Dr. SATHIYA PRABHAKARAN SP

PROFILE

A Ph.D. scholar from NIT Tiruchirappalli with a robust academic background in waste management/disposal & utilization for cement production technology. Devoted to promote economic growth, provide solutions to climate change with experience in leading research projects & committed to continuous learning, professional development with genuine interest in improving environmental quality.

CONTACT

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Google Scholar: https://scholar.google.com/citations?user=hEkoih8AAAAJ&hl=en&authuser=1#
Department of Energy and Environment,
National Institute of Technology- Trichy

AWARDS & HONORS

- *Selected in Top 10 abstract competition in 4th ISWA YPG Online International Conference: "THE PATH TOWARDS 2030. The Envisioned Decade of Changes Toward a Circular Economy Era (2021).*
- *Shortlisted in top 25 teams from 1600 teams in New Normal Hackathon by NEC and Mitsubishi Corporation (2021)*
- *Published Original Research article on COVID 19 Pandemic exponential growth model for 42 countries. Article was Published in Authorea (WHO).*
- *Community Member of the American Chemical Society (ACS) & Reviewer in Journals (Energy Conversion Management, biomass conversion, and bio refinery)*

EDUCATION

- **Ph.D.** Energy and Environment |2021 | CGPA:9.25 | National Institute of Technology-Tiruchirappalli.
- **M.Tech.** Solar Energy | 2014| CGPA:7.4| SRM University
- **B.Tech.** Energy and Environment, 2012| CGPA:7.31|Tamil Nadu Agricultural University, India
- **MBA** [Technology Management] Distance Education(pursuing)]-Karaikudi- Alagappa University

EXPERIENCE

- Half Time Research Assistant (HTRA-MRHD), NIT Tiruchirappalli Feb 2015-April 2021
- Research Scholar, DRDO-BrahMos Project, NIT Tiruchirappalli Feb 2015-Dec 2016
- Assistant Professor, Department of Mechanical Engineering, Faculty of PG Studies Marwadi University| June 2014-Dec 2015. (AGP 6000)

INTERNSHIP

- Environmental Engineering Department of BGR Energy Systems Ltd | 3 Months
- Alternative Fuel and Raw material dept. of ACC cements Ltd| 15 days

WORKSHOPS ORGANIZED

- waste management| Department of Energy and Environment| 24th to 28th Sep 2018
- "ECOFEST" 08 (state level symposium) | Agricultural Engineering college and research institute, TNAU| July 28,2010

RESEARCH PROJECTS

- **Doctoral Research**: "**Thermal degradation kinetics of solid waste materials for co-processing in cement kilns**"
- **Research Scholar**: Usage of alternative fuels and alternative raw materials in cement kiln for co-processing and "**Safe Disposal of Missile canister after missile firing**"–DRDL-BrahMos Project
- **Post-Graduation Research: Experimental Investigation of Solar Assisted Fluidized bed dryer for Agricultural products**
- **Undergraduate Research:** Designed and perfected a Government-funded project titled **"solar Dome dryer for Mushrooms**"

RESEARCH INTEREST:

- *Waste Management Solutions*
- *Waste utilization technologies*
- *Agricultural and post-harvest technologies*
- *Renewable and Sustainable Technologies*
- *Nanomaterials*
- *Circular Economy concepts*

CORE RESEARCH AREAS

- *Energy & Environment Engineering*
- *Waste management disposal*
- *Laboratory Techniques*
- *Life cycle assessment of a product*
- *Developing Thermodynamic kinetic models*
- *Research & analysis*
- *Process Engineering/Optimization*
- *Developing predictive models*
- *Synthesizing 2D,3D and alloy nanomaterials*

CORE RESEARCH SKILLS

- *LCA (Simapro& openLCA)*
- *MATLAB-ANN|ANNFIS*
- *SPSS| Mini Tab,Origin*
- *Python|MS Office*
- *X-pert Highscore(XRD)*
- *Design Expert(optimization)*

LANGUAGE

English, German: A1/A2 from Goethe Institute (German Embassy Affiliated), Hindi: Rastrabhasha Praveena (Equivalent to B.A Hindi Literature) from Dhakshin Hindi Prachar sabha, Tamil

EXTRA CURRICULAR

- *Best Sportsmen of year Award | Sports Development Authority of India (2010)*
- *Stick-fencing: Gold Medal, State (2004,06-10) & National Championship (2009,10)*
- *Karate: Gold Medalist, State (2004-05)*
- *Judo: Gold Medal, District (2006)*
- *NSS Team Lead*
- *Cultural Secretary: NITTFEST*
- *Dramatic Secretory, Planning forum*

CERTIFICATIONS

- Conducted training Program on "solar energy equipment's" in WSS & UGSS and safety aspects" at Tamil Nadu water Supply and Drainage Board
- Hands-on practical training in Energy Efficiency| Dr. Ambedkar Institute of productivity, Chennai(NPC)
- Artificial Intelligence: AICTE Training & Learning (ATAL) Academy Online FDP| Manipal Institute of Technology
- "Application of nanotechnology in solar system" NITT
- International Children's assembly and Integration camp| Theme: Values in Nation Building| National Bal Bhavan| New Delhi
- Healthy youth for healthy India: special camping program at agricultural Engineering college and research institute, TNAU
- Teaching-Learning Aid and Course module development using Aspen Plus| Department of Chemical Technology, Tiruchirappalli

BOOK CHAPTER PUBLISHED

- "Prediction model for Evaluating the Raw Water Quality Parameters and its Significance in Pipe Failures of Nuclear Power Plant" Springer Book Series" Climate Change and Water Security-Lecture Notes in Civil Engineering(Volume 178).

  Authors: P.Suganya,G.Swaminathan,B.Anoop, S.P.Sathiya Prabhakaran et al.

PATENTS PLANNED

- Generation of Quantum dots from Agro waste for bio-imaging applications & thermal energy storage
- Use of magnetic nanoparticles for catalytic conversion of agro-residues for fuel applications and Biomass Pyrolysis and its thermal degradation kinetics
- Use of Nanomaterials for enhancing thermal conductivity of phase change materials

FORTH COMING PUBLICATION

Thermal Degradation studies and hybrid neural network modelling of eutectic Phase change material composites

- Author status: K.R Balasubramanium, SP.Sathiya Prabhakaran (3th) et al
- Journal: International Journal of Energy Research- IF:**5.164** (2022) Q1 (**Minor Revision**)

PUBLICATIONS-SCIE/SCOPUS (Cumulative IF-41.902)

- Life cycle assessment of co-combustion system of single use plastic waste and lignite coal for promoting circular economy
  - Author status: Sathiya Prabhakaran (Corresponding) et al
  - Journal: Journal of Cleaner Production (2021), IF:**9.297** Q1 **ABDC-A**
- Thermal degradation kinetics of Australian lignite coal for pyrolysis, combustion process, and validation by artificial neural networks 2021.
  - Author Status: (First & Corresponding)
  - Journal: Energy, IF:**7.147** Q1.
- Energy conservation: A novel approach of co-combustion of paint sludge and Australian lignite by principal component analysis, response surface methodology, and artificial neural network modeling
  - Author status: Sathiya Prabhakaran (First & Corresponding) et al
  - Journal: Environmental Technology& Innovation (2020) IF: **3.335** Q1
- Thermogravimetric analysis of hazardous waste: Pet-coke, by kinetic models and Artificial neural network modeling
  - Author status: Sathiya Prabhakaran, (First & Corresponding) et al
  - Journal: Fuel (2021), IF:**5.587** Q1
- Thermogravimetric study of textile lime sludge and cement raw meal for co-processing as alternative raw material for cement production using response surface methodology
  - Author status: Sathiya Prabhakaran (First & Corresponding) et al
  - Journal: Environmental Technology& Innovation (2021) IF: **5.263** Q1
- Exploring the growth of COVID-19 cases using exponential modeling across 42 countries and predicting signs of early containment using machine learning
  - Author status: Sathiya Prabhakaran(2nd) et al
  - Journal: Transboundary& Emerging Diseases (2020), IF: **4.187** Q1

- Catalytic pyrolysis of mustard biomass using magnetic FeNi alloy and its predictive modeling
  - Author status: G. Antilen Jacob, S.P. Sathiya Prabhakaran(2nd) et al
  - Journal: Chemosphere (2021) IF:**7.086** Q1
- Systematic literature review on novel corona virus SARS-CoV-2: a threat to human era.
  - Author status: DineshKumar Rajendran SP.Sathiya Prabhakaran (5th) et al
  - Journal: Virus disease- (2020) Q3

INTERNATIONAL CONFERENCE

- S. P Sathiya Prabhakaran* et al Prediction of Unburnt Carbon in Pulverized Coal Fired High-Capacity Boilers Using Response Surface Methodology and Artificial Neural Network First International Conference on Future Technologies in Manufacturing, Automation, Design and Energy (2020) ID114-Page176(*3rd author)
- S.P Sathiya Prabhakaran* et al Evolved Gas Analysis of Printed Circuited Boards and Their Effects On the Environment During Informal Recycling. -Accepted in 4th ISWA YPG Online Conference: "THE PATH TOWARDS 2030. The Envisioned Decade of Changes Toward a Circular Economy Era. Are you a young professional ready for this challenge?"(*Corresponding Author)
- S.P Sathiya Prabhakaran* et al Thermogravimetric Kinetic Study of Textile Lime Sludge and Cement Raw Meal for Co-Processing In Cement Kilns Accepted in 4th ISWA YPG Online Conference: "THE PATH TOWARDS 2030. The Envisioned Decade of Changes Toward a Circular Economy Era. Are you a young professional ready for this challenge?" (*First & Corresponding author)
- S.P Sathiya Prabhakaran* et al (2018) Feasibility of the textile effluent sludge as an alternative raw material for cement production. Third ISEES International Conference on Sustainable Energy and Environmental Challenges (SEEC), Indian Institute of Technology Roorkee, India, pp. 336 – 340. (*2nd author)
- S.P Sathiya Prabhakaran* et al (2018) Investigation of the suitability of the textile sludge as a substitute for cement manufacturing material. International Conference on Advances and Challenges for Sustainable Ecosystem (ICACSE), National Institute of Technology Tiruchirappalli, India, pp. 46 – 47. (*2nd author)

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Thermal kinetic analysis of mustard biomass with equiatomic iron–nickel catalyst and its predictive modeling

G. Antilen Jacob [a], S.P. Sathiya Prabhakaran [b], G. Swaminathan [c], R. Justin Joseyphus [a,*]

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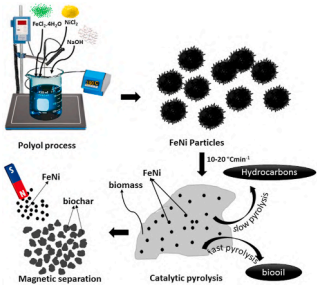
HIGHLIGHTS

- FeNi-mustard biomass synthesized with spike-like FeNi particles.
- Activation energy increases while calorific value decreases with FeNi.
- Uniform conversion independent of heating rate is achieved with 10% FeNi.
- FeNi catalyst enhances the decomposition of lignin in mustard biomass.
- RSM and a suitable ANN model are used to validate the experimental results.

GRAPHICAL ABSTRACT



ARTICLE INFO

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Keywords:
Polyol
Biofuel
Pyrolysis
ANN
Catalysis
Magnetic

ABSTRACT

Mustard waste briquettes are commercially used as a fuel for power production in boilers, whereas the thermal kinetics of the biomass plays a vital role in deciding the process parameters. The pyrolysis process converts biomass to value-added products such as biochar, bio-oil, and hydrocarbon gases based on the heating rates and temperature. To enhance the pyrolytic activity of mustard biomass, magnetically separable and reusable FeNi alloy catalyst is investigated. The thermo-conversion properties are studied under variable heating rates with 2 and 10% FeNi particles prepared through a facile chemical reduction technique. Thermal kinetics is computed using Flynn-Wall-Ozawa (FOW) and Kissinger-Akahira-Sunose (KAS) methods. The activation energies calculated using FOW and KAS methods increase with FeNi addition in mustard while the calorific value decreases. The FeNi alloy particles with the spike-like morphology provide better metal-biomass binding resulting in higher activation energy and facilitates the easy decomposition of lignin. The 10% FeNi -mustard shows uniform conversion independent of heating rates, suitable for magnetically recoverable catalytic pyrolysis. Response surface methodology analysis predicts optimum conversion for 10% FeNi added mustard and less significance for the heating rates in concurrence with the experiments. Artificial neural network utilized to predict and validate mass loss for mustard biomass exhibits best fit for the three neural hidden layer and one output layered topology.

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Full Length Article

Thermogravimetric analysis of hazardous waste: Pet-coke, by kinetic models and Artificial neural network modeling

Sathiya Prabhakaran S.P. [a,*], Swaminathan G. [b], Viraj V. Joshi [a]

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ARTICLE INFO

Keywords:
Pet coke
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Combustion indices
Thermal degradation kinetics
Solid state reaction models

ABSTRACT

Pet coke is a hazardous waste obtained from petroleum refinery on an enormous scale. Understanding pet coke's material characteristics and its decomposition kinetics is a prerequisite for its highly stable combustion behavior. Proximate analysis revealed that high fixed carbon and low volatile matter makes pet coke a low reactive fuel. Advanced analytical techniques like FTIR, XRD, ICP-OES revealed that pet coke is predominantly inorganic, constituting graphitic carbon and hydrogenation materials like nickel & vanadium, respectively. Thermogravimetric studies were conducted, and average activation energy calculated by model-free methods was in the range of 152.70 to 206.18 kJ/mol, respectively. The study of solid state reaction mechanism by Coats-Redfern, Kennedy-Clark and Master plot methods suggested contracting volume ($g(\alpha) = (1-(1-\alpha))^{1/3}$) and two dimensional diffusion reaction mechanism ($g(\alpha) = (1-\alpha)\ \ln(1-\alpha) + \alpha$) models which falls under decelerating type reaction mechanism. Combustion indices of pet coke like CCI, DI, DB were evaluated at different rates of heating. Pet coke's thermal degradation behavior were modelled using an artificial neural network (NN7). The research carried out permits to identify the characteristics of one of the most dominant hazardous waste, along with the futuristic potential usage and the findings provide reliable kinetic parameters for scale up, utilization, optimization, limitation for the system.

1. Introduction

Petroleum coke is a derivative product of crude oil refining & different cracking process in which the principal constituent is carbon [1]. Pet coke consists mostly of carbon and has high sulfur content compared to coal. Pet coke, has drawn the attention of process industries that employ combustion eventhough, it appears to be coal, has more detrimental effects on the atmosphere compared to any other fuel. And, also widely used in cement, steel, aluminum and titanium di oxide production industries. In the case of steel and titanium dioxide manufacturing industries, they consume calcined pet coke, which is desulfurized and carbon enriched, but in the cement industry, pet coke merely blended with 5% of limestone and combusted as an alternative fuel. The broad classification and respective applications of Pet coke are Fuel grade (Combustion in kilns) and graphite grade (electrodes), which are primarily based on carbon and sulfur ratio [2]. Fuel grade Pet coke has low ash & high calorific value, and it is an inexpensive fuel to combust, despite its high pollution property. Global energy demand is forcing the industries to incorporate pet coke in their combustion processes. Even though the recent developments are inclined towards sustainable and green energy sources [3–6] with reduced greenhouse gases, the consumption of Pet coke continues to outweigh the world's environmental needs, and it is in an uptrend in terms of consumption. Demand in the cement, steel, and aluminum industries is rising worldwide because of rapid industrialization and globalization, where Pet coke is at the center of this prerequisite energy supply. Globally production rate of Pet coke has surpassed 150 million metric tons per year, and with an increase in oil demand, the generation rate can even rise further [7]. The worldwide surge in crude oil prices also demands the industry to promote the utilization of the derivative byproducts of oil refineries to expand their marginal profit. Fuel grade Pet coke is widely used in cement, steel, and aluminum industries because of the high heating value of 34.7 MJ/kg and its inexpensive fuel nature [2].

Globally ongoing research areas are focused on creating clean combustion and Co-gasification processes of pet coke. Pet coke is used in chemical looping combustion to improve the gasification process. [8]. The synergetic effect on pet coke and biomass was reported, and biomass ash in the blends had a catalytic effect on the reactivity of petroleum

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Thermogravimetric study of textile lime sludge and cement raw meal for co-processing as alternative raw material for cement production using response surface methodology and neural networks

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Alternate raw material
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ABSTRACT

In the textile industry-water treatment process, lime sludge is generated and usually piled up in nearby barren lands to avoid transportation costs. However, the textile sludge could have disposal value as an alternative raw material in cement kilns. Advanced analytical techniques were employed to investigate the raw material property of textile sludge for cement production. Fourier Transform Infrared(FTIR) Spectroscopy Analysis and Thermo-gravimetric hyphenated FTIR analysis revealed that textile sludge was predominantly inorganic and gas emissions mainly were CO_2. Sludge was fused at calcination temperatures, and the phase transition was compared to the Hot Meal (HM) formed from the raw meal. Inductively coupled plasma optical emission spectrometry(ICP-OES) revealed that textile sludge is rich in metal oxides such as 45% CaO, 11% SiO_2, 0.44% Al_2O_3, 8.57% Fe_2O_3, 7.85% MgO, respectively, which are essential raw materials for the cement manufacturing process. The thermal degradation kinetics were computed under non-isothermal conditions (30–900 °C) at 10, 15, 20°C/min. Response surface regression techniques identified the effect of heating rate and temperature on mass loss. Regression Coefficient of the predictive models were above 0.90. The prediction accuracy increased by Artificial neural network using MSE as performance function and TRANSIG as transfer function.

1. Introduction

The textile industry is one of the leading industries in India, and the wastewater generated in the industrial process is treated, and residue left often in the treatment plant is of major concern and poses a risk to the Environment. The textile industry is an excellent example of the circular economy concept, promoting a zero liquid discharge process. However, wastewater treatment generates sludge and poses a risk to the Environment if not disposed of sustainably. Sludge generation is due to different treatment processes like chemical coagulation, flocculation, and lime-soda treatment (Balasubramanian et al., 2006). It contains toxic metals, residual dyes that are carcinogenic, and hazardous organic chemicals used during textile manufacturing processes (Herek et al., 2012). The conventional disposal techniques adopted in India are landfilling, dumping in the ocean, and composting (Anwar et al., 2018). With the growing concern of reducing

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Combustion and pyrolysis kinetics of Australian lignite coal and validation by artificial neural networks

SP Sathiya Prabhakaran [a, *], Ganapathiraman Swaminathan [b], Viraj V. Joshi [a]

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[b] Department of Civil Engineering, National Institute of Technology, Tiruchirappalli, 620015, Tamil Nadu, India

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Kinetics
Artificial neural network
Solid-state reaction model

ABSTRACT

Lignite (AL), with a calorific value of 5.9 MJ/kg is the most abundant low-rank coal used widely in power generation. AL's combustion and pyrolysis characteristics were investigated to provide scientific findings using thermogravimetric analysis under non-isothermal conditions. Methods utilized in the kinetic investigation included Vyazovkin, Flynn-Ozawa-Wall (FOW), Kissinger-Akahira-Sunose (KAS), Freidman, Doyle, Arrhenius, Freeman-Caroll, and Sharp-Wentworth. Multiple heating rate methods delivered the activation energy (E_a) as 194–211 kJ/mol (combustion) and 450–470 kJ/mol (pyrolysis). Combustion process followed two dimensional diffusional reaction (2D), volume contracting (R3) solid-state reaction mechanism models and pyrolysis followed volume contracting (R3) as determined by CR (Coats-Redfern), KC (Kennedy-Clark) methods. Master Plot method validated the mechanisms and concluded that it is of deaccelerating type. Improper combustion at a higher heating rate (50 °C/min) was indicated with an increase in burnout T_b, ignition T_i, peak T_p temperatures. Combustion indices (CHCI, IG, IB) reported highest values of 4.99 E−10 $mg^2\ min^{-2}\ {}^{O}C^{-3}$, 4.19E-05 $mg^2\ min^{-3}$, 2.65 $mg^2\ min^{-4}$ at lowest heating rates. AL's analytical thermal degradation behavior results were validated using artificial neural networks with best-fit models NNA 7,8. The research study offers a useful guide for spontaneous AL combustion and pyrolysis prediction on site.

1. Introduction

Combustion is the driving force for power generation in thermal and hybrid industries. Combustion of fuel plays a pivotal role in transportation, industrial, and domestic requirements [1]. Unless and until the renewable sources of energy on earth are not fully exploited in terms of their potential for power generation, the dependency of human beings on fossil fuels is seldom ending [2]. Because of fossil fuel combustion, global warming has turned into a serious problem. The most significant contributor to global warming is CO_2 from power generating systems or processes [3]. The power plants which run on coal as fuel adds a share of 33–40% worldwide of carbon emissions, which are anthropogenic [4]. Pyrolysis is a predominant step in the processes like coking, gasification, liquefaction etc. The reactivity of char and cokes, the structure of the pore, and the specific surface area during coking are largely affected by this process [5]. The temperature and heating rate of pyrolysis affect the gasification products, and in hydroliquefaction, it affects the cleavage of macromolecular bonding into fragments [6]. Pyrolysis is the backbone for clean coal conversion technologies. It helps to relate the soot generation rate in coal combustion to tar generation rate and thus predict environmental benefits [7]. Simultaneous series and parallel reactions, and complex coal structures make it difficult to understand the pyrolysis process [8]. When developed economies are concerned, the technological advancement and good quality of fuel help achieve their target of carbon capture and storage. However, for developing economies of the world, the scenario is different [9]. The present rate of discovery of crude oil is approximately half of that of production of fuel, and a downward trend of oil production is supposed to be observed from 2020 to 2030. This will pave the downward trend in oil production that will change the economy and invoke alternative fossil fuels to be used as the primary fuel in the power generation process via the combustion route [10]. Due to the current rate of greenhouse gas emissions, the temperature of the globe

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Life cycle assessment of the co-combustion system of single-use plastic waste and lignite coal to promote circular economy

Viraj V. Joshi [a], Ganapathiraman Swaminathan [b], SP Sathiya Prabhakaran [a,*]

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Keywords:
Synergistic effect
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Life cycle assessment
Response surface methodology
Principal component analysis
Artificial neural networks

ABSTRACT

Single-use plastics waste is a thermosetting-thermoplastic polymer generated specifically from packaging industries. Incineration, landfilling, combustion, open discharge in liquids fail its effective disposal. Co-combustion via co-processing is a novel technique for disposal. In this study, investigative thermogravimetric analysis of the co-combustion of lignite coal (AL) and single-use plastic waste (PW) in the blend ratios of 50:50, 60:40, 70:30 was carried out under non-isothermal conditions to promote co-combustion via co-processing technique for environment-friendly disposal. Thermal degradation behavioral study was carried out at higher blending ratios of 30–50%. The effect of the mass ratio of PW to AL on co-combustion characteristics was analyzed. The Freeman-Carroll, Sharp-Wentworth methods derived energy of activation for the process of co-combustion in the limits of 65–155 kJ/mol, 44–75 kJ/mol. Volume Contracting and Diffusional Reaction 2D solid-state reaction mechanisms were followed by the co-combustion system as derived by Coats-Redfern and Kennedy-Clark methods. Master plot method validated the same results. The co-combustion performance was evaluated using co-combustion (CSI), ignition (IG), burnout (IB) indices. The highest CSI value was reported for the 60:40 blend. Burnout temperature (T_b) decreased with an increase in blending ratio and suggested an effective co-combustion process. Blend (70:30) reported the highest interaction in blends and confirmed the synergistic effect. The principal component analysis described the co-combustion process as three stages (100–200, 265–425, 425–700) ^{o}C with specific materials. The co-combustion process was optimized using the methodology of surface response and validated using neural network models (NNM 4,5) for the effect of temperature and blend ratio on mass loss. The characterization study confirmed the presence of minerals alumino-silicates, dimorphs pyrite, marcasite, gypsum, barite, hydrated sulfates, calcite, siderite, and functional groups –OH, -CH_2, -Si-O responsible for autocatalytic reactions. Life cycle assessment confirmed the sustainability of the co-combustion process of lignite and plastic waste. The present study benefits for scale-up, optimization, waste to energy conversion, pollution reduction, and environmentally friendly disposal via the co-combustion process.

1. Introduction

Single-use plastic waste (PW) disposal is a global problem. COVID-19 Pandemic has exponentially increased the waste generation rate via the production of hand sanitizers, gloves, masks, personnel protective equipment kits, face shields, each contributing to single-use type drastically (Benson et al., 2021). Other sources of PW generation include a variety of polymers (polypropylene, polyethylene, polystyrene, polyvinyl chloride, acrylonitrile-butadiene-styrene) applicable in different industrial and commercial uses (agriculture, healthcare, automotive, construction, cement, packaging, electronics, and electrical) (Huang et al., 2019). An alarming rate of generation has caused human beings to find effective complete disposal, rethink and strategize an optimization policy for its management (Patrício Silva et al., 2020). Disposal of PW in water sources increases its toxicity (bisphenol-A, phthalates) tremendously and leads to the death of marine animals via consumption and entanglement (Gregory, 2009). Landfilling such waste causes leachates containing mercury, heavy metals, cadmium, and other toxic elements to degrade land and water table chemical compositions (Kumar et al., 2009). Open incineration of PW releases tremendous amounts of potentially hazardous greenhouse gases, directly attacking the earth's ozone layer (Council, 2000). Recycling of PW also has a limitation in

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