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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

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A B S T R A C T

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 protect tion 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 re- view represents a scheme for disposing of PPE kits by converting them into alternate fuel through solar thermal engineering.

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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 preventions 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 ad- equate 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

Abbreviations: PPE, Personal protective equipment; CDC, Centre for Disease Control; PP, Polypropylene; SUP, Single Use Plastic.

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Fig. 1. Accumulated disposed PPEs [12].

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 bio-medical 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 carbons configuration is alternatively similar to each other, as shown in Fig. 3(i) (see Figs. 4, 5).

Table 1
Raw materials used for the production of different components of PPE.

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

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 thermo-chemical con- version. 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 differ- ent 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 macromolecules takes place when heated at high temperatures (300–500 °C) and high pressure (573–773 K) [36] in the absence of air.

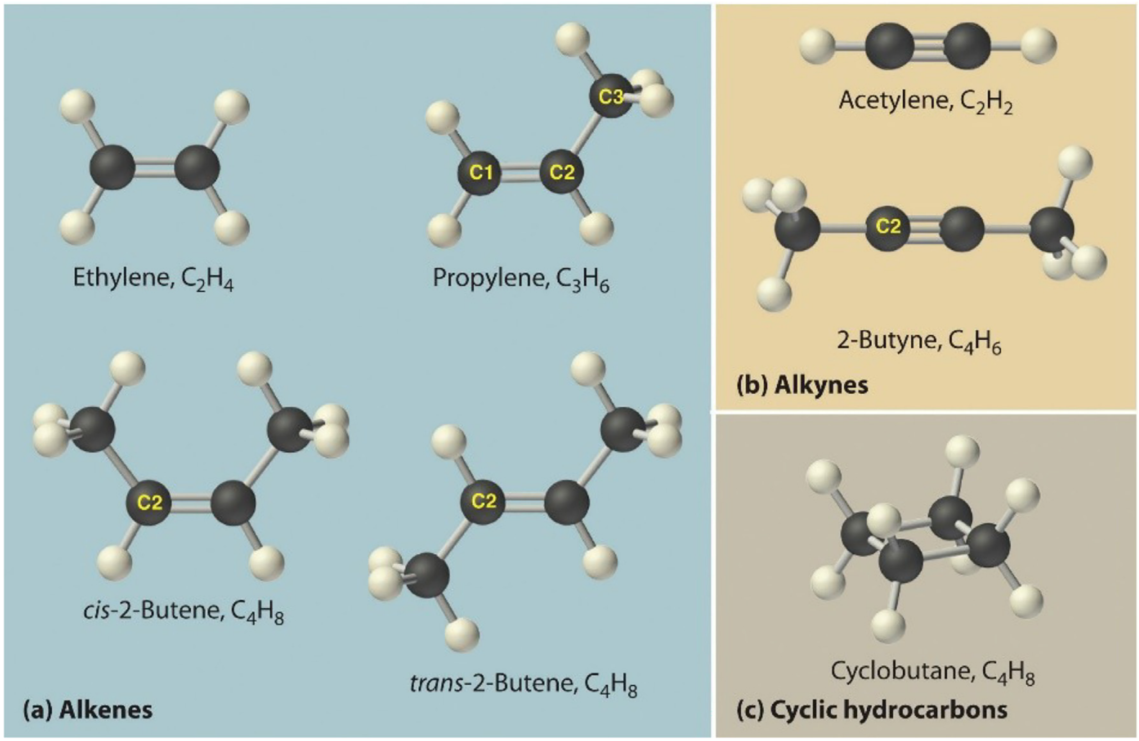

Fig. 2. Monomers with a saturated carbon atom attached [15].

Table 2
Physical Properties and their value of polypropylene [14].

Physical Property	Value
Elasitic Modules	1.5–3 GPa
Melting Point	160–168 °C
Glass Transition Temperature	−10 °C
Tensile Strength	0.95–1.30 N/mm^2
Notched Impact Strength	3.0–30.0 Kj/m^2
Thermal Coefficient of expansion	100–150 × 10^{-6}
Density	0.905 g/cm^3

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-

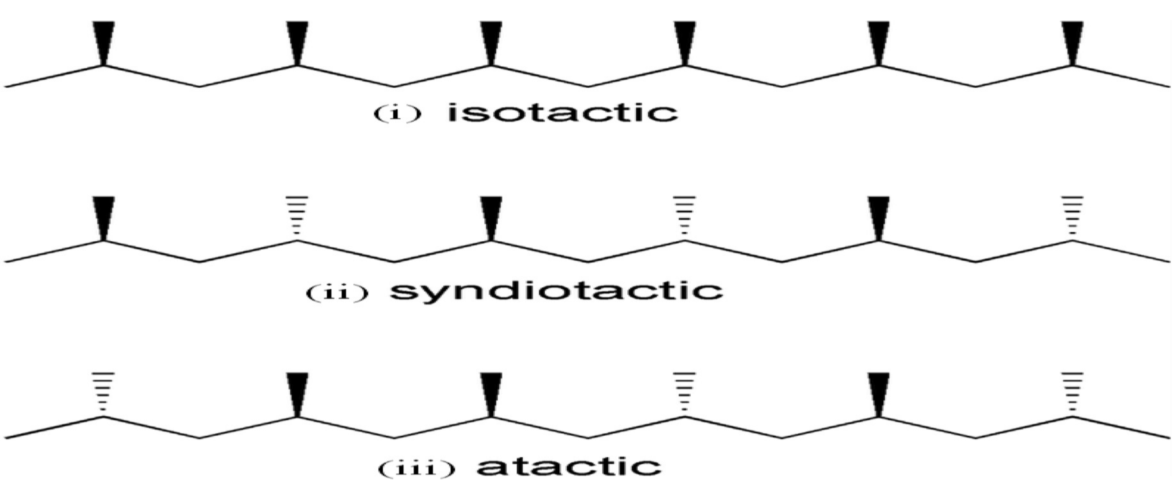

Fig. 3. (i) Isotactic; (ii) Syndiotactic; (iii) Atactic Configuration of Polypropylene.

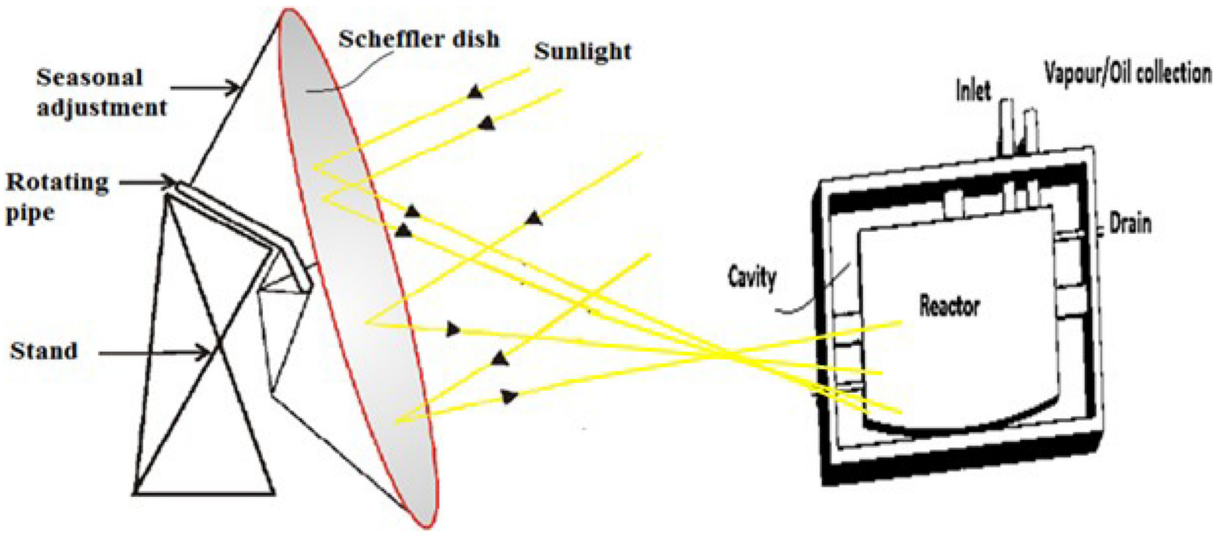

Fig. 4. Schematic Diagram of Scheffler Dish and Pyrolysis Reaction.

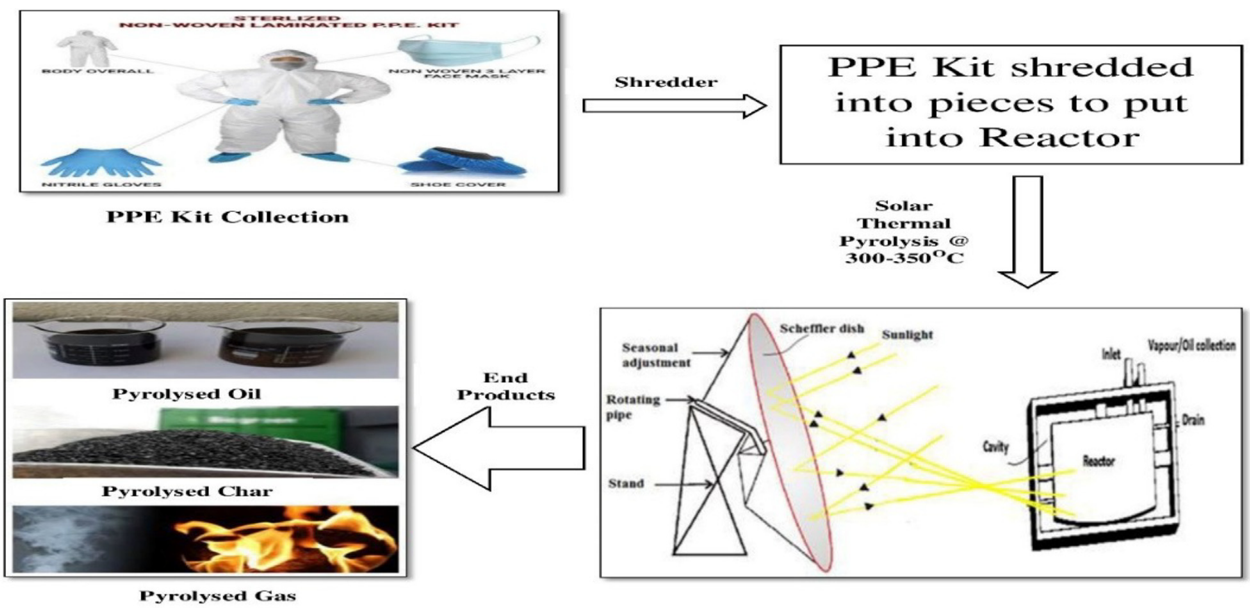

Fig. 5. Schematic Diagram of the Process.

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 energy 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 wit discussion of 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 accumulatios 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.

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