# *Co-combustion studies in North East India: A Physicochemical, TGA and FTIR Analysis of Coal and Biomass blends for Sustainable energy*

*A dissertation submitted for the partial fulfilment of*
*therequirements for the degree of*
*B. Sc. in Chemistry (Paper DSE-603) under Dibrugarh University*

*Under the Supervision of*

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Year: 2025

# Co-combustion studies in North East India: A Physicochemical, TGA, and FTIR Analysis of Coal and Biomass Blends for Sustainable Energy

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# CERTIFICATE

*This is to certify that the dissertation entitled "**Co-combustion studies in North East India: A Physicochemical, TGA and FTIR Analysis of Coal and Biomass blends for Sustainable energy** " is submitted by Priya Saikia, a B.Sc. 6th semester student of the Department of Chemistry, N. N. Saikia College, Titabar for the partial fulfillment of B.Sc. degree in Chemistry (Paper: DSE-603), is a record of original research work carried out by her under the supervision o Dr. Prasenjit Saikia. She has fulfilled all the requirements for submitting the dissertation for the B.Sc. degree. The results embodied with this dissertation have not been submitted to any other college or institute for any other degree or diploma to the best of my knowledge.*

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## FORWARDING

I, here by forwarding the project report entitled **"Co-combustion studies in North East India: A Physicochemical, TGA, and FTIR Analysis of Coal and Biomass Blends for Sustainable Energy"**, submitted by Miss Priya Saikia, a student of B. Sc. 6th semester, Department of Chemistry, Nanda Nath Saikia College, Titabor, Jorhat under the Winter Internship Program for the partial fulfilment of the degree of Bachelor of Science, embodies the record of original investigation carried out by her under my supervision during the period from 01/12/2024 to 20/01/2025 at Coal and Energy Division, CSIR-NEIST, Jorhat.

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From
**Dr. Binoy K. Saikia,**
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## FORWARDING

I, here by forwarding the project report entitled **"Co-combustion studies in North East India: A Physicochemical, TGA, and FTIR Analysis of Coal and Biomass Blends for Sustainable Energy"**, submitted by Miss Priya Saikia, a student of B. Sc. 6th semester, Department of Chemistry, Nanda Nath Saikia College, Titabor, Jorhat under the Winter Internship Program for the partial fulfilment of the degree of Bachelor of Science, under the guidance of Dr. Prasenjit Saikia, Principal Scientist, Coal and Energy Division, CSIR-NEIST, Jorhat

To the best of my knowledge, the matter embodied in the project has not been submitted to any other university/institute for the award of any degree or diploma.

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# DECLARATION BY CANDIDATE

I hereby declare that the project report titled ***"Co-combustion studies in North East India: A Physicochemical, TGA, and FTIR Analysis of Coal and Biomass Blends for Sustainable Energy"*** submitted to the Department of Chemistry, Nanda Nath Saikia College, Titabor, in partial fulfilment of the requirement of the award of the Bachelor Degree of Science in a record of Bonafide work carried out under the supervision of ***Dr. Prasenjit Saikia***, Scientist, CSIR-NEIST, Jorhat. The matter embodied in this project has not been submitted by us for the award of any other degree.

Date: 29/05/2025

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# Abstract

The study investigates the thermochemical behaviour and physicochemical characteristics of coal and biomass, with a specific focus on their co-blending potential. The research begins by exploring coal as a primary energy source and introducing biomass as a viable alternative, highlighting the advantages of co-blending. A comprehensive review of existing literature and the methodology employed, including sample collection and preparation, is presented. The study delves into the detailed characterization of the samples through proximate analysis, ultimate analysis, calorific value determination, and Fourier Transform Infrared (FTIR) spectroscopy. Furthermore, the thermochemical behaviour of coal, biomass and their blends are analysed using Thermogravimetric Analysis (TGA). The results and discussion section focuses on the physicochemical characterization of coal and biomass individually and in blends, analysing proximate and ultimate analyses, as well as FTIR spectra. The chemical characterization of the samples through FTIR analysis is also detailed. The findings of this study provide valuable insights for the development of co-combustion technologies in North East India, contributing to the region's energy security and environmental sustainability.

**Keywords:** *Co-combustion, coal, biomass, sustainable energy, North East India, physicochemical analysis, TGA, FTIR.*

# 1. Introduction:

## 1.1. Coal, the source of energy:

Coal is a combustible black or brownish-black sedimentary rock with a high amount of carbon and hydrocarbons. Coal is classified as a nonrenewable energy source because it takes millions of years to form. Coal contains the energy stored by plants that lived hundreds of millions of years ago in swampy forests. Layers of dirt and rock covered the plants over millions of years. The resulting pressure and heat turned the plants into the substance we call coal[1].Today, coal is both the second most important source of primary energy and the largest source for electricity generation - accounting for 27% and 36% of the global mix respectively, and the most polluting fossil fuel. Coal provides stability and reliability powering the grids, it can be used as a raw material in the production of steel, iron and chemical products and, in countries with little access to clean fuels for cooking, and it is often used in the kitchens [2].

### 1.1.1. The dirtiest source of energy:

All living organisms consist primarily of carbon-based molecules. Thus, fossil fuels, deriving from once-living matter, also contain carbon. Regardless of the fuel, they must be burned to generate energy and the heat content of a certain fuel, or in other words, the amount of energy released during combustion, is mainly determined by their carbon and hydrogen content. Here's where the carbon and hydrogen which are stored inside are released as carbon dioxide and water vapor. Also, the more carbon is chemically found inside the fuel, the higher the carbon emissions.

Burning coal produces about 15 billion tones of $CO_2$ each year. But that's not all: $CO_2$ is not the only by-product of its combustion and that is the reason why coal is the dirtiest source of energy. Sulphur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) are released contributing to air pollution, respiratory illnesses, and acid rains. On top of that, there are mercury - a toxic metal which, when dissolved into water, accumulates in ecosystems posing a threat to aquatic life and human health - and particulate matter that, depending on the coal composition, can contain toxic and irritant elements such as cadmium, silicon dioxide, arsenic and calcium oxide[2].

### 1.1.2. Types of Coal:

Coal is classified into five main types, or ranks: anthracite, bituminous, sub bituminous, lignite and peat. The ranking depends on the types and amounts of carbon the coal contains and on the amount of heat energy the coal can produce. The rank of a coal deposit is determined by the amount of pressure and heat that acted on the plants over time.

#### (i)Anthracite:

Fig 1: lumps of Anthracite Coal

**Anthracite** contains 86%–97% carbon and generally has the highest heating value of all ranks of coal. Anthracite accounted for less than 1% of the coal mined in the United States in 2022. All anthracite mines in the United States are in northeastern Pennsylvania. In the United States, anthracite is mainly used by the metals industry.

#### (ii)Bituminous:

Fig 2: lumps of Bituminous Coal

**Bituminous** coal contains 45%–86% carbon. Bituminous coal in the United States is between 100 million and 300 million years old. Bituminous coal is the most abundant rank of coal found in the United States, and it accounted for about 46% of total U.S. coal production in 2022. Bituminous coal is used to generate electricity and is an important fuel and raw material for making coking coal for the iron and steel industry. Bituminous coal was produced in at least 16 states in 2022, but five states accounted for about 78% of total bituminous production. The top five bituminous producing states and their percentage share of total U.S. bituminous production in 2022 were:

- West Virginia—31%
- Illinois—14%
- Pennsylvania—14%
- Kentucky—11%
- Indiana—9%

### (iii)Sub bituminous:

Fig 3: lumps of Sub bituminous Coal

**Sub bituminous** coal typically contains 35%–45% carbon, and it has a lower heating value than bituminous coal. Most sub bituminous coal in the United States is at least 100 million years old. In 2022, sub bituminous coal accounted for about 46% of total U.S. coal production. The five sub bituminous producing states and their percentage share of total U.S. sub bituminous production in 2022 were:

- Wyoming—89%
- Montana—8%
- New Mexico—2%
- Colorado—2%
- Alaska—<1%

**(iv)Lignite:**

Fig 4: Lumps of Lignite Coal

**Lignite** contains 25%–35% carbon and has the lowest energy content of all coal ranks. Lignite coal deposits tend to be relatively young and were not subjected to extreme heat or pressure. Lignite is crumbly and has high moisture content, which contributes to its low heating value. In 2022, five states produced lignite, which accounted for 8% of total U.S. coal production. The five lignite-producing states and their percentage share of total U.S. lignite production in 2022 were:**[1]**

- ❖ North Dakota—56%
- ❖ Texas—36%
- ❖ Mississippi—7%
- ❖ Louisiana—1%
- ❖ Montana—<1%

**(v)Peat:**

Fig 5: Lumps of Peat Coal

**Peat**, spongy material formed by the partial decomposition of organic matter, primarily plant material, in wetlands such as swamps, muskegs, bogs, fens, and moors. The development of peat is favored by warm moist climatic conditions; however, peat can develop even in cold regions such as Siberia, Canada, and Scandinavia. Beyond its considerable ecological importance, peat is economically important as a carbon sink, as a source of fuel, and as raw material in horticulture and other industries.

The wetlands in which peat forms are known as peat lands. The peat formed and housed in these special ecosystems is the largest natural terrestrial carbon store, and it sequesters more carbon than all other vegetation types in the world combined. Peat is thus critical for preventing and mitigating the effects of anthropogenic global warming. Peat lands also help minimize flood risks and filter water, both of which are invaluable ecosystem services. Peat harvesting and land-use changes that damage peat lands are a major source of greenhouse gas emissions, and in the 21st century the use of peat increasingly has been discouraged in an attempt to protect these valuable ecosystems**[4].**

### 1.1.3. Sulphur in coal:

Coal is the world's most abundant fossil fuel. The existing accessible stock of gas and oil will last for approximately another 50 years while the coal resources will be able to supply power at least for three centuries. The world demand for coal with low ash and low sulphur is due mainly to environmental pressure and is already changing the value of coals.

High sulphur coals have a deleterious effect on the environments especially when these are used as a fuel. There are vast deposits of high-sulphur coals throughout the world, i.e., in countries where coals have been found. Australia is an exception in which most of the coals are low in sulphur content. In India although we have coal reserves that are likely to last for 200 years at the present rate of consumption, the present thermal power plants are able to achieve only 38-40% efficiency since nearly 71% of Indian coals contain high ash and high sulphur. The high-sulphur Indian coals occur in the North Eastern part of the country; the reserves of Assam coals predominate over the others.

**Location and Geology:** Prior to the early 1960s, coals from North Eastern Region of India were commonly known as Assam coals. With the separation of the region on grounds of religion, language and political interest into different states, namely, Assam (capital – Dispur), Meghalaya (capital- Shillong), Tripura (capital – Agartala), Mizoram (capital – Aizawl), Manipur (capital – Imphal), Nagaland (capital – Kohima) and Arunachal Pradesh (capital – Itanagar), the geographical boundary of the present-day Assam became much smaller.

**Forms of sulphur and desulphurization:** The presenceof high-sulphur content in Assam coals has been reported in 1931 by Fox. Sulphur in these coals generally occurs in the range of 2.7-7.8%. Iyanger et al. termed the Assam coals as abnormal coals and suggested that the Abnormal behaviour is attributed to high-sulphur content. The total sulphur content of Margherita coal is 5.7%, for Nagaland coal is 3.63% and for Arunachal coal is 2.67%.The distribution of sulphur in these coals has been reported by various workers. The upper seams of these coals contain more sulphur than the seams lying below. However, chemical studies have revealed that there is no uniformity in the variation of sulphur in the seams in the lateral or in the vertical directions.

In regard to the incorporation of sulphur, two groups are of the same opinion that the presence of high sulphur in Assam coals is due to the atomic exchange reaction in which oxygen is substituted by elemental sulphur; however, these groups did not show any experimental evidence of such a reaction. A ligand substitution reaction mechanism in aqueous solution in which hydroxo is replaced by bisulphide.

Assam coal has three forms of sulphur- **sulphate, pyritic** and **organic sulphur.** The major portion of sulphur is in the organic form which is about 70-80% of the total sulphur. Combustion of high-sulphur coal forms $SO_2$ which is toxic and corrosive. Sulphur dioxide is subsequently converted to $SO_3$, which in contact with water, forms sulphuric acid. The presence of sulphur in coke beyond a certain limit makes it unsuitable for metallurgical purposes. In weathered coal sulphur percolates with ground water making the water the water highly acidic and causes the problem of acid mine drainage. The presence of moisture and sulphur are indications of the liability of coal to spontaneous combustion during storage. Other deleterious effects observed are – formation of acid rain, corrosion of boilers, underground pipelines, and metallic installations, mine machineries, etc. These problems caused by the presence of sulphur in coal indicate the need for the development of an effective desulphurization method for all coals in the world.

Various gases such as steam, ammonia, coal gas, hydrogen, nitrogen and water gas have been known to remove sulphur from Assam coal. A coal sample when allowed to be exposed to the atmosphere up to 106 days showed a decrease in the total sulphur content to the permissible limit of utilization. The sulphur content of coal has decreased on storage under water; this could be due to bacterial oxidation of reduced sulphur. Hydrogenation of Assam coal using anthracene oil has been shown to remove 90% of the total sulphur whereas with tetraline, removal of the total sulphur was only as high as 40-48%. Although the removal of sulphur using sodium alkyl or aryl has been known the extent of sulphur removal by chlorinolysis (using methanol) was only 48.70 to 56.45%. A large number of chemicals such as CaO and $CaCl_2$, Na2CO3 and NaHCO3, chlorides of Na, Mg, Zn and Sn, carbonates of Li, Na and K and sodium borohydride, aqueous hydrogen peroxide, silica, inorganic compounds, ore and tar have been used for removal of sulphur from Assam coal**[6]**.

### 1.2. What is Biomass?

Biomass refers to the organic material that is used for production of energy. This energy production process is referred to as Bioenergy0. Biomass is primarily found in the form of living or recently living plants and biological wastes from industrial and home use. Due to the breadth of the term, the physical composition of biomass is inconsistent, but generally includes carbon, water and organic volatiles. For the production of energy from biomass, the term feedstock is used to refer to whatever type of organic material will be used to produce a form of energy. The feedstock must then be converted to a usable energy form through one of many processes.

$$\text{Feedstock + Process} \longrightarrow \text{Usable Energy Form}$$

Some common biomass conversion processes include:

- **Combustion**: the process by which flammable materials are burned in the presence of air or oxygen to release heat. It is the simplest method by which biomass can be used for energy. In its rudimentary form, combustion is used for space heating (i.e. a fire for warmth) but can also be used to heat steam for electricity generation[1]
- **Gasification**: is the conversion of biomass into a combustible gas mixture referred to as Producer Gas ($CO+H_2+CH_4$) or syngas. The gasification process uses heat, pressure and partial combustion to create syngas, which can then be used in place of natural gas **[3]**.

The gasification of coal began in the 1800s century, and many developments are stated in the last 200 years, and since then coal is considered as a potential feed for gasification to produce syngas and liquid fuel. Biomass is more abundantly distributed over the earth and has an advantage over the other renewable sources. Also, biomass is the fourth-most important source of energy after coal, petroleum, and natural gas, and presently fulfil >10% of the global energy requirement. It is projected that biomass and different types of waste may contribute one-third of global primary energy demand by 2050. However, the biomass gasification has some limitation due to its intrinsic properties like high moisture content, low calorific value, high hydrogen content, and hygroscopic nature, low density, which makes it more crucial during transportation, storage and preparation for gasification [5].

- **Pyrolysis**: Consists of thermal decomposition in the absence of oxygen. It is the precursor to gasification, and takes place as part of both gasification and combustion[3]. The products of Pyrolysis include gas, liquid and a sold char, with the proportions of each depending upon the parameters of the process.
- **Anaerobic digestion** (or bio digestion): is the process whereby bacteria break down organic material in the absence of air, yielding a biogas containing methane and a solid residue. The methane can then be captured to produce energy. Similarly, the solid residue can also be burned to produce energy.
- **Fermentation**: involves the conversion of a plant's glucose (or carbohydrate) into an alcohol or acid. Yeast or bacteria are added to the biomass material, which feed on the sugars to produce ethanol (an alcohol) and carbon dioxide. The ethanol is distilled and dehydrated to obtain a higher concentration of alcohol to achieve the required purity for the use as automotive fuel. The solid residue from the fermentation process can be used as cattle-feed and in the case of sugar cane can be used as a fuel for boilers or for subsequent gasification **[3].**

Prior to the industrial revolution, biomass was the primary source of energy. Biomass now makes up only a small percentage of total world energy use. However, for approximately 2.5 billion people, it remains the primary source of energy for cooking and heating. The use of biomass is highly contextual to the region in which it is used – availability of resources, availability of technology and economic viability are all drivers of biomass use. Some jurisdictions – especially those with sustainable forestry initiatives – have declared biomass a "carbon neutral" energy source. This is based upon the logic that carbon emissions from burning biomass will be recaptured by the plants grown to feed biomass reactors in the future, thus forming a carbon cycle for the plant. The environmental benefits and costs are highly contextual depending on the technology and feed stocks used. While some biomass processes such as waste-to-energy are touted for their lower $CO_2$ emissions, some processes, such as combustion, release carbon dioxide and particulate matter that are a significant concern for human health. The world's most energy-poor peoples and regions still rely on biomass for the majority of their energy needs. The lack of appropriate ventilation mechanisms for burning biomass is a major health concern and contributes to short life expectancies in much of the developing world. Concerns associated with biomass go beyond human health. Depending upon the source of biomass used, deforestation, cropland degradation (due to diverting agricultural residues), and land use alteration can all be relevant issues associated with biomass **[3]**.

### 1.3. Co-blending:

Co-blending is a process that combines multiple materials to create a new material with specific properties. The properties of the new material are a result of the combination of the properties of the individual materials.

**1.3.1.Co-blending of Coal and Biomass**: Co-blending of coal and biomass is a process where coal and biomass are mixed together to create a fuel blend for power generation. This blend offers several benefits, including reduced greenhouse gas emissions and improved combustion efficiency. By combining coal with biomass, which is a renewable energy source, the overall carbon footprint of the fuel blend is reduced. Biomass can also improve the combustion efficiency of coal, leading to more efficient energy production. This approach can be cost-effective, as it can be done using existing coal-fired power plants. However, co-blending also presents some challenges. The quality of the biomass and coal can affect the overall performance of the fuel blend. Biomass can be more difficult to handle and store than coal, requiring specialized equipment and facilities. Co-blending is commonly used in coal fired power plants to reduce emissions and improve efficiency. It can also be used in industrial applications, such as cement production and paper manufacturing. The type and quality of biomass used can significantly impact the performance of the fuel blend, and the ratio of coal to biomass can affect the overall performance and emissions.

In the 21st century, renewable energy substitutes such as biomass are expected to surpass fossil-based resources due to their wider availability, abundance, $CO_2$ neutrality, and transportability. Henceforth in a need to protract global carbon emissions, pyrolysis emerges as a bottleneck on the unequivocal exacerbation of the anthropogenic $CO_2$ emissions into the atmosphere and produces clean fuel to increase the added value of pyrolysis products. The motivation and focus gearing up the drivers behind coal and biomass energy research is the sustainable formulation of energy products, primarily liquid fuel through the blending of biomass with coal in a process termed as co-pyrolysis.Co-pyrolysis is an integral section of the chemical industry and has several positive upshots concerning emissions, energy requirements, and pyrolysis product quality. It reduces the emissions of SOx, and NOx during pyrolysis and resulted in higher calorific value fuel including various oxygenated compounds. A brief exposition on co-pyrolysis of coal and biomass blends explores the sustainable development of energy resources to pacify the ongoing oil crisis. Literature exudes a review on the yields when biomass is co-pyrolyzed with coal; few of which shed light on its blending characteristics, devolatilization properties and others on its kinetics[7].

**Advantages:**

- **Reduced emissions:** Co-blending can reduce emissions of Sulphur Oxide($SO_2$), Nitrogen Oxide ($NO_x$), and greenhouse gases ($CO_2$).
- **Lower fuel costs:** Biomass can be used as a supplemental fuel to reduce the amount of coal needed.
- **Avoid landfills:** Biomass can be used instead of being land filled, which can help to reduce the cost of landfills.
- **Environmentally friendly**: Biomass fuels are considered environmentally friendly because they consume the same amount of CO2 from the atmosphere as they release during combustion.
- **Reduces $SO_2$ emissions:** Biomass fuels have little or no sulphur, whereas coal contains sulphur in both organic and inorganic forms, so co-blending can reduce $SO_2$ emissions.

## 2. Review of literature:

## 3. Materials and Methods:

### 3.1. Sample Collection:

The Coal sample was collected from the mines of Nagaland, Tuli. Whereas, the biomass was prepared from bamboo stalk (*Bambusa tulda Roxb.*) that was collected from Thengal gaon, Titabor, Assam.

## (2) REVIEW OF LITERATURE:

Growth in energy consumption resulting from the surge in population has led to increase in greenhouse gases emission and quickened the progression of climate change (World Energy Council, 2015). These issues, along with the exhaustion of fossil fuel reserves have inspired the need for the transformation of the energy map towards sustainability.

This utilisation of fossils contributes to the alarmingrise in $CO_2$ emissions worldwide. Reduction of such emissions have beenproposed by utilisation of various low carbon energy sources (renewable andnuclear energy), these alternatives contribute to less than 20% of the globalenergy demands (BP, 2016)**[36]**.

Since, the high pollution associated with coal usage demands investigation into ways of improving thermal conversion of coal while reducing the resulting environmental issues. Past researchers have highlighted the role of biomass usage as a supplementary fuel to improving the combustion behaviours of coal. Co-combustion of coal and carbon-containing fuels, especially biomass, is thought to be a good choice for the goal of carbon neutrality. Regardless of tremendous studies on the co-combustion characteristics, the effects of biomass blending on the emission behaviour of toxic heavy metals are still not so clear due to the differences in volatility of heavy metals, the wide variety of raw blended materials, the changeable operating conditions, and the huge difference in experimental scale**[37]**.

As a result, several studies have investigated the influence of co-firing on thermal decomposition profiles using thermogravimetric approaches and their observations highlight the importance of evaluating changes in combustion profiles. In addition, the role of catalytic and non-catalyticsynergy influences hadalso been extensively discussed but only a handful of studies have experimentallyapproached the isolation of both mechanisms of synergy.The co-firing of coal with biomass is a simple but cost-effective approach to large-scale deployment of biomass in pulverized fuel utility boilers. However, owing to the significant difference in the combustion characteristics of biomass and coal, only partial substitution of coal is acceptable in order to reduce the degree of performance incompatibility to an acceptable level in utility boilers.This partial substitution of coal with biomass offers benefits such as reduced emissions of $NO_x$, $SO_x$ and greenhouse gases due to the low sulphur, low nitrogen and carbon lean nature of biomass compared with coal. This will also improve energy conversion efficiency and economics of biomass utilization as well as its energy conversion efficiency.Furthermore, co-blending can lead to the improvement in the efficiency power plants with minimal technical risks on implementation**[38]**. This study also reported that the char that was obtained after the pyrolysis of co-blended samples can reduce the use of inorganic fertilisers that are employed in large-scale crop cultivation as the char contained large amount of $N_2$.

### 3.1.1. Sample Preparation:

For sample preparation the coal and biomass were crushed using mortar and pestle. Then it was further crushed in the Rotor Beater mil to a size of 212 µm and was sieved in the Sieve Shaker. The sample thus prepared was further used for analysis and studies.

Fig 6: Biomass sample after sieving

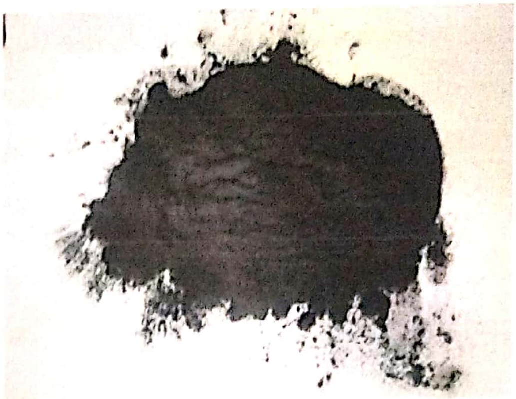

Fig 7: Coal sample after sieving.

## 3.2. Sample Characterisation:

### 3.2.1. Proximate Analysis:

It provides information on moisture content, ash content, volatile matter content and fixed carbon content of the material that was taken for analysis. Fixed carbon other ash does not vaporise when heated in anaerobic conditions. The fixed carbon content was determined by subtracting the sum of moisture content, volatile matter content and ash content from 100. In most cases ash is an undesirable residue that is also a source of pollution. The heat value of a material comes from after excluding moisture, volatile matter and fixed carbon content.For analysing the moisture percentage in the samples Hot Air Oven (Model No. PID 702) was used and for ash and volatile matter analysis of the samples muffle furnace (Okay Model: 60F6) was used Method No. IS-1350(Part 1)-1984(Reaffirmed 2019) was employed as reference for the analysis. For biomass sample Method No. ASTM D3173-75 was employed for the analysis of moisture, ash and volatile matter.

#### (a)Determination of moisture content:

Total moisture is the loss in weight in an air atmosphere under rigidly controlled conditions of temperature, time, airflow and residual moisture. 1g of sample was taken in a crucible and was dried at 105 °C to 110 °C in Hot Air Oven for an hour.

Equation for Moisture Content Determination:

$$\text{Moisture\%} = 100\left(\frac{M_2 - M_3}{M_2 - M_1}\right)$$

$M_1$ = mass in g of the vessel + cover
$M_2$= mass in g of the vessel + cover + sample before heating
$M_3$= mass in g of the vessel + cover + sample after heating

**(b)Determination of ash content:**

The non-combustible residue left after the sample is burnt is called ash;a clean dry empty silica dish is weighed. Into the dish about 1g of sample is weighed accurately. The sample is equally distributed in the dish. Then the uncovered dish was inserted into the muffle furnace that was maintained at room temperature. The temperature was raised to 800° C ± 10° C for 2 hours and maintained at this temperature for an hour.

Equation for determination of ash content:

$$\text{Ash\%} = 100\left(\frac{M_3-M_4}{M_2-M_1}\right)$$

$M_1$= mass in g of the dish
$M_2$= mass in g of dish and sample
$M_3$= mass in g of the dish and ash
$M_4$= mass in g of the dish after brushing out the ash and on reweighing

**(c)Determination of volatile matter content:**

The method consists of heating of 1g of the coal sample taken in a crucible at a temperature 900°C ± 10°C for seven minutes. The crucible is then removed from the furnace and cooled and is weighed as soon as it is cold.

Equation for determination of volatile content:

$$\text{\% of volatile content} = 100\left(\frac{M_2-M_3}{M_2-M_1}\right)-M_0$$

$M_1$= mass of the empty crucible along with the lid

$M_2$= mass of the crucible + lid + sample before heating

$M_3$= mass of the crucible + lid + sample after heating

$M_0$= percentage of moisture in the sample on air dried basis

**(d)Determination of Fixed carbon content:**

Fixed carbon is the solid combustible residue that remains after a biomass particle heated and the volatile matter expelled. The fixed carbon content of a biomass is determined by subtracting the percentage of moisture, volatile matter and ash content from the sample.

Fixed carbon content (%) = 100- [moisture (%) + ash (%) volatile matter (%)]

### 3.2.2. Ultimate Analysis:

The ultimate analysis is performed to determine the elemental composition of the material. Ultimate analyses are used to determine the carbon, hydrogen, nitrogen, sulphur, ash, oxygen contents of the material. For the specific applications, other chemical analyses can be employed. These include identifying the forms of sulphur present. Sulphur occurs in the form of sulphide minerals, sulphate minerals, or organically bound sulphur. Other specific cases the analyses may involve determining the trace elements present which influences the suitability of the material for a particular purpose. This may include methods for reducing environmental pollution and so forth.

It was carried out in Leco Truspec- CHN Elemental Analyser (630-300-100) which provides carbon, hydrogen, nitrogen and sulphur percentage composition. The ASTM Standard of D-5373-21 was employed as reference for analysis of hydrogen and carbon in coal and biomass sample.

### 3.2.3. Calorific Value:

The heating value or calorific value of a substance is the amount of heat released during the combustion of a specified amount of it. The calorific value is a characteristic for each substance. It is measured in units of energy per unit of the substance, usually mass, such as: kcal/kg, kJ/kg, J/mol, Btu/m$^3$. Heating value is commonly determined by use of a bomb calorimeter. The heat of combustion for fuels is expressed as the HHV, LHV, or GHV:

The quantity known as higher heating value (HHV) (or gross calorific value or gross to the original pre-combustion temperature, and in particular condensing any vapour produced. This is the same as the thermodynamic heat of combustion since the enthalpy change for the reaction assumes a common temperature of the compounds before and after combustion, in which case the water produced by combustion is liquid.

The quantity known as lower heating value (LHV) (or net calorific value) is determined by subtracting the heat of vaporization of the water vapour from the higher heating value. This treats any $H_2O$ formed as a vapor. The energy required to vaporize the water therefore is not released as heat.

Gross heating value accounts for water in the exhaust leaving as vapour, and liquid water in the fuel prior to combustion. This value is important for fuels like wood or coal, which will usually contain some amount of water prior to burning.

For this process a weighted amount of sample is kept in a silica crucible, which is supported over the ring. Sufficient amount of oxygen is supplied to the bomb till a pressure of

25-30atm, is reached. After through stirring, initial temperature of the water in the calorimeter is noted. Current is supplied and fuel in the crucible burns producing heat which is transferred to water which is stirred throughout the experiment by stirrer. The maximum temperature shown by the thermometer enclosed with the calorimeter is recorded and the calorific value of fuel can be calculated [8][9].

### 3.2.4. FTIR Analysis:

Fourier Transform Infrared spectroscopy (FTIR) is an important analysis technique that detects various characteristic functional groups available in the sample. Interaction of an infrared light with sample the chemical bond with stretch, contract and absorb infrared radiation in a specific wavelength range in the presence of the rest of molecules. Based on this, principle functional groups present in the coal were identified. The FTIR spectra were collected generally in the range of 400-4000 $cm^{-1}$ region. Absorption in the infrared region makes changes in the vibrational and rotational states of the molecules. The absorption frequency depends greatly on the vibrational frequency of the molecules. The absorption intensity depends on the change in the dipole moment that occurs as a result of molecular vibration. A molecule will absorb infrared light only if the absorption causes a change in the dipole moment. All compounds except for elemental diatomic gases such as $N_2$, $H_2$ and $O_2$, have infrared spectra and most components present in a flue gas is also analysed by their characteristic infrared absorption. If only one species is analysed, a species-specific instrument can also be used. The analysis is carried out in a narrow wavelength interval, where the species of interest has a characteristic absorption. Other components present in the sample also absorb at the analytical wavelength, so the spectrometer should be calibrated for cross-sensitivities. Quantification of several components absorbing in the mid-infrared region (0-4500 $cm^{-1}$), either conventional dispersive infrared analysis or Fourier Transform Infrared (FTIR) spectroscopy can also be used. Compared to dispersive IR analysis, FTIR analysis is faster and has a better signal to noise ratio.

In an FTIR instrument, the monochromatic and the slits are replaced by an interferometer of Michelson type. A beam of radiation is divided into two beams by means of beam splitter. A path difference between the beams is also introduced whereupon it is allowed to recombine. In this way, interference between the beams is obtained. The intensity of the output beam from the interferometer is monitored as a function of path difference using an appropriate detector.

In order to determine the functional groups, present in the sample, Fourier Transform Infrared Spectroscopy of the sample is being analysed in the Perkin – Elmer Infrared Spectrometer.

## 4. Thermochemical behaviour of Co-blending of Coal and Biomass Samples:

### 4.1. Thermo-Gravimetric Analysis (TGA):

Thermo-gravimetric analysis or thermal gravimetric analysis is mainly considered as a type of testing on samples which determines changes in weight to a temperature program in a controlled atmosphere. It relies on a high degree of precision in two basic aspects which are weight and temperature. As most weight loss curves look more or less similar, the weight loss curve may require keen analysis before results may be interpreted. A derivative weight loss curve can identify the point where weight loss is most prominent. Interpretation is limited without further modifications of the overlapping peaks. For the determination of the composition and purity, one must take the mass of the substance in the mixture by using thermal gravimetric analysis.

Thermo-gravimetric analysis is a process which involves heating a mixture to a temperature that is high enough to decompose a component to gaseous form that dissociates into the air.

Thermo-gravimetric analysis is a process which utilises heat and stoichiometry ratios to determine the percent by the mass ratio of a substance. If the compounds in the material remain known, then the percentage by mass is determined by taking the weight of the leftover in the mixture and dividing it by the initial mass. After knowing the mass of the original mixture, the total mass of impurities liberating upon heating then the stoichiometric ratio can be used to calculate the percent mass of the substance in a sample. TGA is used in research and testing to determine characteristics of materials such as absorbed moisture content of materials, the level of inorganic and organic components in materials, polymers, to determine degradation temperatures, decomposition points of explosives, and solvent residues. It is also often used to estimate the corrosion kinetics in high-temperature oxidation.

The analyser consists of a high-precision balance with a pan of platinum loaded with the sample. Pan resides in a furnace and is heated or cooled during the experiment. Different process using a quartz crystal microbalance is devised for measuring smaller samples on the order of a microgram versus milligram with conventional TGA. The sample placed in a small electrically heated oven with a thermocouple for accurate measurement of the temperature. The atmosphere may be supplied with an inert gas to prevent oxidation or other undesired reactions. A computer is employed to control the instrument.

Pyrolysis is heating of a substance in the absence of air at a particular temperature. Therefore, the temperature for effective Pyrolysis of the coal sample and bamboo stalk powder has to be determined. For this purpose, thermo-gravimetric analyses (TGA) of the samples were done using simultaneous TG-DTA/DSC Apparatus (Model: STA 449 F3 Jupiter). Thermo-gravimetric Analyzer Instrument. Around 10 milligrams of sample was taken and heated up to a final temperature of 1000°C. TGA was performed at a heating rate of 5°C/Min and 10°C/Min. Thermo-gravimetric weight loss curve was plotted against temperature. It provides a range of temperature in which maximum thermal degradation of bamboo stalk powder and coal sample takes place.

## 5. Results and Discussion:

### 5.1. Physicochemical characterisation of Coal and Biomass:

### 5.1.1. Proximate Analysis:

Table 1: Proximate Analysis of the samples:

| Sample | Moisture content % | Volatile matter content % | Ash content % | Fixed Carbon content % |
|---|---|---|---|---|
| 1.CT (Coal Tuli, Nagaland) | 7.64% | 40.5% | 5.53% | 46.31% |
| 2. Biomass (*Bambusa tulda Roxb)* | 8.54% | 71.20% | 3.24% | 17.02% |

The proximate analysis of the samples of coals and biomass were performed under physicochemical analysis. The moisture content, volatile matter content, ash content and fixed carbon content of the coal sample was found out to be 7.64%, 40.5%, 5.53% and 46.31% respectively. Similarly for the biomass samples the moisture content, volatile matter content, ash content and fixed carbon content was found out to be 8.54%, 71.20%, 3.24% and 17.02% respectively.

### 5.1.2. Ultimate Analysis:

Table 2: Ultimate Analysis of elemental composition of Carbon and Hydrogen in the samples

| Sample | Carbon | Hydrogen |
|---|---|---|
| Coal (CT) | 64.6 | 5.11 |
| Biomass *(Bambusa tulda Roxb)* | 45.9 | 5.84 |

Ultimate analysis of the samples was performed in CHN Elemental Analyser from which the compositional percentage of carbon and hydrogen for coal sample was found to be 64.6% and 5.11% similarly, for biomass it was 45.9% and 5.84% respectively.

## 5.2. Chemical Characterisation of the Samples:

### 5.2.1. FTIR Analysis:

#### 5.2.1.1. FTIR Analysis of the Coal Sample:

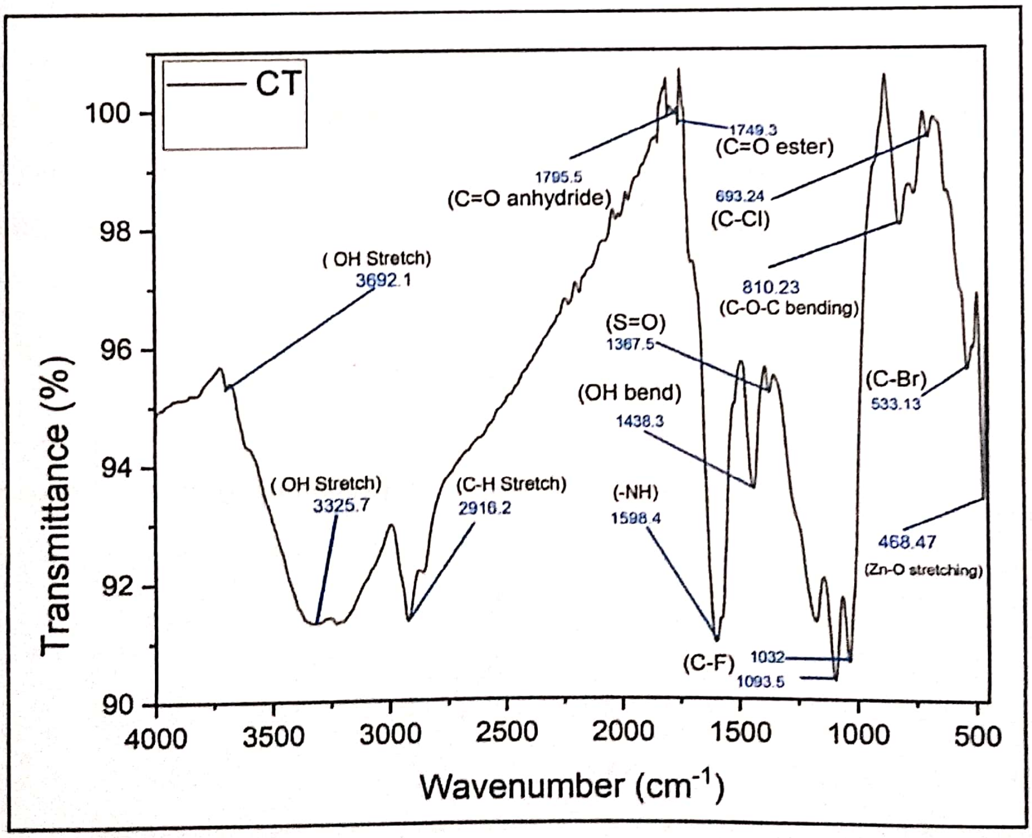

Fig 8: FTIR Analysis of Coal Sample of TULI, NAGALAND

This FTIR spectrum of Tuli coal reveals absorption peaks at certain wave numbers ($cm^{-1}$), proving the existence of various chemical bonds. Approximately 3400 $cm^{-1}$ (broad peak): O-H stretching (due to hydroxyl group presence in moisture or organic material). This is because the O-H bonds oscillate with this frequency and absorb corresponding IR energy. Approximately 2900 $cm^{-1}$: C-H stretching (from alkyl groups in the structure of the coal). Absorption of energy by stretching vibration of C-H bonds occurs in this region. Approximately 1780-1740 $cm^{-1}$: C=O stretching (potentially from anhydrides and esters, showing oxygen containing functional groups). The higher frequency vibration of the double bond of carbon and oxygen gives rise to absorption in this region. Approximately 1600 $cm^{-1}$: C=C stretching (from aromatic rings or coal containing unsaturated compounds). Carbon-carbon double bond stretching absorbs IR energy in this region. At about 1030 $cm^{-1}$: C-O stretching (from ethers, alcohols, or carboxylic acids). Single bond vibration between carbon and oxygen leads to absorption at this lower frequency. There are other weaker peaks too, which may be due to S=O bonds (about 1150 $cm^{-1}$), C-Cl bonds (about 700 $cm^{-1}$), and C-Br bonds (less than 600 $cm^{-1}$). The most prominent peak seems to be the broad absorption band with a centre at about 3400 $cm^{-1}$. The width of the peak indicates the existence of hydrogen bonding, which reduces the strength of the O-H bond and causes the absorption to shift towards lower frequencies, as well as broadening the band.

Each bond type in a molecule oscillates at certain frequencies, similar to a spring. When infrared light with the same frequency as a bond's vibration is directed onto sample, the bond absorbs the energy, leading to a reduction of transmitted light at that frequency.

Table 3: FTIR analysis of Coal Sample (CT)

| **Sample code** | **Absorption ($cm^{-1}$)** | | **Appearance** | **Group** | **Compound class** |
|---|---|---|---|---|---|
| CT | 700-600 | 693.24 | Strong | C-I stretching | Halo |
| | 800-700 | 751.73 | Strong | C-Cl stretching | Halo |
| | 950-810 | 810.23 | Strong | C-O-C stretching | Ether |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  | 1400-1000 | 1032 | Strong | C-F stretching | Fluoro compound |
|  | 1400-1000 | 1093.5 | Strong | C-F stretching | Fluoro compound |
|  | 1370-1335 | 1367.5 | Strong | S=O stretching | Sulphonamide |
|  | 1420-1330 | 1438.3 | Medium | O-H Bending | Alcohol |
|  | 1650-1580 | 1598.4 | Medium | NH Bend | Amine |
|  | 1750-1735 | 1749.3 | Strong | C=O | Ester |
|  | 1818-1750 | 1795.5 | Strong | C=O | Anhydride |
|  | 3000-2840 | 2916.2 | Medium | -C-H | Alkane |
|  | 3550-3200 | 3325.7 | Strong | OH stretch | Alcohol |
|  | 3700-3584 | 3692.1 | Medium | OH stretch | Alcohol |

### 5.2.1.2. FTIR Analysis of the Biomass Sample:

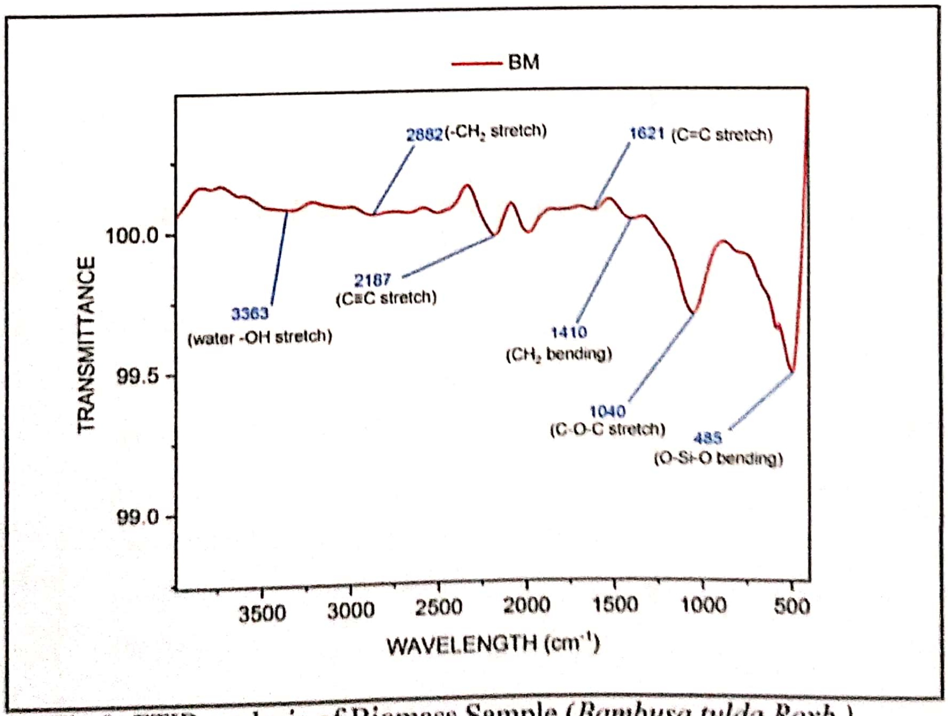

Fig 9: FTIR analysis of Biomass Sample (*Bambusa tulda Roxb.*)

The FTIR spectrum of (*Bambusa tulda Roxb.*) biomass between 400-4000cm-1 reveals major functional groups by its peaks. Intensive absorption at around 3363cm-1 signify rich O-H stretching from water and structural carbohydrates (lignin, hemicelluloses, cellulose) and the intensive peak at 1040cm-1 signify C-O-C stretching in glycosidic linkages. Smaller peaks at 2882 cm-1 (CH2 stretching), 1621 cm-1 (C=C stretching in aromatic lignin), 1410 cm-1 (CH2 bending), and 485 cm-1 (O-Si-O bending from silica) offer additional compositional information, with a small peak at 2187 cm-1 possibly indicating alkynes. These spectral peaks are due to absorption of infrared radiation at particular vibrational frequencies of the existing chemical bonds, with peak height a measure of concentration. The high content of carbohydrates and lignin indicates favorable potential for bio fuel, pulp, paper and composite uses, while the high water content and possible alkynes may present difficulties. Silica presence can be advantageous in some uses, like in the creation of specific composites or as a source of silicon materials. But high silica levels may be harsh on processing machinery in some uses.

This FTIR examination of (Bambusa tulda Roxb.) biomass provides a carbohydrate (cellulose and hemicelluloses) and lignin-rich composition with the inherent presence of silica. The very prominent water peak indicates the need for moisture regulation based on intended application. Continued analysis and comparison to reference spectra can yield greater quantitative and qualitative insight into this biomass.

Table 4: FTIR analysis of biomass sample (*Bambusa tulda Roxb.)*

| **Sample code** | **Absorption(cm$^{-1}$)** | | **Appearance** | **Group** | **Compound class** |
|---|---|---|---|---|---|
| *Bambusa tulda Roxb.* | 465-485 | 485 | Weak | O-Si-O | Silicates |
| | 1400-1000 | 1040 | Strong | C-O-C stretching | Ethers, esters |
| | 1420-1330 | 1410 | Medium | $CH_2$ Bending | Alkanes, alkyl groups |
| | 1650-1580 | 1621 | Medium | C=C stretching | Alkenes |
| | 2260-2100 | 2187 | Weak | C≡C stretching | Alkynes |

| | | | | | |
|---|---|---|---|---|---|
| | 3000-2850 | 2882 | Medium | $CH_2$ stretching | Alkanes, alkyl groups |
| | 3700-3100 | 3363 | Strong | Water –OH stretching | Alcohol |

### 5.2.2. TGA Analysis:

### 5.2.2.1. TGA Analysis of Coal Sample:

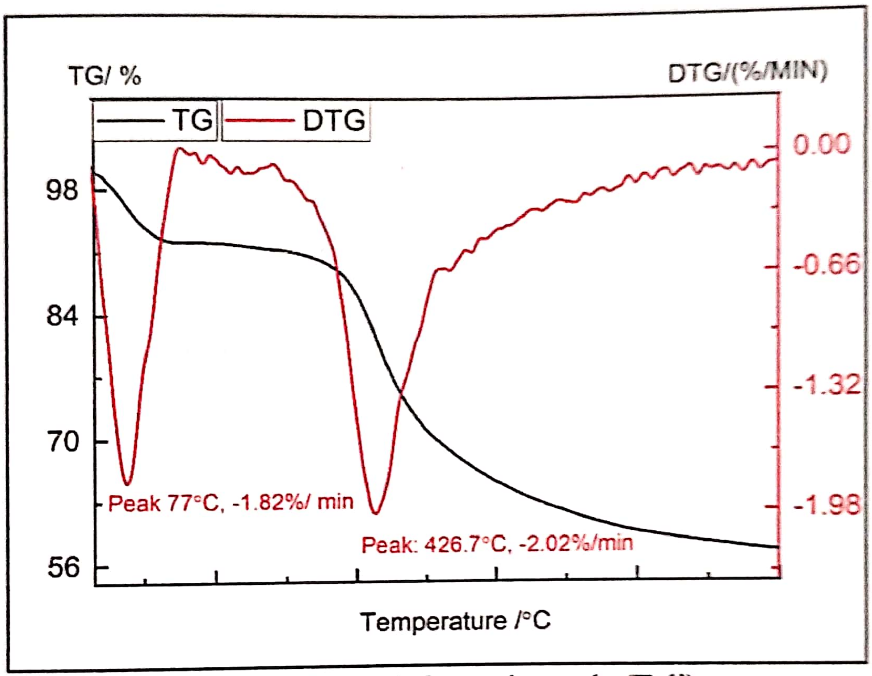

Fig 10: TGA graph for coal sample (Tuli)

The TGA graph for coal sample Tuli represents the weight loss of the coal sample as the temperature increases. In the TG Curve there is a preliminary, comparatively abrupt decline in mass from about 98% to about 90-92% as temperature rises from ambient to around 150-200°C. In DTG Curve there is a major peak at about 77°C with a mass loss rate of -1.82%/min. This is typical of the evaporation of water (moisture) from the coal sample. Coal is porous and has surface moisture and inherent moisture. This first mass loss is the evaporation of this water.There is then a much greater and more gradual mass loss that begins from about 200°C and extends through to about 600-700°C. The mass drops from about 90% to around 56% in the TG Curve. In DTG Curve there is a wide and very high peak, with the peak rate of mass loss (the "Peak") at about 426.7°C at a rate of -2.02%/min.This area is the devolatilization process, where the organic content of the coal breaks down and emits different volatile substances like hydrocarbons, CO, CO□, H□O (from breakdown), etc. High rate of mass loss in this period reflects that huge amounts of volatile material have existed in the sample of the Tuli coal. The top at 426.7°C indicates the temperature upon which the significant devolatilization takes place in activity. Following the initial devolatilization, the mass loss rate slows drastically, and the TG curve becomes flat as temperature continues to rise above 700°C, forming a plateau around 56% residual mass. This shows that the majority of the volatile material has been lost, and what remains is char (fixed carbon) and ash.The DTG curve tends toward zero, which shows that the rate of mass loss is very slow or none in this high-temperature zone. The last stable mass percentage on the TG curve, about 56%, is the total content of fixed carbon and ash left after the complete pyrolysis of the coal sample under the conditions. Individual percentages of fixed carbon and ash would require additional analysis (e.g., ultimate analysis, or running the TGA under an oxidizing atmosphere to consume the fixed carbon).

#### 5.2.2.2. TGA Analysis of Biomass Sample:

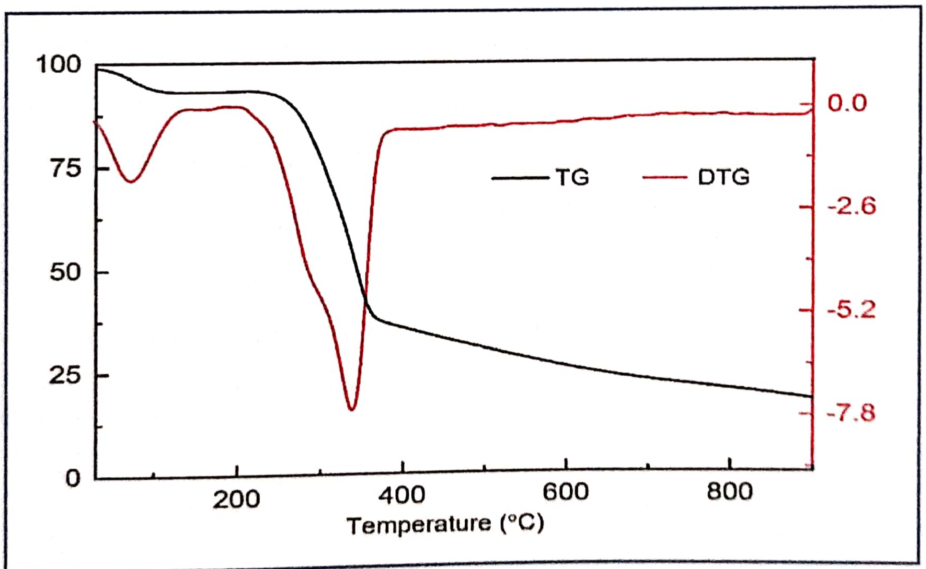

Fig 11: TGA Graph for Biomass (*Bambusa tulda Roxb.*) Sample.

This TGA analysis provides valuable information about the thermal decomposition behaviour of the (*Bambusa tulda Roxb.)* biomass sample. It reveals the different stages of decomposition related to the release of moisture, hemicelluloses, cellulose, and lignin at specific temperature ranges, ultimately leaving behind residual ash content. This kind of information is crucial for understanding the thermal stability and potential applications of this biomass, such as in bioenergy production or material science.

The TGA and DTG curve of the (*Bambusa tulda Roxb.)* biomass sample depicts that in TG Curve there is a slight initial mass loss between room temperature and up to about 100-150°C. The mass drops from 100% to about 90-95%. In DTG Curve there is a small peak at below 100°C. The peak shows the evaporation of moisture in the biomass sample.There is a high mass loss between around 200°C and 400°C, with the mass going from around 90% to around 25% in TG curve. In DTG Curve a broad, high peak is seen in this range of temperatures.The DTG curve presents lower peaks or shoulders at higher temperatures, reflecting decomposition of thermally more stable parts and char formation. The last stable mass percentage on the TG curve, attained at temperatures of over 600°C, is the residue mass, which is the sum of ash and fixed carbon. For this instance, the residue mass is approximately 25%.

### 5.2.2.3. TGA Analysis of Co-blended Sample of Coal and Biomass:

This study examines how blending biomass with coal affects the thermal breakdown of the mixture. It analyses different ratios of biomass and coal heated at a constant rate, observing the resulting mass loss at temperatures up to 1000°C. The process is broken down into dehydration, devolatilization, and carbonization stages. The study aims to address the negative effects of using coal alone, such as the release of toxic gases, by combining it with biomass in varying proportions.

The biomass and coal percentages along with the resulting residual mass percentages after the thermal analysis:

Table 5: Blending ratios Biomass (*Bambusa tulda roxb.)* and Coal (Tuli) sample

| **Biomass (%)** | **Coal (%)** | **Residual Mass (%)** |
|---|---|---|
| 50 | 50 | 30.20 |
| 60 | 40 | 31.76 |
| 66 | 34 | 28.92 |
| 75 | 25 | 25.42 |

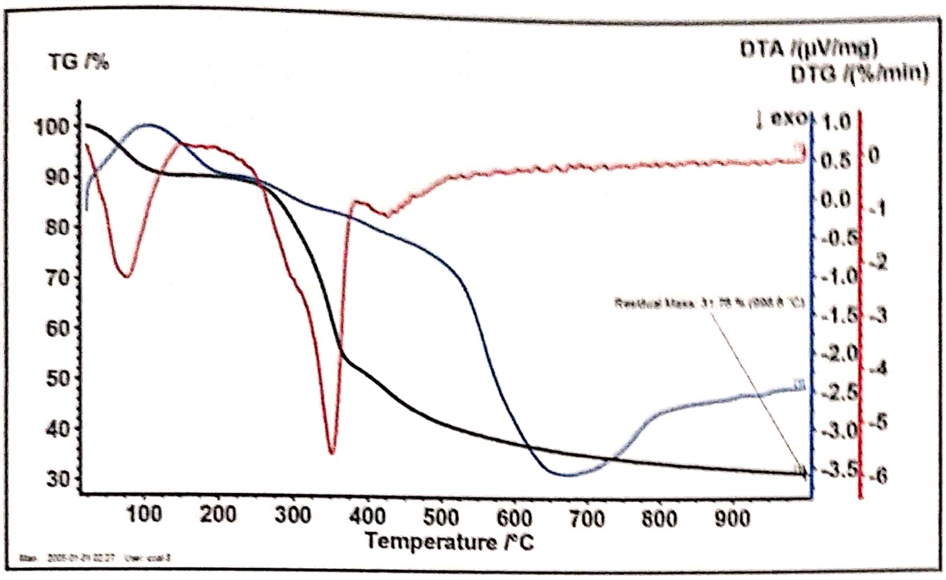

Fig 12: TGA analysis graph for co-blended samples of Coal and Biomass(40:60)

The thermogravimetric Analysis (Fig 12) graph provides insight into the mass lossof the material break down in a 40:60 co-blended of coal-biomass sample. In X-axis: Temperature (°C), rangebetween100-900°C; Left Y-axis: TG (%) - percentage of the mass ofthesampleremainingupon heating; Right Y-axis: DTG (%/min) - rate of mass loss andameasure of relative intensity of all the decomposition processes operating simultaneously at different temperatures. Test conditions: The sample (11.203 mg) was heated at 40°C/min under nitrogen conditions (N2 1000 mL/min) from 35°C to 1000°C.

The TG curve (Black Line) indicates the mass loss of the sample as temperature rises. From 100°C to ~200°C, there's a minor initial mass loss (~5-10%), probably due to the evaporation of moisture (drying phase).Between ~200°C and 500°C, there is a major mass loss (from ~90% to ~40%). This is in agreement with the initial decomposition of volatile matter, mainly from the biomass fraction, which normally decomposes at lower temperatures (200°C–400°C) than coal. From 500°C to 900°C, the rate of mass loss reduces, levelling off at 31.76% residual mass at 998.6°C. This residual mass is presumably the ash content and fixed carbon, with coal adding more to this phase as it devolatilizes at higher temperatures (400°C–800°C). The DTG Curve (Red Line) indicates the rate of mass loss, and the peaks represent the temperatures at which the decomposition happens most quickly. There are two prominent peaks: The first peak (~300°C–350°C) is presumably because of thermal decomposition of biomass materials such as hemicellulose and cellulose, which decompose at lower temperatures. The second peak (~400°C–500°C) represents decomposition of lignin (from biomass) and initiation of coal devolatilization minor shoulder or a prolonged tail beyond 500°C represents slow decomposition of coal's fixed carbon and perhaps some char combustion or gasification reactions.DTA Curve (Blue Line): The Differential Thermal Analysis (DTA) curve (in µV/mg) represents the changes in energy in the process. Positive exothermic peaks (marked as "exo") around 400°C–500°C imply heat release, probably due to combustion or decomposition of volatile matter. The DTA curve follows the DTG peaks, indicating that the significant mass loss phenomena are linked to exothermic reactions. The 40:60 coal-to-biomass ratio implies a blend where biomass is predominant. Biomass usually pyrolyzes at low temperatures (200°C–400°C) because it contains high amounts of volatiles (hemicellulose, cellulose, lignin), whereas coal pyrolyzes at elevated temperatures (400°C–800°C) because it contains more fixed carbon. The DTG overlap peaks show there is some interaction between the two materials, and it could be synergistic effects where the biomass decomposition helps in the breakdown of coal volatiles.

The residual final mass at 998.6°C (31.76%) represents the fixed carbon and ash content. Coal tends to have higher ash content than biomass, so the value of this parameter is more affected by the coal fraction. Moisture loss happens up to around 200°, following biomass decomposition of 200°-400°, which is marked by considerable mass loss from volatiles. Coal decomposition occurs in the 400°-800° range with lower mass loss and higher temperature range. Above 800°, char and ash residue are left. This TGA/DTG analysis is helpful in investigating the thermal behavior of coal-biomass blends, especially for co-firing in power plants. The increased volatile content in biomass may result in greater ignition and combustion efficiency, while higher fixed carbon content coal supports more steady energy output. Residual mass and decomposition pattern may be used to optimize the blend ratio and process conditions to avoid slagging or fouling.

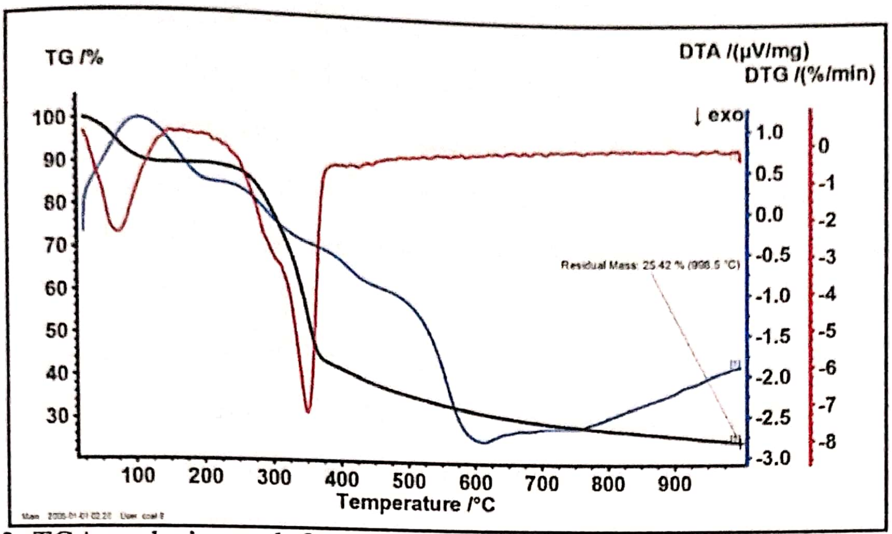

Fig 13: TGA analysis graph for co-blended samples of Coal and Biomass (25:75)

The TGA graph (Fig 13) of the co-blended sample of coal and biomass at a 25-75% blending ratio depicts the final residual mass is 25.42% at 998.5°C, i.e., 74.58% of the sample combusted or decomposed. There is a small mass loss (~5-10%), with a DTG peak (red line) at about 100°C. This is because water evaporation occurs from the coal and biomass. The 75% biomass proportion, which would have more water content, triggers this initial loss. There is an extensive mass loss between 200°C and 500°C, with the TG curve (black line) from ~90% to ~40%. The DTG curve is characterized by a steep peak at 350°C, which reflects quick decomposition. This is the stage where volatile matter, mainly from the biomass, is released and burned. Biomass fractions such as hemicellulose (220-315°C), cellulose (315-400°C), and lignin (150-500°C) decompose and burn when exposed to 30% oxygen. The DTA curve (blue line) has an exothermic peak (exo, upward) at approximately 350°C, which is indicative of combustion. Coal makes little contribution in this case, since its volatile matter burns at higher temperatures, but the oxygen atmosphere supports the burning of biomass volatiles. Above 500°C, the TG curve indicates a reduced rate of mass loss, levelling off at 25.42% by 900°C. The DTG curve exhibits a lower peak between 500-600°C, which suggests char combustion.The DTA curve also reveals an exothermic peak around 550°C that is associated with the combustion of char in biomass and coal. The 25% coal composition helps the char, since coal contains more fixed carbon than biomass. The amount of residue mass (25.42%) is less than in an entirely inert atmosphere (as in the previous graph), because the oxygen causes more complete burning. The 30% oxygen, 20% nitrogen atmosphere favors burning, as opposed to the inert nitrogen atmosphere of the previous graph. This gives rise to exothermic peaks in the DTA curve and a reduced residual mass due to the oxidation of carbon to CO□.The biomass-rich blend (75%) is more easily burnt in this oxidizing atmosphere, adding to the high mass loss.The 25-75% blend is biomass-dominated during the initial phases (combustion of volatiles), whereas coal fixed carbon assists in the char combustion at high temperatures. Oxygen present increases the combustion of both coal and biomass, resulting in a reduced residual mass compared to pyrolysis in an inert atmosphere.

The TGA plot of the 25-75% coal-biomass co-blend in the oxidative atmosphere (30% O□, 20% N□) presents three phases: loss of moisture (100-200°C), combustion of volatiles (200-500°C), and combustion of char (500-900°C). The biomass-rich mixture produces extensive initial mass loss and burning, as evidenced by the DTG and DTA peaks, while coal helps form the residue char. The residual mass at the end of 25.42% represents the increased burning due to the oxygen environment and is thus apt for co-firing purposes where complete burning is required.

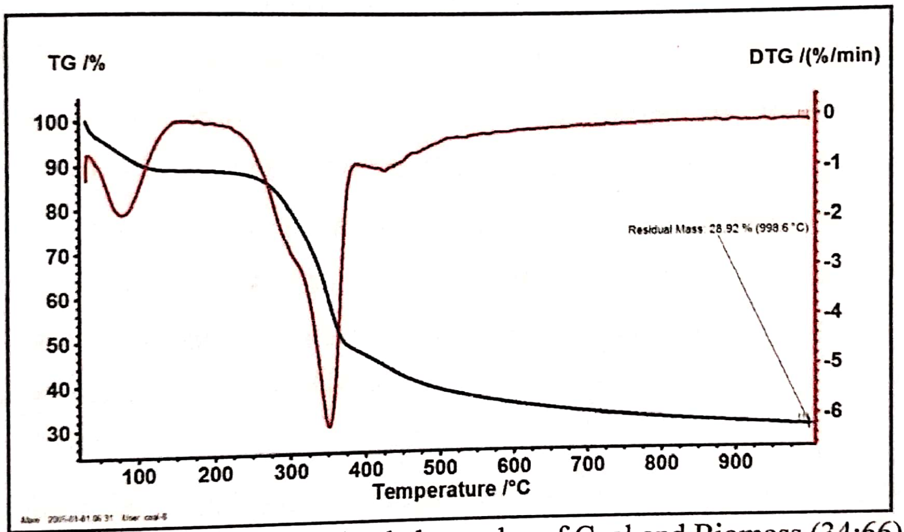

Fig 14: TGA analysis graph for co-blended samples of Coal and Biomass (34:66)

The TGA (Thermogravimetric Analysis) curve (Fig 14) depicts the thermal decomposition characteristic of a co-blended coal-biomass sample in a 34-66% blending ratio (34% coal, 66% biomass) under a nitrogen environment with a heating rate of 10 K/min. From 100°C to 900°C, indicating the temperature trend in the experiment. In left Y-axis (TG, %) the residual mass percentage of the sample, starting at 100% (initial mass) and going down as the sample decomposes. Final residual mass of 28.92% at 998.6°C indicates that 71.08% of the sample decomposed or volatilized.Early minor mass loss (~5-10%) is observed with a peak occurring around 100°C, as indicated by the DTG curve (red line). This is probably because of evaporation of moisture content in the coal and biomass. Biomass will generally contain more moisture content than coal, and hence this initial fall is greaterin a 66% biomass mixture.There is a large mass loss between 200°C and 500°C, with the TGcurve (black line) falling steeply from ~90% to ~40%. The DTG curve presents a large peakat approximately 350°C, reflecting maximum mass loss rate. This is the region associatedwith thermal decomposition of volatile components, mainly of the biomass fraction. Biomass (presumably having cellulose, hemicellulose, and lignin) undergoes decomposition at lower temperatures (200-400°C) than coal. Hemicellulose usually breaks down between 220-315°C, cellulose between 315-400°C, and lignin between wide ranges of temperatures (150-500°C).Coal, being richer in fixed carbon, makes a smaller contribution to this phase since its release of volatile matter takes place at elevated temperatures. After 500°C, the mass loss decelerates, with the TG curve levelling off at 28.92% by 900°C. The DTG curve gives a smaller but wider peak around 700-800°C, corresponding to slower decomposition. This step comprises the degradation of more heat-resistant components like fixed carbon from coal and the residual lignin from biomass. The 34% coal composition probably accounts for this residual mass since coal contains a higher char yield than biomass. The 34-66% coal-biomass mixture exhibits a decomposition profile that exhibits contributions from both materials. Biomass is the major contributor to the early volatile release (200-500°C), and coal is a significant contributor to the residual char at higher temperatures. The mixing can result in synergies, wherein the high volatile content of biomass can facilitate enhanced devolatilization of coal, and the fixed carbon in coal can stabilize the char structure, such that a greater residual mass than that for biomass alone results.

The experiment was carried out in a nitrogen environment (inert), and hence the mass loss due to pyrolysis (thermal decomposition) and not combustion. 10 K/min heating rate provides a slow decomposition, which is characteristic for investigation of thermal behaviour of such blends.$Al_2O_3$ crucible and $N_2$ gas flow (1000 mL/min) provide an inert atmosphere and inhibit oxidation.Between 100-200°C moisture loss, 200-500°C major volatile evolution from biomass, and minor char decomposition of coal and lignin (500-900°C) are recorded in the TGA plot of the 34-66% coal-biomass co-blend. The 28.92% residue mass at 998.6°C shows the greater char yield of coal, and the peaks in DTG indicate the prominence of the thermal decomposition of biomass in the early stages.

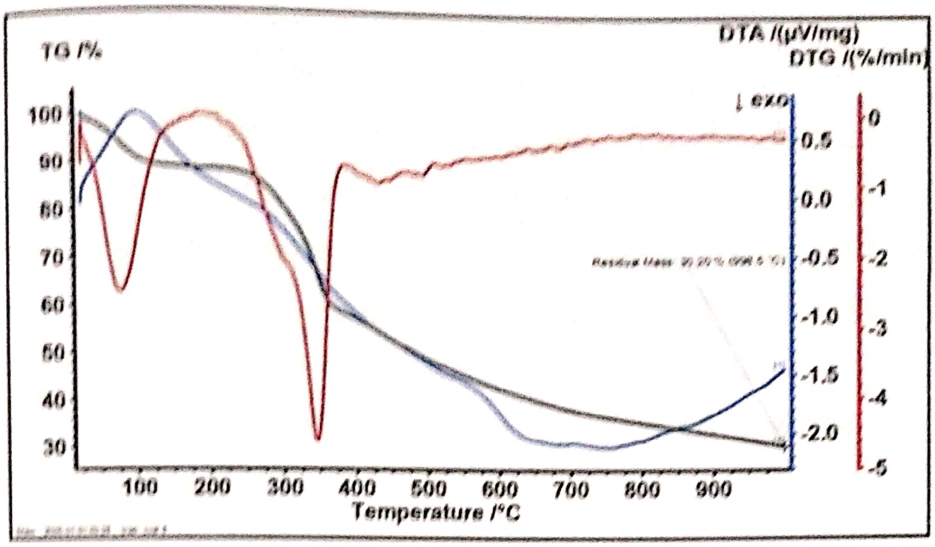

Fig 15: TGA analysis graph for co-blended samples of Coal and Biomass (50:50)

The TGA (Thermogravimetric Analysis) graph (Fig 15) illustrates the thermal decomposition of a 50-50% co-blended sample of coal and biomass. The ultimate residual mass is 30.20% at 998.5°C, so 69.80% of the sample combusted or decomposed. There is a small loss in mass (~5-10%), with a DTG peak (red line) at approximately 100°C. This is caused by evaporation of moisture from coal and biomass. The 50-50% mixture harmonizes the water content, as biomass contains higher water content compared to coal. There is a major weight loss between 200°C and 500°C, with the TG curve (black line) falling from ~90% to ~40%. The DTG curve exhibits a clear peak at 350°C, reflecting the fast decomposition. This phase comprises the evaporation and burning of volatile matter, mostly from the biomass. Biomass constituents such as hemicellulose (220-315°C), cellulose (315-400°C), and lignin (150-500°C) breaks down and burn in the 30% oxygen environment. DTA curve (blue line) demonstrates an exothermic peak (exo, up) at around 350°C, which proves combustion.The volatile matter in coal also begins to release within this temperature range but to a lesser extent compared to biomass since it has a higher content of fixed carbon.After 500°C, the TG curve illustrates a reduced rate of mass loss, which becomes constant at 30.20% by 900°C. The DTG curve has a smaller peak at 500-600°C, representing char combustion.The DTA curve exhibits another exothermic peak at about 550°C, representing char combustion of both biomass and coal. The 50% coal composition plays a major role in the char since coal contains more fixed carbon than biomass.The residual mass (30.20%) is greater than in the 25-75% mixture (25.42%), corresponding to the higher content of coal, which forms more char.The 30% oxygen, 20% nitrogen atmosphere supports combustion, which results in exothermic peaks in the DTA trace and a smaller residual mass than with an inert atmosphere. The oxygen burns the carbon to CO□, decreasing the end mass. The 50-50% blend that is balanced has contributions from coal (later char burn) and biomass (early volatile burn).Biomass fuels the initial volatile combustion, while coal assists in char yield and combustion at elevated temperatures.Oxygen atmosphere improves the combustion of both fractions, resulting in a more complete reaction than pyrolysis in an inert environment. In comparison to the 34-66% blend in an inert atmosphere (residual mass 28.92%), the 50-50% blend in an oxidative atmosphere has a slightly greater residual mass (30.20%), indicating greater coal content but also greater combustion due to oxygen. In comparison to the 25-75% blend in a similar oxidative atmosphere (residual mass 25.42%), the 50-50% blend has a greater residual mass, as greater coal content yields more char.The TGA graph of the 50-50% coal-biomass co-blend in a 30% O□, 20% N□ atmosphere indicates three phases: loss of moisture (100-200°C), combustion of volatiles (200-500°C), and combustion of char (500-900°C). The equimolar mixture generates high volatile combustion from biomass and char combustion from coal, evident in the DTG and DTA peaks. The mass of 30.20% left behind corresponds to the greater char yield from coal, and the oxygen environment provides more thorough combustion, suitable for co-firing applications.

## 6. Conclusion:

This comprehensive study evaluated the resource potential of co-blending high-Sulphur Nagaland coal, which is representative of the large coal reserves available in North East India, with locally plentiful Assam bamboo biomass (Bambusa tulda Roxb.) as anopportunity for more sustainable energy utilization. The initial physicochemical characterization indicated distinct physicochemical characteristics of the coal and biomassfeed stocks: the coal had both higher fixed carbon and lower volatile matter and moisture contents,while the biomass exhibited the opposite trend. FTIR of the coal presentedsignificant functional groups that are relevant to its thermal behaviour.

Thermogravimetric analysis (TGA) of the individual coal and biomass samples elucidated their distinct thermal decomposition pathways.The main devolatilization ofcoal occurred between 100-600°C, withthe combustion of fixed carbon occurring above 600°C. Biomass sampleshad multiple stages of decomposition. The first stage had significant weight loss between 200-400°C due to hemicellulose and cellulose degradation, followed by biomassthatagain lost weight at higher temperatures due to lignin decomposing at a much slower rate.Crucially, the TGA analysis of co-blended coal and biomass samples demonstrated a combined thermal behavior influenced by the blending ratios.The DTG curves of the blends exhibited characteristic decomposition peaks of both biomass (around 300°C) and coal (around 550°C), indicating their simultaneous thermal breakdown. The residual mass after TGA varied with the biomass-to-coal ratio, suggesting a direct influence of the blend composition on the final ash and biochar yield. The DTA curves indicated exothermic reactions during the main decomposition phases, consistent with combustion processes [10]. The two-stage decomposition observed in the co-blended samples demonstrates that the initial phase is more dominated by biomass devolatilization, while the second stage was dominated by combustion of coal and coal char combustion. This insight will prove useful in modifying other thermochemical conversion processes such as combustion, gasification or pyrolysis. Depending on the blending ratio, co-blended fuels could utilize the higher volatile matter of the biomass component to ignite and combust the coal, while reducing the overall Sulphur content of fuel mix and SO□ emissions associated with high-Sulphur coal that is prevalent in this region.

Ultimately, this study provides valuable insights into the thermal characteristics of co-blended coal and bamboo biomass, paving the way for the development of more sustainable energy solutions in North East India. The findings suggest that co-blending offers a promising route to utilize the region's abundant coal reserves more cleanly and efficiently by integrating them with locally available renewable biomass resources. Further research should focus on analyzing the gaseous emissions during the thermochemical conversion of these blends to fully evaluate their environmental benefits and optimize the process for practical applications.

## 7. Future trends in co-blending of biomass with coal:

The future of energy production in Assam and globally, points towards a greater emphasis on sustainability and reducing reliance on fossil fuels. In this context, the trends for the energy sources discussed, particularly the co-blending of biomass with coal, are significant.Coal will presumably be part of the energy mix for some number of years, however, its dominant role as a fuel source is in decline as alternatives become cleaner, despite still being fossil based.Future trends will include investments in technologies like carbon capture and storage (CCS) and combustion advances which will reduce emissions for coal-based power generation. Coal based power plants will also operate in more cutting edge ways to better integrate within the renewables landscape. For example, operating flexibility due to some plants' base load operations, may allow coal to supply renewable energy generation when intermittent supply is at play. Whereas Biomass is expected to have a larger part in the future energy mixes, due to its renewable characteristics and potential for carbon neutrality (when derived from sustainable sources). R&D will be aimed at improving biomass conversion technologies, advanced combustion, gasification, pyrolysis, and anaerobic digestion, to be more efficient and less costly. More focus will be placed on the sustainable sourcing of biomass feed stocks, to avoid forests being cut down, land-use changes, and competition with food production. This encompasses the use of agricultural residues, energy crops cultivated on marginal lands, and waste streams.

Biomass co-firing with coal is increasingly being pursued worldwide as a short-term solution for lowering the carbon intensity of legacy coal power stations without considerable capital overhauls to infrastructure. Co-firing is being mandated or encouraged in many countries, including India. Present co-firing rates are generally low (in the range of 5-10%). Projected trends in the future could involve raising these ratios as biomass handling and processing technologies, as well as supply chains, develop. To counter issues related to biomass properties (e.g., reduced calorific value, increased moisture content, heterogeneity), innovative pre-treatment technologies such as torrefaction, pelletization, and pyrolysis will gain more significance. These operations improve the fuel quality and handle ability of biomass, and make it compatible with coal-based power plants. Policies, regulations, and incentives of the government will play an important role in spurring adoption and expansion of co-blending. This will entail requirements for percentages of co-firing, subsidies on biomass fuel, and carbon credits. A major emphasis will be on securing stable and sustainable supply chains for biomass feedstock, such as collection, processing, storage, and transportation. This will mean involving local farmers, communities, and industries. Power plants will have to invest in retrofitting their current infrastructure to effectively deal with and burn biomass-coal blends. These involve changes to fuel handling equipment, boilers, and emission controls technology. Sophisticated digital solutions for fuel blending and fuel inventory management will also gain significance. Co-blending will be increasingly considered a key lever for lowering greenhouse gas emissions ($CO2$, $NOx$, $SOx$) from the electricity generation industry and helping meet climate change mitigation goals. Future studies could examine the possibility of integrating biomass co-firing with carbon capture technology to achieve still deeper net CO2 emissions reductions. If the biomass is used sustainably and the CO2 from the combustion is captured, this strategy might be able to produce net-negative emissions.

Biomass is carbon neutral when sustainably produced, since the $CO_2$ emitted when it is burned is matched by the $CO_2$ taken up when it is growing. Co-firing decreases the net carbon emissions compared to sole combustion of coal. Biomass tends to contain less sulphur and nitrogen than coal, resulting in lower emissions of sulphur oxides (SOx) and nitrogen oxides (NOx), which cause acid rain and air pollution. Co-firing decreases dependency on a single source of fossil fuel and can improve energy security through the use of readily available locally based biomass resources. Biomass feed stocks may comprise agricultural residues, forest waste, and other organic wastes that otherwise would have been land filled or combusted in open fields, resulting in pollution. Co-firing offers these materials an effective use. Developing biomass supply chains has the potential to open up new income streams for farmers, pellet makers, and rural transportation sectors. In certain instances, biomass is a lower-cost fuel option than coal, particularly when considering the avoided waste disposal costs and government incentives. Co-firing enables power plants to utilize their current coal-fired boilers and infrastructure with comparatively minimal adjustments, minimizing the necessity for huge investments in completely new renewable energy plants. When combined with sustainable biomass supply and carbon capture technologies, co-firing can potentially extract $CO_2$ from the air.

In conclusion, the energy future will be dominated by cleaner and more sustainable energy sources. Co-blending biomass with coal is a major trend in this direction, providing an effective and economical means of curtailing emissions, fuel diversity, and local economic benefits while capitalizing on existing power infrastructure. Further improvement in technologies, policy support, and biomass supply chain development will be important to fully exploit the potential of this solution.

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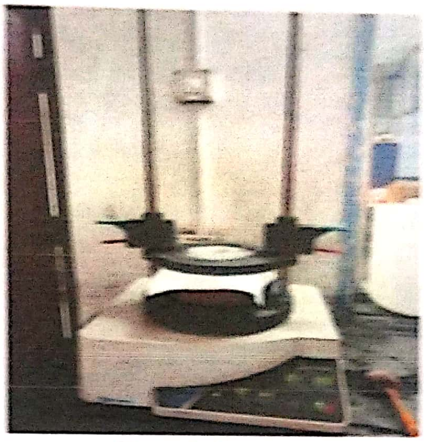
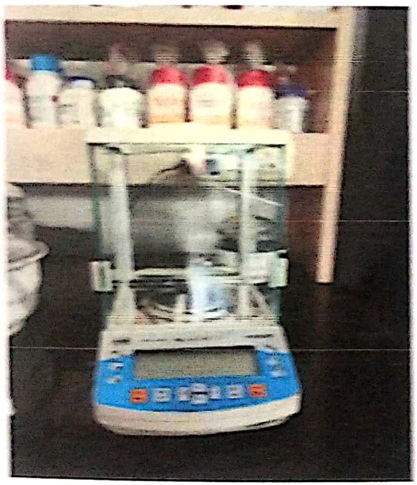
**9. Photograph:**

**Photos of major instruments used during the experiment:**

Rotor beater mil
(Used to crush the Coal sample)



Sieve shaker
(Used to sieve the sample)



Electronic balance
(Used to know the weight of a substance)

Hot air oven (Model No. PID 702
(Used to dry wet substance)