Global Transitions Proceedings 3 (2022) 100–103

Contents lists available at ScienceDirect

Global Transitions Proceedings

journal homepage: http://www.keaipublishing.com/en/journals/global-transitions-proceedings/

Automated segregation and microbial degradation of plastic wastes: A greener solution to waste management problems

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ARTICLE INFO

Keywords:
Artificial intelligence
plastics
non-bio degradable wastes
microbial degradation
waste segregation
watse disposal
waste management
micro plastics
environmental pollution

ABSTRACT

The increasing accumulation of mess up plastic waste in natural environments creates a serious threat to our oceans, human health, flora and fauna. There is an urgent need to develop new approaches towards the disposal of non-biodegradable waste materials like plastics. It is now possible to develop novel biological treatment strategies concerning non-biodegradable waste (plastics) management because of the increasing literatures on the microbial degradation of the synthetic polymers like plastics. The valuable enzyme sources of microbes are capable of degrading synthetic polymers. The proposed waste segregator and decomposer (WSD) model focuses on the segregation of the non-biodegradable wastes automatically using AI techniques and also to frame an effective degradation strategy for commonly used synthetic plastics using novel microorganisms and associated enzymes.

1. Introduction

Efficient waste management is the need of the hour and it is a big challenge for any municipal corporation or private sectors. The key to any waste management system is to ensure the waste segregation. Automation of this process will help the people those who are working in this field from health hazards. A range of Artificial Intelligence (AI) applications have been developed for waste management. Conventionally, waste management is mostly manual process and the innovative technologies like AI, machine learning, computer vision, robotics has allowed to eliminate the need for manual labor thereby reducing the costs and improves efficiency. Recently, various types of synthetic plastic materials like styrene-based polymers, thermoplastic polymer, polymers of vinyl chloride like poly vinyl chloride, resin, and polyester are generally used in our day-today life as a very basic requirement. It is reported that the worldwide accumulation of plastics has reached 347 million tons in 2018 [1] according to the recent data of Plastics-Europe, (Plastics Europe, 2018). European Union and China account for 18.5 and 29.4%, ranking second and first among all the glob's plastic use, respectively. Simultaneously increasing exploitation of non-biodegradable waste materials like plastics, the generation of the same has also been increased worldwide quickly. Also, it is anticipated that 30 billion tons of plastic waste materials will be generated in 2050. Most of the waste materials will be dumped into landfills which leads to the entry of these materials into water bodies like sea and other water bodies resulting in severe pollution of the environment [2]. In future plastic wastes will set off a malicious figure of our wasteful society. Hence, it is notified that the accumulation of plastic waste materials on our earth is currently a serious dispute and that has to be addressed rapidly. It is now possible with the advent of technologies such as AI to lessen the non-degradable waste materials. The present plastic waste management system is highly unproductive because of problems in engaging employees, high input costs and segregation process [3]. To overcome this problem a smart waste management process using AI is proposed that replaces the human labor force. Once after identification of waste materials it is suggested to be degraded using microbial methods [4]. In the present paper, strategy for the development of robots based on AI equipped with computer vision technology is suggested and it can be skilled to segregate plastic waste through building on their algorithm. The waste segregator and decomposer (WSD) model are expected to work faster and longer than humans with high efficiency.

2. Related works

Landfilling, burning, mechanical and chemical recycling are the existing approaches of discarding plastic wastes [5]. Mostly in the emerging nations, rubbish dumb is the primary means of elastic waste removal because of their handling besides less cost [6]. But, ever increasing accumulation of plastic wastes filled a huge volume of terrestrial. Burning of elastic wastes be able to decrease the claim of dumping and recuperate thermal energy, however, it is similarly necessary towards lessen the ecological impacts of ancillary pollutants made from the burning

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https://doi.org/10.1016/j.gltp.2022.04.021

Available online 3 April 2022

practice. While mechanical recycling has become the major reprocessing process and it has been exploited for recycling thermoplastic wastes, the characteristics of many of the reprocessed materials are considerably negotiated subsequently several processing cycles therefore, marketable values are thus inadequate. The chemical reprocessing can retrieve the monomers and other elements from plastic wastes as a substitute, however its victory depends upon the inexpensiveness of methods and the competence of catalysts [7]. Currently from the published reports, merely 10 and 15% of worldwide elastic wastes is reprocessed and burnt, whereas up to 79% is dumped towards the native surroundings, specifying that there is an abundant requirement of discovering advanced reprocessing process to set of plastic wastes.

Hence, the suggested method uses microbes and associated enzymes to degrade synthetic plastics. Several microbes are capable of degrading single kind of plastics like polypropylene and polyethylene and was screened from the native surroundings, like the soil of a plastic-landfill spot, left-over of mulch films, ocean water, soil obtained from a crude oil contaminated site, dirt slurry, waste material dump site, and the gut bacteria of wax worm. The isolation of plastic-deteriorating microbes is essential for categorizing the de-polymerases and associated major enzymes involved in plastic deterioration. In the proposed study, not only focus on the biodegradation however, the organic refurbishing of plastic wastes, which is even more attractive.

Abdallah et al., (2019) examined the application of artificial intelligence (AI) in different solid waste management arenas, including estimating the waste features, waste bin level detection, process parameters calculation, vehicle routing, and SWM development [8]. Abbasi et al., (2018) studied four intellectual system algorithms such as support vector machine (SVM), adaptive neuro-fuzzy inference system (ANFIS), artificial neural network (ANN) and k-nearest neighbors (kNN) were analyzed for their capability to foresee the regular surplus production in a local area in Queensland, Australia [9,10]. Helen et al., (2017) reported a mangrove sediments based polypropylene degrading microbes such as *Bacillus cereus* and *Sporosarcina globispora* which were obtained from Peninsular Malaysia and screened for their capacity to destroy neoprene using a mineral salt media [11,12]. A new thermophilic bacterial strain isolated from humus agricultural residual in Vietnam in shaking liquid medium at 55°C after 30 days. It destroys different types of plastic bags with various chemical nature.

Danso et al., (2019) reviewed the ecological and biotechnological standpoints on microbial degradation of synthetic plastics and also the extent at which the microorganisms that could degrade plastics in the environment through the current microbial approach has been elaborated [13,14]. Ibiene et al., (2013) studied the ability of *Bacillus mycoides* and *Bacillus subtilis* (native *Bacillus species* of Niger Delta mangrove soil) to biodegrade thermoplastic polymer [15]. Montazer et al., (2019) reported the challenges in verifying microbial degradation of polyethylene [16]. The author highlights the need to develop a biochemical means of characterization towards the bio-deterioration of thermoplastic polymer besides other synthetic plastics to ease the evaluation of outcomes of testing dedicated for the microbial degradation of thermoplastic polymer [17]. The recycling of synthetic polymers in soils were also reported and the author presented a new method that agrees tracing of carbon from biodegradable polymers towards CO_2 and microbial biomass [18]. Mohanan et al., (2020) demonstrated the microbial and enzymatic deterioration of synthetic plastics [19,20].

Puglisi et al., (2019) reported the discriminating bacterial establishment practices on neoprene waste samples in a wild plastic-dump site [21]. The authors have done a multidimensional method comprising culturomics, next-gen sequence analyses and fine-scale physico-chemical dimensions to describe plastic wastes recovered in landfill abandoned for more than 40 years, besides to evaluate composition of bacterial populations flourishing as biofilms on the exteriors. Chamas et al., (2020) demonstrated the rate of degradation of plastics in the environment. The author reviewed the prevailing works on environmental degradation rates and pathways for the key types of thermoplastic polymers [22]. The plastic biodegradation was assessed with the use of frontline microbes and associated enzymes. The authors explore approaches to improve the degree of bio-deterioration of polyethylene using physical and organic means. The bacterial species *Bacillus subtilis* was confirmed for its prospective in utilizing polyethylene by means of their sole carbon source and described the microbial degradation of plastics using biofilms and several degradation pathways. The authors reported the impact of biofilm forming microbes in the degradation of commonly used plastics. Also, the biodegradation effectiveness of soil intrinsic novel sp. *Bacillus tropicus* (MK318648) was evaluated against low density polyethylene matrix.

The current status of polymer degradation was evaluated by Buragohain et al., (2020) [23] and also reported the microbial waste degradation. The author studied the potentials for degradation of non-biodegradable junk, basically plastics and similar materials with the help of microorganisms and to find out ways to appropriately manage these materials in view of their relation to global warming and other such matters [24].

3. Methods

An Artificial intelligence framework has to be designed for estimating and segregating the plastic wastes. The proposed framework (Fig. 1) uses convolutional neural networks for smart waste management. An algorithm is to be designed to segregate the plastics waste from waste mass and it is to be implemented using python and Raspberry Pi. It is proposed to develop an intelligent waste bin from where the plastics wastes are procured. This instigates with the use of intelligent garbage bins that exploits machine learning to recognize, group and segregate wastes instantaneously after it is discarded away. The proposed model can do the automated sorting of wastes with AI and it is reported that the human force can segregate between 40 to 50 cycles per minute however, the suggested AI-powered machine is expected to handle up to 170 and round the clock. After the segregation process complete, the sorted plastic waste materials are subjected to microbial based degradation using the procedures were discussed in the next sections. It is proposed to purchase a lightweight plastic material (LDPE) of 8 μ thickness. The LDPE material of size 7 cm × 4.5 cm is to be wash away by way of deionized water and then sterilize it by place it into 70% (v/v) ethanol for 30 min. Then it is planned to dry for 3 hrs. at 50°C followed by air-dry in a closed hood preferably laminar airflow cabinet for 15 min. The media composition to be adopted for the culturing and isolation of microbes is as follows, agar powder and LB media with tryptone, yeast extract, M9 minimal salts, 5X medium, 2.5 g/L Nacl.

The soil samples are planned to collect from the landfill place, Chennai, India. The pH of soil and moisture content will be measured. Then serial dilution is recommended for isolation of microbes. To isolate the microbes, specific culture media will be designed based on the above formulation. Then the serially diluted sample will be plated on the media and incubated. Using the 5X minimal salt medium, the colonies appearing on the surface of the media are vetted for LDPE degradation through batch process. Amongst all these isolates, the reporting microbe is establishing to be the best capable of degrading the lightweight plastic material (LDPE). Various biochemical analysis and Gram staining reactions will be performed to identify the bacteria. The isolated new bacterial strain will then be inoculated in the liquid medium along with the sterilized LDPE film. The detailed mechanism of microbial degradation of plastic wastes have been shown in Figure. 1. It is proposed to identify the plastic degrading microbial strain possibly through 16S rRNA sequencing to do the taxonomic and phylogenetic study. Sequencing is highly suggested beyond all because the 16S rRNA gene comprises of 1500 bp (basic pair), which is really enormous to be used. The DNA of the separated novel bacterium will be isolated by using the Mag-Bind® Universal Pathogen 96 Kit on ABI 3730xl Genetic Analyzer

(Thermo Fisher Scientific, USA). It is suggested to do the growth kinetics study of the isolated bacteria to evaluate whether it is having

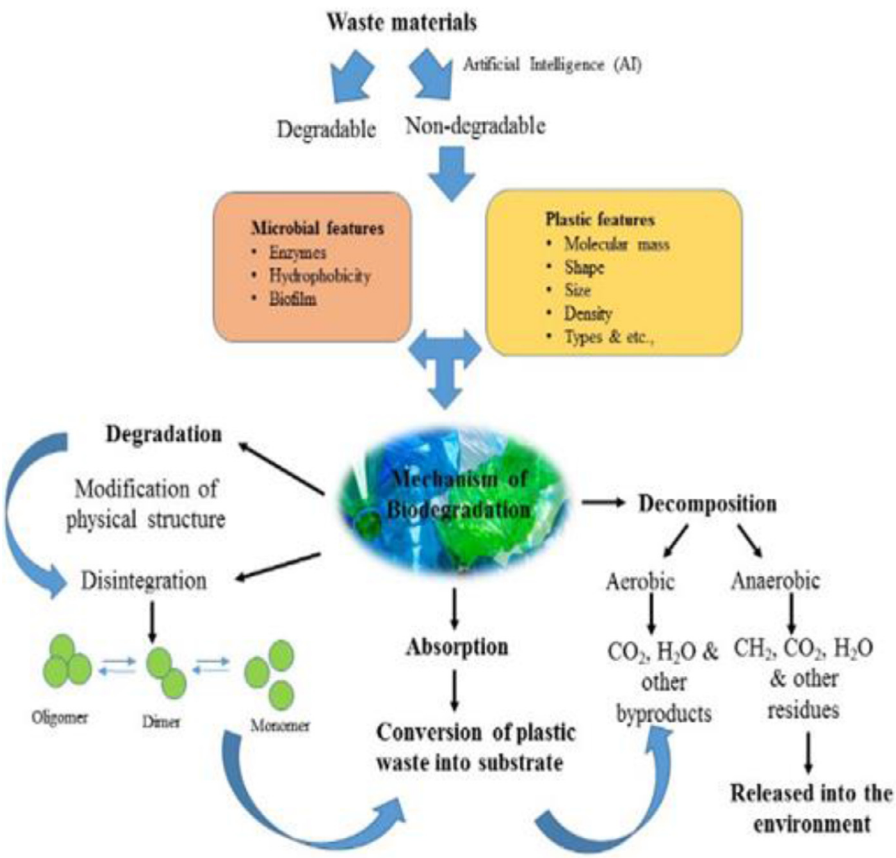

Fig. 1. Proposed mechanism of microbial degradation of plastic waste

Table 1
Comparison of efficiency of plastic waste degradation through the proposed methodology.

S. No	Method	Rate of degradation (years)
1	Photo-degradation	More than 50 years
2	Hydrolytic-degradation	More than 50 years
3	WSD method	Within a month

the ability to get adjusted in the new situation to metabolize certain substrate in which it is inoculated and it will be determined by the optical density (OD) of the culture through UV spectrophotometer. It is recommended to do the in-vitro degradation study. Then it is proposed to harvest the lightweight plastic material (LDPE) after 10, 20, 30 and 40 days of incubation for other characterization studies like polymer degradation studies by microbes by measuring the weight, pH and contact angle of the degraded plastic material. Then it is suggested to do FTIR, SEM, AFM to assess various apparent changes in the chemical nature of the materials, surface morphological study of LDPE films and to analyze the 3-D structure of the specified sample exterior at a deep resolution respectively. Then finally it is proposed to do the mechanical and optical property studies of the degraded material.

The WSD method uses AI for segregation of plastic wastes followed by microbial degradation to considerably increase the rate of decomposition. The rate of degradation is comparatively higher (Table 1) than other conventional methods.

4. Discussion

The name of the proposed model in the present study is a waste segregator and decomposer (WSD). It segregates different kinds of waste materials into bio-degradable and non-biodegradable such as plastics through AI tools. Thus, segregated non-biodegradable materials are then decomposed by a microbe based decomposer model which completely degrade the plastics without the release of any micro plastics in the environment. To follow the proper non-degradable waste disposal techniques, segregation at source is important. The intelligent garbage bins which utilizes machine learning techniques to sort the plastics wastes from food and other bio-degradable wastes at the source of waste generation. The bins are labelled clearly and the plastics are separated from biodegradable wastes which goes to the municipal landfill. The plastics waste materials are decomposed through a microbial based decomposer model. The merits of the proposed model is that the entire system brings about automation and thus decreases the human interference essential in sorting the waste and offers fruitful collection of the garbage from the bin at the suitable time. Also, the proposed model keeps the environment clean and fresh and thereby reducing the environmental pollution. The demerit of the proposed model is that it requires certain initial investment and monitoring.

Rajendran et al., (2019) reported waste segregation using AI techniques like machine learning algorithms and sorts the waste materials into plastic and non-plastic items with 80 % accuracy [24]. The proposed model in the present study is designed to sort the plastics and subsequent decomposition through microbial means and hence, the proposed methodology will work better than that of the existing models. Dong-Moon Kim (2022) demonstrated the detection and degradation of plastic wastes through UAV based multispectral data and deep learning followed by degradation using microbial means [25]. But they were not able to attain good results due to poor model presentation and shortage of data. Anadkat et al., (2019) who presented a drone based smart solid waste detection based on deep learning and image processing tools through feature extraction that helps to recognize waste contaminated places and sends the location coordinates as a notification [26]. The drone based model detects the solid wastes but it has not equipped with the decomposition of the recognized waste. Montazer et al., (2020) outlined the challenges in polyethylene degradation experiments and elucidated the parameters needed to attain polyethylene decomposition [27]. Venkatesh et al., (2021) elaborated the essence of microbes on degradation of plastics and various approaches to evaluate the effect of degradation of plastics by different microbes [28].

The review of literature shows there is a lack of experimental information on how precisely AI improves waste segregation. By means of moving to AI for smart recycling and trash management, trash sorting and disposal procedures can be automated, resulting in more sustainable recycling methods. Waste management is set to be modernized by AI-driven smart recycling equipment leading to preserving the environment for a positive and more sustainable future.

5. Conclusion

Still in most of the countries landfill is the only option for treatment of plastic waste materials and hence, a new solution is the need of the hour. In this paper a WSD frame work for the effective segregation and degradation of plastic waste materials was proposed. Since the effects of microbes that degrades plastics and other non-bio degradable materials are poorly understood, the relationship between plastics and microbial communities need to be studied urgently. Also the accumulation of plastic waste might force the microbes to adapt to newer substrates and hence it is now possible to exploit these microbes in the degradation studies. Based on this a waste segregator and decomposer (WSD) model was suggested which utilizes AI to ease the influence of plastics on the environment with subsequent decomposition of the segregated non-biodegradable wastes. The limitations of the proposed WSD model is that it requires some initial investment and monitoring. Further research is needed to emphasis on the scheming cost effective tools based on AI to confirm the maximum utilization of these tools. There is a need to strategically design low-cost AI based waste management system.

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