A STUDY ON THE SYNERGISTIC INTO CO-PYROLYSIS OF COAL AN BIOMASS VIA TGA AND FTIR-ANALYSIS

A dissertation submitted for the partial fulfilment of the requirements for the degree of

B. Sc. in Chemistry (Paper DSE-603) under Dibrugarh University

Under the Supervision of

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A STUDY ON THE SYNERGISTIC INSIGHTS INTO CO-PYROLYSIS OF COAL AND BIOMASS VIA TGA AND FTIR-ANALYSIS

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CERTIFICATE

This is to certify that the dissertation entitled "A STUDY ON THE SYNERGISTIC INSIGHTS INTO CO-PYROLYSIS OF COAL AND BIOMASS VIA TGA AND FTIR-ANALYSIS" is submitted by Priyanuj Hazarika, 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 of Dissertation Project He 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 **"A Study on the Synergistic Insights into Co-pyrolysis of Coal and Biomass via TGA and FTIR-Analysis"**, submitted by Mr. Priyanuj Hazarika, 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, Energy and Material Sciences Division, CSIR-NEIST, Jorhat.

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FORWARDING

I, here by forwarding the project report entitled **"A Study on the Synergistic Insights into Co-pyrolysis of Coal and Biomass via TGA and FTIR-Analysis "**, submitted by Mr. Priyanuj Hazarika, 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, Energy and Material Sciences Division, CSIR-NEIST, Jorhat

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ACKNOWLEDGEMENT

I,a student of B.Sc. 6th semester of Nanda Nath Saikia College, under Dibrugarh University has completed my project on "**A STUDY ON THE SYNERGISTIC INSIGHTS INTO CO-PYROLYSIS OF COAL AND BIOMASS VIA TGA AND FTIR- ANALYSIS**"under the supervision of Dr. Prasenjit Saikia, Scientist, CSIR-NEIST, Jorhat.

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Finally, I would extend my love and gratitude to the members of my family for their constant love and support. It would have been difficult for me in completing my project without you people.

DECLARATION BY CANDIDATE

I hereby declare that the project report titled ***"A study on the synergistic insights into co-pyrolysis of coal and biomass via TGA and FTIR- Analysis "***submitted to the Department of Chemistry, Nanda Nath Saikia College, Titabar in partial fulfillment 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.

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Abstract

In this report the benefits of co-pyrolysis of coal and biomass samples with the help of TGA analysis are been discussed. This report includes the adverse effects of pyrolysis of coal for power generation on the environment. A new approach in this study includes some of the future implications of the of co-pyrolysis of the blended samples of biomass and coal and the biochar obtained. Biochar that is obtained from coal contains high doses of N_2 which can be put to use as a fertiliser for crop cultivation instead of throwing it away as waste. It was found that on blending biomass with coal, as the percentage of biomass in the blended samples increased there was an increase in the residual mass (char) which contained the intoxicants that was released during the pyrolysis of the coal, present in the blends. It denoted the neutralisation of the harmful effects of the intoxicants which could have been released in the form of volatiles into the atmosphere thus reducing CO_2, SO_2, etc. emissions and converting them to heavy precipitates. It was also observed that the biomass lowered the ignition temperature of the coal due to which volatiles present in the blended samples were released at relatively lower temperature that was analogous with the release of volatiles in biomass. The co-pyrolysis of the blended samples was carried out at lower active pyrolysis zone but if it was conducted in the higher active pyrolysis zone as the temperature will shift to higher □, it will eventually increase the yield of volatile content and could have been employed as stand-alone power generation system as the thermal efficiency of the co-blended samples will increase.

Keywords: *Co-Blending, Co-pyrolysis, Coal, Biomass, Gasification,Thermogravimetric analysis, FT-IR, Char,Fertilisers*

(1) INTRODUCTION:

(1.1) Coal a source of energy:

Environment is the surrounding of all living organisms, which includes living things and natural forces. Due to increase in demands of urbanisation, technology, mobilisation and so on coal plays a vital role due to its ability of energy production.

Coal is a combustible black or brownish-black sedimentary rock, formed as rock strata called coal seams. Coal is mostly carbon with variable amounts of other elements, chiefly hydrogen, sulphur, oxygen, and nitrogen. Coal is a type of fossil fuel, formed when dead plant matter decays into peat which is converted into coal by the heat and pressure of deep burial over millions of years **[1]**.

From several decades, coal has greatly influenced human civilisation as a key source of energy. Moreover, coal has many uses; such as coke material for burning steel, anode material for lithium or sodium batteries, etc. Through various processes, coal and its by – products can also produce various new products such as ethanol, methanol, and Dimethyl Ether (DME). Coal is generally a heterogeneous material and has a complex chemical structure **[2]**.

(1.1.1) Coal Types:

Different coal types are all minerals and rocks made largely of carbon. This fossil fuel generates **~40% of the world's electricity and about 25%** of the world's primary energy **[11]**. However, not all coals used are the same; it comes in different quantity levels of carbon—which dictates the quality of the coal. Higher quality coal produces less smoke, burns longer, and provides more energy than lower quality coal.

The table below includes the carbon contents, and energy densities of coal. In addition, it states the moisture content before drying, and the amount of volatile content, after it's dried.

Coal	Carbon content (%)	Moisture content (%)	Volatile content (%)	Ash Content (%)	Heat Content (GCV)(MJ/kg)
Anthracite	86-92	7-10	3-14	6-16	32-33
Bituminous coal	76-86	8-18	14-46	10-12	23-33
Sub-Bituminous coal	70-76	18-38	42-53	15-20	18-23
Lignite	65-70	35-55	53-63	6-19	17-18
Peat	<60	75	63-69	2-8	15

Table 1: Types of carbon and their moisture, volatile matter and ash content composition

(i) Peat:

Peat is a soft, crumbly, dark brown substance that is formed from generations of dead and partially decaying organic matter. Peat is the first step in the formation of coal, and slowly becomes lignite after pressure and temperature increase as sediment is piled on top of the partially decaying organic matter. In order to be turned into coal, the peat must be buried from 4-10 km deep by sediment**[19]**. Peat exhibits the lowest carbon content (less than 60%) and has an energy density of 15 MJ/kg**[11]**.

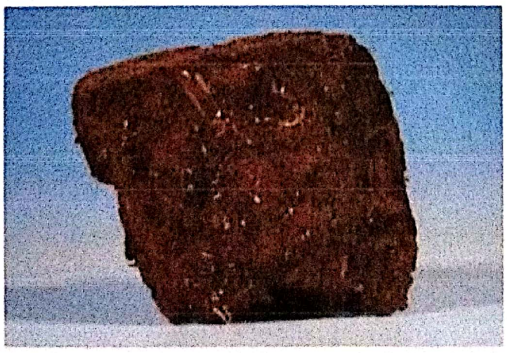


Fig 1: Lump of peat

(ii) Lignite:

Lignite or brown coal is brown in colour and the lowest quality of coal. The carbon content of lignite ranges from 65-70%,**[11]** therefore, compared to other types of coal it contains the greatest amounts of compounds other than carbon—such as sulphur and mercury**[20]**. Lignite is the youngest fossil fuel produced, with an age of approximately 60 million years. Its relatively short lifespan means it exhibits quite a low energy density at 18 MJ/kg**[11]**.Lignite's high moisture content and lower carbon content results in morecarbon dioxide emissions than harder black coals.

Fig 2: Lump of Lignite or brown coal

(iii) Sub-Bituminous:

Sub-bituminous coal or black lignite is a grey-black or dark brown coal. It ranges from hard to soft as it represents an intermediate stage between low quality lignite and higher quality bituminous coal. The carbon content of sub-bituminous coal varies from 70-76%**[15]**. Sub-bituminous coals are among the younger coals geologically—approximately 251 million years old. Therefore, the longer burial time compared to lignite increases its energy density ranges from 18-23 MJ/kg**[11]**. This type of coal is the most commonly used, with 30% of coal resources being sub-bituminous**[21]**.

Fig 3: Lump of Subbituminous Coal

(iv) Bituminous:

Bituminous coal is the second highest quality of coal, with a carbon content that ranges from 76-86%. It is the most abundant type, and one of the longest buried fossil fuels—with an age of approximately 300 million years old. Therefore, its energy density is relatively high at 27 MJ/kg**[11]**. The high carbon and low moisture content of this particular type of coal makes it

breathing difficulties, to brain damage, heart problems, cancer, neurological disorders, and premature death[3].

(1.1.2) Forms of Sulphur in North-Eastern Coal

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 [31]. High-sulphur coals have a deleterious effect on the environments specially 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 [32]. 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 presence of 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%. Iyenger et al.termed the Assam coals as abnormal coals and suggested that the abnormal behaviour is attributed to high-sulphur content. 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 [15]. 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. On the other hand, we have ruled out the possibility of such an atomic exchange reaction. Instead, we have proposed a ligand substitution reaction mechanism in aqueous solution in which hydroxo is replaced by bisulphide. This reaction has been experimentally verified. It appears, therefore, that the presence of high-sulphur content in Assam coal is attributed to exchange reactions occurring in different manners. Assam coal has three forms of sulphur -sulphate, pyritic and organic sulphur. No elemental sulphur has been reported so far in case of Assam coal. The major portion of sulphur is in the organic form which is about 70-80% of the total sulphur. Moreover, the occurrence of another type of sulphur in high-sulphur Assam coals has recently been established and reported elsewhere. This sulphur has been termed as secondary sulphur containing Fe-S moieties associated with coal organic matter.

(1.1.2.1) Inorganic sulphur:

Two forms of inorganic sulphur - sulphate and pyritic sulphur are known to occur in Assam coal. The occurrence of sulphate sulphur is very low and is a lesser amount in comparison to other forms. Sulphate sulphur in the form of ferrous sulphate has been reported which formed by the oxidation of pyrite. Identification of melanterite (a form of ferrous sulphate, $FeSO_4$. $7H_2O$) in Assam coal by powder X-ray method has been reported. In regard to distribution of sulphate sulphur in Assam coal seams, the content of this sulphur normally remains approximately constant from the floor to the roof of the seam. Further, as the percentage of total sulphur increases there is a decrease in the sulphate sulphur content. Pyrite is an important sulphur-containing mineral occurring in Assam coal. Its presence has been verified by chemical and physicalmethods. The presence of pyrite in various forms like stringers,

individual crystals and disseminated grains has also been reported.Pyrite in Assam coal was reported to form through different ways. Most researchers agree that the constituents of pyrite formation were accumulated at an early stage of coal formation; fresh water being the main supplier of iron while sea water supplied sulphur (in the form of sulphate). A hypothesis for the formation of pyrite has been proposed, according to which iron and sulphate combine to yield ferric sulphate and the resultant product of the reaction of this ferric sulphate and hydrogen sulphide is pyrite. Formation of pyrite during the progressive coalification process has been studied. It has been considered that secondary sulphur having Fe-S moieties associated with organic matter might crack under conditions of high temperature and pressure resulting in separation of iron disulphide, i.e., pyrite. It has been suggested that the low amount of pyritic sulphur in Assam coal is due to incomplete rupture of Fe-S moieties from the coal organic matter and release of H_2S from pyrite during the formative stage of this coal.

(1.1.2.2) Organic sulphur:

The nature of organic sulphur in Assam coals has not yet been precisely determined and the literature on this is meagre. Some workers reported that organic sulphur in Assam coal occurs as mercaptan and disulphide whereas others believed that thiol, sulphide, disulphide and ring compounds are the types of organic sulphur in these coals. However, these workers could not show any precise experimental evidences of the nature of organic sulphur in Assam coals. While studying aerial oxidation of Assam coals, identified three different types of organic sulphur: (a) sulphur estimated during the initial stage of oxidation. The workers could not identify the types of sulphur but observed that the value increased with increasing sulphur content of coal, (b) the second type, on oxidation, resulted in sulphonic acids and was identified as thiophenol, and (c) a type resistant to oxidation and assumed by them to be thiophene. Further, if sulphur were present as R-S-R, then this type, on oxidation, would convert into sulphane.If sulphane was formed by oxidation of sulphide, the oxygen content of the product should have been higher, which was not the case, thus eliminating the possibility of the occurrence of sulphide in coal. It was further reported that the sulphur as thiophenol is remarkably constant and thiophene is particularly constant in coals containing less than 3% organic sulphur. In coals with more than 3% sulphur, organic sulphur generally increases with an increase in the total sulphur content. The possibility of the occurrence of organic sulphur as disulphide was also reported. Recently, the presence of five types of organic sulphur functional groups in the Tipong coal of Assam, namely disulphide, thiol, sulphide, thiophenic and thioketonic have been reported. The precise nature of organic sulphur could not be identified. In regard to the nature of distribution of organic sulphur in Assam coals, there is an increase of organic sulphur content from the floor to the roof of the seam. Organic sulphur predominates in these coals containing less than 81% carbon.

(1.1.2.3) Secondary sulphur:

It is well-known that sulphur present in coal-forming vegetations cannot account for high-sulphur percentage in coal. Therefore, an adventitious sulphur source must have existed in peatbogs and this sulphur incorporated into the coal precursor under suitable environmental conditions leading to the occurrence of secondary sulphur in coal. The occurrence of

secondary sulphur in coal was reported in the late 1950s. Three groups have been known so far to work on secondary sulphur in high-sulphur coals. According to the Russian group, the major portion of secondary sulphur in coal came from elemental sulphur. This secondary sulphur could vulcanize the coal substance during the formation of pyrite. The American group reported that humic acid (a coal precursor) could take up sulphur from an environment containing elemental sulphur or hydrogen sulphide to form organic sulphur. This group could not show any probable mechanism for sulphur incorporation into the coal precursor.In India, extensive investigation on the organo-geochemical aspects of the formation of different forms of sulphur in coal have been carried out by Baruah. A mechanism for incorporation of adventitious sulphur in coal organic matter was hypothesised which involves interaction of humic acid with bisulphide, in the presence of iron, forming coordination compounds containing Fe-S bonding. This concept has been experimentally verified and it has been demonstrated for the first time that the chemical bonding and thermal stability of products formed by incorporation of sulphur in coal precursor can occur. It has been observed that sulphur distribution in coal is dependent on iron distribution. Moreover, metalloproteins such as ferrodoxin(containing Fe-S clusters) and related compounds, derived from sulphate-reducing bacteria, has also been presumed to contribute a certain percentage to the Fe-S moieties associated with coal**[32]**.

(1.2) Biomassas an alternative to coal:

As energy is an indispensable resource for the overall economic growth of a nation. Although traditional fossil energy still occupied the most part of energy consumption, and overuse can lead to threats to the environment. Recently research has gradually shifted to efficient use of clean renewables and improved the development of energy structure. Among these major renewable natural resource biomass energy as a representative carbon energy is sustainable and low in pollution, which has a wide range of sources. Biomass is the organic materials originated from plants and animals. Biomass consists of organic components such as 40-48% cellulose, 24-28% hemicellulose & 20-26% lignin. It contains about 42-47% carbon, 40-44% oxygen, and 6% hydrogen. But the composition varies in species.

Researchers characterise the various types of biomassesin different ways but one simple method is to define four main types, namely:

- woody plants
- herbaceous plants/grasses
- aquatic plants
- manures

Biomass combustion produces heat and electric power traditionally employed in the process industry. Since, biomass is the only fuel available for renewable, combustion-based electricity generation.

(1.3) Co-blending of coal and biomass and its advantages:

Seeing the harmful environmental effects of coal this motivated the researchers into investigating various clean coal processes such as the increased interest in co-blending of coal with alternative fuels like biomass due to its carbon lean nature[4]. Biomass combustion produces heat and electric power traditionally used in the process industry. Biomass gasification is a promising thermochemical process that converts biomass into gas under different atmospheres and produced syngas could also be used highly valued chemical production[5]. Co- firing is the process of blending biomass with coal, this reduces emissions, improves air quality, reduces fuel costs & also reduce waste production. Co-gasification of coal and biomass is emerging as the potential clean fuel technology to achieve high thermodynamic efficiency with relatively low CO_2 emission. The coal and biomass have been exclusively gasified for more than a century to obtain gas–liquid fuels and the production of chemicals. Co-gasification has higher efficiency than the solitary coal gasification because the cellulose, hemicellulose, and lignin content of biomass helps to ignite and enhance the rate of gasification. It is suggested that the extensive research on carbon reactivity pattern, heat release, reaction kinetics, and so on may support to reduce the uncertainties in the co-gasification performance of coal and biomass blends[6]. The thermal analysis was carried out using a thermogravimetric analyser. The influence of biomass organic and inorganic constituents on coal samples during the co-blending reaction, especially the synergy influence on the char oxidation reaction has been investigated. The observations in the results included substantial decrease in the peak temperature, burnout temperature and activation energy of the char oxidation stage of most of the fuel blends. This is representative of the non-additive interaction between the coal and biomass samples. These fundamental results have provided insights into coal and biomass co-blending behaviour during co-firing and gasification that can be used in aiding the design considerations and optimising the biomass blending ratio to ensure appropriate operation of co-fired fuel reactors[7]. Pyrolysis of coal–biomass blends are considered to be significant research area for the researchers who endeavour to find the best fuel alternatives. The product gas composition and quality depend on the moisture content of coal and biomass, temperature, gasifying agent. Thermal gravimetric analysis (TGA) is a conventional method to follow the thermochemical reactivity of fuels. Moreover, combination of Fourier Transform Infrared (FTIR) spectroscopy with TGA makes the gaseous products analysis possible during thermochemical conversion. Thermal decomposition tested by TGA under inert and air atmospheres allows to develop fundamental understanding of pyrolysis and combustion processes, respectively. Findings of TGA based on time and temperature were also used to determine the decomposition kinetics[9] [10].

The co-gasification of high ash coal and variety of biomass to produce syngas by improving the performance of energy systems. Co- blending of biomass with coal can still maintain the same amount of energy output by reducing the amount of coal. As formation of large amount of tar can cause corrosion, blockage in the pipelines, etc. co- blending process of biomass along with coal can reduce the process of tar formation because ash in the biomass acts a catalyst and improves the gasification process of the coal and even increases the temperature which enhances tar cracking.

Although coal gasification is a well-established technology, very little information on co-gasification of coal and biomass is available. Co-gasification of coal and biomass seems to be an attractive technology to produce heat, power, liquid and gaseous biofuels using synthesis gas**[25]**.In this view, the focus has been made for co-gasification of coal and biomass efficiency estimation and performance of the process owing to larger inorganic content influences the carbon conversion **[26]**.The experience of large-scale coal and biomass gasification can be utilized for efficient coal, and biomass is co-processing, particularly considering the high and unstable moisture-content to obtain syngas of optimal thermal and economic competence**[27,28]**.

The primary objective of co-gasification of high ash coal and biomass is to produce clean combustible gases and liquid fuel. Several gasification researchers report that higher energy syngas can be obtained by optimizing the ratios of high ash coal and biomass. Typically, biomass is carbon-neutral, more reactive and has higher volatile content than coal which supports to initiate gasification process at a lower temperature. Hence, lower temperature minimizes the amount of heat loss and substantial problems related to high temperatures. Also, biomass helps to lower SO_x emission with low sulphur content. The addition of a specific amount of biomass in high ash coal can control the slagging and fouling problems caused by high alkali contents like sodium and potassium of biomass. Fascinatingly, coal and biomass have synergistic reaction rates with lower gross power output, but higher thermal efficiency.The large cellulosic and lignin molecules of biomass break into lighter molecules and finally transformed to gases like CO, H_2, CH_4 and lighter hydrocarbons, ash, char, tar and minor impurities**[30]**.

(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) MATERIALS AND METHODS:

(3.1) SAMPLE COLLECTION:

The coal sample was collected from the mines of Margherita, Assam. Whereas,the biomass sample was prepared from bamboo stalk (*Bambusa tulda Roxb.*) that was collected from Thengal Gaon, Titabar, Assam.

(3.1.1)SAMPLE PREPARATION:

For sample preparation the sample was crushed using mortar and pestle then it was further crushed in the Rotor Beater mill to a size of 212µm 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 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 I) – 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 & 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:

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

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

(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 1 g 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 roomtemperature. 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: $Ash\ \% = 100\ (\frac{M_3 - M_4}{M_2 - M_1})$

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

(c) Determination of volatile matter content:

The method consists of heating of 1g of the sample taken in a crucible at a temperature 900◦C ± 10◦ C for 7 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:

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

M_1 = mass of the empty crucible along with the lid (in g)
M_2 = mass of the crucible + lid + sample before heating (in g)
M_3 = mass of the crucible + lid + sample after heating (in g)
M_o = 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 sampleparticle is heated and the volatile matter is expelled. The fixed carbon content of the sample 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 sample. Ultimate analysis is used to determine the carbon, hydrogen, sulphur, nitrogen, ash, oxygen contents of the given sample. Some other chemical analyses are also employed that is the determination of the forms of sulphur present.

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:

Calorific value is represented as higher calorific value (HCV) or Gross calorific value (GCV) and Lower calorific value (LCV) or Net Calorific Value (NCV). The calorific value of coal is determined by Bomb calorimeter. For this process a weighted amount of fuel 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 25-30 atm. is reached. After thorough stirring, initial temperature of the water in the calorimeter is noted. Current is supplied and the fuel in the crucible burns producing heat which is transferred to water which is stirred throughout the experiment by electric stirrer. The maximum temperature shown by the thermometer enclosed with the calorimeter is recorded and the calorific value of fuel can be calculated. It is found that the calorific value of Indian coal 2450 -3000 kcal/kg **[17] [18]**.

(3.2.4) FTIRANALYSIS

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 will 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 was identified. The FTIR spectra were collected generally in the range of 400 – 4000 cm^{-1} regions. 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 how the infrared photon energy can be transferred to the molecule. This 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 the compounds except for elemental diatomic gases such as N_2, H_2, and O_2 have infrared spectra. 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 monochromator 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

Thermogravimetric 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 into basic aspects which are weight and temperature. As most weight loss curves look more or less similar, the 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.

Thermogravimetric 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.

Thermogravimetric 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 is 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, thermogravimetric analysis (TGA) of the samples were done using Simultaneous TG-DTA/DSC Apparatus (Model: STA 449 F3 Jupiter). Thermogravimetric Analyser Instrument. Around10 milligrams of sample was taken and heated up to a final temperature of 1000□. TGA was performed at a heating rate of 5□/min and 10□/min. Thermogravimetric 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:

Sample	Moisture content %	Volatile matter %	Ash content %	Fixed Carbon content %
1. CM (Coal Margherita)	2.85%	39.85%	9.74%	47.56%
2. Biomass (*Bambusa tulda Roxb*)	8.54%	71.20%	3.24%	17.02%

Table 2: Proximate Analysis of the samples

Under physicochemical analysis proximate analysis of the samples of coal and biomass was performed. The moisture content, volatile matter content, ash content and fixed carbon content was found out to be 2.85%, 39.85%, 9.74% & 47.56% 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% &17.02% respectively.

(5.1.2)ULTIMATE ANALYSIS:

Sample	Carbon	Hydrogen	Sulphur
1. Coal (CM)	68.3	4.93	5.7
2. Biomass (BM)	45.9	5.84	-

Table 3: Ultimate analysis of elemental composition of carbon and hydrogen in the samples

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 68.3% and 4.93% similarly, for biomass it was45.9% and 5.84% respectively. The coal sample contains 5.7% of sulphur.

(5.2) Chemical Characterisation of the Samples:

(5.2.1) FTIR Analysis (Fourier Transform Infrared Spectroscopy)

(5.2.1.1) FTIR Analysis of the Coal sample:

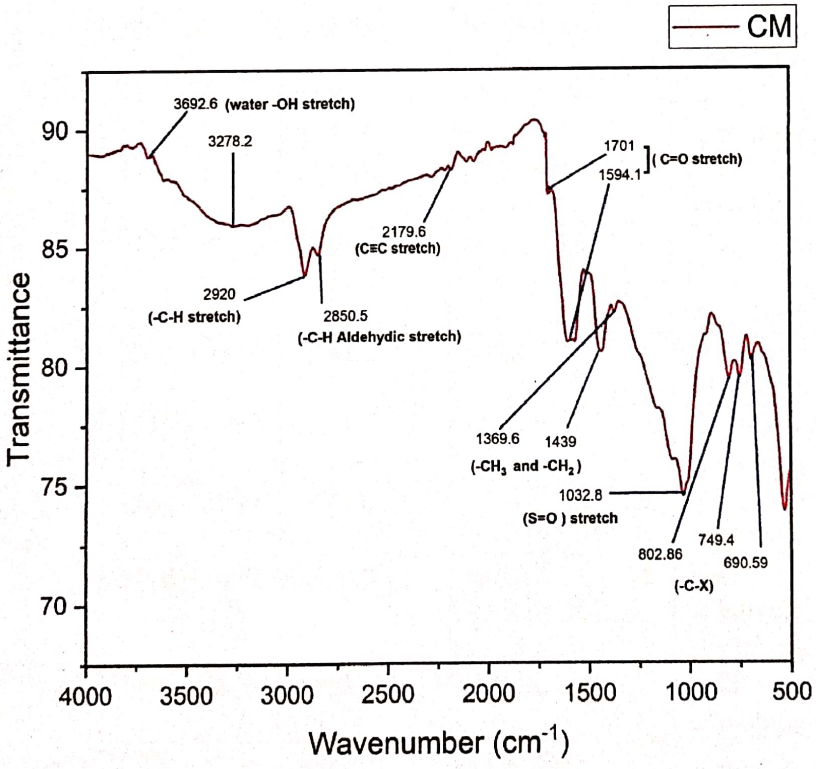


Fig 8: FTIR analysis of Coal Sample (CM)

The Fourier TransformInfrared Spectroscopic analysis of the coal sample of Margherita revealed peaks at different identifiable band positions outside the fingerprint region in terms of major functional groups and types of bonds present: carbon to halogen (C-X) bonds was observed around 690.59 cm^{-1} to 802.86 cm^{-1}, a strong peak was observed at 1032.8 $cm^{-1}$was denoted the presence of sulfone group (S=O) which had sulphur to oxygen double bond, a medium peak was observed in the region 1369.6 cm^{-1} to 1439 cm^{-1} which confirmed the presence of alkyl groups (CH_3 and CH_2), a strong carbon to oxygen double bond (C=O) stretching was observed in the region 1594.1 cm^{-1} that confirmed presence of amide group, at 1701 cm^{-1} another strong peak was observed which confirmed the presence of ketone stretching (C=O), a weak and variable peak was observed in the region 2179.6 cm^{-1} belonged to carbon to carbon triple bond (C≡C) stretch, in the region 2850.5 cm^{-1} we observe a weak and variable peak which confirms the presence of carbon to hydrogen single bond aldehydic stretch (C-H).Similarly, in the region 2920 cm^{-1} a weak peak is observed which denoted carbon to hydrogen single bond stretching (C-H), and at region 3278.2 to 3692.6 cm^{-1} a broad and strong peak was observed with denoted oxygen to hydrogen single bonded (O-H) water stretching. The presence of these functional groups and their associated bonds were all revealed by the infrared analysis of the sample.

SAMPLE	ABSORBANCE (cm^{-1})		APPEARANCE	GROUP	COMPOUND CLASS
CM	700 - 600	690.59	STRONG	C-I stretching	Halo
	850 - 700	749.4, 802.86	STRONG	C-Cl stretching	Halo
	1200 - 800	1032.8	STRONG	S=O stretching	Sulfone
	1480 – 1365	1369.6, 1439	MEDIUM	CH_3 and CH_2 stretching	Alkyl
	1700 – 1500	1594.1	STRONG	C=O amide stretching	Amide
	1745 – 1700	1701	STRONG	C=O ketone stretching	Carbonyl
	2260 - 2100	2179.6	WEAK & VARIABLE	C≡C stretching	Ethyne
	2900 - 2800	2850.5	WEAK & VARIABLE	C-H aldehydic stretching	Carbonyl
	2950 - 2840	2920	WEAK	C-H stretching	Alkane
	3700 - 3100	3692.6, 3278.2	STRONG	OH stretching	Hydroxyl

Table 4: Functionalgroups of Coal Sample (CM)

(5.2.1.2) FTIR Analysis of Biomass sample:

The Fourier Transform Infrared Spectroscopic analysis of the *Bambusa tulda Roxb.* revealed the following peaks at different identifiable band positions outside the fingerprint region in terms of major functional groups and types of bonds present: a broad and strong peak was observed at 3363 cm^{-1} which was due to (-OH) stretching present in water. A peak at 2882 cm^{-1} was observed which represented ($-CH_2$) and (-CH) stretching vibration which is a key component of carbohydrates present in the biomass. The peak at 2187 cm^{-1} belonged to carbon - carbon triple bond (C≡C) stretch. The intense band at 1621 cm^{-1} belonged to C=C olefinic stretching vibrations and 1410 cm^{-1} band is due to (CH_2) bending vibrations. The strong band in the region 1040 cm^{-1} indicates the presence of C-O-C pyranose ring stretching vibrations in lignin, cellulose and hemicellulose. As these are the major components of carbohydrates in the biomass sample. And an intense peak at 485 cm^{-1} was observed which typically indicates the O-Si-O bending vibrations. This band is a fingerprint to the silica content, which can be present in various biomass components.

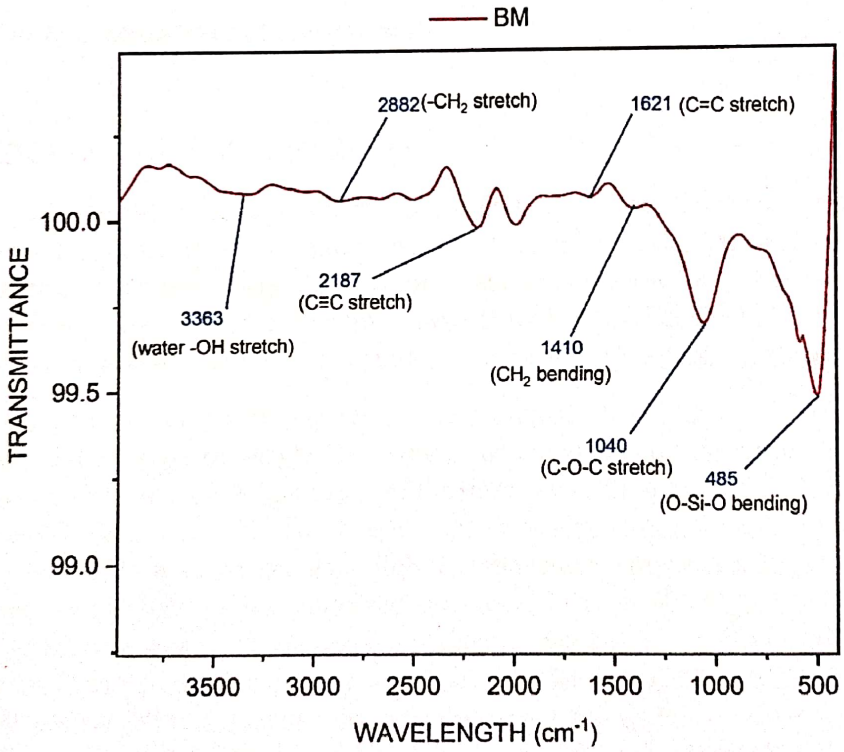


Fig 9: FTIR Analysis of the Biomass (*B.tulda roxb.*)sample (BM)

SAMPLE	ABSORBANCE (cm^{-1})		APPEARANCE	GROUP	COMPOUND CLASS
BM	495 -460	485	Strong	O-Si-O	Silica
	1250-1000	1040	Strong	C-O-C stretch	Ether
	1480-1365	1410	Weak &Variable	CH_2 bend	Alkyl
	1680-1600	1621	Weak	C=C stretch	Alkene
	2260-2100	2187	Strong	C≡C stretch	Alkyne
	2950-2840	2882	Weak & Variable	-CH & CH_2 stretch	Alkane and alkyl
	3700-3100	3363	Strong	OH stretch	Hydroxyl

Table 5: Functional Groups of the Biomass sample

(5.2.2) TGA (Thermogravimetric Analysis)

(5.2.2.1) TGA Analysis of the Coal Sample:

The weight losses observed in TG and DTG curves are found to be relevant to the composition fractions in the coal sample. Generally, three different regions can be distinguished from a particular TG curve. Weight change of a sample is recorded as a function of time or temperature and portrayed by a TG curve; on the other hand, DTG emphasizes the zones of reaction where various reaction steps are taking over the entire temperature range.

In the current investigation the temperature around 60-100°C in the TG curve was observed as the first stage of weight loss, which corresponds to drying of the sample where water/moisture was removed. Slight decay of the sample weight around 10.85% was observed signifying the DTG peak at 81°C. The second stage of weight loss observed corresponds to the devolatilization of the coal sample with high decomposition rate known as active pyrolysis zone. A rapid decomposition was observed between 375°C to 625°C, representing around 18.43% of weight loss, and DTG curve shows maximum degradation peak occurring at 446.6°C for this region. Decomposition in this region indicates the formation of volatiles. About 49 wt.% of the coal sample formed volatile fraction and about 51 wt.% is in the form of solid carbonaceous residue. After 500°C, the degradation rate of the coal sample becomes relatively constant.

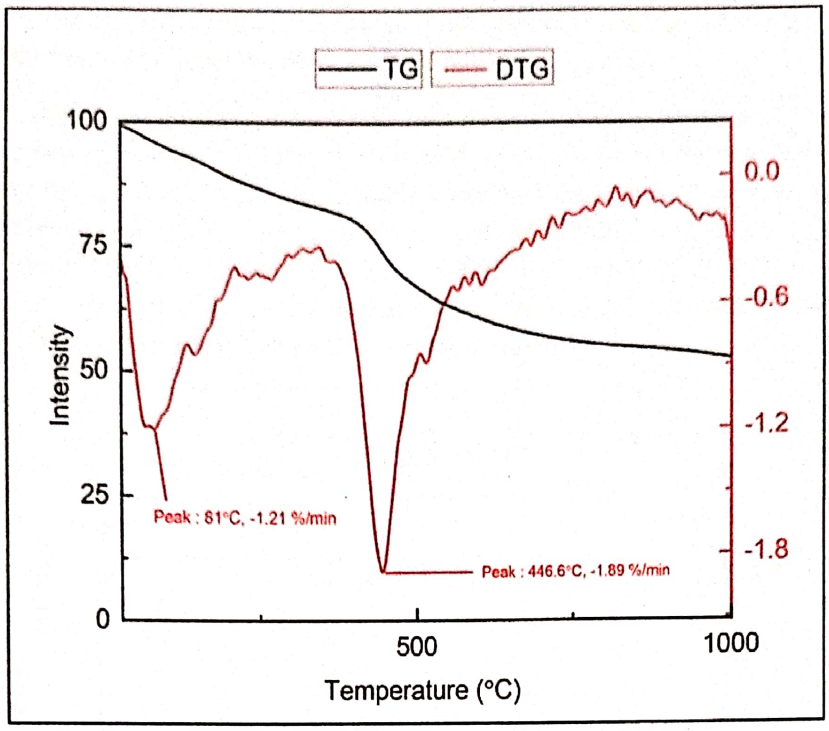


Fig 10: TGA analysis of Coal Sample (CM)

(5.2.2.2) TGA Analysis of the Biomass Sample:

The weight losses observed in TGA and DTG curves are found to be relevant to the composition of cellulose, hemicellulose and linin fractions in biomass.

In the current investigation, a temperature around 115°C in the TG curve was observed as a primary step of weight loss, which corresponds to the drying of the sample (*B.tulda*) where moisture was liberated. Slight decay of the sample weight around 7% was observed signifying the DTG peak at around 100°C. The second stage of weight loss observed corresponds to the de-volatilisation of the biomass material with high decomposition rate at the pyrolysis zone. At this stage, the intermolecular associations and weaker chemical bonds are destroyed. And even some small gaseous molecules were liberated due to low temperature. Rapid decomposition was observed between 270°C and 400°C, representing around 59% of weight loss, and the DTG curve shows degradation peak occuring at approx 325°C for this region. The decomposition in this region indicates the formation of volatiles due to the thermal decomposition of the hemicellulose followed by cellulose in the biomass sample.

At this stage, the weight of the sample material is reduced to below 50%. This is primarily due to fact that about 80-90% of the biomass decompose to form volatiles and only 10-20 wt.% is in the form of carbonaceous residue. This shows that volatile products play a very important part in pyrolysis of biomass materials and product gas composition. After

reaching the temperature mark of 500°C, the degradation rate of the biomass sample decreases and at around 800-900°C the decomposition becomes constant.

During the third stage, the lignin residue slowly decomposed, with the weight loss velocity becoming smaller and the residue ratio tends to be constant at the end the decomposition of hydrocarbon. Higher temperatures lead to further pyrolysis of lignin which slowly decomposes over a much wider temperature range (160-900°C), mostly yielding char [23,24]. At higher temperature, chemical bonds are broken and the parent molecular skeletons are destroyed. As a result, the larger molecule decomposes to smaller molecules and additional release of volatiles from decomposition of lignin at abpove 600°C.

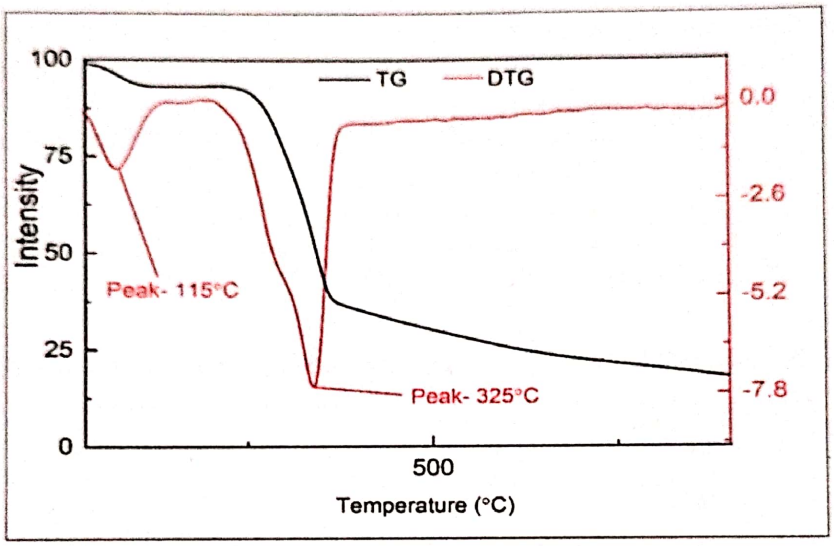


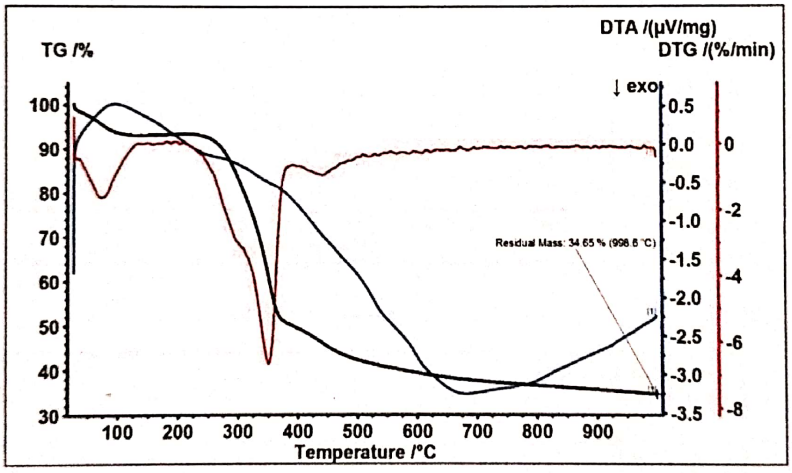
Fig 11: TGA analysis of biomass (*Bambusa tulda Roxb.*)

(5.2.2.3) TGA Analysis of the Co-blended Sample of Coal and Biomass:

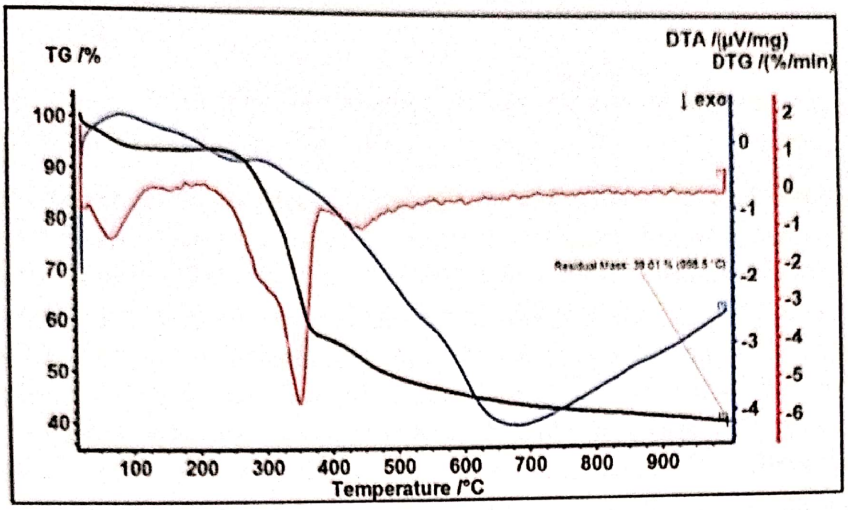
The present investigation visualises the positive and negative upshots of blending of biomass with coal. The thermal degradation patterns of coal and biomass blends of various ratios at a single heating rate of 10°C min^{-1} rate for the maximum temperature range of 1000°C. The pyrolysis of the co-blended samples was divided into three major stages (dehydration, devolatilization, and carbonisation). Coal consisted of highly crosslinked hydrocarbons that are bound by stable C-C bonds. Similarly, if the coal contains more C-C bonds, it will generate fewer volatiles which affects the ignition temperature and even releases toxic components in the form of gases. So, to tackle these negative aspects, the biomass was co-blended with coal in different proportions:

SL No.	BIOMASS(%)	COAL(%)	RESIDUAL MASS(%)
1.	75	25	34.65
2.	66	34	39.01
3.	60	40	42.99
4.	50	50	29.64

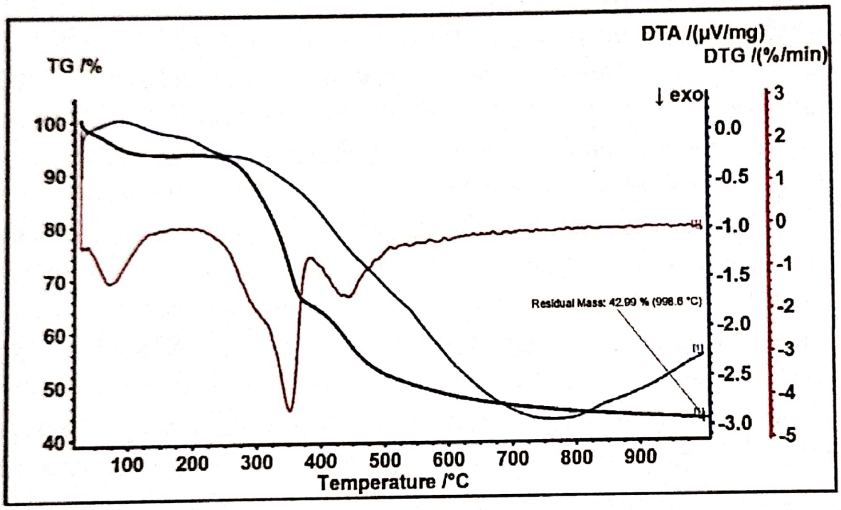
Table 6: Blending ratios of Biomass (*Bambusa tulda Roxb.*) and Coal (Margherita) Sample



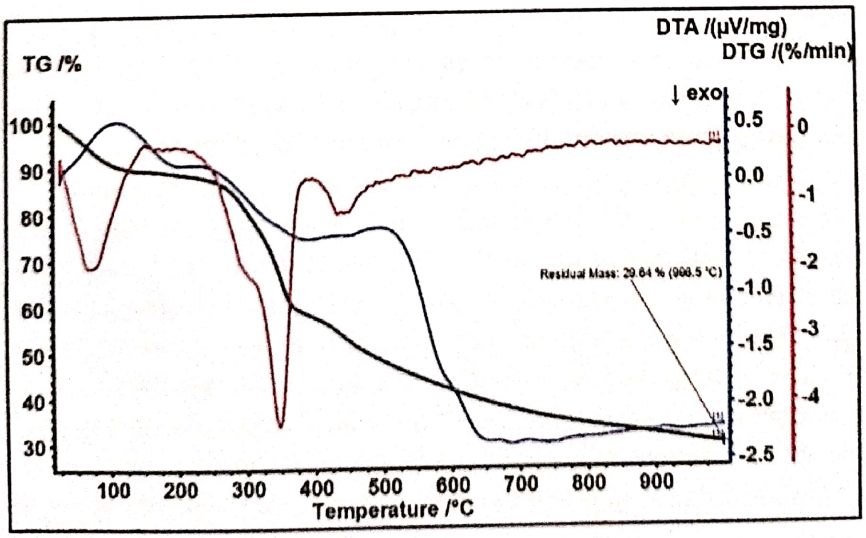
(a) 75:25 blend



(b) 66:34 blend



(c) 60:40 blend



(d) 50:50 blend

Fig 12: TGA analysis of biomass and coal blends of different ratios (a)75:25 (b) 66:34, (c) 60:40 and (d)50:50

The TGA analysis of the co-blended samples of coal and biomass showed that the degradation of biomass decreased when percentage of coal was increased. It was observed that when the biomass sample was blended with coal, a decrease in mass loss was observed with the rise in the % biomass in the co-pyrolysis samples. A peak initially at 80°C to 95°C was observed in each of the blends and a maximum degradation peak was observed at 93°C which was the primary stage of pyrolysis that denoted dehydration (loss of moisture in the form of light volatiles). The active pyrolysis zone for the biomass and coal blends was observed initially at 285°C to 400°C that was analogous with degradation peak of biomass and maximum degradation temperature of about 325°C was observed.The final char residue increased from 29.64% to 34.65% as the blending of biomass increased in coal by 50%,60%,66% and 75% respectively. The mass of the sample degraded in the active pyrolysis zone also decreased with the rise in biomass blending, the yield of volatiles decreased subsequently. But it was observed that when the co-blended samples of coal and biomass degrades thermally, the samples released the volatile matter at comparatively lower temperature than the raw coal sample. This indicated that the presence of biomass in the blends degraded the ignition temperature of coal. Eventually, it was observed that when the %biomass in the co-blended samples was increased, there were higher quantities of residual mass which indicated that the intoxicants that was usually emitted during the pyrolysis of coal was transformed into char by the components present in the biomass. Since, there are weaker chemical bonds present in the biomass samples. The functional groups such as alkanes, alkenes, carbonyls, etc. present in the biomass samples dissociates at comparatively lower temperature due to which they forms bonds with the sulphur, heavy earth metals (evident based on the geographical locations),arsenic,etc. and reducing the toxicity by converting them into heavy precipitate in the form of residual mass. The co-pyrolysis of coal and biomass will help in transformation of N_2 into char rather than emitting them as pyrolysis vapour. The transformation of N_2 will enhance the fertility of char.

A second DTG peak was observed initially at 400°C upto 500°C and maximum degradation peak was observed at 453°C which denoted the enormous decomposition of the coal and biochar. This peak is observed because biomass contained a large amount of volatiles compared to coal and biochar, which shifts the primary combustion process towards the low temperature intervals. The presence of biomass improved the combustion performance of the blends. Since, the process of devolatilisation of biomass started at 285°C, by its lower ignition temperature, many soft residues were generated, which adhere to the surface of the coal or biochar particles and reduce the heating efficiency of coal or biochar to some extent. However as the temperature increased, the soft residues that were produced from the biomass at the beginning decomposed and started to react with the free radicals (H^+, Cl^-,OH^-,O^{2-},CH_3^+,etc) of coal or biochar that promoted to the ignition of the coal or biochar. Since, most of the low temperature volatiles are released in the form of pyrolysis vapours,the pyrolysis of char contain very lesser % of volatile matter content and higher C/H ratio, and also the calorific value of char increases.

(6) CONCLUSIONS:

In this report, thermochemical behaviour of co-blended samples of coal and biomass was observed using thermogravimetric analysis. It was induced that biomass (*Bambusa tulda Roxb.*)is relatively easy to react due to its higher thermochemical reactivity. At a coal-biomass blending ratio 50%,60%,66%and 75% , the wt% had risen from 29.64% to 42.99%. This could have been due to synergistic interactions of alkali and alkaline earth metals that renders and auto-catalytic effect in catalysing the polyaromatic hydrocarbon group chains of coal linked with biomass lignin and hemicellulose.It was observed in the thermogravimetric analysis that the residual mass increased on increasing biomass% in the blends, at the lower active pyrolysis zone but if it was conducted in the higher active pyrolysis zone as the temperature will shift to higher □, it will eventually increase the yield of volatile content and could have been employed as stand alone power generation system as the thermal efficiency of the co-blended samples will increase. From the analysis it was also observed that there was a higher yield of solid residue as the biomass% in the samples was increased. This was because the heavy earth metals, sulphur, arsenic and other intoxicants that might have been present in coal was converted into char by the functinal groups that were present in the biomass samples. Preventing from causing adverse effects on the environment. The co-pyrolysis of coal and biomass blends transforms the N_2 that would have been yielded during pyrolysis of coal, into char which boosts the fertility of char. The potential enviromental impications of utilising coal and biomass blends in economically and environmentally viable as it would reduce the emissions of greenhouse gases, than the conevntional coal pyrolysis. Eventually the char can also be used in the from of fertilisers which will reduce the implications of inorganic chemical fertilisers that has carcinogenic effects on living organisms.

(7) FUTURE TRENDS IN CO-BLENDING OF BIOMASS WITH COAL:

- Future trends in blending of biomass with coal for power generation will likely to increase the focus on maximising the biomass utilisationfor power generation and reduce the utilisation of non-renewable resources like coal that causes adverse effects to the environment.
- Initiation for the development of innovative technologies like co-gasification and Bio-CCS, or Bioenergy with Carbon Capture and Storage which will potentially neutralising the negative emissions.
- The char that was obtained during lower active pyrolysis of coal and biomass had higher percentage of N_2 in it, which can be employed as bio-fertiliser that will eventually replace the inorganic fertilisers that are employed in large-scale crop cultivation.
- There was also formation of large amount of char during pyrolysis of co-blended samples of coal and biomass which contained large amount of sulphur, alkali and alkaline earth metals, arsenic, etc. which if emitted in the form of volatile would have been a threat to the environment, the biomass neutralised the intoxicants and converted them to heavy precipitates (char).
- Pyrolysis transforms waste (including coal and biomass) into valuable products like char, bio-oil, and syngas, reducing landfill waste and generating energy**[33]**.
- Char can be converted into activated carbon, a highly porous material used for adsorption in various applications, including water purification and gas filtration**[34]**.
- Pyrolysis char can be used as an alternative starting material for the fabrication of building materials, enhancing insulation properties and moisture buffering.
- Bio-oil and syngas from pyrolysis can be used as fuels or as feedstocks for biofuel production, contributing to a cleaner energy future **[35]**.

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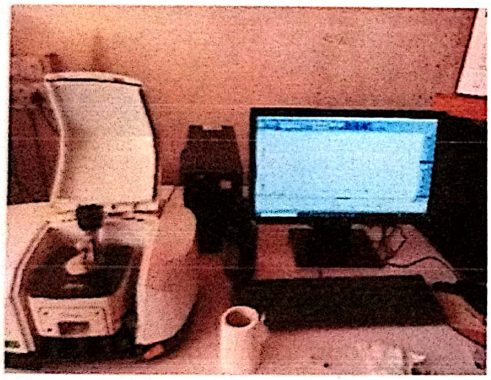
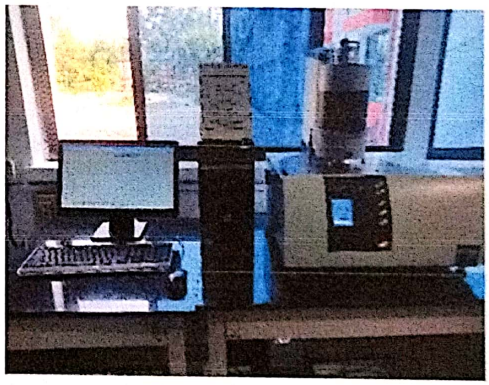
PHOTOGRAPHS:

(1)Hot Oven (Model No. PID 702)

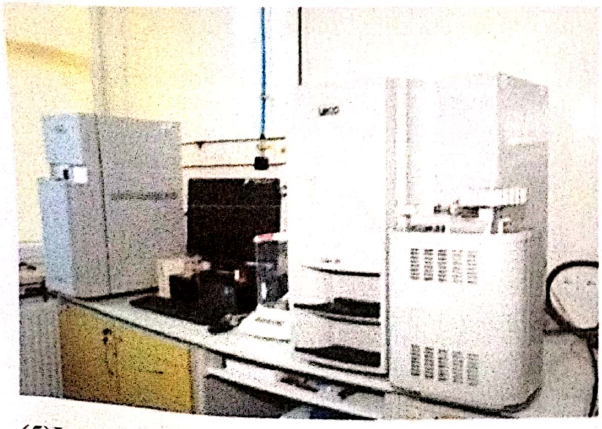
(2)Muffle Furnace (Okay Model: 60F6)



(3)Perkin–Elmer Infrared Spectrometer



(4) TG-DTA/DSC Apparatus (Model: STA 449 F3Jupiter)



(5)Leco Truspec-CHN Elemental Analyser (630-300-100)

(6) Co-Blended Sample