Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Environmental catastrophe amidst COVID-19 pandemic: Disposal and management of PPE kits for the production of biofuel with the sustainable approach in solar thermal energy

Surajit Mondal
Dept. of Electrical and Electronics, Electrical Cluster, Centre for Alternate Energy Research, UPES, Dehradun 248007, India

Article info
Article history:
Available online 8 April 2022

Keywords:
Covid19
PPE
Polypropylene
Thermochemical conversion
Pyrolysis
Solar thermal application

Abstract
COVID-19, a condition associated with severe acute coronavirus two respiratory syndromes (SARS-CoV-2), has impacted the lives of billions of people worldwide. Scientists around the world are trying to find ways to cure the disease in the vaccine strain. Out of all essential prerequisites for the health workers and doctors, Personal protection equipment (PPE) has acted as an essential part of the virus’s protection purpose. While PPE kits are reported to provide adequate protection against pathogens, their removal can have a devastating impact on the environment. National authorities ensure the proper elimination of PPE following the guidelines provided by the WHO. The plethora of PPE kits will further boost the polymer load on our planet. This review represents a scheme for disposing of PPE kits by converting them into alternate fuel through solar thermal engineering.

Selection and peer-review under responsibility of the scientific committee of the Innovative Technologies in Mechanical Engineering-2021.

1. Introduction

An infectious disease outbreak was reported in Wuhan, Hubei Province, Central China, during the last week of December 2019 [1]. The World Health Organization (WHO) confirmed the public health emergency of international concern on January 30, 2020, and was popularly known as coronavirus disease (COVID-19). Later, on March 11, 2020, the COVID-19 outbreak was declared pandemic and was adopted by the official name as severe acute respiratory syndrome coronavirus (SARS-CoV-2) by the International Committee of Taxonomy of Viruses [2]. According to the WHO dashboard, more than 168 million cases have been confirmed as of May 27, 2021, with a death toll of more than 3.5 million, making it one of the deadliest pandemics in history [3]. The primary cause of the transmission of the virus is by the aerosols or droplets of the infected person inhaled by the other person in close contact [4]. The crowded indoor areas and the poorly ventilated settings have seen the spread of the virus more often. This is major because the aerosols or the particles caused by coughing or sneezing remain suspended in the air for a couple of meters. The virus also gets deposited on the surfaces for some duration, and people may also get infected even by touching the contaminated surface [5]. Worldwide research is underway to combat the spread of the disease; however, specific prevents are helping us reduce the transmission of the virus. On the other hand, the emerging new virus variants include a long incubation period, the transmission of the virus from asymptomatic people, tropism for mucosal surfaces such as the transmission of the virus even after recovery, conjunctiva, etc. the prevention more difficult [6,7]. During this pandemic, the community of healthcare workers, frontline workers, and civil defense workers, including disaster management volunteers, municipal workers, and so on, are at maximum risk [8].

India is the second-largest manufacturer of PPE as per global basis, currently manufactures 4.5 lakhs PPE kits on an average daily basis [9]. Recent evidence indicates the importance of the availability and use of PPE and requires immediate attention to ensure the correct application and disposal of PPE. Lack of access to adequate PPE, frequent reuse, or inadequate disposal may increase the risk of infection and adversely affect the environment by accumulation of disposed PPEs as shown in the Fig. 1, while they are as same as...
plastic wastes. They will be incinerated and greenhouse gases directly into the atmosphere. World Health Organization and National Centre for disease control (CDC), USA have brought out specific guidelines for the disposal of Personal Protective Equipment (PPE). Along with this, the Indian CDC has also published guidelines for the administration and management of biomedical waste produced during the global crisis [10,11].

1.1. Chemical Composition of PPE

The raw materials used for the production of Personal Protective Equipment (PPE) are summarized in Table 1 [13]. Polypropylene (PP) is the widely used polymer for the production of PPE. It is a non-woven, needle-punched material referred to as single-use plastic (SUP), serving to protect doctors and healthcare workers from transmissible hazardous agents including deadly virus. Polypropylene is obtained by the polymerization of propylene monomer and is known as one of the recent lightest petrochemical products. A saturated carbon chain has a methyl group attached to an alternate carbon atom, as shown in Fig. 2, which forms the basic construction of polypropylene.

The presence of the methyl group imparts hardness to polypropylene, making it different from polyethylene. This material is preferred because of its inherent and durable electrostatic charge, which traps particles, effectively protecting the person from any kind of infection. Also, its lightweight, hardness, and high tensile strength, as shown with Table 2, make it suitable for industrial manufacturing [14].

There are three different stereo specific configurations for the synthesis of polypropylene [16]:

i. Syndiotactic: This type of configuration alternately has methyl groups above the plane and the next below the plane. The chiral carbon configuration is alternatively similar to each other, as shown in Fig. 3(i) (see Figs. 4, 5).

ii. Isotactic: This configuration has all the methyl groups present above and below the plane. The chiral carbons belonging to the methyl group have the same configuration as shown in Fig. 3(ii).

iii. Atactic: In this type of configuration, the methyl groups are irregularly present on both sides, and the chiral carbons do not have a standard configuration, as shown in Fig. 3(iii).

The isotactic polypropylene gives an upper edge because of its more crystalline nature out of the three. The crystalline nature comes from the regular arrangement of the chains of the polymer, unlike other configurations. The perfectly isotactic polypropylene melting point is 171 °C, and the thermal stability is up to 171 °C [17]. This makes the application of polypropylene in medical use by allowing the steam sterilization of the products. Additionally, chemical resistance, bacterial resistance, good fatigue resistance, high dimensionally stability, and flexible packaging [18] promote polypropylene in PPE and other surgical instruments.

During such a critical situation like now, the PPEs are designed for single-time use, and it is pretty tricky to degrade the used PPE at ambient temperatures. Therefore, the plastic materials produced to act as fate to the environment by being discharged into oceans and landfills. Decomposition of such bio-medical waste by the microbial organism requires decades to become evident. The physical and chemical method involving recycling of the polymers is another way of disposal of the waste. It involves three pillars of sustainable development goals: reduction, reuse, and recycling that can help prevent the disposal of bio-medical waste into the environment [19]. As bio-based methods needs a longer time chemical treatment of polypropylene could be useful and promising for the efficient disposal of such bio-medical waste. It involves the thermochemical conversion of large hydrocarbon chains by the process of pyrolysis into liquid fuel. This method would make the recycling of polypropylene; effective and economical.

1.2. Conversion of PPE into biofuels to obtain valuable end products

The bio-medical waste or the plastic waste produced by the PPE can be chemically and thermally treated. The catalytic and non-catalytic treatment of plastics helps us convert them into corresponding chemicals and, therefore, manage the waste effectively and efficiently. The chemical treatment of plastic helps us change its chemical structure, making it viable for various treatments [20]. For converting the plastic waste into a valuable product, some of the processes opted are hydrogenation [21], hydrolysis [22], gasification [23–25], glycolysis [26,27], aminolysis [28], and pyrolysis [29–31]. For converting solid waste into biofuels, pyrolysis is the most promising method among the other conversion methods [32,33]. The high-value products obtained after the treatment makes the most common and practical techniques for thermochemical conversion. To mitigate the effect of plastic disposal on the environment, pyrolysis is the best treatment for plastic or bio-medical waste thermochemical conversion. It is a chemical reaction that involves the molecular breakdown of long-chain polymer molecules into smaller molecules in the absence of oxygen. This process takes place at relatively high temperatures and pressure for a short duration of time. Like other pretreatments of solid waste, pyrolysis does not require the characterization of different types of plastic waste for chemical conversion. Therefore, a mixture of plastics of different compositions is also feasible for converting them into valuable end products [34,35].

This thermochemical method of recycling biowaste is eco-friendly and protects the environment from the contamination of landfills and oceans. In this process, the thermal cracking of macro-molecules takes place when heated at high temperatures (300–500 °C) and high pressure (573–773 K) [36] in the absence of air.

---

**Table 1**

| Component of PPE       | Raw Material Used                                      |
|------------------------|--------------------------------------------------------|
| Single Use Protective Gowns | Normally Polypropylene                                  |
| Normal Surgical Masks  | Polypropylene                                           |
| Powered Air Purifying Respirators | Rubber or Silicone                                    |
| Goggles                | High Quality Polycarbonates                             |
| N95 Respirators        | Polypropylene                                           |
| Face Shields           | Polycarbonate, Propionate, Acetate, Polyvinyl Chloride and Polyethylene Terephthalate Glycol |
| Coveralls              | High Density Polyethylene                                |

**Fig. 1.** Accumulated disposed PPEs [12].
The end products are liquid, char, and gas, and each can be used for different purposes without harming the environment. The liquid produced has applications in kilns and boilers, sterling engines, gas turbines, and generators as biofuel or renewable fuel [34,35].

Along with the study on different variants of COVID-19 and their ill effects, the environment-friendly procedures for the disposal of the PPE are also need of the hour to curb the spread of this disease. PPE comprises majorly of polypropylene plastic which acts as an environmental hazard affecting the complete ecological cycle. Thermochemical Pyrolysis conversion of PPE as discussed above will help us in dealing with this challenge ineffectual and sustainable way.

1.3. The process involved in the pyrolysis of polypropylene

Polypropylene has a branching structure [36,37], and the presence of tertiary carbon atoms makes it easily degradable during thermal pyrolysis. The process involved in the thermochemical treatment of plastic waste involves three significant steps, includ-
ing initiation, propagation, and termination. Initiation refers to the formation of free radicals by the breakage of the molecules when heated at high temperatures. Also, during the propagation reaction, the free radicals can further be cracked into smaller molecules. Free electrons or unpaired electrons are unstable. The Termination step involves the coupling and disproportion of free radicals to make them stable.

1.4. Need of end product as liquid fuel

The rapid growth in the world's population has accelerated energy consumption and, therefore the carbon emission. As per the recent data provided by BP statistical review 2018 [38], energy consumption has increased at a rate of 2.9% as compared to the previous years. To meet the energy demands globally, some alternative methods need to be adopted for survival. Also, the depletion of fossil fuels is a significant concern [39]. To overcome these challenges, alternative fuels can help us to achieve the global crisis economically. Therefore, the fuel obtained after plastic waste pyrolysis can directly be used as liquid fuels for various applications. This renewable method of energy conversion will help us to mitigate the energy crisis globally. The enormous content of carbon and hydrogen [40], high calorific value, and absence of oxygen make up the value of the liquid fuel substantially high [41]. Also, these fuel properties decrease the need for further upgrading the liquid fuel into biofuel [40].

2. Solar thermal technology

Solar Thermal Technology is one of the most promising renewable technologies. This technology has certain advantages, including environment-friendly, inexhaustible and abundant, making it among the widely used and effective renewable technologies [42]. Technology is helping the world meet the electricity demands, but it is also of great importance for the environmental problems globally. It has an extended bandwidth in terms of its
operational characteristics, applications, and economics—they include very simple to complex technologies like solar water heating, cooking, air conditioning, and even solar thermal power generation [43]. Solar Thermal Technologies employ by converting solar radiations into heat or thermal energy. Collector plays a crucial role in this technology to collect the sun's heat or solar radiation. Depending on the type of the collector [48], the working fluid that is heated by the sun's rays can either be liquid or gas, including oil, nitrogen, water, salt, air, and so on [44]. As far as large-scale energy production is concerned, solar thermal technology offers easier and efficient heat storage. In particular, the heat is stored during the daytime and is then converted into electricity during the late hours [45].

Based on their working temperature, solar thermal technology is of three types [46].

2.1. Low-Temperature technologies

The temperature range of this type of technology is <70 °C. It uses radiation from the sun to heat simple and small applications like solar water heating, solar space heating, and solar pond.

2.2. Medium temperature technologies

This technology has a temperature range from 70°C to 200°C. This type of technology is used to utilize the diffused form of solar energy in domestic and industrial applications. It includes solar cooling, solar distillation, Pyrolysis [49] and so on.

2.3. High-temperature technologies

This technology uses curved lenses to concentrate solar radiation, resulting in increased temperatures in the range of greater than 200°C. Examples of high-temperature technology include solar thermal power generation, solar tower power plants, etc.

3. Solar thermal pyrolysis

Nowadays, Solar Thermal Pyrolysis is of great importance to cater to the energy demand globally. The applications of solar thermal pyrolysis range from the use of flat plate solar collectors in water heating to dish receivers in the solar thermal power station. In the areas where water access is a significant issue, this technology marks as an advantage. This technology involves converting biomass into byproducts with the help of solar energy by the process of thermochemical pyrolysis. The solar radiation is incident on the pyrolysis reactor and is transferred to biomass for further process. When the temperature inside the pyrolysis reactor reaches (300–350°C [47], the conversion takes place to produce the byproducts, namely liquid, char and gas. More details procedural details will be discussed in below figures.

The above diagram represents the procedure of processing and converting the disposed PPE kits into useful oil which has an appreciable calorific value along with the by-products such as synthetic gas and synthetic char by a promising technology known as pyrolysis. The utilized or disposed PPE kits are initially shredded into fine pieces such that surface area of the raw materials (shredded pieces) will be increased which ultimately improves the quality of reaction in pyrolyser at higher temperatures which can be obtained by either burning biomass or by heating the pyrolyser with the help of solar energy by installing a solar concentrator to converge and concentration or intensity of solar radiations which improves thermal energy output to the reactor. The products formed will be having wide applications as they can be used as fuels, lubricants, adsorbents, etc. This strategy helps in reducing the waste disposals accumulation which directly show adverse impact on the environment when they are incinerated or landfilled.

4. Conclusion

The proposed strategy is a suggestive measure addressing the anticipated problem of disposal of PPE. Presently, the world is focusing on combating COVID-19; however, we can also foresee the economic crisis and ecological imbalance issues. We have to prepare ourselves to meet the challenges forcefully imposed by the COVID-19 pandemic to maintain sustainability. There is high production and utilization of PPE to protect the community of health workers and the other frontline warriors of COVID-19. The disposal of PPE is a concern owing to its material, i.e., non-woven polypropylene. The authors are proposing an effective means of recycling PPE kits (used and defective) using pyrolysis. The pyrolysis of the PPE kit can be done in a closed thermal reactor by using the heat of Solar Thermal, and the reaction temperature will be between 250 and 350°C for 120–150 min, which will convert the polypropylene into liquid fuels, gas, and char. This production of end-products from the PPE kit will save the environment and provide pyrolyzed oil, gas for various automobile applications and char in cement industries. So, the challenge to clean the environment and waste management can be converted into opportunities by producing oil and gas. The produced liquid fuel from plastic is clean and can replace fossil fuel due to similarities of fuel properties present in diesel and petrol.

Credit authorship contribution statement

Surajit Mondal: Conceptualization, Methodology, Data curation, Writing – original draft, Visualization, Investigation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] H. Lu, C.W. Stratton, Y.W. Tang, Outbreak of pneumonia of unknown etiology in Wuhan, China: the mystery and the miracle, J. Med. Virol. 92 (4) (2020) 401–402.
[2] A.E. Gorbalenya, S.C. Baker, R.S. Baric, et al., severe acute respiratory syndrome-related coronavirus: the species and its viruses— a statement of the Coronavirus Study Group, Nat. Microbiol. 5 (2020) 536–544.
[3] Coronavirus disease (COVID-19) pandemic. https://www.who.int/emergencies/diseases/novel-coronavirus-2019, (accessed 2020 Apr 30).
[4] C. Rothe, M. Schunk, P. Sothmann, et al., Transmission of 2019-nCoV infection from an Asymptomatic Contact in Germany, N. Engl. J. Med. 382 (10) (2020) 970–971.
[5] G. Kampf, D. Todt, S. Pfandsen, et al., Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents, J. Hosp. Infect. 104 (3) (2020) 246–251.
[6] Z. Chen J. Fu Q. Shu et al. Diagnosis and treatment recommendations for pediatric respiratory infection caused by the 2019 novel coronavirus World J. Pediatr. 16(3) 2020 pp. 240–1007./s12519-020-00345-5.
[7] Jin Y, Cai L, Cheng Z, for the Zhongnan Hospital of Wuhan University Novel Coronavirus Management and Research Team, Evidence-Based Medicine Chapter of China International Exchange and Promotive Association for Medical and Health Care (CPAM), et al. A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version). Mil Med Rev. 2020;7(1) 4.
[8] Coronavirus disease (COVID-19) outbreak: rights, roles and responsibilities of health workers, including key considerations for occupational safety and health, 2020, https://www.who.int/publications/i/item/coronavirus-disease-(covid-19)-outbreak– rights-roles-and-responsibilities-of-health-workers-including-key-considerations-for-occupational-safety-and-health. (accessed 2020 May 5).
S. Mondal

Materials Today: Proceedings 64 (2022) 1266–1271

[9] Sangeetha Ojha, 2020. India now manufactures 4.5 lakh PPE suits a day in the fight against Covid-19.

[10] India now has clear guidelines to deal with coronavirus-related biomedical waste. 2020. https://qz.com/india/1824884/india-frames-rules-for-disposing-covid-19-related-medical-waste-from-hospitals/. (accessed 2020 May 5).

[11] Guidelines for handling, treatment, and disposal of waste generated during treatment/diagnosis/quarantine of COVID-19 patients, 2020. https://ncdc.gov.in/showfile.php?id=551. (accessed 2020 May 5).

[12] Ruchir Kumar, the litter flew all over the place on the hospital campus, Hindustan Times, https://www.hindustantimes.com/india-news/used-ppe-kits-dumped-in-the-open-at-patna-hospital-ring-alarm-bells/story-YM8gcwV4hWZowGMDcIgK.html.

[13] Novel Coronavirus Disease 2019. (COVID-19): Guidelines on rational use of Personal Protective Equipment, 2020. https://www.mohfw.gov.in/pdf/GuidelinesonrationaluseofPersonalProtectiveEquipment.pdf. (accessed 2020 May 5).

[14] Polypropylene: Properties, Processing, and Applications, 2020. https://matmatch.com/learn/material/polypropylene. (accessed 2020 May 5).

[15] Names of Formulas of Organic Compounds August 25 https://chem.libretexts.org/MenuPages/13792 2020 Retrieved August 26, 2021, from.

[16] A.H. Maddah, Polypropylene as a suitable plastic: a review, Am. J. Polym. Sci. 6 (1) (2016) 1–11.

[17] Q.T.H. Shubhra, A. Alam, M.A. Quaissym, Mechanical properties of polypropylene composites: a review, J. Thermoplast. Compos. Mater. 26 (3) (2013) 362–391.

[18] Plastic Properties of Polypropylene (PP), https://www.dynalon.com/PublicStore/pages/Polypropylene_Properties.aspx. (accessed 2020 May 5).

[19] M. Sarker, M.M. Rashid, M. Molla, et al., A new technology proposed to recycle waste plastics into hydrocarbon fuel in the USA, Int. J. Energy Environ. 3 (2012) 149–156.

[20] S.M. Al-Salem, P. Lettieri, J. Baeyens, Recycling and recovery routes of plastic solid waste (PSW): a review, Waste Manage. 29 (10) (2009) 2625–2643.

[21] D. Simon, A.M. Borreguero, A. de Lucías, et al., Glycolysis of flexible polyurethane wastes containing polymeric polyols, Polym. Degrad. Stabil. 109 (2014) 115–121.

[22] R. Sharma, R.P. Bansal, Use of different forms of waste plastic in concrete: a review, J. Clean Product. 112 (2016) 473–482.

[23] M.P. Aznar, M.A. Caballero, J.A. Sancho, et al., Plastic waste elimination by co-gasification with coal and biomass in a fluidized bed with air in a pilot plant, Fuel Process Technol. 87 (5) (2006) 409–420.

[24] V. Sinha, M.K. Patel, J.V. Patel, PET waste management by chemical recycling: a review, J. Polym. Environ. 18 (1) (2010) 6–25.

[25] A.K. Panda, R.K. Singh, D.K. Mishra, Thermolysis of waste plastics to liquid fuel: A suitable method for plastic waste management and value-added manufacturing products - a world perspective, Renew. Sust. Energy Rev. 14 (1) (2010) 233–248.

[26] P.T. Williams, Pyrolysis of waste tires: a review, Waste Manage. 33 (8) (2013) 1714–1728.

[27] B. Danon, A. de Villiers, J.F. Goërgens, Elucidation of the different devolatilization zones of tire rubber pyrolysis using TGA-MS, Thermochim Acta. 614 (2015) 59–61.

[28] B. Danon, N.M. Mkhize, P. van der Gryn, et al., Combined model-free and model-based devolatilization kinetics of tires rubbers, Thermochim Acta. 601 (2015) 45–53.

[29] B. Dou, K. Wang, B. Jiang, et al., Fluidized-bed gasification combined sorption-enhanced steam reforming system to continuous hydrogen production from waste plastic, Int. J. Hydrol. Energy 41 (6) (2016) 3803–3810.

[30] J. Wang, H. Zhao, Evaluation of CaO-decorated Fe2O3/Al2O3 as an oxygen carrier for in-situ gasification chemical looping combustion of plastic wastes, Fuel 165 (2016) 235–243.

[31] J.A. Onwudili, P.T. Williams, Catalytic supercritical water gasification of plastics with supported RuO2: A potential solution to hydrocarbons–water pollution problem, Process. Safe Environ. Protect. 102 (2016) 140–149.

[32] A. Strubinger, A.R. Oliveros, M.A. Araque, Assessment of the energy recovery of aloe vera solid residues by pyrolysis and hydrothermal conversion, Chem. Eng. Trans. 57 (2017) 19–24.

[33] M. Martinis E. Mulyazmi Winanda et al. Thermal Pyrolysis of polypropylene plastic waste into liquid fuel: reactor performance evaluation 2018 West Sumatera Indonesia.

[34] A. Demirbas, Pyrolysis of municipal plastic wastes for recovery of gasolinerange hydrocarbons, J. Anal. Appl. Pyrol. 72 (1) (2004) 97–102.

[35] Y. Kodera, Y. Ishihara, T. Kuroki, Novel process for recycling waste plastics to fuel gas using a moving-bed reactor, Energy Fuels 20 (1) (2006) 155–158.

[36] F. Abhisai, D.U.W. Wan, A review on co-pyrolysis of biomass: an optional technique to obtain a high-grade pyrolysis oil, Energy Convers Manage. 87 (2014) 71–85.

[37] I. Hakkı Metecan, A.R. Özkan, R. Isler, et al., Naphtha derived from polyolefins, Fuel 84 (5) (2005) 619–628.

[38] J. Aguado, D.F. Serran, F. Garagorri, et al., Catalytic conversion of polyolefins into fuels over zeolite beta, Polym. Degrad. Stabil. 69 (1) (2000) 11–16.

[39] Bp, statistical review of World Energy 2019 68th edition, 2019.

[40] B.R. Sharma, B.R. Moser, K.E. Vermillion, et al., Production, characterization and fuel properties of alternative diesel fuel from pyrolysis waste plastic grocery bags, Fuel Process. Technol. 122 (2014) 79–90.

[41] N. Miskolczi, A. Angyal, E. Bartha, et al., Fuels by Pyrolysis of waste plastics from agricultural and packaging sectors in a pilot-scale reactor, Fuel Process. Technol. 90 (7–8) (2009) 1032–1040.

[42] B. Kunwar, T. Misra, Upgrading bio-oil with a combination of synthesis gas and alcohol, in: 245th ACS National Meeting and Exposition, New Orleans, LA, USA, American Chemical Society, Division of ENFL, New Orleans, LA, USA, 2013, 90.

[43] G. Eldrid, M. Olazar, G. Lopez, et al., Catalytic Pyrolysis of HDPE in continuous mode over zeolite catalysts in a conical spouted bed reactor, J. Anal. Appl. Pyrolysis. 85 (1–2) (2009) 345–351.

[44] V. Chintala, S. Kumar, J.K. Pandey, Assessment of performance, combustion, and emission characteristics of a direct injection diesel engine with solar-driven jatropha biomass pyrolyzed oil, Energy Convers Manage. 148 (2017) 611–622.

[45] S. Czernecki, A.V. Bridgwater, Overview of applications of biomass fast pyrolysis oil, Energy Fuels 18 (2004) 590–598.

[46] S. Murugan, S. Gu, Research and development activities in pyrolysis – contributions from Indian scientific community – a review, Renew. Sustain. Energy Rev. 46 (2015) 282–295.

[47] K.P. Shadangi, K. Mohanty, Comparison of yield and fuel properties of thermal and catalytic Mahua seed pyrolytic oil. Fuel 117(2014) 372–380.

[48] D. Pradhan et al., Pyrolysis of Mahua seed (Madhuca indica) – production of biofuel and its characterization, Energy Convers. Manage. 108 (2016) 529–538.

[49] S. Mondal et al., Thermochemical Pyrolysis of Biomass using Solar Energy for Efficient Biofuel Production: A Review, Taylor and Francis, 2018.