

Preface

Energy is regarded as a critical component for the worldwide development and financial prosperity of present-day society. However, rising energy use in recent years has resulted in issues such as depletion of fossil-based energy resources and ecological destruction. The agricultural, industrial, transportation, and residential sectors have an increased energy demand. Over the last two to three decades, significant global research and development efforts have been devoted to developing different renewable energy supplies to meet energy demand while decreasing environmental challenges. Renewable energy resources such as biomass, solar, wind, and hydro have been identified as potential possibilities for a country like India. Lignocellulosic biomass has received substantial consideration over other renewable energy resources due to its inherent advantages. Biomass has drawn the attention of policymakers and academics worldwide among the many categories of renewable energy sources because of its renewable and sustainable character and its continuous and extensive availability in various forms. In this thesis, three different types of low-value biomass such as *Lagerstroemia speciosa* (LS), mustard straw (MS), and *Sesbania bispinosa* (SB), were chosen as a feedstock for pyrolysis in order to determine their bioenergy potential. The LS biomass was collected from the campus of IIT (BHU) Varanasi, whereas the MS and SB biomass was collected from the village (Bindwal) of Azamgarh district, Uttar Pradesh, India. The samples were dried and then powdered to get the desired particle size. Further, physicochemical characterization such as proximate, ultimate, and fiber analyses were carried out. The calorific value and bulk density were also measured to determine the energy content and ease in storage and transportation, respectively. The FTIR spectroscopy was carried out to determine the different functional groups attached to the respective biomasses, whereas thermogravimetric analysis was carried out to determine the thermal stability of the biomass.

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Chapter-1 deals with the introduction of energy scenario in India. This chapter describes the production and consumption of different petroleum products in India. Further, the classification and properties of the available biomass resources have been described. The chemical composition of the biomass, such as hemicellulose, cellulose, and lignin, and the technologies applied for converting biomass into valuable products were presented.

Chapter-2 mainly deals with the physicochemical characteristics of different types of biomasses reported in previously published literature. The kinetic analysis of different types of biomasses using different models was studied. The thermal pyrolysis based on different operating conditions of various types of biomass and their optimum pyrolytic yield were presented. The yield of pyrolysis products, for example, type of biomass, catalyst employed, heating rate, feedstock size, sweeping gas (N₂) flow rate, reactor layout, and temperature, were studied. The pyrolysis products were optimized using response surface methodology (RSM) based on central composite design (CCD). The research gaps were identified from the literature. The scope and objectives of the present research work are described.

Chapter-3 deals with material and methods, collection, and preparation of the biomass. The preliminary characterization of the sample such as proximate analysis (moisture content, volatile matter, ash, and fixed carbon content), ultimate analysis (carbon, hydrogen, nitrogen, and sulfur), calorific value, bulk density, fiber analysis (cellulose, hemicellulose, and lignin) were carried out using the standard protocols, whereas thermal degradation analysis was carried out using a thermogravimetric analyzer. Fourier transform infrared spectroscopy (FTIR) was employed for the determination of functional groups present in the biomass. The kinetic and thermodynamic parameters were also calculated using the respective equations. This chapter also comprises the details of the experimental setup used in different experimental works.

Chapter-4 aims to investigate the thermochemical characteristics and thermal degradation behavior of LS biomass. LS sample was characterized by proximate study, elemental study, calorific value, fiber analysis, and thermal stability study, whereas; isoconversional models such as Ozawa-Flynn-Wall (OFW), Kissinger Akahira Sunose (KAS), Vyazovkin (VZK), Tang method (TM), and Starink method (ST) were used for performing the kinetic study. The physicochemical study of LS revealed its bioenergy capability to create renewable fuel and valued compounds. Further, isoconversional models such as OFW, KAS, TM, ST, and VZK yielded average activation energy of 164, 154.35, 154.63, 154.61, and 141.93 kJ/mol. The master plot and thermodynamic study of LS confirmed that the pyrolysis process passed through multifaceted reaction mechanisms. Important pyrolysis parameters such as heating rate, temperature, and inert gas (N₂) flow rate were optimized using the Response Surface Methodology (RSM). The experimental findings revealed that the optimum condition for the maximum bio-oil yield (45.6%) production was: temperature = 550°C, heating rate = 65°C/min, and N₂ flow rate = 60ml/min; however, at this condition, the predicted bio-oil yield using RSM was 44.98%. The obtained bio-oil was characterized based on its physicochemical properties such as GCMS, FTIR, and ¹H-NMR.

Chapter-5 aims to investigate the thermochemical characteristics and thermal degradation behavior of mustard straw. The model-free methods of Ozawa-Flynn-Wall (OFW), Kissinger Akahira Sunose (KAS), and Vyazovkin were employed for kinetic analysis and Coats-Redfern (CR) method was employed for elucidating the reaction mechanism. Response surface methodology (RSM) with a central composite design technique was employed to optimize the pyrolysis process parameters to gain the maximum amount of bio-oil. The highest bio-oil yield (44.69%) was obtained at the heating rate of 25 °C/min and a temperature of 500°C under inert conditions (N₂ gas flow rate=100 ml/min). Further, FTIR and GCMS analysis of bio-oil revealed the presence of different functional groups

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and valuable chemicals, whereas physicochemical characterization revealed its fuel characteristic. The results confirmed the suitability of mustard straw as a feedstock for obtaining cleaner fuel and value-added products.

Chapter-6 deals with the aim of optimizing the process parameters and experimental situations for the pyrolysis of *Sesbania bispinosa* (SB) to acquire the utmost bio-oil yield. A stainless steel fixed bed reactor was employed for pyrolysis to attain the pyrolysis product. The thermogravimetric analyzer (TGA) was employed to measure the thermal degradation profile at dynamic heating rates. The model-free approaches of Ozawa Flynn Wall (OFW), Kissinger Akahira Sunose (KAS), Tang (TM), Starink (ST), and Vyazovkin (VZK) were used to predict kinetic parameters. The average activation energy obtained was 181.37, 180.63, 180.91, 180.90, and 161.31 kJ/mol using the OFW, KAS, TM, ST, and VZK methods, respectively. The thermal pyrolysis results revealed that the highest bio-oil yield (42.53 wt. %) was achieved at a temperature of 585 °C, a heating rate of 60 °C/min, and an inert flow rate of 125 ml/min. Characterization results of biochar confirmed its candidacy to be used in different industrial applications.

Chapter-7 presents the overall summary, including important conclusions and the scope of future work.
