Article

An evocative approach to utilize castoff PPE kits (Covid-19): Sustainable approach

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Abstract

Severe acute respiratory syndrome-corona virus-2 (SARS-CoV-2) responsible for causing Covid-19 has taken millions of life. Globally, combating COVID-19 pandemic is the primary aim of all the researchers working in any field of study viz. pharmaceutical, chemistry, physics, economics etc. One of the warrior against Covid-19 is Personal Protection Equipment (PPE), which is an indispensable requirement for healthcare workers and others working closely with Covid-19 patients. The kits are providing protection from direct infection. They are made of different types of plastics and their disposal is going to be a serious menace, if not taken care of properly. The disposal of PPE is being done as per the guidelines provided by World Health Organization. However, the final fate of polymer is yet to be decided. This study is critical suggestive approach to value add the disposed PPE kits by converting them to bio-oil. In addition to environmental advantages, it could also minimize the dependency on non-renewable fossil fuels.

Keywords value addition; environment; biofuel; remediation.

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1 Introduction

It was the last week of December 2019, that, World Health Organization (WHO) was informed by the China health authority about numerous cases of pneumonia. These cases of unaccustomed etiology have been reported in the Wuhan City of Central China (Lu et al., 2020). Now, we all know this loathing and widespread diseases as COVID-19 (Das et al., 2019; Yadav et al., 2021, 2022).

The droplets during coughing and sneezing can spread the disease as they get transferred to some meter distances and remain on to the surfaces (Rothe et al., 2020). The virus remains lively on the surfaces for specific time depending on their shelf life on the material and causes transmission of disease (Kampf et al., 2020).

The unpredictable and sadly unbelievable growth of virus in all the parts of world has failed our all calculations to control it. On the other side, it is well established that precautions and self-care are some of the ways to minimize the chances of getting infected (Shams and Khansari, 2019; Zhang et al., 2020). However, healthcare workers and cleaning staff are working tirelessly in close contact of Covid-19 patients. So, the threat of emerging Covid-19 has highlighted the need for effective personal protective equipment (PPE) to protect healthcare workers against the biological agents. The various component of PPE includes N95 respirators, face masks, gloves, Goggle, single used protective gowns, face shields, coveralls normal surgical mask and powdered air purifying (IHS Market News Release, 2020).

Before the onset of Covid-19, India was not making a single PPE kit and at present we are into manufacturing of about 2 lakhs of PPE kit on daily basis (The Times of India Report, 2020), that is expected to rise in the near future.

Although various research laboratories are working on the vaccination of Covid-19, the development of vaccine is a protracted process that requires various testing and trails. Until the vetting of vaccination and its worldwide availability due care should be taken that demands the regular use of PPE by the health care workers.

With the large scale manufacture of PPE around the world there is a requirement to know the disposal and consequences of adding PPE in the environment. Although guidelines have already been given by World health organization (WHO) and National Center for Disease Control (CDC). For disposal of PPE kit. Indian Central for Disease Control has also given course of action for the management and propel treatment of infected biomedical waste (Health Services, 2020; Quartz India Daily Brief, 2020). However converting the discarded PPE to value added product will definitely provide benefit to the mankind.

In order to dispose or value add PPE kit it is very important to have knowledge of the material and their properties used for making the same.

1.1 PPE: Gowns

Following gloves, Gowns are identified as the second-most-used component of PPE, in the healthcare industry (Guidelines for Quarantine facilities, 2020; Gruendemann, 2020). Various studies showed that the material (fabric) play a vital role in the chain of infection caused by microorganisms such as viruses and bacteria. Bacteria and viruses can survive for extended periods on materials that comprise of PPE component (Scott, 2005).

Among various available gowns, for Covid-19 health workers, single use non-woven gowns made of polypropylene are more preferred. The gowns are assembled using thermal, mechanical or chemical seaming. The important properties of the PP, which makes it suitable for the application are crystallinity, high melting point of PP (171°C) due to regular arrangement of chains (Sidwell et al., 1996) , hardness due to presence of methyl group on alternate carbon atom, lightweight (density of 0.90 g/cm^3) and high strength to weight ratio.

1.2 Face shield & goggles

Face shields mainly consists of a screen in a frame, and a suspension system (elastic straps, Velcro, headbands etc.) that attaches it to the wearer’s head. Face shield are worn over masks and goggles to provide protect from microorganism as while treatment one can inadvertently touches the eyes/nose/mouth with a contaminated hand that may spread the infection so face shields/goggles forms an integral part of the PPE. The screen is generally made up of plastics such as polyethylene terephthalate glycol (PETG), polycarbonate and polyvinyl chloride. The excellent transparency, anti-static, anti-fog and anti-glare property of the mentioned plastics makes them a strong contender for their application as visor and goggles.

1.3 N95 respirators

Mask mainly prevents the entry of microorganism through the upper and lower respiratory tracts hence prevent transmission of virus. Among the available masks, Surgical N95 respirators are highly recommended because of its high filtration efficiency to airborne particles. It should be worn by everyone especially heath workers to prevent the inhalation of the microorganism in sterile environments or who are at risk of airborne or fluid hazards such as sprays. These masks require high chemical resistance thus made up of Polypropylene.

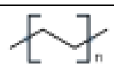
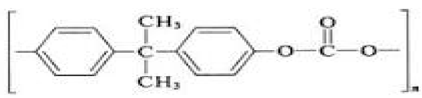
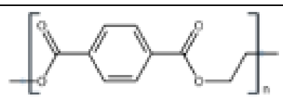
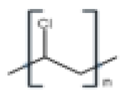
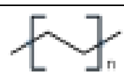
1.4 Coveralls

India is leading the world, after China, in manufacturing of PPE body coveralls to ensure the safety amid Covid-19 pandemic (First post NEWS, 2020). They are designed to cover the whole body, i.e. from head to feet and thus provide 360-degree protection from harmful biologically agents and chemicals. It is made of High Density Polyethylene (HDPE), possessing excellent resistance to all types of acid, alkali and organic solvents.

2 Value Addition of Castoff PPE Kits

The common plastics used in the PPE kit include PP, PC, PET, PVC and HDPE, which falls into the category of thermoplastics. The monomer, structure and the physical properties of all the mentioned plastics are given in Tables 1 and 2. The used and infected PPE kits disposed in the environment will enter either in the oceans or land-fills, as their degradation under normal temperature pressure conditions requires many centuries. Plastics, because of low degradation rate, disrupt the environment in a serious way. In addition to environment, it is also affecting the flora and fauna. The alternative to handle cast off PPE kit effectively is to convert them into their constitute chemicals via catalytic or thermal treatments that will change the chemical makeup of the material (Martynis et al., 2019; Budsaereechai et al., 2019). It comprises numerous treatment methods that results in high end value. Some of the methods are glycolysis (Simon et al., 2014; Sharma et al., 2016), hydrogenation (Aznar et al., 2006), aminolysis (Sinha et al., 2018), hydrolysis (Panda et al., 2010), pyrolysis (Williams 2013; Danon et al., 2015; Danon, 2015) and gasification (Dou et al., 2016; Wang et al., 2016; Onwudilia et al., 2016).

Table 1 Monomer & structure of polymers used for PPE kit.

POLYMER	MONOMER	Structure
Polypropylene PP	**C_3H_6**	
Polycarbonate PC	**$C_{15}H_{16}O_2$ and $COCl_2$**	
Polyethylene terephthalate PET	**$C_{10}H_8O_4$**	
Polyvinylchloride PVC	**C_2H_3Cl**	
High density polyethylene HDPE	**C_2H_4**	

Of the various mentioned process, thermo-chemical treatment namely pyrolysis is the most promising techniques (Strubinge et al., 2017) as it provide several environmental and operational advantages

Pyrolysis is the process of degradation of polymers with catalyst (catalytic pyrolysis) or without (thermal process) in inert atmospheres. As a result, the long chain of the hydrocarbons results in the formation of smaller and less complex ones by controlling the heat flow and pressure of the operation.

Table 2 Physical properties of polymers used for making PPE kit.

Properties	**PP**	**PC**	**PET**	**PVC**	**HDPE**
Glass Transition Temperature	-10°C	147°C	67-81°C	82°C	-120°C
Density	0.09–1.06 g/cm^3	1.20-1.22 g/cm^3	1.38 g/cm^3	1.1-1.45 g/cm^3	0.93-0.97 g/cm^3
Elastic modulus	1.5 – 3 GPa	2.0-2.4 GPa	2.8-3.1 GPa	3.4 GPa	0.6-1.5 GPa
Impact strength, Charpy notched	2 – 6 kJ/m^2 at 20°C	20-35 kJ /m^2	3.6 kJ/m^2	2 – 5 kJ/m^2	2.60 kJ/m^2
Coefficient of thermal expansion	6-10 X10^{-5} –1X10^{-4} K^{-1} at 20°C	6.5-7.0X10^{-5} K^{-1}	7.0X10^{-5} K^{-1}	5.0X10^{-5} K^{-1}	10-20 X10^{-5} K^{-1}
Max. service temperature, short	140°C	115-130°C	150°C	60-100°C	120°C
Melting point	160 – 168°C	155°C	>250°C	100-500°C	120-180°C
Specific heat capacity	1.52 kJ/(kg.K) at 20 °C	1.2-1.3 kJ/(kg.K)	1 kJ/(kg.K)	0.9 kJ/(kg.K)	1.3 kJ/(kg.K)
Thermal conductivity	0.41 W/(m.K) at 20°C	0.19-0.220.41 W/(m.K) at 23 °C	0.14-0.24 W/(m.K)	0.14-0.28 W/(m.K)	0.45-0.52 W/(m.K)
Flammability	UL 94 HB	V0-V2	-	-	HB
Dielectric constant	2.8 at 20°C	2.9	3-4	4	2.3
Electrical resistivity	10^{13}–10^{14} Ω.m at 20°C	10^{12}-10^{14}Ω.m	16X10^{13}Ω.m	10^{12}-10^{15}Ω.m	10^{13}-10^{16}Ω.m

The pyrolysis products of the above-mentioned plastics are different. Pyrolysis of PP produces almost no solid residue (Matsuzawa et al., 2019). Pyrolysis of HDPE yields high liquid (60%) and gas (37%) fractions) (Obeid, 2014). On the other hand, pyrolysis of PET and PVC leaves small amount of solid residue (<10%) (Brems et al., 2011). Some parts of the volatile products from PET pyrolysis can be in the form of solid due to the nature of the compounds such as benzoic acid and terephthalic acid (Kumagai, et al., 2015). For PVC, hydrogen chloride can be emitted at temperatures >300°C. The main liquid products from PVC pyrolysis are aromatic hydrocarbons, e.g., benzene, and PAHs (Yu et al., 2016; Zhou et al., 2015). Pyrolysis of PC results mainly in liquid product, which consisted mainly of phenols and substituted phenols as well as the original monomer (Antonakou et al., 2014). The liquid products from pyrolysis of plastics can be upgraded into fuels and other chemicals (Pinto et al., 1999).

3 Production of Bio-oils

PPE kit once discarded can be directly subjected to pyrolysis as it does not require prior separation, a mixture of plastics can be directly converted into bio-oil, which as such can be used for many industrial applications (Pingale et al., 2010; Sánchez et al., 2011). In a study, the pyrolysis of different types of plastics (LDPE, HDPE, PP, and mixture of all three) in presence of sulfated zirconium as catalyst showed a yield of 79% of oil. The oil mainly contained C10-C24 hydrocarbons (Panda et al., 2019). They concluded that the fuel quality was at par with the standard required parameters. Christine et al studied the pyrolysis of Polythene bags in presences of silica, alumina, Y zeolite, barium carbonate, zeolite, between 400°C and 550°C. They have also done the engine performance analysis result shows that the lower blends percentage oils show results close with that of diesel (Cleetus et al., 2013).

Budsaereechai et al. (2019) studied pyrolysis of four different plastic waste namely low density polyethylene, high density polyethylene, polypropylene, and polystyrene binder-free bentonite clay pellets. The results showed that the low density polyethylene and high density polyethylene oils product had similar functional groups that were consistent with commercial diesel (96% similarity match) (Budsaereechai et al, 2019). However, pyrolysis-oil from polystyrene showed similar chemical and physical properties as of gasohol and Pyrolysis-oil from all other polymers demonstrated comparable performance to diesel in engine power tests. The pyrolysis of plastics is an endothermic process and requires a high temperature to (950-1200K) to get a decent yield (Panda et al., 2019).

Ahmad et al. (2014) reported the pyrolysis of PP in a temperature range of 250-400°C, and reported the formation of liquid product 98.7%w/w; gaseous product 69.8%w/w, and 28.8%w/w residue. Pinto et al. conducted the thermal treatment of mixture of Polyethylene and Polypropylene in an autoclave (33) 0.14 MPa pressure, 450°C temperature, for 30 minutes. The product obtained with carbon atoms between 5 and 11, rich in alkanes and with very low concentration of branched and cycled alkanes. Sakata et al. also reported pyrolysis of PP at a temperature of 380°C the products obtained comprises of 80.1 wt % liquid, 6.6 wt% gas and 13.3 wt% solid residue (Sakata et al., 1999).

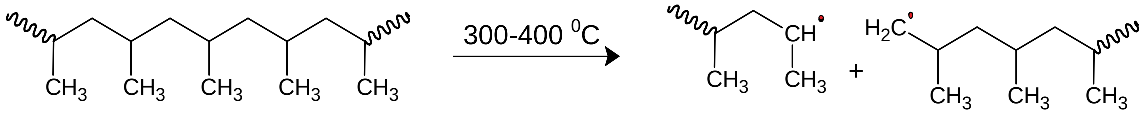
Miskolczi et al. (2014) conducted pyrolysis of mixture of polyethylene and polypropylene (polyolefin) to produce liquid fuel and concluded that the quality and yield of the final product depends on the type of the polymer and reaction time (Miskolczi et al., 2014)

4 Chemistry of Pyrolysis

The polymers are third generation petrochemicals, derived from petrochemical refineries where different products from crude oil are processed through various stages to give it final form. Conversion of the polymers back into hydrocarbons (pyrolysis oil) involves different steps, which constitutes the mechanism of the process. The mechanism of conversions to hydrocarbons for the five mentioned polymers is given to make the understanding easier for the scientific community.

The thermal decomposition of polymers PP & PE proceeds through chain reactions, which involves initiation, propagation, and termination. Initiation involves homogenous cleavage of initiator to form free radicals that will initiate the reaction. The free radicals will react with the molecular species to form smaller molecules and radicals during the propagation reactions. The free radicals are highly reactive and get stabilized by disproportionation and coupling. A general scheme for PP depicting the mechanism (Jain et al., 2020) is given in Fig. 1.

i) Initiation: generation of free radicals



ii) Propagation: Free radicals react with other species giving olefins and new free radical

iii) Termination: free radical may combine or transfer of proton from one radical to other takes place to give mixture of hydrocarbon (liquid product)

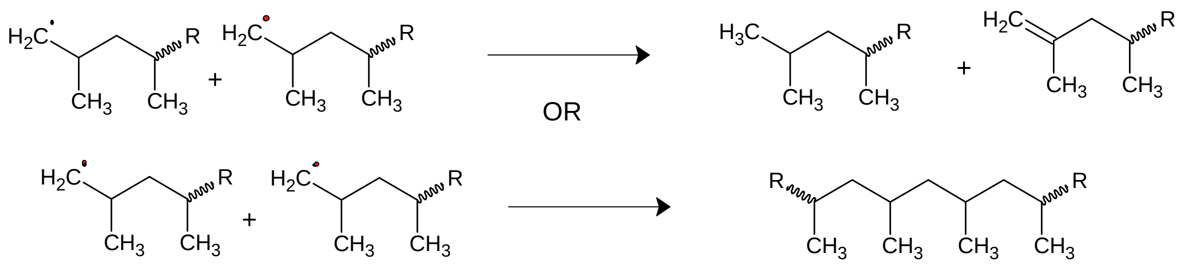


Fig. 1 Decomposition of PP during pyrolysis.

In PET, among the linkages, the C–O bonds in the polymer chains, adjacent to the CO bonds are most susceptible to thermal cleavage and degradation to form phthalic and benzoic acid and finally to benzene with CO_2 (Brems et al., 2011). A diagram depicting the mechanism is given in Fig. 2.

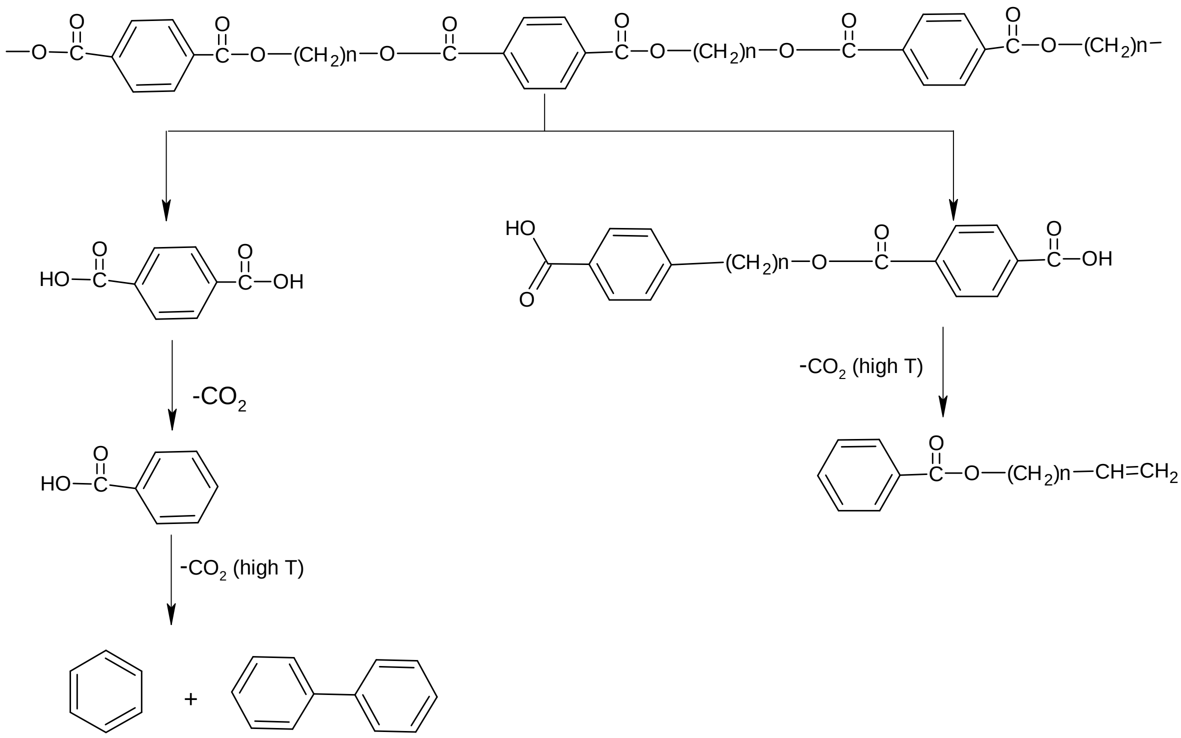


Fig. 2 Decomposition of PET during pyrolysis.

In case of PVC pyrolysis starts via dehydrochlorination, leading to the formation of conjugated polyene sequences resulting from backbone cracking, the same is depicted in Fig. 3 (Braun et al., 1969).

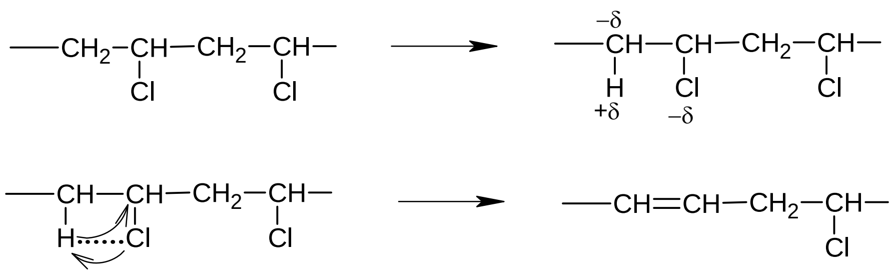


Fig. 3 Decomposition of PVC during pyrolysis.

Thermal degradation of polycarbonate has been investigated by many researchers. Fig. 4 shows a reactions mechanism which happen during the pyrolysis process of PC (Xiao et al., 1969)

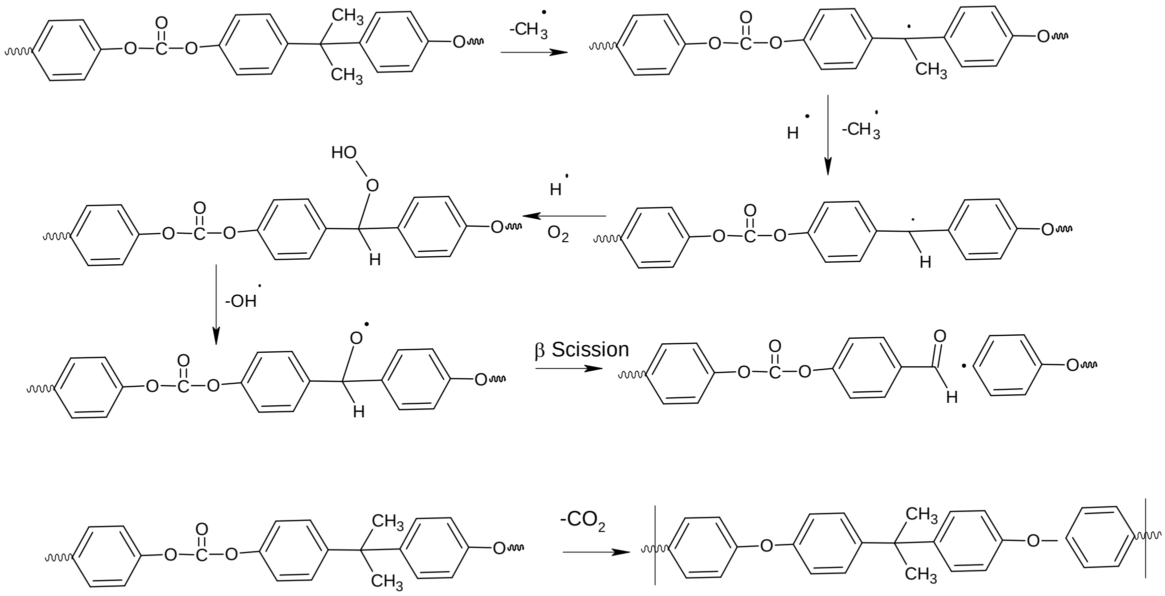


Fig. 4 Decomposition of polycarbonate during pyrolysis.

Thus, Pyrolysis is a resourceful method, which can be applied to mixed plastics to produce a range of useful hydrocarbons that after certain chemical treatment can be used as chemical feedstock or as energy. In addition to environmental advantages, this can solve the landfilling problem and can provide an alternate to non-renewable fossil.

5 Conclusion

Currently, the global problem is to control spread of SARS-CoV-2 virus and save human beings. PPE kits are playing a key role in protection of professionals working closely with Covid-19 patients. We are proudly producing huge number of different components of PPE kits and trying to develop different models to cut the cost and increase the effectiveness of PPT kits.

However, we cannot neglect the environment problems associated with the use of these plastic materials. We may address this issue by proper disposal and conversion of the single use plastic into some useful / valuable item like fuel. There are Environmental laws applicable for commissioning or operation Common Bio-medical Waste Treatment and Disposal Facility (CPWTF), which states that plastics should not be sent to landfill sites. Nevertheless, a sincere plan of disposal treatment of PPE kits is highly desirable at the current stage of pandemic, where we are indiscriminately producing and using plastic made PPE kit. Pyrolysis is suggested as an effective and workable method to convert PPE kit into valuable hydrocarbons that can be used as an alternative fuel.

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