{incr,\ act}$)		litre	Volume of the laboratory sample	litre

Appendix 3: CV result report with change in temperature trend of DMS-41-R-CY1* Sample

CV Report Sheet

Testing Date	24/07/2021	Experiment No.	452	Sample No.	DMS-41-R-CY1*
Sample Weight	1 g	Ignition Fuse CV	14 J	Instrument HC	9931 J/K
Temperature Rising	1.2803 C	Had(%)	0	Mar(%)	0
Mad(%)	0	St.ad(%)	0	Sample Provider	
Qgr,ad	0 MJ/kg(0.0 CAL/g)		Qnet,ar	0MJ/kg(0.0 CAL/g)	
Bomb CV	12.78 MJ/kg(3044.3CAL/g)		Qgr,d	0.000 MJ/kg (0.0 CAL/g)	

Experiment Department: Operator: Check:

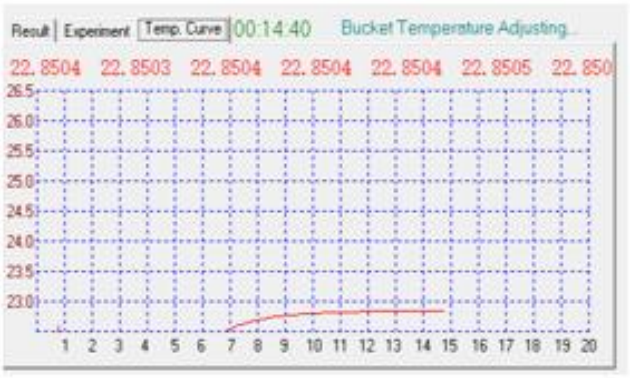


Appendix 4: result report with change in temperature trend of DMS-PR-ST7 Sample

CV Report Sheet

Testing Date	24/07/2021	Experiment No.	453	Sample No.	DMS-PR-ST7
Sample Weight	1 g	Ignition Fuse CV	14 J	Instrument HC	9931 J/K
Temperature Rising	1.295 C	Had(%)	0	Mar(%)	0
Mad(%)	0	St.ad(%)	-0.33	Sample Provider	
Qgr,ad	12.5MJ/kg(2989.3 CAL/g)		Qnet,ar	12.5 MJ/kg(2989.3 CAL/g)	
Bomb CV	12.48 MJ/kg(2984.5CAL/g)		Qgr,d	12.500 MJ/kg (2989.3 CAL/g)	

Experiment Department: Operator: Check:

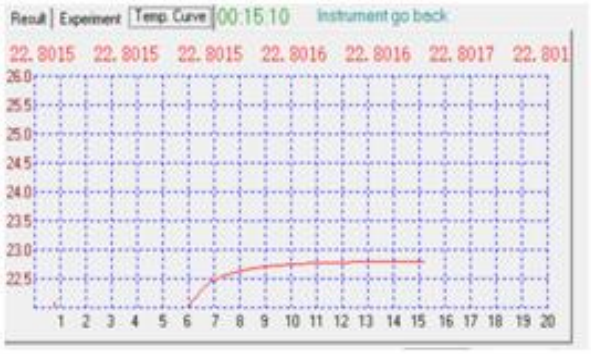


Appendix 5: CV result report with change in temperature trend of DMS-41-ST8-21 Sample

CV Report Sheet

Testing Date	24/07/2021	Experiment No.	454	Sample No.	DMS-41-ST8-21
Sample Weight	1 g	Ignition Fuse CV	14 J	Instrument HC	9931 J/K
Temperature Rising	1.3918 C	Had(%)	0	Mar(%)	0
Mad(%)	0	St.ad(%)	-0.36	Sample Provider	
Qgr,ad	13.87 MJ/kg(3316.9 CAL/g)		Qnet,ar	13.87 MJ/kg(3316.9 CAL/g)	
Bomb CV	13.85 MJ/kg(3312.1 CAL/g)		Qgr,d	13.870 MJ/kg (3316.9 CAL/g)	

Experiment Department: Operator: Check:

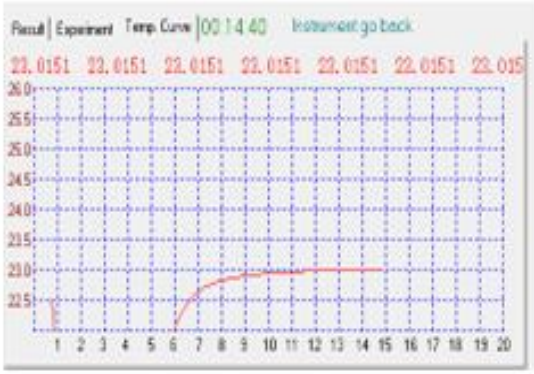


Appendix 6: CV result report with change in temperature trend of DMS-29-R14-CY2 Sample

CV Report Sheet

Testing Date	24/07/2021	Experiment No.	455	Sample No.	DMS-29-R14-CY2
Sample Weight	1 g	Ignition Fuse CV	14 J	Instrument HC	9951 J/K
Temperature Rising	1.5657 C	Had(%)	0	Mar(%)	0
Mad(%)	0	St.ad(%)	-0.41	Sample Provider	
Qgr,ad	15.62 MJ/kg(3735.4CAL/g)		Qnet,ar	15.62 MJ/kg(3735.4 CAL/g)	
Bomb CV	15.6MJ/kg(3730.6 CAL/g)		Qgr,d	15.620 MJ/kg (3735.4 CAL/g)	

Experiment Department: Operator: Check:



Based on the net calorific value of the dry basis, the ISO 17225-1:2014 [E] standard shows how to compute the net calorific value as received (at constant pressure) as received (the moisture biofuel) using the following formula:

$q_p net, ar = q_p net, d \times \left(\frac{100-Mar}{100}\right) - 0.02443 \times Mar$, where

$q_p net, ar$ – is the net calorific value in mega joules per kilogram (MJ/kg) as received at constant pressure.

$q_p net, d$ - is the net calorific value in mega joules per kilogram (MJ/kg) in dry materials (at constant pressure)

Mar –is the moisture content as received (w-%)

0.02443 is the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture content) at 25 ºC (in MJ/kg per 1W-% of moisture)

From the equation, it is easier to find the net calorific value as received, where as an example using sample pile DMS-41-R-CYI; 1MJ/kg=239 Kcal /kg

$q_p net, ar = 14.38 \times \left(\frac{100-43.8}{100}\right) - 0.02443 \times 43.8$

$q_p net, ar$ = 7.01MJ/kg