CHARACTERIZATION OF THE PROPERTIES OF SOME BIOMASS SPECIES AND ESTIMATION OF THEIR POWER GENERATION POTENTIALS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

Master of Technology

in

Mechanical Engineering

by

RAMYARANJAN LENKA

Roll No: 214MM2500

Under the supervision of

Prof. M. Kumar

Dept. of Metallurgical and Materials Engineering

National Institute of Technology, Rourkela

2016

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2016

DEDICATED

TO MY

PARENTS

Declaration

I hereby declare that the work which is being presented in this thesis entitled "**Characterization of Some Biomass Species and Estimation of their Power Generation Potentials**" in partial fulfilment of the requirements for the award of M.Tech. degree, submitted to the Department of Metallurgical and Materials Engineering, National Institute of Technology, Rourkela, is an authentic record of my own work under the supervision of Prof. Prof. M. Kumar. I have not submitted the matter embodied in this thesis for the award of any other degree to any other university or Institute.

Date: 26-05-2016 RAMYARANJAN LENKA

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CERTIFICATE

This is to certify that the thesis entitled, "**CHARACTERIZATION OF THE PROPERTIES OF SOME BIOMASS SPECIES AND ESTIMATION OF THEIR POWER GENERATION POTENTIALS**" submitted by Mr. RAMYARANJAN LENKA, Roll no. 214MM2500 in partial fulfillment of the requirements for the award of Master of Technology Degree in Mechanical Engineering with specialization in Steel Technology at the National Institute of Technology, Rourkela is an reliable work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree.

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Date: 26.05.2016 **RAMYARANJAN LENKA**

Place: Rourkela

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ABSTRACT

India is an energy needing country. India has most of the energy resources but limited. Now a days, energy demand leads to use of conventional energy resources (i.e. fossil fuels, such as hard coal, lignite, oil and natural gas) which cause critical environmental problems like global warming due to increase in greenhouse gases which can bring drastic change in environment. Renewable energy sources release less pollution to atmosphere. So If the country wants to meet its energy demand and to be less dependent on importing energy and to minimize greenhouse gas effect and to keep environment safe then it should use renewable energy sources. Rapidly increase in energy demand and world pollution due to use of conventional fuel, scientists looked for alternatives as renewable energy sources. Among all the renewable energy sources, biomass considered as an important source of power production due to its wide availability, lower ash content and low Cox, SOx and NOx emission to the atmosphere. In this article, five different portion(leaf, new branch, main branch, bark and root) were taken from residues of two different woody biomass species and three fruit husk/peel of which don't have any commercial use. These species are *Vachellia nilotica*(local name- Babool), *Azadirachta indica*(local name- Neem), *Musa acuminata*(local name- Banana), Cocos nucifera (local name- coconut) and *Arachis hypogaea*(local name- Groundnut). Proximate analyses and gross calorific values (GCV) of all the biomass sample were determined. Among all the biomass species studied, the fixed carbon content (FC) in Coconut husk was found to be the highest (i.e. 25wt.%) while Neem leaf has the lowest value(i.e. 11wt%), the volatile matter content (VM) in main branches of Neem is the highest(i.e. 74wt.%) While Groundnut husk has the lowest (i.e. 57wt.%) among all studied biomass samples. The ash content (A) in Neem root is the highest (i.e. 17wt.%) while Babool main branch has the lowest ash content (i.e. 1wt.%). Among all thirteen biomass species studied, husk of Coconut and bark and new branches of Neem are found to be high in moisture content (i.e. 11wt.%) while bark of Babool is found to be the lowest (i.e. 7wt.%).

Similarly, the Babool leaf is the most favorable one with the highest calorific value followed by its root. Next in the order, the bark of Neem and Babool were also found to have considerably high amount of energy contents suitable for power generation. In addition, bulk densities of all the biomass species have been determined. Leaves of Neem and Babool biomass species have

been found to have lower bulk densities while bark has higher bulk densities as compared to their other components. It is worthy to note that among all the studied biomass species, bark of babool has highest (i.e. 443 Kg/m3) bulk density followed by banana peel (i.e. 422 Kg/m3) while husk of Coconut has lowest bulk density(i.e. 163 Kg/m3) followed by husk of Groundnut(i.e. 262 Kg/m3).

Ash fusion temperature plays a vital role in Ash related problems such as slagging and fouling in different kinds of combustion, corrosion problems, in bed-agglomeration and potential problems they may cause in a boiler when the fuel is fired. Further, the ash fusion temperatures of some selected biomass (Neem root, babool leaf and coconut husk) have been measured as these temperatures are the influential factors for the determination of bed agglomeration and other boiler fouling related problems.

It has been found that Initial Deformation Temperature (IDT) varies from 995 to 1178ºC, softening temperature (ST) varies from 1132 ºC to 1218 ºC and hemispherical temperature (HT) varies from 1161 ºC to 1253 ºC which is suitable for safe boiler operation. The ultimate analysis has also been carried out on some selected biomass samples of Neem bark, Babool leaf and Husk of coconut. It has been found that Carbon and Hydrogen present in babool leaf and neem bark are higher compared to husk of coconut and have higher calorific value as compared to other selected samples. It is observed that around 80.868 and 154.236 hectares of land area are required for energy plantation considering Neem and Babool biomass species and respectively. It is also found that the husk of Groundnut, Coconut, and Banana peel are needed approximately 58.795, 100.95 and 407.23 hectares of land to generate that much of electricity per year. Approximately 7234.532, 6811.524, 7349.375, 7228.739, and 6732.355 tonnes of Neem, Babool, Groundnut Husk, Banana peel and Coconut husk biomass respectively was calculated to provide same amount of energy per year.

Key words: ***Volatile matter; Ash content; Calorific value; Ash fusion temperature; Bulk density; decentralized power generation.***

NOMENCLATURE

A - Ash content

AFT-Ash fusion temperature

FC   Fixed carbon content

GCV - Gross calorific value

H – Hydrogen content

HHV – Higher heating value

HT – Hemispherical temperature

IDT – Initial deformation temperature

LHV – Lower heating value

M – Moisture content

N – Nitrogen content

NCV – Neticalorific value

O – Oxygen content

ST – Softening temperature

VM - Volatile matter content

W.E. – Water equivalent

wt.% - Weight percentage

ΔT – Maximum rise in temperature in 0C

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CHAPTER 1

INTRODUCTIO

1. INTRODUCTION

1.1 Over View

Currently Increase in energy demand is a big problem. Fossil fuels can meet the energy demand, but these are limited in reserve and costly. Fossil fuels emit a higher quantity of pollutants to the environment which leads to increase in greenhouse gasses and considered as the main cause of drastic change in climatic condition. The continuous decrease in reserve of world fossil fuel has given a challenge to the scientists for the invention of a promising energy source that can take the place of conventional fuel. Renewable energies became the most attractive options for power generations because of theses are capable of meeting the world energy demand and environment-friendly. Biomass becomes effective as it is cheap and widely available, carbon neutral and emits very less amount of pollutant to the environment.

Over last few decades the Indian economy has shown continuous growth. Today, India is the ninth largest economy in the world, driven by a real GDP growth of 8.7% in the last five years (7.5% over the past ten years).In 2010, India placed at 5th position in world GDP (gross domestic product) growth. As of March 2012, the per capita total consumption in India was estimated to be 879 kWh. As per the 2011 Census, 55.3% rural households had access to electricity. However, NSS results show that in the year 1993-94, 62% households in rural India were using kerosene as the primary source of energy for lighting. After the US, China, and Russia the fourth largest user of natural gas is India. [1].As conventional fuels are limited and emit maximum amount of greenhouse gasses to the atmosphere, it should be minimized or replaced by other energy sources for minimization of pollution. In India, more than 65% of the electricity is produced from coal-fired power plants. With limited availability of coal, the future energy demand may suffer. So for the security of future energy supply, the alternate power source is essential.

Biomass became a most attractive option for energy demand due to its advantages. It is widely available and carbon neutral and releases very less pollutants. Fossil fuels release more amounts of Cox, SOx and NOx to the atmosphere which is the main cause of global warming lead to drastic climate change. Application in biomass in generating energy can solve the problems related climatic condition, energy emergency and waste land development. Biomass can be the most promising energy source due to its wide availability. The geographical area of 21.23% of the country covered by forest. Around three crore hectares of waste land can be utilized by forestation in India which is a big advantage [2]. As per the 2011 Census, almost 85% of rural households were dependent on traditional biomass fuels for their cooking energy requirements. As on 31.03.2013 and 30.03.2014 the total biomass power generated in India were 3601.03MW and 4013.55MW. The total energy production from conventional sources decreased from 13409.47 Peta joules during 2012-13 to 13400.15 Peta joules during 2013-14 [3].

Currently, biomass playing an important role to meet the world energy demand. Continuous increase in energy demand and world pollution and limited status of conventional fuel has shown a symbol of interest within scientists for research on biomass species. Different biomass species have different properties which properties can be considered for the design of the power plant and also influence its efficiency.

For getting maximum benefits at low cost, it is important to know the different properties of the chemical composition, energy values, bulk densities, ash fusion temperatures, combustion reactivity, etc. The present thesis describes the studies on some selected biomass species. The study includes proximate analysis, ultimate analysis, and evaluation of calorific values, bulk densities, and ash fusion temperatures of different residual components of some biomass samples. These species are Vachellia nilotica(local name- Babool), Azadirachtaindica(local name- Neem), Musa acuminata(local name- banana), Cocosnucifera (local name- coconut) and Arachishypogaea(local name- groundnut). Some experiments were conducted on these biomass samples and their effect on power generation is discussed.

1.2 Different Sources of Renewable Energy

As the fossil fuels are limited and give rise to environmental pollutants, renewable energy sources became an alternative for power generation.

The alternative renewable energy sources are as follows:

a. Solar energy

b. Ocean energy

c. Wind energy

d. Geothermal energy

e. Biomass energy

1.2.1 Solar Energy

The heat and radiation energy coming from the sun is collected and converted into electricity by some technologies just as solar photovoltaic, solar heating and solar thermal power generator are called as solar energy. It does not produce smoke or any pollutant. But it is not active at night time, cloudy climate like rainy season and costly. Those countries away from the equator were not able to get adequate solar energy. Due to these disadvantages, solar power cannot be productive everywhere [3].

1.2.2 Wind Energy

Wind energy can be produced by utilizing the wind force with the help of turbines and then by converting into electric power. Pumping of water can be done by wind pumps and also mechanical power can be achieved by windmills by utilizing the wind force. It is a clean source of energy, don't produce pollution or greenhouse gasses. The significant disadvantage of wind power is, is cannot be obtained throughout the year. When there is no wind, energy cannot be obtained. If site selection is improper, then there will be a significant loss in wind energy production. Also, the cost associated with the installation of wind power is very high [3].

1.2.3 Ocean Energy

There is two type of energy derived from the ocean. One is mechanical energy derived from waves and tides, and another is thermal energy from the heat of the sun. With the help of some mechanical equipment, electricity can be produced. The top surface of ocean water absorbs the heat radiated by the sun which is used as ocean thermal energy. The tides and waves are the result of the gravitational pull of Moon and blowing of the wind. But these are not continuous or cannot be achieved every time we need. Also, the types of equipment and processes used for ocean energy production are costly.

1.2.4 Geothermal Energy

Geothermal energy is thermal energy generated and stored in the Earth crust. Temperatures at the core–mantle boundary may reach over 4000 °C (7,200 °F). Some rock present in earth's interior may melt due to high temperature and pressure, and solid mantle may behave plastically which may cause the mantle convecting upward as it is lighter than the surrounding rock. Rock and water are heated in earth's crust up to 370 °C, which can be used for thermal energy. Drilling and exploration of geothermal wells for deep resources are very expensive and can't be installed everywhere. When geothermal wells are drilled, it releases greenhouse gasses trapped inside earth's crust, but the emission is lower than that of fossil fuel [4].

1.2.5 Biomass Energy

Biomass is defined as a non-fossilized, biodegradable organic material derived from plants, microorganisms, and animals which include products, by-products, residues and wastes from woody, agricultural industries including the biodegradable organic waste from the industrial and municipal operation[5].

Biomass is a renewable energy source which has the advantage of re-growing over a short period as compared to fossil fuels. It is Carbon Neutral. Chlorophyll in plants uses the sunlight for producing carbohydrates by taking carbon dioxide from air and water from the ground. When these are burnt, it emits very less quantity of carbon dioxide as compared to fossil fuels.

Biomass became the most attractive renewable energy source due to its wide availability and environment-friendly nature. Currently, the aggregate use of bio-energy is around 12 % of the world's total energy consumption, and the advantages of bio-energy will be able to meet the world energy demand in coming days. Large wastelands can be reutilized by forestation which can be helpful in producing biomass. The bio-power installation in India as per March 2014 was 4013.55 MW, which was the second largest renewable energy source [6].

1.3 Fossil fuel Reserves In the World

More than two third of the primary fuels are consumed for the production of electricity in the world [7]. The table 1.1 shown below gives the idea about some important assumption on world fossil reserves and consumption. If the current estimated level of consumption of fossil fuels will remain constant by assuming correct estimated reserves of fossil fuels, then the existence of fossil fuel may vanish from the world. Technological advances, new discoveries, and conservation may result in the use of fossil fuels last longer. The consumption of resources as in Table 1.1 is due to population growth and developments. From several studies, it is expected that the reserves of crude oil may vanish from the year 2050 to 2075 [8,9]. So effective steps should be taken on the development of biomass power production.

Table 1.1 World fossil fuel reserves(Petroleum, Natural Gas and coal) and projected depletion [10]

Reserves of global fossil fuels	Petroleum (Billion barrels)	Natural Gas (Trillion cubic feet)	Coal (Billion short tons)
World reserves (Jan 1,2000)	1017	5150	1089
World potential reserve growth	730	3660	--
World undiscovered potential	939	5196	--
Total reserves	2686	14006	1089
Annual world consumption	27.34	84.196	4.74
Years of reserves left	**98**	**166**	**230**

1.4 Power Generation Potential of Different Renewable Energy Sources in the World

Renewable energy demand is increasing continuously worldwide, provided global energy of 22% approximately in 2013. In the year 2013 biomass provided around 10% (56.6EJ) of global primary energy from which the share of the modern biomass was approximately 13EJ for heat supply to buildings and industrial use and 5EJ of energy used to produce 116 billion litres of biofuel, and another 5EJ of energy was used for 405TWh of world's electricity. The United States was estimated to be the top producer of electricity from biomass.

Geothermal resources have provided a total of estimated 600 PJ (167 TWh) in 2013 from which 76TWh was used for electricity generation and remaining 91TWh used for direct use. In 2013 at least 76TWh/annum capacity of geothermal power came online. In 2013, hydropower estimated capacity of 40GW was commissioned increasing global capacity to 1000GW by about 4%.About 39GW solar PV capacity was added which turns the total capacity of 139GW. For almost one-third of global installation, China accounted to triple its capacity to 20GW.In 2013, the addition of total wind power capacity was 35GW, which turns the global total above 318 GW [11]. Table 1.2 shows Global Electricity Capacity from Renewable Energy in the year 2012. In 2012, the capacity of the total renewable energy increased 1470GW globally which is 8.5% more than that of the previous year. Hydroelectric power increased by 3% to 990GW and different renewable energy sources increased 21.5% to 480GW. In 2012, 39% of renewable power limit was represented by wind force and solar PV and hydropower both represents approximately 26%. In 2012, roughly 50% of electric production was compensated by renewable sources as compared to all other sources. The renewable energy sources contributed 26% of global generating power and estimated for supply 21.7% of global power from which 16.5% of power was from hydropower by the year's end [12].

EIA(Energy Information Administration) predicts that by 2020 biomass will able to produce 0.3%(15.3 billion kWh) of the total anticipated power generation. It is forecasted that the power generation from biomass should increase significantly in situations which explain the use of a 20% RPS (renewable portfolio standard) and situations when greenhouse gasses based on the Kyoto Protocol should be minimized [13].

Table 1.2: Global Electricity Capacity from Renewable Energy in the year 2012[12]

Technology	**Electricity capacity in GW**								
	World Total	EU-27	BRICS	China	United States	Germany	Spain	Italy	India
Bio power	83	31	24	8	15	7.6	1	3.8	4
Geothermal power	11.7	0.9	0.1	0	3.4	0	0	0.9	0
Ocean (tidal) power	0.5	0.2	0	0	0	0	0	0	0
Solar PV	100	69	8.2	7	7.2	32	5.1	16.4	1.2
Concentrating solar thermal power (CSP)	2.5	2	0	0	0.5	0	2	0	0
Wind power	283	106	96	75	60	31	23	8.1	18.4
Total renewable power capacity (not including hydropower)	480	210	128	90	86	71	31	29	24
Per capita capacity (W/inhabitant, not including hydropower)	70	420	40	70	280	870	670	480	20
Hydropower	990	119	402	229	78	4.4	17	18	43
Total renewable power capacity (including hydropower)	1470	330	530	319	164	76	48	47	67

1.5 Power Generation Potential of Different Renewable Energy Sources in India

In India various sources like biomass, solar, wind and small hydro have high potential to produce renewable energy. As on 31st March 2014, it was estimated that the potential for production of renewable in India is approximately 94126 MW which includes 17538 MW of biomass power potential, 49132 MW of wind energy potential and 19750 MW of small-hydro power potential [14]. As compared to the available potential of energy production the installation capacities are much less. Biomass power accounting 4013 MW and small hydro power of 3804 MW and solar power project of 2647 MW of installation capacity. Wind energy is dominating by 21132 MW of installation capacity. These installed projects are much less as compared to the energy potential. Fig. 1.1 shows the potential and installation capacity of wind power, small hydro power and biomass power [15].

Karnataka state has 14464 MW of renewable capacity and securing the highest share in India followed by state Gujarat comprising the second highest share of 12494 MW of capacity followed by Maharashtra of 9657 MW which are 15.37%, 13.27% and 10.26% of total renewable energy capacity respectively in India as per report on 31st March,2014. In 21st century biomass has become the most promising renewable energy source among all renewable energy sources due to its easy use in power plants and less pollution emission. The use of biomass can be in variety ways like thermo chemical conversion, biochemical conversion, by direct combustion, the coal-biomass mixture in the co-firing process which is efficient. As coal and traditional fuels are limited and mostly responsible for pollution emission, biomass is the perfect replacement for these fuels because of its wide availability, low pollution emission and of its recycling potential [14].

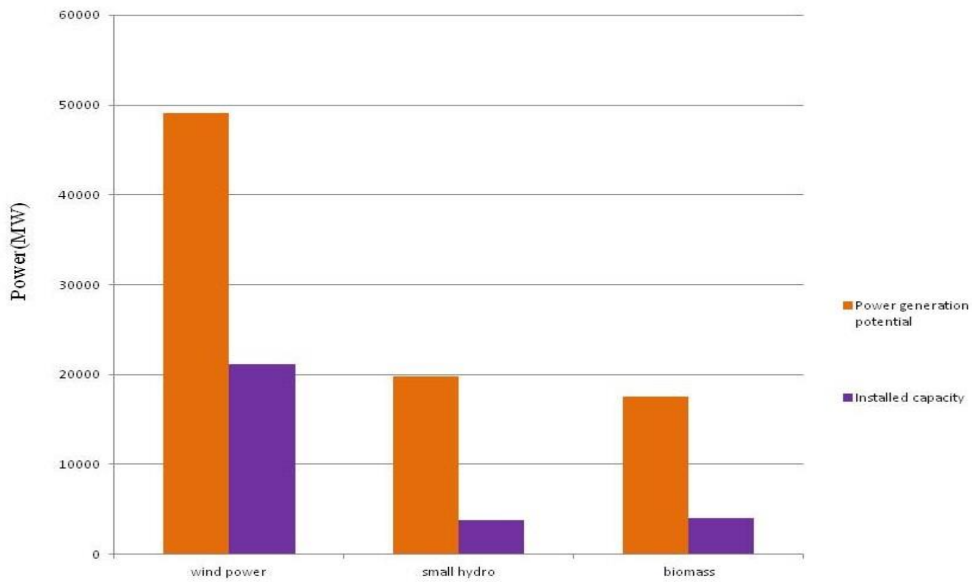

Fig. 1.1: Source wise Estimated Potential and Installed Renewable Power in India as on 31.03.2014 [14,15]

1.6 Classification of Biomass

1.6.1 Woody Biomass

Furniture plants like sagwan, mahua, sheesham, banyan, papal, etc. and fruity plants like mango, guava, etc. and energy plants like acacia, subabul, casuarinas, eucalyptus, etc. are some of the woody plants come under this category. Some medicinal plant like Neem also comes under woody biomass. Low moisture content, low ash content, higher bulk density and calorific value are the advantages of woody biomass. Cultivation of trees like poplar and eucalyptus which have fast-growing potential and perennial grasses gives good biomass feedstock [16,17].

1.6.2 Non-woody Biomass

Agricultural residues like rice, cereal straw, maize, corn straw, Sudan grass, millet, white sweet clover, etc., energy crops like bagasse and forest residues like leafs, thin stems, etc. comes under this category [18]. It also includes municipal waste, biodegradable wastes. As compared to woody biomass these have high moisture and ash content, high void space and low bulk density and energy value.Around 64% of total biomass energy is derived from wood and its wastes and municipal wastes gives around 24% of total biomass energy and agricultural waste contributes around 5% of total biomass energy [17].

1.7 Electricity Generation Methods from Biomass

It is broadly classified in to two categories:

a. Thermo chemical process

b. Combustion process.

1.7.1 Thermo chemical Process

1.7.1.1 Torrefaction

Torrefaction is the process of thermo-chemical treatment of biomass in the absence of oxygen at 200–320 ºC which is carried out under atmospheric conditions. Torrefaction improves fuel quality of biomass largely for ignition and gasification purposes. During the process, the cellulose, lignin, and hemicellulose present in biomass partially decompose to give different volatile matters and remaining final product is called ‘‘torrefied biomass" or ‘‘bio-coal". Also with densification, it can provide remarkable energy and minimum pollution emission [19].

1.7.1.2 Pyrolysis

It is the basic thermo-chemical biomass conversion process. The thermal decomposition of biomass in the absence of oxygen is called pyrolysis which gives a more functional fuel. Pyrolysis is carried out in the temperature range 300-600ºC [20]. This process produces liquid and gas and solid residue consisting higher percentage of carbon. Carbonization is the process of extreme pyrolysis which produces carbon residue largely. Pyrolysis varies from other high-temperature combustion methods as there is no use of oxygen, water or any other agents [19].

1.7.1.3 Gasification

Biomass gasification is the thermo-chemical biomass conversion process which converts all the raw materials into gas in an oxygen deficient environment. Gasification is carried out in the temperature range of 600-800 ºC. Biomass gasifiers are the devices which can convert biomass into high energy fuel to be used in gas turbines. This process consists of two stages. Producer gas and charcoal is formed in the first stage by partial combustion of biomass.Then in the next stage, the CO2 and H2O produced in the former phase are chemically lowered by the charcoal, forming CO and H2. The composition of the gas is 18-20% CO, an equal portion of H2, 2-3% CH4, 8-10% CO2 and the rest nitrogen [21].

1.7.2 Combustion Processes

1.7.2.1 Direct Firing

Direct firing is the process of direct combustion of solid fuels in the steam boiler. Due to the generation of more amount of moisture, direct firing is not so efficient. During the heating process, the flame temperature decreases due to the excess moisture. The moisture behaves as a heat sink which takes away the thermal energy and may cause combustion trouble. The cellulose containing fuel bound oxygen helps in reducing the theoretical requirement of air.[22]

1.7.2.2 Co-firing

The Diversification of fuels or concurrent ignition of two dissimilar fuels in a boiler is called co-firing. It describes the replacement of fraction amount of conventional fuels by biomass in the boiler [23]. In co-firing 5-15% of biomass can be used along with coal for power production without affecting the efficiency of the power plant. Co-firing process decreases COX, SOx and NOx emissions compared to fossil fuels [24]. There are Variety of co-firing processes are as follows.

A) Direct co-firing
B) Indirect Co-firing
C) Parallel Co-firing

In the direct co-firing process two heterogeneous fuels are used. Up to 15% of biomass is milled and directly added for better combustion. Some ash related problem arises in this technology due to the variation of the property of biomass. In the indirect Co-firing process, the solid bio-fuel is converted into flue gas with the help of a gasifier. The corrosion and the fouling problem of the boiler are reduced by the certain extent in this process. In parallel co-firing both biomass and coal combustion is done by separate processes. Biomass is burnt for generating steam, and then the steam is used in the coal-fired plant which increases the temperature and pressure in boiler [25].

1.8 Benefits and Limitations of Biomass Use in Power Production

1.8.1 Benefits

Effective use of biomass can provide several social and environmental benefits mentioned below [26].

A) Biomass use in power plants provides clean energy. The use of fossil fuels in power plants releases carbon dioxide and other pollutants which are the cause of global warming. But biomass is carbon neutral as CO_2 is absorbed by the plant through photosynthesis and released when it is burnt which maintains the cycle of CO_2 in the atmosphere. Plantation of trees again results in absorption of CO_2 from the atmosphere. Effective use of biomass power can fulfill the world energy demand and can lower the greenhouse gas concentration.

B) As compared to coal, biomass reacts with oxygen and carbon dioxide more easily. This characteristic of biomass helps in saving energy by operating the boiler at low temperature.

C) E and F grade coals, which are used in Indian power plant mostly, have comparatively low Calorific value than biomass.

D) Generally, biomass has 2-15% of ash content, which is very less as compared to coal (30-50%). Hence use of biomass gives rise to decrease in amount of suspended particulate matters in the atmosphere.

E) Biomass gasifiers can be installed easily at any location. The installation near villages reduces transmission losses by decentralized power generation technique and eliminates the transportation cost as well.

F) Unlike intermittent solar, wind and tidal energy production, biomass energy can be produced throughout the year. Biomass is more uniformly distributed over earth, use of which provides security against fuel import from the Middle East.

G) The wide availability and uniform distribution of biomass energy make it the most attractive renewable energy among all. Decentralized power generation near hilly areas can be very useful due to availability of biomass resources and can give job opportunity in rural areas.

H) Biomass can be helpful in preventing soil erosion and will prompt better usage of infertile lands.

1.8.2 Limitations

Besides some important benefits of biomass combustion, it also has some limitations as listed below [26].

A. A particular fuel is always assigned to a certain combustion unit. The conventional boilers are designed for a range of volatile mass and ash content. During biomass co-firing process, it is crucial to change some features of the existing boiler.

B. Biomass is relatively less efficient as compared to coal. The calorific value of the biomass co-fired fuel is low as compared to only conventional coal fuel due to the low calorific value of biomass.

C. There is a comparatively high chance of fouling problems due to large amounts of alkalis content and presence chlorine in biomass.

D. Before mixing with pulverized coal, biomass needs to be milled and palletized to be feed in the boiler, and also moisture content of biomass should be maintained regarding boiler specification.

E. The Large feedstock is needed for large plants throughout the year which requires large forest area near the location of the plant.
F. Biomass occupies large space in the boiler which makes the combustion less effective due to its low bulk density.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 Energy Crisis and Renewable Energy Scenario in India

The net domestic energy generation will be 669.6 million tons of oil equivalents (MTOE) by 2016-2017 and 844 MTOE by 2021-2022 according to the report by Ministry of Statistics and Programme Implementation and the energy consumption in those years satisfied to be 71% and 69% respectively. It has been projected by 2016-2017 and 2021-22, import of 267.82 MTOE and 375.68 MTOE respectively. In most recent decades there is a continuous development in Indian economy which results in higher energy demand can be practically fulfilled by renewable energy sources [1].

Due to the remarkable economic growth rate of India, the energy requirement is expected to be high which results in the emission of the higher greenhouse gas to the atmosphere. By efficient utilization of energy or renewable energy can minimize the energy crisis. Parikh and Parikh [24] evaluated that the CO_2 emission reduction can be around 30% by 2030 by looking over the fact and figure of energy needs in India and options regarding low carbon. This can be possible by implementing options of renewable energy sources like nuclear, biomass, solar and wind power for energy production as alternative sources [27].

India is a developing country with more than 1.2 billion population. Electricity growth rate is stable as compared to other forms of energy which are the biggest consumer of energy which leads to increase in emission of the greenhouse gas like carbon dioxide. Dunn and Flavin observed that CO_2 is the important greenhouse gas that causes the "anthropogenic climate change". The formation of new commercial enterprises, plants, business hubs and expanding populace are the reasons for the rise in electricity consumption in India and the CO_2 emission levels. The only way to minimize the anthropogenic climate change by the implementation of various renewable energy projects mainly biomass energy [28].

Due to the continuous rise in energy demand made India to think about other renewable energy sources for future due to ongoing regional and political problems in the Middle East as India imports around 71% of its oil requirement from which 66% from the Middle East according to Rastogi, who studied the energy consumption pattern of India [29].

India is decided to the implementation of renewable energy share which can highly contribute to electricity production. It was estimated that by the year of 2020 it will provide about 15% of total electricity [30]. To minimize climatic issues, the government is also launching new energy initiatives. One of the most important environment-friendly energy solution initiatives taken by both combination of Ministry of New and Renewable Energy and Ministry of Power is Jawaharlal Nehru National Solar Mission. By 2022 National Solar Mission concentrating on solar grid powers of capacity 20 GW, an off-grid capacity of 2 GW, solar thermal collector area of 20 million square meters and solar lighting systems of 20 million. In the last few years number of new initiatives has been taken for progress in renewable energy production and it was found that Biomass energy and wind power have become successful sectors in India. In the year 2013, efficient use of wind power of 2079 MW and biomass power of 411 MW have shown a symbol of increased use of renewable energy in the country. Modern biomass, bio-fuels, and wood pellets have become the source for international trade. Worldwide production and transport of wood pellets increased 22 million tons excluding 8.2 million tons of pellets sold globally. Liquid bio-fuels like ethanol and biodiesel has increased and stood at 83.1 billion liters and 22.5 billion liters respectively.

For the minimization of CO2 emission to the atmosphere, India has taken so many initiatives for the improvement and installation of renewable energy sources. According to British Petroleum, renewable energy consumption hits 11.7 MTOE in India in the year 2013 which indicates 4.2% of the total renewable energy consumption which is increased from 2010. The increase in renewable energy consumption shows a sign of minimization of CO2 and other harmful emissions [31].

Among all the renewable energy, bio-energy has a significant portfolio which consists of efficient biomass stoves, biogas, biomass direct combustion, co-firing and biomass gasification. India has been concentrating on one of the largest renewable energy programs on the planet by knowing the potential of renewables. Ravindranath and Balachandra studied that the technical and economic sustainability of bio-energy in India where coal and fossil fuel is dominating the other source of energy leading to resource crisis. They concluded that India needs to implement various innovative policies and projects to encourage quality bio-energy technologies [32]. The success is very less compared to the potential available.

Conventional wood stoves without any suitable chimney and ventilation are used in rural India, which is inefficient and causes severe pollution problems inside the house affecting health. Innovation can replace traditional stove at rural areas by improved stoves with greater efficiency and minimal greenhouse gas and pollution emission as per Ministry of New and Renewable Energy [15]. Hence, modern biomass cooking stoves have the tendency to reduce the consumption of conventional fuels with greater efficiency around 30-35%.

Municipal and industrial residues are being utilized for power generation. Ravindranath et al. studied the availability of rural biomass and discovered that wood, animal manure and residues of the crop are the predominant biomass fuels but are used inefficiently. The energy from crop residues, Municipal, and Industrial residues can be used for different efficient applications [33].

2.2 Biomass as a Renewable Energy Source and its Potential

Thermal power plants use coal for combustion which emits greenhouse gases mainly carbon dioxide, oxides of nitrogen, oxides of sulphur, CFCs, and other trace gases. Carbon dioxide released from combustion of coal have a greater effect on global warming among all other greenhouse gases. Raghuvanshi et al. studied and suggested the use of renewable energy sources for the coal-based power generation in India for minimization of CO2 emissions. They discovered that combustion of coal resulting CO2 was the leading cause of global warming presently contributing over 60% to the greenhouse effect. It is estimated that 750 kg of CO2 is released into the atmosphere when 1 tonne of fossil fuel is burnt. Biomass consisting very less percentage of sulphur and other pollutants can be used as fuel in power plants [34].

Though the substitution quantity of fossil fuels by biomass is fractional, it played a major role regarding global warming as it is CO2 neutral. Werther et al. analyzed that the forest-related residues of biomass such as wood chips, bark, leaf, etc. providing nearly 65% of the biomass potential and rest provided by agricultural residues [35]. Developed countries like USA, Finland, Sweden, and Austria obtain around 5%, 19%,17% and 14% respectively from biomass which is a comparatively significant share of their principal energy. Presently in Western Europe, biomass energy provides 2 EJ out of 54 EJ per year.

Chauhan studied on the biomass potential of two states Punjab and Haryana, which describes the crop residue in these states. In Haryana per year around 40.142 MT and 24.697 MT of overall crop residue is produced from various crops respectively and only 71% is utilized and remaining 29% can produce approximately 1.5101 GW and 1.4641 GW of power respectively in Punjab. The basic surplus is roughly 45.51%; the productive surplus is of 37.48% and 34.10% as a net surplus of total biomass available in Haryana [36,37].

It was found that in India about 400 million people didn't have access to electricity as on 2011 and for cooking around 72% of the population depended on traditional biomass. So maximum percentage of the population of the country need cleaner and existing form of energy [38]. Hence, a step for productive biomass power production is needed in India.

2.3 Biomass Conversion Processes

Biomass conversion processes are of different types. Kucuk and Demirbas[39] studied three biomass conversion processes named chemical, thermo-chemical, and biochemical processes having different parameters.

The most efficient biomass conversion process is co-firing process among all other processes. It is helpful in minimization of CO_2 emission from combustion of fossil fuels in power plants in a near term. Carbon loop combustion, oxy-firing, carbon dioxide sequestrations are some long term practical technologies which can reduce CO_2 emission. In all fossil fuelled power plants CO_2 emission can be decreased rapidly by quick usage of biomass co-firing with minimum alterations and reasonable financing. The aggregate reduction in carbon dioxide emissions could be remarkable if most of the conventional power plant in the world will adopt the co-firing method. Co-firing is discovered to be the most promising technique for production of electricity from biomass, and subsequently, carbon dioxide emission is very less. Basu et al. [40] studied on some co-firing with external firing or indirect firing utilizing combustion. They studied that in pulverizing mills direct firing of biomass gasification is more efficient and cost advantageous than indirect firing option and efficiency of direct co-firing is more than the indirect co-firing process.

Mukunda et al. made a study about such devices the design of which are played a significant role in biomass conversion process and prioritize on the requirement for renewable energy in developing countries [41]. They classified the biomass by woody and pulverized and compared its energy with fossil fuel. For both woody and pulverized biomass some of the technologies involved such as gasifier-combustor, combinations of the gasifier, engine, and alternator. To get high-grade heat, more preference is given to the use of pulverized biomass in cyclone combustors. In global scenario to show the feasibility of these mechanisms, the techno-economic aspects have conversed.

2.4 Chemical Properties and Ash Fusion Temperature Test of Biomass

Before selecting a fuel to be used in power plant the study of its chemical properties like proximate analysis, ultimate analysis, calorific value, ash fusion temperature, etc are important. Kumar et al.[42] studied the characteristics of four different non-woody plants species named Eupatorium, Anisomales, Sida, and Xanphium and calculated their power production potential. They found good energy value of biomass as compared to locally available coal. Similar studies were carried out by Kumar and Patel [43] on two non-woody biomass species named Ocimum canum and Tridax procumbens. Later, in a similar way Kumar et al. [44] studied the power production potentials of three forestry non-woody biomass species named Sida Rhombifolia, Vinca Rosea, and Cyperus. Also, they found higher fusion temperature of those biomass specimen which can avoid problems associated with boilers.

Also, coal and biomass blends play an important role in minimizing CO2 emission. Demirbas [45] analyzed the blending characteristics of biomass with coal in the coal-fired boiler and found that the co-firing process is more efficient and advantageous by comparing the co-firing process with other conversion processes. Later, Demirbas [46] proposed the significant change in properties of the fuel with respect to coal. He discovered that the ash content varies between 1-16% while nitrogen percentage varies between 0.2-1%. Similarly, carbon percentage varies between 35-43%. Variation of sulphur in biomass is very less and lies below 0.1%. Other properties as compared to coal are high moisture content, high chlorine content, low bulk density and low heating value are found. Biomass has less carbon content but, the oxygen content is higher as compared to coal. He suggested biomass still as the most eligible renewable source to replace fossil fuels irrespective of these variations.

To avoid bed agglomeration and some problem associated with the boiler the study of ashes of biomass are important. Hiltunen et al. [47] analyzed various types of ashes of biomass and categorized the biomass ashes into three groups according to their composition such as i) Ca, K-rich and Si lean biomass ash, ii) Si-rich and K, Ca lean biomass ash, and iii) K, Ca and P-rich biomass ash. The first set belongs to woody biomass, and the rest belong to agricultural biomass. They also analyzed the effect of combustion and their effect on boilers which are very popular for biomass combustion namely circulating fluidized bed boilers. Slagging and fouling are two important ash-related problems associated with the boiler. When ash deposited on the furnace surface which is exposed to high-temperature flame radiation, then it is called slagging, and the deposition of ash in the convective section of the boiler is called fouling. Slagging and fouling can cause excessive deposition of ash on the heat transfer surfaces of boilers which decrease the effectiveness of boiler functioning and can shut down the power unit in extreme condition. These problems can be avoided by complete knowledge about ash fusion temperature [48].

2.5 Decentralized Power Generation Structure in Rural Areas

As the name suggests, decentralized energy is produced close to the location where it should be used rather than at a large plant elsewhere and sent through the national grid. Transmission losses are reduced by this local generation and also lower carbon emissions. Kumar and Gupta [49] made a broad statement on land and biomass calculation in rural areas for decentralized power generation by considering a group of 15-20 villages consisting of nearly 3000 families and accordingly one power plant can be planned which can provide per day 20000 kWh of electricity or 7300 MWh/year. Kumar et al. [42] considered four biomass species such as Eupatorium, Anisomales, Sida, and Xanphium. They calculated that from these biomass species, around 118, 66, 90 and 114 hectares lands would be required for the continuous generation of desired electricity respectively. Further, Kumar and Patel [43] studied on Ocimum canum and Tridax procumbens plant species approximately of 18 years old and calculated the land requirements to be 650 and 1274 hectares respectively to produce the same amount of desired electricity. Similarly, Kumar et al. [44] considered Sida Rhombifolia, Vinca Rosea, and Cyperus non-woody plants and calculated that around 44, 52 and 82 hectares of land area would be required to produce the said amount of electricity.

In the similar way, Kumar and Patel [50] studied some blends of coal, cattle dung and rice husk power generation potential considering decentralized power generation process and found that there is a decrease in coal requirement for power generation with the increase in the percentage of cattle dung and rice husk. Hence, total energy contents, land area and the requirements of coal-biomass blends should be calculated for betterment for power generation by the decentralized process.

2.6 Summary

Biomass energy constitutes a remarkable portion of renewable energy source, but there is a deficiency of research on the study of power production potential of biomass species which can be clearly understood from the literature review. The research on studies on chemical properties of biomass fuels which include the analyses of ash fusion temperature, proximate, and ultimate parameters and also on co-firing with limited local coal. It is also observed that there is a need to study on decentralized power generation aspects of biomass.

2.7 Objectives of the Present Project Work

The aims and objectives of the present project work are as follows:

a. Selection and collection of some woody biomass species from the local area.

b. Experimental investigation of proximate analysis of different components of some selected woody biomass species.

c. Characterization of these biomass components for their energy values.

d. Determination of bulk densities of the selected biomass species.

e. Calculation of ash fusion temperatures of ashes obtained from some of the selected biomass species.

f. Determination of ultimate analysis of some selected biomass species.

g. Estimation of power generation potentials, requirements of land area for decentralized power generation.

CHAPTER 3

EXPERIMENTAL WORK

3. EXPERIMENTAL WORK

3.1 Materials Selection

For the present project work, five different components (leaf, new branch, main branch, bark, and root) were taken from residues of two separate woody plant species and fruit husk/peel of three biomass were taken from local areas which have no commercial use. These plant species are Vachellia nilotica(local name- Babool), Azadirachta indica(local name- Neem), Musa acuminata(local name- banana), Cocos nucifera (local name- coconut) and Arachis hypogaea(local name- groundnut). Considering all the components of selected biomass samples total of thirteen numbers of samples were taken for proximate analysis and calorific value determination. By keeping these samples in a cross-ventilated room for 20-30 days, the equilibrium in moisture contents of these components was attained. Before experimental work air, dried samples were grinded into powder. Three selected woody biomass samples namely Neem bark, Babool Leaf and Coconut husk were considered for ultimate analysis.

3.2 Proximate Analysis of Studied Biomass Samples

Proximate analysis is deemed for characterizing biomass and coal samples. The quantitative analysis of the distribution of constituent products obtained when the sample is heated under designated conditions is called proximate analysis. As per ASTM D121 [51], proximate analysis separates the constituents into four categories: a) Moisture, b) Ash, c) volatile matter and d) fixed carbon.

3.2.1 Moisture Content Determination

The quantity of water present in the sample expressed in weight percentage (Wt.%) of the sample is moisture content of fuel. This is expressed regarding dry basis or wet basis. In the case of dry basis, only ash and ash free matter is considered, but the aggregate water, ash, and ash free matter content are considered in wet basis. It is crucial to mention the basis on which moisture is determined because moisture plays a vital role in differentiating biomass fuel [52].

The selected biomass sample was grinded into powder and by using a –72 mesh sieve, required –72 mesh size biomass materials were collected. A –72 mesh size sieve describes 72 holes per square inch, and the negative sign indicates passing of biomass powder particles through the holes. As per BIS 1350 [53], one gram of –72 mesh size air dried biomass sample powders were taken in borosil glass discs and heated for one hour in the furnace at a temperature of 100 ºC. After the designated time, the borosil glass discs were taken out of the oven, and the samples were weighed by electronic balance. By using the expression given below, the percentage losses in weights were calculated.

Percentage moisture content (%) = (Weight of residue obtained × 100) / Initial wt. of simple (3.1)

3.2.2 Ash Content Determination

Ash is the inorganic residue left after the complete burning of the biomass. It is a vital constituent present in biomass which largely affects ash fusion characteristics. Ash contains calcium, ferrous carbonate, magnesium and phosphorus, sand with clay, etc. which influence the boiler properties at a high temperature of combustion and gasification. Ash content affect the design of boiler. If the fuel comprises greater quantity of ash, then it can cause severe problems like Slagging, fouling and clogged ash removal problem associated with boilers [54].

Fig. 3.1: Muffle Furnace

One gram of each –72 mesh size samples was air dried and then were taken in shallow silica disc and put in a muffle furnace which is shown in Fig. 3.1. The temperature inside muffle furnace was maintained at 775- 800 ºC. The muffle furnace used for this experiment have a measuring range of temperature 0-1000 ºC with a resolution of 1 ºC and accuracy of ±5 ºC . The biomass samples were kept in maintained temperature in the muffle furnace and heated till their complete combustion usually half an hour. Then the residues obtained were measured with the help of electronic balance for each sample and expressed in a percentage similar to moisture content [53].

3.2.3 Volatile Matter Determination

The portion of the fuel that will volatilize rapidly when it is burnt at a high temperature under a particular condition is called volatile matter. When the fuel has low volatile matter by heating char formation occurs, but fuels have high volatile mass produce volatile gasses by heating. Biomass has high volatile matter content that may up to 80%, unlike coal which has very low percentage of volatile matter below 20%. Volatile matter consists of methane, hydrogen, carbon monoxide, ammonia, tar, etc. excluding moisture as residual moisture has not taken into account [51,52].

Cylindrical silica crucibles covered with the close-fitting silica lid were pre-weighted and each biomass sample of one gram of –72 mesh size powder was taken in the crucible. Then the crucibles were heated in a muffle furnace at temperature 925±10 ºC for exactly seven minutes. Then the crucibles were taken out from the furnace and air cooled. Then the weight of samples was measured with the help of electronic balance as soon as possible, and the percentage of weight loss was determined [53]. The following formula is used for calculating the weight percentage of volatile matter in dry basis.

$$\text{Volatile Matter (wt.\%)} = \text{\% loss in weight(wt.\%)} - \text{moisture content (wt.\%)} \qquad (3.2)$$

3.2.4 Calculation of Fixed Carbon Content

The value of fixed carbon content can be calculated by subtracting the aggregate percentages of moisture, volatile matter and ash from 100. Fixed carbon content is the quantity of solid carbon residue that remains after the combustion of the sample with the removal of volatile matter. The value of fixed carbon content helps for evaluating the productivity of biomass fuel. At lower combustion temperature it improves the reactivity of fuel [53].

Fixed Carbon Content (wt.%, dry basis) =100 – {Moisture + Volatile matter + Ash} (wt %, drybasis)   (3.3)

3.3 Calorific Value Determination

Calorific value or energy value of any fuel may be the quantity of heat energy obtained by complete combustion of a specified quantity of fuel in the presence of oxygen. It is an important property of any fuel and influences design and controlling of the power plant which is expressed in terms of kcal/kg or MJ/kg. It is evaluated by the help of a calorimeter. Based on the effect of water vapour on energy value, calorific value is classified into two types.

a) Gross calorific value (GCV) or Higher heating value (HHV)
b) Net calorific value (NCV) or Lower heating value (LHV)

The GCV considers the latent heat of vaporization of water which is the quantity of heat generated by combustion when the water vapour produced during combustion is allowed to return to the liquid state under standard condition of temperature and pressure. When the water vapour produced during combustion remains gaseous and doesn't return to liquid state, the quantity of heat generated is called Net calorific value (NCV). Here, the condensation of water is not taken into account. Calculation of energy value is calculated using an adiabatic calorimeter [55].

Fig. 3.2 : Oxygen Bomb Calorimeter

In the present project, the gross calorific value or higher heating values of some biomass species were determined with the help of Oxygen Bomb Calorimeter, which is capable of calculating the GCV of any solid fuel [53]. This oxygen bomb calorimeter used in the present have a temperature scale resolution of 0.01 ºC and an accuracy of ±0.02 ºC. The measuring range is 0-10 ºC. First, briquetting device is used to produce briquettes of each biomass samples, and briquettes were taken in a nichrome crucible. A cotton thread of 10-15 cm long was positioned over the sample in the crucible for facilitating ignition. A fuse wire is connected between two electrodes of the crucible, and the cotton wire is suspended by using the fuse wire as shown in the Fig. 3.2. Before conducting the experiment Oxygen gas was poured into the oxygen bomb calorimeter up to a pressure 25 to 30 atm and the bucket of calorimeter were filled with two liters of water and were stirred continuously by the help of a motor and stirring mechanism maintain a uniform temperature. Then after switching on the current, the ignition of the sample was started, and the temperature of the water was recorded by thermometer attached to it. Then from the reading, the rise in temperature was calculated. With the help of rising in temperature (ΔT), water equivalent of apparatus (W.E) in cal/ºC, initial weight of the sample (w) in gram, the GCV can be calculated by the following empirical formula [56].

$$\text{Gross calorific value} = \{(\text{W.E.} \times \Delta T) / (w) - (\text{heat released by cotton thread} + \text{heat released by fusedwire})\} \quad (3.4)$$

3.4 Bulk Density Determination

The bulk density of fuel gives an idea about the weight of that fuel to be provided sufficiently in a given volume of the boiler. It influences the transportation and storage costs largely. The combustion devices also largely influenced by bulk density. Higher, the bulk density lesser, will be the transportation cost. It is expressed as the weight per unit volume of material, expressed in kg/cubic meter.

The bulk densities of the biomass samples were calculated according to the ASTM E873-82 standard [57]. Each biomass sample of -72 mesh size powder was taken in a cubic container of dimension 65mm × 65 mm × 65 mm made of mild steel. Each sample was fully packed in the container and leveled at the top surface. The weight of the samples filled in the container was measured with the help of electronic balance of sensitivity 0.01gm. Then bulk density was calculated by the weight obtained from electronic balance and initially measured dimension of the container.

Bulk Density = Wt. of the sample packed in container (kg)/Volume of the container (cubic meter) (3.5)

3.5 Ash Fusion Temperature Determination

Ash fusion temperature plays a significant role in selection of fuel because at high-temperature fuel ash creates slag better known as clinker. That can pose a mechanical problem in combustion process associated with the boiler which largely influences boiler design and efficiency. Deposition of ash at high-temperature region causes slagging and fouling problems in the boiler. Hence, ash fusion temperature determination plays a crucial role in the selection of fuel which includes i) initial deformation temperature (IDT), ii) softening temperature (ST), iii) hemispherical temperature (HT) and iv) fluid temperature (FT). IDT is the temperature, at which first change in shape occurs and the temperature at which the sample starts shrinking and the corners of the sample melt is called ST and the temperature at which the cubical sample becomes hemispherical in shape is called HT and the temperature at which the sample melts and lays flat is called FT [44].

The ash fusion temperatures of biomass ashes were calculated according to DIN: 51730 [58]. Ashes of some selected biomass samples were taken and crushed and by mixing one drop of distil water 3mm sizes of cubic shaped sample are prepared for ash fusion test. Then the sample was put inside Leitz heating microscope which is shown in Fig.3.3. The rise in temperature was maintained at 8ºC/min, and the current was maintained at 25Amp and heated up to a maximum temperature of 1450 ºC with an accuracy of ±5 ºC and resolution of 1ºC. The external shape of the cubes was observed, and the temperatures were noted during the deformation, shrinkage of cubic samples.

Fig. 3.3: Leitz Heating Microscope

3.6 Ultimate Analysis: Determination of Chemical Composition

Ultimate analysis gives complete results as compared to proximate analysis. It is capable of calculating some valuable ash free organic components like carbon, oxygen, hydrogen, nitrogen, etc. and is carried out by an elemental analyzer. In general practice, 200 mg of each sample were heated at 900 ºC in the presence of oxygen. Carbon has transformed into $CO2$, hydrogen into $H2O$, sulphur into $SO2$ and nitrogen into $N2$ during the experiment. By using an infra red detector the quantity of Carbon, hydrogen and sulphur were calculated and by using a thermal conductivity detector quantity of $N2$ is determined [55]. In the present work, CHN analysis was carried out for some of the selected biomass samples at Sophisticated Analytical Instrumentation Facility, Punjab University, Chandigarh, India.

CHAPTER 4

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

Table 4.1 shows the moisture content, ash content, volatile matter and fixed carbon content of different components of selected biomass samples from proximate analysis.

Table 4.1: Proximate Analyses and Gross Calorific Values of Different Components of Studied Biomass Species

Components	Moisture content (Wt%,Dry)	Ash Content (Wt%,Dry)	Volatile Matter (Wt%,Dry)	Fixed Carbon Content (Wt%,Dry)	GCV (Kcal/kg)
Neem					
Leaf	**8**	**10**	**71**	**11**	**3241**
Bark	**11**	**8**	**58**	**23**	**3667**
New Branch	**11**	**9**	**64**	**16**	**3358**
Main Branch	**9**	**5**	**74**	**12**	**3387**
Root	**9**	**17**	**58**	**16**	**3330**
Babool					
Leaf	**9**	**11**	**61**	**19**	**3721**
Bark	**7**	**7**	**65**	**21**	**3625**
New Branch	**9**	**5**	**67**	**19**	**3558**
Main Branch	**9**	**1**	**71**	**19**	**3586**
Root	**9**	**8**	**64**	**19**	**3670**
Groundnut husk	**10**	**11**	**57**	**22**	**3349**
Banana Peel	**9**	**10**	**64**	**17**	**3405**
Coconut Husk	**11**	**6**	**58**	**25**	**3656**

From the table 4.1, it is found that the moisture content of Neem bark and new branch are highest (i.e., 11Wt. %) followed by groundnut husk (i.e., 10Wt. %) among all other selected samples. Babool bark has lowest (i.e., 7Wt. %) moisture content. The moisture content of various components of Neem and Babool samples are compared in Fig. 4.1 below.

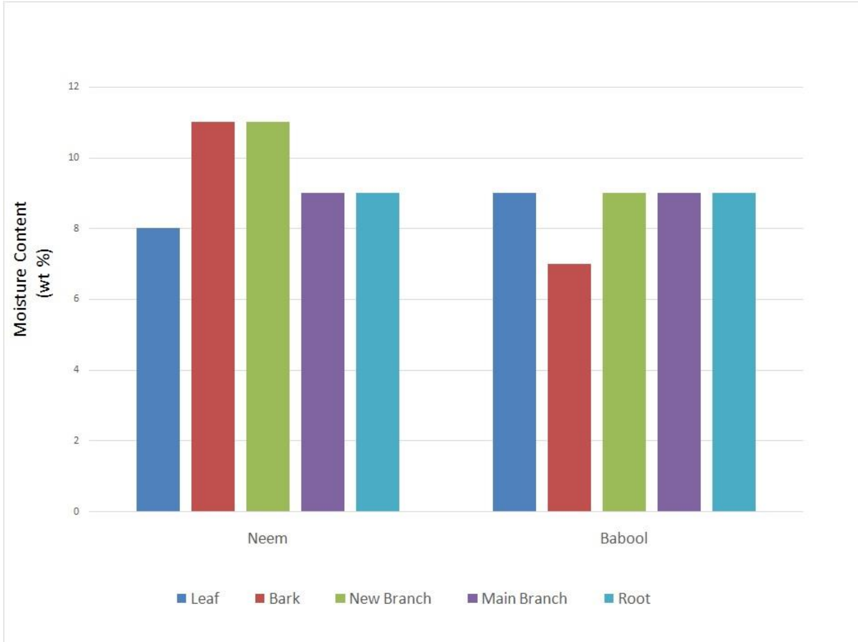

Fig. 4.1: Comparison of Moisture Content in Neem and Babool Samples.

Very high ash content is obtained in the case of Neem root (i.e., 17 Wt. %) followed by babool leaf (i.e., 11 Wt. %). The main branches of Babool are found to be lowest (i.e., 1 Wt. %). The ash content in different Neem and Babool samples are compared in the chart given below.

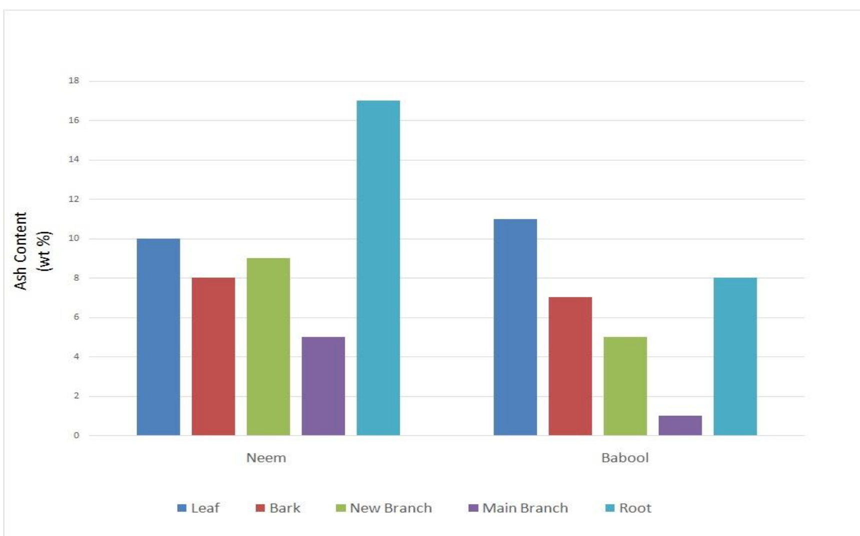

Fig. 4.2: Comparison of Ash Content in Neem and Babool Samples.

From all components of selected biomass samples the fixed carbon content is found to be highest in Coconut husk (i.e., 25 Wt. %) followed by Neem bark (i.e., 23 Wt. %). And fixed carbon content found lowest in case of leaves of Neem (i.e., 11 Wt. %). The fixed carbon content in Barks of Neem and Babool are found to be higher as compared to its other components. Also, the outer covers of Coconut, Groundnut, and Banana fruit shows comparatively higher fixed carbon content. Fixed carbon content in Neem and Biomass sample are compared in the chart in fig. 4.3.

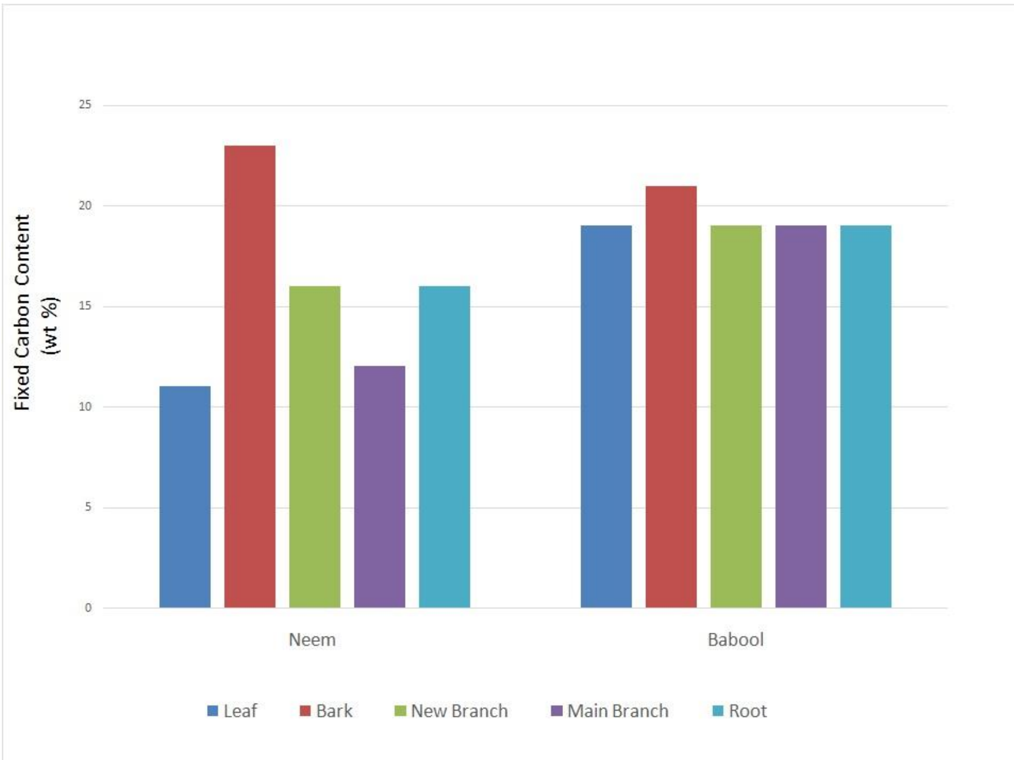

Fig. 4.3: Comparison of Fixed Carbon content in Neem and Babool Biomass samples

The table 4.1 shows that the branches have comparatively higher volatile matter than other components. Also, bark contains comparatively low volatile matter. Volatile matter is found to be highest in main branches of Neem (i.e., 74 Wt. %) followed by its leaves and the main branch of Babool and the husk of Groundnut has the lowest value of volatile matter (i.e., 57 Wt. %). A comparison of Volatile Matter Content in Neem and Biomass samples is shown in Fig. 4.4 below.

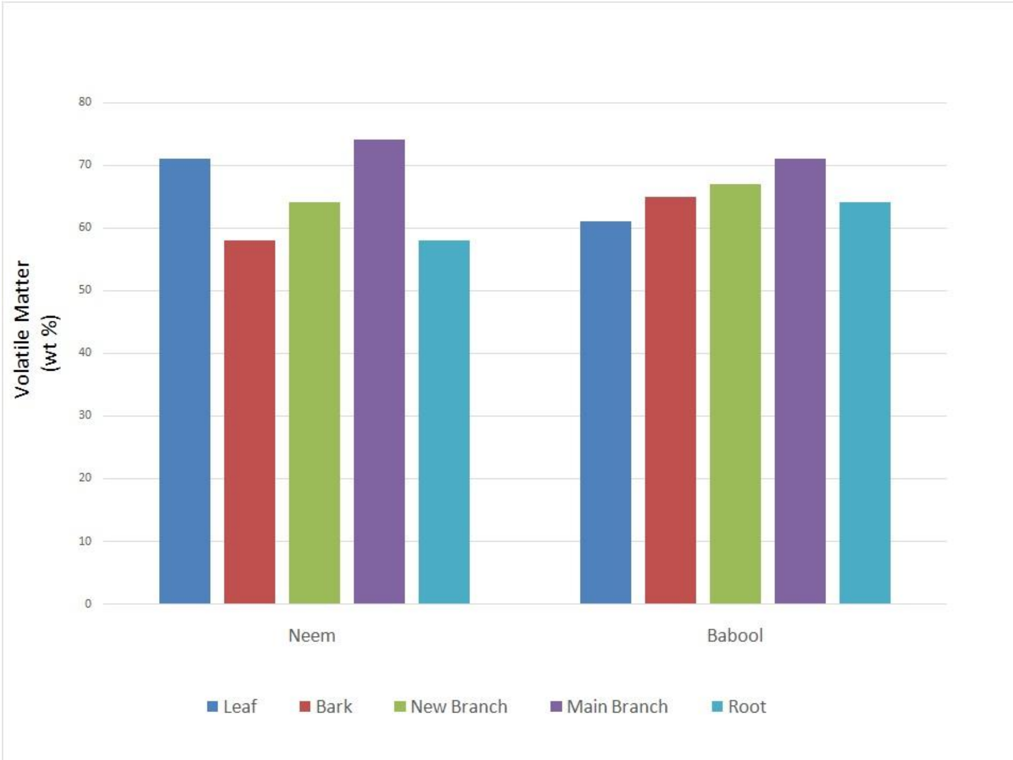

Fig. 4.4: Comparison of Volatile Matter Content in Neem and Babool Biomass samples

If the fuel consists of greater volatile matter and fixed carbon, then it helps in enhancing the combustion process by facilitating easy ignition and high reactivity. High ash content gives rise to slagging, and fouling problems prevent heat transfer and decreases combustion efficiency. If the moisture content is high, then it decreases its effective bulk density which leads to increase in cost associated with transportation and storage. The increase in ash and moisture content will reduce the energy value of the fuel [59].

4.1 Gross Calorific Values of Studied Biomass Components

Calorific value is an important characteristic which gives an idea about power generation potential of a specific fuel. It plays a vital role in the selection of fuel for power plants.

The leaf of Babool biomass species is considered for the calculation of GCV. Maximum rise in temperature was found to be 0.55 °C. The initial weight was measured to be 0.29g. The water equivalent of Oxygen Bomb Calorimeter is 1987 cal/0C and Heat released by cotton thread and fused wire is specified as 48 kcal/kg.

GCV of Babool leaf = (1987 x 0.55)/0.29 = 3721 kcal/kg.

Similarly, GCV for all other biomass species were calculated and are presented in Table 4.1.

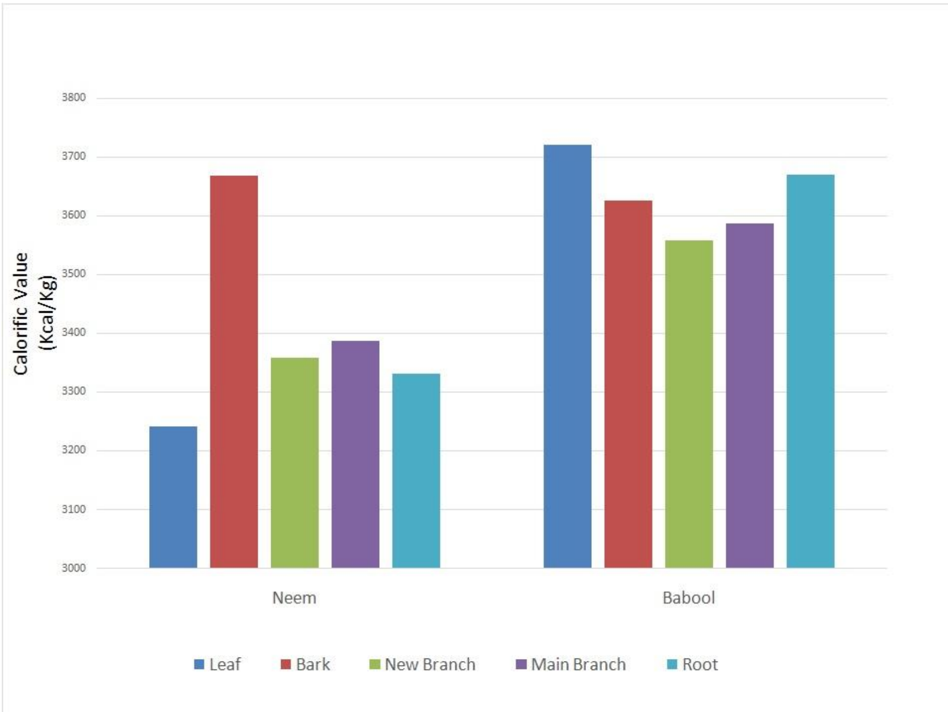

Fig. 4.5: Comparison of GCV of Neem and Babool Biomass samples.

The calorific values presented in Table 4.1 shows that the leaves of Neem have the lowest calorific value, and its bark has the highest calorific value among other components of Neem biomass samples. But in the case of the components of Babool biomass species, leaves has highest calorific value, and its branches have comparatively lowest value. It is observed from fig. 4.5 that, all the components of Babool biomass species have relatively higher GCV. It should be noted that the leaves of Babool have highest calorific value while Neem leaves have the lowest value among all the selected biomass samples. Also, Babool root, coconut husk, and bark of both Neem and Babool are found to be good at calorific value.

4.2 Determination of Bulk Densities

Bulk density is an important property which decides the cost associated with transportation and storage capacity.

The bulk density of all selected biomass samples was determined and is listed in Table 4.2.

Table 4.2: Bulk Densities of Different Components of Biomass

Components	Bulk Density(Kg/m3)
Neem	
Leaf	321
Bark	382
New Branch	346
Main Branch	342
Root	328
Babool	
Leaf	316
Bark	443
New Branch	352
Main Branch	349
Root	372
Groundnut Husk	262
Banana Peel	422
Coconut Husk	163

Table 4.2 shows that leaves of biomass species have lower bulk density while barks have high bulk density compared to other components. Also, it is observed that the outer cover or husk have lower bulk density while only Banana peel have a higher bulk density (i.e. 443Kg/m3). It should be noted that bark of Babool have highest bulk density followed by Banana peel (i.e. 422Kg/m3) while Coconut husk(i.e. 163Kg/m3) have the lowest bulk density followed by Groundnut husk(i.e. 262Kg/m3).

4.3 Ash Fusion Temperature Determinations of Selected Biomass Components

Ash fusion temperatures of four selected biomass samples were measured, i.e., Neem root, Neem leaf, Babool leaf and the husk of Coconut were considered for the test by using Leitz Heating Microscope. The values of IDT, ST, and HT of different selected samples were calculated and presented in Table 4.3 below.

Table 4.3: Ash Fusion Temperatures of Different Biomass Samples

Ash of Biomass Samples	**Ash fusion temperatures, ^0C**		
	IDT (Initial Deformation Temperature)	**ST** (Softening Temperature)	**HT** (Hemispherical Temperature)
Neem Root	**995**	**1132**	**1253**
Babool Leaf	**1131**	**1158**	**1189**
Coconut Husk	**1108**	**1134**	**1161**
Neem Leaf	**1178**	**1208**	**1232**

It was found that Initial Deformation Temperature (IDT) varies from 995 to 1178ºC, softening temperature (ST) ranges from 1132 ºC to 1218 ºC and hemispherical temperature (HT) ranges from 1161 ºC to 1253 ºC. The IDT of Neem leaf was found to be the highest value as shown in Table 4.3. For safe boiler operation, the IDT of the ash of the fuel should be at least 150 ºC more than the boiler operation temperature. The operating temperature of the boilers based on biomass is around 800-900 ºC [47]. The value of IDT of all the selected sample is found to be above the boiler operating temperature. Hence, these selected biomass ashes will not create any problem associated with combustion in boilers. Due to the limitation of the instrument, the picture of the sample inside furnace during IDT, ST and HT could not be obtained.

4.4 Ultimate Analyses of Selected Biomass Components

Ultimate analyses give the data about the different constituent present in components of various biomass species. These elements are carbon, hydrogen, nitrogen and oxygen. Carbon and hydrogen positively contribute to gross calorific value, as those are oxidized to CO_2 and H_2O exothermically. But the reduction of oxygen negatively contributes to the gross calorific value while nitrogen has least effect on it. Nitrogen is almost totally converted to gaseous N_2 and NO_x [60]. The calorific values of carbon and hydrogen are approximately 33.829 MJ/kg and 144.444 MJ/kg respectively [43]. So both of them can be assumed to be an important factor in deciding the calorific value of the fuel.

Table 4.4: Ultimate Analysis and Corresponding Gross Calorific Values of Biomass Samples

Components	Ultimate analysis (wt %, dry basis)				Calorific Value (Kcal/kg)
	Carbon	Hydrogen	Nitrogen	Oxygen	
Neem bark	45.4	5.62	1.028	41.731	3667
Babool leaf	46.891	4.928	1.223	43.864	3721
Coconut husk	45.234	5.562	0.925	41.896	3656

The results found from ultimate analyses of three selected biomass samples (Neem bark, Babool leaf, and Coconut husk) along with their gross calorific values have been shown in Table 4.4. Due to less availability of time and instrument, the ultimate analysis of only three selected components was possible.

A similar type of results was obtained from the Table 4.4. It is observed that all three selected biomass samples are good at hydrogen content and also the gross calorific value. Neem bark has the highest hydrogen content (i.e., 5.62 wt%) while Babool leaf has the lowest value (i.e., 4.928 wt%). The carbon content in Babool leaf is observed to be the highest while husk of Coconut is the lowest value among the selected biomass samples. It is observed from the Table 4.4, that the gross calorific values have a direct relationship with hydrogen content. The leaves of

Babool have lower hydrogen content but have the highest calorific value. But the difference is negligible. Hence, the higher concentration of carbon and hydrogen is the reason of higher gross calorific values of the fuel and also plays an important role in the selection of fuel.

4.5 Calculation of Land and Biomass Requirement for Decentralized Power Generation in Rural Areas

The necessity of decentralized power generation in rural areas is due to intermittent power supply and damage of electrical equipment due to fluctuation in voltage and frequency. The requirements of electricity can be estimated in rural areas by considering a group of 15-20 villages comprising of nearly 3000 families and accordingly one power plant can be designed. Approximately 6000 kWh/day of electricity is considered to be required by 3000 families. Considering the prerequisites from the watering system and small-scale commercial enterprises near the cluster of the village, approximately an additional energy of 14000 kWh/day is also considered [49]. A total electricity of 20000 kWh/day or 7300 MWh/year can be obtained by a power plant in that location.

The approximate production quantity in tonnes per hectare of all the thirteen biomass samples was calculated by field studies and presented in Tables 4.5-4.7. Also, the calorific values in MJ/kg and energy values in MJ/ha were calculated on the dry basis and presented in the same set of tables.

Table 4.5: Total Energy Contents and Power Generation Structure from Neem Biomass Species (Ten Years old approximately)

Component	Calorific value (MJ/t, dry basis)	Biomass production (t/ha)	Energy value (MJ/ha)
Leaf	13570	25.827	350472.39
Bark	15353	21.439	329152.967
New Branch	14059	12.216	171744.744
Main Branch	14181	21.226	301005.906
Root	13942	8.753	122034.326

Data collected from field studies (approximate values)

Table 4.6: Total Energy Contents and Power Generation Structure from Babool Biomass Species (Fifteen Years old approximately)

Component	Calorific value (MJ/t, dry basis)	Biomass production (t/ha)	Energy value (MJ/ha)
Leaf	15579	4.863	75760.677
Bark	15177	5.621	85309.917
New Branch	14897	8.128	121082.816
Main Branch	15014	18.685	280536.59
Root	15366	6.866	105502.956

Data collected from field studies (approximate values)

Table 4.7: Total Energy Contents and Power Generation Structure from Groundnut Husk, Banana Peel and Coconut Husk Biomass Species (Per Year Production approximately)

Component	Calorific value (MJ/t, dry basis)	Biomass production (t/ha)	Energy value (MJ/ha)
Groundnut Husk	14022	125	1752750
Banana Peel	14256	17.751	253058.256
Coconut Husk	15307	66.69	1020823.83

Data collected from field studies (approximate values)

In general practice, the thermal and overall efficiencies of a power plant are considered as 30% and 85% respectively [50]. The land requirement for Neem sample is calculated below.

Referring Table 4.5, the total energy production in MJ per hectare of land is found by adding the energy values of all the components (leaf, bark, new branch, main branch and root) of Neem tree.

i.e.

$$350472.39 + 329152.967 + 171744.744 + 301005.906 + 122034.326 = 1274410.333 \text{ MJ/ha.}$$

The energy output by taking thermal efficiency of 30%, is

$$1274410.333 \times 0.3 = 382323.1 \text{ MJ/ha.}$$

Then the net energy output by considering overall efficiency of 85%, is

$382323.1 \times 0.85 = 324974.635$ MJ/ha.

Then by multiplying a factor of 0.0002778, the above energy value can be converted in MWh/ha as shown below,

$324974.635 \times 0.0002778 = 90.27$ MWh/ha

Hence, land required for supplying electricity from Neem biomass species for the whole year

$= 7300/90.27 = 80.868$ ha.

Then the total biomass production in t/ha can be obtained by adding biomass production of each component of Neem biomass sample.

i.e.

$25.827 + 21.439 + 12.216 + 21.226 + 8.753 = 89.461$ t/ha

Then the biomass requirement for supplying electricity from Neem biomass species for the whole year can be found out by multiplying 89.461 t/ha with the total land required for Neem biomass.

i.e.

$89.461 \times 80.868 = 7234.532$ tonne

Likewise, the land requirement and biomass requirement for all studied biomass samples was calculated and presented in Table 4.8.

Table 4.8: Land Area and Biomass Requirements for Production of 7300 MWh Electricity per Year

Biomass species	Land requirement (hectare)	Biomass requirement (tonne)
Neem	80.868	7234.532
Babool	154.236	6811.524
Groundnut Husk	58.795	7349.375
Banana Peel	407.23	7228.739
Coconut Husk	100.95	6732.355

It is observed from the Table 4.8, the husk of Groundnut needs the lowest and Banana peel needs the highest land area among all studied biomass species for the supply approximately 20000 kWh of electricity per day or 7300 MWh per year continuously. Also, it is observed that, the Coconut husk biomass may provide the same amount of energy with least quantity (i.e. 6732.355 tonne).

CHAPTER 5

CONCLUSION

5. CONCLUSIONS

The following conclusions may be drawn from the results obtained from the present project work:

i. The root of Neem was found to have the highest ash content (17 wt.%) while main branches of Babool were found to be the lowest value (1 wt.%). Both the main branches of Neem and the new branches of Babool were also found to be lower (5 wt.%) in ash content followed by branches of Babool. Hence, these biomass species with lower ash content can be efficient for boiler operation.

ii. The volatile matter in the branches of Neem was found to be highest (74 wt.%) followed by both leaves of Neem and main branches of Babool(71 wt.%). The husk of Groundnut was found to be the lowest (57 wt.%) in volatile matter content.

iii. Out of all the tested biomass samples, Coconut husk has been found to have the highest (25 wt.%) fixed carbon content followed by Neem bark (23 wt.%).

iv. The energy value of Babool leaf is found to be highest followed by its root among all the selected biomass species. The energy value obtained in the case of all components of Babool biomass species is comparatively higher than the components of Neem biomass samples.

v. The bulk density of the bark of Babool biomass is found to be highest followed by Banana peel. So, a higher quantity of material or biomass fuel can be accommodated in a given volume of the reactor.

vi. The IDT and ST of all selected biomass samples were found to be much higher than the boiler operation temperature. The leaves of Neem biomass is expected to offer less ash-related problems in the boiler due to its highest IDT and ST.

vii. The calculation for the generation of 7300 MW of electricity indicated the 7234.532, 6811.524, 7349.375, 7228.739, and 6732.355 tonnes of Neem, Babool, Groundnut Husk, Banana peel and Coconut husk biomass required respectively. And 80.868, 154.236, 58.795, 407.23 and 100.95 hectare of land is required for Neem, Babool, Groundnut Husk, Banana peel and Coconut husk biomass respectively for the production of same 7300 MW of electricity. From the analysis of the present results, Coconut husk appears to be the best biomass for utilization in power generation.

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