Evidence of Plastic Degrading Bacteria in Aquatic Environment

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ARTICLE INFORMATION

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ABSTRACT

Introduction: Water bodies are influential part of vitals and help to keep the balance on the earth, to nourish the growing population, as a financial backbone of development, and to save ecosystem along wildlife. Globally, WWF and collaborators are working on plans to secure aquatic resources and are managed sustainably, that's why water bodies are secure and beneficial for upcoming generations.

Findings: The research on pollution, bioremediation and related fields has found that plastic consists of certain chemicals which leach out and mix up with food, drinks and eatables. The health issues are created because of these chemicals that are being linked to health problems such as obesity, indigestion, fertility and immunity etc. Recently a lot of studies identified the involvement of several microorganisms and their enzymes, which are capable of breakdown the plastic material. The microorganism involved in material degradation specifically plastic is identified and well-studied, they consist on seven bacterial and eight fungal species. Among those seven bacterial species five belong to Gram positive while two are Gram negative. The fungal species are of Aspergillus. The species that gave prominent results were Gram +ve: *Staphylococcus, Streptococcus, Micrococcus*; Gram –ve: *Moraxella, and Pseudomonas*; and of fungal: *Aspergillus glaucus, A. niger*.

Conclusion: Most of developing countries are using biodegradable plastic instead of ordinary plastic. It is very easy to destroy, after use, and it can minimize the negative effects of marine pollution and environment. It is just like the practice of using biofuel. It can be overcome by environmental pollution.

Original Research Article

Introduction:

History:

Plastic is being produced on a large scale. Its production started in 1950 taking into account many factors, efforts were made to improve plastic from other materials. Plastic production had increased twenty times in the five decades since 1964. Its production or need exceeds 300 million tons annually. In 2015, it has grown to 335 million tons. At the same time, it is being said that in the next 20 years, the production of plastic will become double and will be almost four times in 2050.

Plastic Synthesis and Chemicals:

Plastics are derivations of organic and natural materials, including crude oil, natural gas, coal, cellulose and salt. The crude oil processing plays central role in plastic synthesis, it is the mixture of many compounds, it is processed through distillation in oil refinery [1]. The result of distillation results in separation of heavy to lighter groups of components known as fractions. Fractions consist on carbon and hydrogen containing compounds in form of hydrocarbon chains. These hydrocarbon chains are variable in terms of size and shape of molecules. Naphtha plays important role during processing of plastic production.

There are two main procedures applied for plastic production one of them is polymerization and other one is polycondensation. Specific catalyst is required to proceed through both. In reactors for polymerization, two types of monomers e.g., ethylene and propylene are used to be linked together for synthesis of long polymer chains. Depending on the nature of monomers to be used, variation in size and shape created.

- Thermoplastics is a kind which can be moulded easily after heating
- Thermosets are those never be moulded after getting a shape

Examples of Thermoplastics	Examples of Thermosets
ABS: Acrylonitrile butadiene styrene PC: Polycarbonate PE: Polyethylene PET: Polyethylene terephthalate PTFE: Polytetrafluoroethylene PVC: Polyvinyl chloride PMMA: Polymethyl methacrylate PP: Polypropylene PS: Polystyrene EPS: Expanded Polystyrene	EP: Epoxide PF: Phenol-formaldehyde PUR: Polyurethane UPR: Unsaturated polyester resins

Major categories of polymer families are divided into two groups. These groups are known as families.

Plastics from Biological Resources

Plastics originated from Bio-based material are fully or partially from these resources, to understand this ethylene is produced from sugar cane, which is further utilized to produce polyethylene. Polylactic acid (PLA) is produced from lactic acid which is ultimately from starch.

Plastics can be Biodegraded

Under specified conditions provided, the plastic which converts into water, carbon dioxide/methane and biomass by microorganisms is called biodegradable plastic [2]. To spread awareness among consumers, regarding biodegradation of plastics and to facilitate them a lot of steps has been considered. Implementation of universal standards, development of alternative materials and introduction of logo exhibiting compostable material are some of them.

Plastics Engineering

Standard materials are less worthed than engineering plastics, The performance of these materials at lower standard than engineering plastics, enables engineering plastics more reliable for tough utilizations. Engineering plastics are replacing traditional wooden/metal engineering parts, these are not only exhibiting benefit over others in weight to strength ratio but they are easier to manufacture in various complicated shapes too.

Epoxy Resins

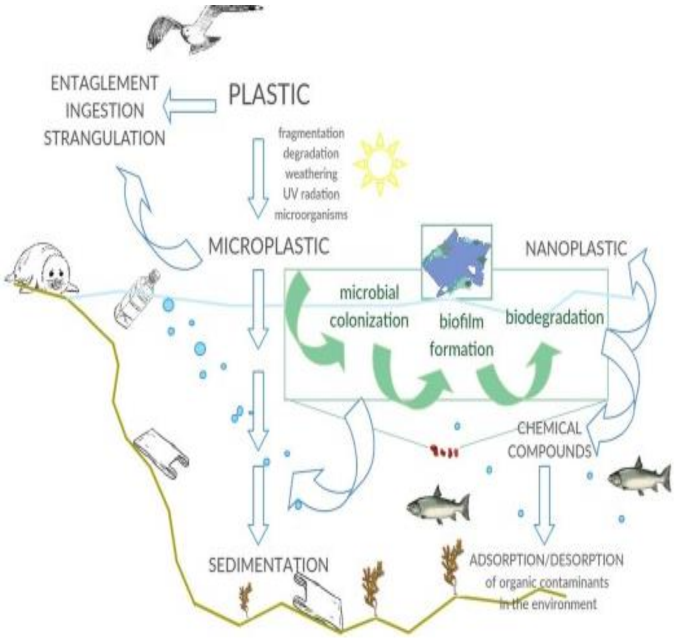
Epoxy resins are recently introduced, as a kind of plastics, it is in use since 50 years being one of most successful plastic in plastic families. Its physical state is easily converted to a solid of high melting point from liquid of low viscosity, that's the reason, it is utilized to prepare wide range of products.

Expanded polystyrene

EPS is abbreviation of expanded polystyrene which is used as commodity polymer. It is on priority in choice to use because of its economic value, durability and variation in application.

Impact On Surroundings:

Plastic products are becoming important ones in daily life utilities. Plastic production is rapidly growing day by day due to its low-cost processing although it has had severe impact on the environment, which cannot be overcome easily. The pollution is spread to the several square kilometers of the ocean [3]. It has come to know that 10 to 20 million tons of plastic waste is dumped in the sea and there is no other way to eliminate or exclude it. The plastic debris has been found on the surface and in the depth of the ocean. These are mainly found in micro plastics and macro plastic. The plastic pieces that are less than 5 mm in size are called micro plastics. Above 5 mm plastic particles or plastic pieces called macro plastics. These micro plastic particles are added in the water from the cosmetics industry. Micro plastics spread is far and far more harmful than macro plastics [2-4]. Because living beings absorb it and take it inside their digestive system, which becomes part of their body and proves to be harmful. It has a bad effect on Marine life. Different types of Marine organisms take these plastic particles into the body through their diet and these plastic particles affect their digestive system.



Biofouling

Due to density, some of the plastic particles are floating in the waves above the sea while some particle levels sit on the sea. Marine pollution also contains biotic factor as well as abiotic factor. These biotic and abiotic factors are collected over some plastic pieces called bio-fouling [5]. Biotic factor includes plastic and its culture. Biotic factor includes the remains or parts of plants and living organisms. Biofouling is completed in five stages, the first step is abortion, the immobilization, consolidation, micro fouling and macro fouling [6-7].

The most important bacteria for biofouling are bacteria, they make primary colonization on plastic surface. Micro filling is mainly completed in two stages. The first phase is primary colonization and the second is secondary colonization. The primary colony is made of bacteria and diatoms [7-8].

The first report on plastic pollution in the offshore sea parts of the north ocean was published in the 1970s. In those days, it was paying close attention to the amount of plastic and its properties. They reached 3500 particles per km². The size of these bullet like plastic pieces which were not more than 5 mm. The diatoms and bacteria come and start colonizing [7].

Modern research that was done in the oceans of North Sea west Europe, was about the number of small plastic particles that were floating above the sea level has reached 1.5 cubic meters. The number of plastic particles that have been deposited on the ocean floor has reached an amazing extent and is range on 3146 particles per kg. This research proves that these plastic particles inside the ocean layer can remain for a long time. These plastic particles in the ocean layer, the reason for staying longer is that the sunlight cannot reach the bottom of the ocean, the temperature in the bottom of the ocean is very low, due to which the plastic in the bottom of the ocean cannot break as quickly as the plastic in the top layer of the ocean breaks [2-9].

The first thing that is needed to break the plastic is the UV light and oxygen. The UV light plays the most important role in breaking the hydrocarbon of the plastic and oxygen is essential for the oxidation of these hydrocarbons. However, neither the UV light can reach the bottom of the ocean, nor oxygen, due to which the process of breaking the plastic in the bottom of the ocean does not begin itself. It should be clear that large pieces of plastic affect fish and birds but small pieces of plastic are found in water, affect the organisms of lower trophic level such as zooplankton, dumb and oysters.

The natural ability of microorganisms is that they can survive in all kinds of environments. They are found almost everywhere, whether there is a snowy mountain or a frozen lake, sea or a humid place [10]. Even if there is a little moisture in the ocean, bacteria can be found from millions to billions in number. However, anything floating inside the ocean cannot be without bacteria or microorganisms, even if it is a plastic piece. Because of this, bacteria are found on top of all kinds of plastic that are thrown inside the ocean. There are many researches dare to explain the relationship between plastics and these micro-organisms.

Unfortunately, we have not yet been able to find out how bacteria survived on the surface of plastic. However, it has been studied those bacteria can make a bio film by connecting the plastic surface, which helps it to survive in the marine environment [11]. And there are many ways due to which bacteria survived in ocean environment, such as collecting nutrients, the horizontal gene exchange, and avoid toxic substances. The plastic pieces present in the ocean become a colony of microorganisms this process gets complete in a few hours and these microorganisms cover the entire plastic surface within a few moments.

Due to this colonization of bacteria above the plastic surface, the process of plastic breakdown becomes easy to start and due to this colonization, other microorganisms such as algae and zooplankton are also attached to that surface of plastic and are helpful in the process of plastic breakdown [12]. The number of these organisms can vary from one another above the plastic surface. They contain some bacteria; some fungi and some zooplankton are also present. The bounty proportion between these creatures can differ; the cell proportion of bacteria/diatoms/beats on polymer plates from the White Sea was 640:4:1, while the extent of different life forms was about 0.15%. Because a variety of living organism are found on this plastic surface therefore plastic surface is also known as bioplastic sphere [12-13].

Biodegradation is the process in which microorganisms break different types of plastic and plastic pieces into small parts which came into the ocean via different ways [15]. These microbes also can change its chemical structure. As it is already discussed that big plastic pieces enter the ocean, these plastic pieces are first converted into small parts and then converted into microplastics [14]. These processes are controlled by different types of biotic and abiotic factors. Now it is clear that the process of making colony above the plastic surface does not depend only on the bacteria but also on the chemical properties of this plastic, surface roughness, topography surface free energy, i.e., surface electrostatic, interaction and surface hydrophobicity [15-16].

However, many other environmental factors are useful in the process of plastic de-gradation, such as the temperature, the basicity, the level of oxygen and the amount of light. These are all the factors that are helpful in biofilm formation and are useful in the process of plastic de-gradation [18-17-13]. For example, increasing the temperature accelerates the process of de-gradation. Environmental change also affects the process of plastic de-gradation, as the environment breaks the surface of the plastic, over which the bacteria colonize and the process of plastic breakdown starts. However, it cannot be proved that how environment plays its role in the process of plastic de-gradation.

Scientist who was working on marine environment observed the microorganism which were present on the plastic piece, they characterized them and studied them in detail which led them toward the bacteria which were actually degrading the plastic. Scientist also characterized some bacteria which can't degrade plastic but they were colonizing at plastic surface. Some scientist also observed that biofilm formation takes place only on the four types of plastic such as oxo biodegradable d2w and EPI polythene bag, biobags and standard polythene bags and the formation of biofilm starts after 30 days of exposure of plastic to marine water. Scientist also observed that the plastic products made up of biodegradable plastic compounds can easily be degraded as compared to the plastic products which are made up of conventional chemicals [18]. The biofilm formation on the biodegradable plastic is quite easy and quick due to this reason the biodegradable plastic is easy to break. So, at the first plastic surface crowded, degraded and there is the formation of biofilm and bacteria present in biofilm start the process of plastic degradation which completes in 4 weeks [19].

When the scanning of ordinary plastic and biodegradable plastic was observed through electron microscope, it became clear that colonization at the normal plastic level required more than a month, and only the process of colonization of bacteria was difficult. The process of colonization on biodegradable plastic gets start within ten to fifteen days and on top of it colony is easily formed. This makes it relatively easier to break down the biodegradable plastic than conventional plastic [20].

Moreover, the investigation makes it clear that when a small part of the bio film is separated from the plastic, the physio chemical properties of the plastic return to their original state [19-21]. As much as the part of the biofilm is extracted, the part starts to become again because there exist the bacteria that makes the biofilm. In a study the process of biofilm formation on PS and PE plastic is observed. When some pieces of plastic were removed after keeping two weeks inside the cold sea, bacteria of the genus *erythrobacter* were found on top of this plastic. Bacteria belonging to this genus are characteristic of breaking polycyclic compound. These bacteria were eligible of breaking plastic.

However, scientists do not know much about the bacteria that break the plastic in the ocean but scientist determined that bacteria which make only degrade plastic, but it is not enough to understand the process of plastic breaking in the marine environment.

Most of the planet's atmosphere is cold and most cold parts do not have human intervention. Basically 70% of the planet contains seawater. However, some bacteria are found in this cool environment and cold water. Cold water surprisingly useful to break the plastic. In any case, a few examinations show the potential of isolated cold marine microorganisms to corrupt plastic (Table 1).

Lamentably, the primary issue with this investigation is distinguishing proof of the isolated microorganisms even on the chance that this movement is affirmed. The 16s rRNA groupings recouped in many investigations reveal the nearness of primarily obscure living beings just remotely identified with known separates. The examination on degrading microorganisms is mostly centered around scanning for them in deep sea silt where temperature diminishes under 4 °C (in the instance of 90% of the ocean bottom). Two kinds of PCL-degrading microorganisms were isolated from profound seawater at 320 m profundity in Toyama Bay. The isolated strains were distinguished as the *Pseudomonas* class and had the option to corrupt PCL at 4 °C. Also, Sekiguchi isolated microorganisms having a place with the *Shewanella, Moritella, Psychrobacter*, and *Pseudomonas* genera from remote ocean silt tests acquired from a profundity of 5000–7000 m. Six isolated strains demonstrated degrading capacities against a biodegradable polyester PCL. The creators also tried other biodegradable plastics, for example, PLA, PBSA, PBS, and polyhydroxybutyrate (PHB), however no movement was watched [22].

In any case, in the following report, it was expressed that PCL, PHB, and PBS strands were degradable in profound sea waters in spite of low temperatures. Next, increasingly five PCL-degrading strains were isolated from profound water (320–650 m profundity), recognized as microscopic organisms from the genera *Pseudomonas*, *Alcanivorax*, and *Tenacibaculum*. Two of them, *Pseudomonas sp.*, strains RCL01 and TCL04, were seen as adjusted to states of low temperature (4 °C) and, high hydrostatic weight.

Raghul watched obvious breaks and depressions on the outside of a polyvinyl alcohol-low straight thickness polyethylene (PVALLDPE) mix film following 15 weeks of hatching with a bacterial consortium comprising of *Vibrio alginolyticus* and *Vibrio parahaemolyticus* isolated from the benthic zones of various marine situations from [22].

Table 1

Microorganism	Source	Plastic	References
Shewanella, Moritella sp., *Psychrobacter* sp., *Pseudomonas* sp.	Deep-sea sediment, the Kurile and Japan Trenches	PCL	Sekiguchi et al. (2010)
Vibrio alginolyticus, Vibrio parahemolyticus	Benthic zones of marine environments	PVA-LLDPE	Raghul et al. (2014)
Pseudomonas sp., *Clonostachys rosea, Trichoderma* sp., *Rhodococcus* sp.	The Arctic soil	PCL, commercial available bag based on potato and corn starch	Urbanek et al. (2017)
Zalerion maritimum	Marine environment	PE	Paco et al. (2017)
Aspergillus versicolor, Aspergillus sp.	Kovalam coast—off the Bay of Bengal, 500 m away from shore at the depth of 5 m	LDPE	Pramila and Vijaya Ramesh (2011
Pseudomonas sp.	Deep seawater of Tottori Prefecture and offshore in Toyama bay	PCL	Sekiguchi et al. (2009)
Pseudomonas sp., *Alcanivorax* sp., *Tenacibaculum* sp.	Deep seawater	Monofilament fibers of PCL, PHB/V, PBS	Sekiguchi et al. (2011)

Table 2

Microorganism	Source	Plastic	References
Phormidium, Lewinella	Microbial communities attached to PET drinking bottles submerged in the North Sea off the UK coast[a]	PET	Oberbeckmann et al. (2016)
Phormidium sp., *Rivularia*	Microplastic from the North Atlantic	PP, PE	Zettler et al. (2013)
Stanieria, Pseudophormidium	Microbial communities attached to PET drinking bottles submerged in the North Sea off the UK coast[a]	PET	Oberbeckmann et al. (2014)
Pseudophormidium sp., *Phormidium* sp.	Plastic particles harvested off the coasts of the UK, Germany, and Denmark	PP, PE	Oberbeckmann et al. (2014, 2016
Proteobacteria, Bacteroides	Microplastic harvested off the Belgian part of the North Sea	Microplastic	De Tender et al. (2015)
Arcobacter Colwellia spp.	Coastal marine sediments within the Humber Estuary, UK	LDPE	Harrison et al. (2011)

profundity of 8 m. In an ongoing report, bacterial and fungal strains from cold districts with the capacity to debase bioplastic were isolated . In that review, the microbial action against PLA, PCL, PBS, and PBSA was tried [24]. The most elevated action was watched for fungal strains distinguished as *Clonostachys rosea* and *Trichoderma sp*., and bacterial strains having a place with the *Pseudomonas* and *Rhodococcus genera*. PCL films were 53% debased (w/w) during 30 days of brooding. In addition, bountiful development on PLA films was watched, which may recommend the limit with respect to PLA debasement under certain conditions.

Conclusion:

Plastic material is a great threat to the lives of living creatures in the sea. Fortunately, public awareness about this poison of plastic is increasing. Unfortunately, many countries use landfilling method to get rid of plastic substances and plastic never ends with landfilling. Plastic recycling techniques were used for the first time in 2016. Most of developing countries are using biodegradable plastic instead of ordinary plastic. It is very easy to destroy, after use, and it can minimize the negative effects of marine pollution and the environment. It is just like the practice of using biofuel. It can be overcome by environmental pollution. Biodegradable plastic can easily be degraded by the bacteria present in marine water. Because the bio-fouling process is not considered very well. However, there is a need to study the relationship between bacteria and plastics more deeply. We can control this plastic pollution, growing in the sea to protect our land and its water.

References:

1. Geyer R, Jambeck JR, Law KL. Production, use, and fate of all plastics ever made. Science Advances. 2017;3(7).
2. Gewert B, Plassmann MM, MacLeod M. Pathways for degradation of plastic polymers floating in the marine environment. Environmental Science: Processes & Impacts. 2015;17(9):1513-21.
3. Maes T, Van der Meulen MD, Devriese LI, Leslie HA, Huvet A, Frère L, et al. Microplastics Baseline Surveys at the Water Surface and in Sediments of the North-East Atlantic. Frontiers in Marine Science. 2017;4.
4. Austin HP, Allen MD, Donohoe BS, Rorrer NA, Kearns FL, Silveira RL, et al. Characterization and engineering of a plastic-degrading aromatic polyesterase. Proceedings of the National Academy of Sciences. 2018;115(19).
5. De Tender CA, Devriese LI, Haegeman A, Maes S, Ruttink T, Dawyndt P. Bacterial Community Profiling of Plastic Litter in the Belgian Part of the North Sea. Environmental Science & Technology. 2015;49(16):9629-38.
6. Debroas D, Mone A, Ter Halle A. Plastics in the North Atlantic garbage patch: A boat-microbe for hitchhikers and plastic degraders. Science of The Total Environment. 2017;599-600:1222-32.
7. Eich A, Mildenberger T, Laforsch C, Weber M. Biofilm and Diatom Succession on Polyethylene (PE) and Biodegradable Plastic Bags in Two Marine Habitats: Early Signs of Degradation in the Pelagic and Benthic Zone? PLOS ONE. 2015;10(9):e0137201.
8. Lebreton L, Slat B, Ferrari F, Sainte-Rose B, Aitken J, Marthouse R, et al. Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports. 2018;8(1).
9. Kedzierski M, D'Almeida M, Magueresse A, Le Grand A, Duval H, César G, et al. Threat of plastic ageing in marine environment. Adsorption/desorption of micropollutants. Marine Pollution Bulletin. 2018;127:684-94.
10. Cameron KA, Hodson AJ, Osborn AM. Structure and diversity of bacterial, eukaryotic and archaeal communities in glacial cryoconite holes from the Arctic and the Antarctic. FEMS Microbiology Ecology. 2012;82(2):254-67.
11. Caruso G. Plastic Degrading Microorganisms as a Tool for Bioremediation of Plastic Contamination in Aquatic Environments. Journal of Pollution Effects & Control. 2015;03(03).
12. Bryant JA, Clemente TM, Viviani DA, Fong AA, Thomas KA, Kemp P, et al. Diversity and Activity of Communities Inhabiting Plastic Debris in the North Pacific Gyre. mSystems. 2016;1(3).
13. Cole M, Lindeque P, Halsband C, Galloway TS. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin. 2011;62(12):2588-97.
14. Cole M, Lindeque PK, Fileman E, Clark J, Lewis C, Halsband C, et al. Microplastics Alter the Properties and Sinking Rates of Zooplankton Faecal Pellets. Environmental Science & Technology. 2016;50(6):3239-46.
15. Cózar A, Echevarría F, González-Gordillo JI, Irigoien X, Úbeda B, Hernández-León S, et al. Plastic debris in the open ocean. Proceedings of the National Academy of Sciences. 2014;111(28):10239-44.
16. Cózar A, Martí E, Duarte CM, García-de-Lomas J, van Sebille E, Ballatore TJ, et al. The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation. Science Advances. 2017;3(4).
17. Kolvenbach BA, Helbling DE, Kohler H-PE, Corvini PFX. Emerging chemicals and the evolution of biodegradation capacities and pathways in bacteria. Current Opinion in Biotechnology. 2014;27:8-14.
18. Oberbeckmann S, Kreikemeyer B, Labrenz M. Environmental Factors Support the Formation of Specific Bacterial Assemblages on Microplastics. Frontiers in Microbiology. 2018;8.
19. Oberbeckmann S, Loeder MGJ, Gerdts G, Osborn AM. Spatial and seasonal variation in diversity and structure of microbial biofilms on marine plastics in Northern European waters. FEMS Microbiology Ecology. 2014;90(2):478-92.
20. Oberbeckmann S, Osborn AM, Duhaime MB. Microbes on a Bottle: Substrate, Season and Geography Influence Community Composition of Microbes Colonizing Marine Plastic Debris. PLOS ONE. 2016;11(8):e0159289.
21. Pathak VM, Navneet. Review on the current status of polymer degradation: a microbial approach. Bioresources and Bioprocessing. 2017;4(1).
22. Pauli N-C, Petermann JS, Lott C, Weber M. Macrofouling communities and the degradation of plastic bags in the sea: an in situ experiment. Royal Society Open Science. 2017;4(10):170549.
23. Eriksen M, Lebreton LCM, Carson HS, Thiel M, Moore CJ, Borerro JC, et al. Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. PLoS ONE. 2014;9(12):e111913.
24. Raghul SS, Bhat SG, Chandrasekaran M, Francis V, Thachil ET. Biodegradation of polyvinyl alcohol-low linear density polyethylene-blended plastic film by consortium of marine benthic vibrios. International Journal of Environmental Science and Technology. 2013;11(7):1827-34.