Microbiological perspectives on the effects of microplastics on the aquatic environment

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Abstract. Plastic waste has been known as threatening pollution, especially to the aquatic environment. Larger-sized plastic particles have noticeable impacts on the marine ecosystem. Current studies have revealed serious menaces of small plastic particles namely Microplastics (MPs). In contrast to the larger particles, little is known about the interaction between MPs and the surrounding microorganisms. MPs pose more threats to the environment and human health due to their abilities to influence the microbial ecology of the marine environment. This paper will discuss the MPs effect on the aquatic environment from the microbiological points of view consisting of the biofilm formation on MPs, the exchange of microbial genes on MPs particles and also the role of MPs as the reservoir for antimicrobial and metal resistance genes.

1. Introduction

The world nowadays is facing the most hazardous threat, namely plastic pollution. Since its first discovery in 1893 by Charles Goodyear and its mass production in the 1940s, plastic has become a widely used commodity in the world. The proportion of plastic disposal is 10% of the global generated waste [1, 2]. Global Industry Analyst reported that the plastic consumption in the world had reached 297.5 million tons by the end of 2015 [3]. This number does not only describe the rate of consumption, but also reflects the magnitude of the pollution. The small amount of plastic has been recycled and incinerated (12%) meanwhile the large amount (79%) of it still covers the landfills and floats on the water system. The accumulation of plastic disposal over the century is related to its ability to resist degradation. The aquatic environment such as marine and freshwater systems are both threatened by plastic pollution [1, 2, 4].

The plastic debris called macroplastics has been known as the common pollutant to the marine system it aesthetically and biologically disrupting. The accumulation of plastic waste has negatively impacted marine tourism and disturbed the marine ecology primarily by causing the death of marine organisms [2]. In the late 2000s, the researchers began to focus on small plastic particles namely Microplastics (MPs), later known as emergence contaminants [1].

Microplastics is a terminology used to define the plastic particles less than 5 mm in size. This definition was arguable at first but later accepted because plastic particles of this size can be ingested by the aquatic organisms [1, 5, 6]. Based on the way they are produced, there are primary and secondary MPs. The primary
MPs are defined as MPs produced by the industrial or domestic discharge. They are commonly related to the cosmetic and pharmaceutical products [7]. The secondary MPs are produced as degraded part of larger plastic particles on the environment. This degradation can be processed through mechanical and biological degradation and photo-oxidation [8, 9].

Microplastics as well as macroplastics are defined as a serious threat to the aquatic environment. Because of their small size, MPs are ingestible by the organisms living in the aquatic atmosphere, such as invertebrates, zooplankton, fish, seabirds and mammals. A previous study showed that the digested MPs varied in terms of particle sizes and types of the fibers and polymers [10]. The threats of MPs are not limited to the aquatic organisms, but also to the surrounding environment, including the humans. Recent studies showed that MPs have contributed to the spread of pathogenic microorganisms, such as *Vibrio cholerae*, through water systems. The findings also revealed the correlation between MPs and microbial populations in the aquatic environment [11]. This article will further discuss the microbiological perspectives on the existence of MPs in the aquatic environment.

2. Microplastic-related Issues on Microbiological Settings

For decades, MPs have been critically assessed due to their impact on the aquatic environment. However, little is known about the biological interaction between MPs and aquatic microorganisms. It has been acknowledged that the aquatic microorganisms are able to attach to the surface of MPs and perform biological interaction known as plastisphere. This protective niche is designated as vector to Fecal Indicator Organisms (FIOs) and Harmful Algae Bloom species (HABs) on bathing water and also the beach [6]. The involvement of MPs as a vector of pathogenic bacteria which will impact human health is still potentially considered. There was evidence that revealed the ability of MPs in harboring pathogenic microorganisms, such as *Vibrio Spp*, *Stenotrophomonas maltophilia*, *Escherichia coli*, *Aeromonas salmonicida* and *Bacillus cereus* [12].

A recent study showed that there was a specific type and size of plastic-microbiome pattern which also differed from the naturally-derived materials [13, 14]. There are variants of plastic polymers, such as Polystyrene, Polyvinylchloride (PVC), Polypropylene (PP), Polyethylene (PE) and Poly (Ethylene terephthalate)/PET [15]. Each polymer differed in density and shape and demonstrated different manners of MPs in the aquatic environment [8].

2.1. Microplastics and biofilm formation

Biofilm formation is one of the mechanisms developed by bacteria in order to survive in distressing conditions. The bacteria congregate on the surface of solid materials and are encapsulated by Extracellular Polymeric Substances (EPS) consisting of polysaccharides, protein and DNA matrix [16]. The microorganisms attach to the surface of MPs within hours and continue to form colonization. The contact between ambient water and MPs surfaces promotes the formation of a layer/film consisting of organic and inorganic materials through absorption. The attachment of the microorganisms is mediated by the repulsive and attractive interaction between the cell wall, surface and medium [17]. The physical modification of the surface through Ultra Violet radiation or wave abrasion also supports the formation of biofilm [18]. The formation of biofilm occurs within 72 hours and there is no difference in the period of formation between plastic and glass materials. The colonization might be a result of MPs substrates utilization as source of carbons [19] which is often triggered by a low level of nutrients [20]. A previous study using exposure experiment confirmed that the composition of bacteria within plastisphere was also influenced by the types of polymers, geographical locations and seasons [19].

Microbial assemblage is more than just a conservation for aquatic microorganisms. It is also involved in the weathering process and vertical transport which determine the fate of MPs in the aquatic environment. Weathering process is defined as a disruption of the physical integrity of MPs through biotic and abiotic
pathways which lead to degradation. The most common abiotic pathway is photo-oxidation which exposes the materials to the UV light [21]. This exposure leads to the change of the roughness and chemistry of the MPs surface (biodeterioration). The MPs surface attract more microorganisms to colonize, increase the contribution of biodegradation by altering the particle density, buoyancy and sinking rate. However, the biofilm formation may block the UV light exposure on the MPs surface or change the vertical position of MPs on the water and prevent the abiotic pathway to occur [17].

In terms of biodegradation, the MPs polymers encounter the chemical cessation induced by the exoenzymes expressed by microorganisms and form shorter fragments. The chemical breakdown later pass the cell membranes and being utilized as source of carbons then mineralized into carbon dioxides, water and methane [21]. Biofilm formation also influences the sinking rate and sedimentation of MPs since it is formed by heteroaggregates with different densities. These aggregates supports the vertical transport of MPs including upward/surface and downward/sedimentation movement [17].

Biofilm also plays an important role in the transportation of plastic-associated contaminants such as Hydrophobic Organic Chemicals (HOCs) due to its ability to absorb and metabolize the compounds. Microplastics will release the pollutants during their presence in the sea. The MPs have higher chemical load than the sea water. The PE polymers perform high capacity work in absorbing the HCOs [22]. Biofilm is able to act as the barrier to prevent the release of HCOs because the plastisphere communities are able to degrade the chemical pollutants [17].

The biological structure and composition of biofilm are correlated to the future fate of MPs. Previously it has been explained that the type of MPs polymers determines the microbial taxa composing plastisphere [14, 20]. A study demonstrated the variation in gene expression pattern of microorganisms, especially in sugar biosynthesis pathway on different type of polymers. This study indicated the substrate-specific adaptation mechanism. The gene expression determined the composition of EPS and subsequent aggregates [23]. This phenomenon correspondingly determines the transportation of MPs, whether it is going to be sunk or floated. The potential accumulation of certain heteroaggregates increases the uptake and ingestion of MPs by the susceptible organisms which is known as trophic transfer [10, 17].

The biofilm formed on the MPs surfaces can be used to determine the toxic substances and their adverse effects consisting of direct and indirect effects. The direct effect relies on the absorption of the chemicals through the microorganism’s cell wall. Meanwhile, the indirect effect relies on the HCOs leakage from the polymers. The toxicity can be measured using flow cytometry method but it is still difficult to distinguish the direct and indirect effects [24].

2.2. Microplastics preserve the antimicrobial and metal resistance genes

Triclosan is one of the antimicrobial compounds used in polymer synthesis. Triclosan and polymers share similar molecular properties and polarities which lead to compatibility. The addition of triclosan to the polymer formulation has increased the toughness and strength of the polymers [25]. On the other hand, the presence of triclosan in plastic waste can contaminate and hamper the aquatic environment by inducing the spread and adaptation of antimicrobial resistance genes (ARGs) among aquatic organisms. A previous study showed that there were 64 ARGs isolated from MPs in the marine environment. The dominating ARGs consist of aminoglycoside, bacitracin, macrolide-lincosamide-streptogramin (MLS) and multidrug resistance genes [26].

Not only do MPs have the ARGs, they also become reservoirs for the metal resistance genes (MRGs) due to its robust ability to absorb the metal pollutants. The types of polymers were strongly correlated to the kinds of absorbed heavy metals. It was known that PS and PVC showed higher amount of metal ion absorption than other polymers [27]. A study had succeeded in isolating 47 subtypes of MRGs from marine environment and encoding resistance to 11 metals which consisted of arsenic, chromium, cobalt, copper, mercury, iron, lead, nickel, silver, zinc and multi-metals [26].
The presence of both ARGs and MRGs is defined as non-random co-occurrence which later is explained as the specific pattern of resistome on MPs microbiome. This pattern is formed because the ARGs and MRGs share the same regulation of efflux pump mechanism. Both resistance genes are also connected and can be co-transferred by the same mobile genetic elements (plasmids) [26].

2.3. Microplastic and horizontal gene transfers

Biofilm formation on MPs allows forceful interaction between microorganism cells and high nutrients content-environment. This condition supports the horizontal gene transfer (HGT) among the members of plastisphere. A study on HGT in aquatic environment revealed that the rate of HGT was higher on biofilm than aqueous phase [28].

Microplastics played a pivotal role as a hot spot for HGT to occur and spread antibiotic resistance genes in aquatic environment. High density and intense interactions among the microorganisms predispose the HGT through conjugation of plasmids. The resistance strain in MPs biofilm is able to transmit the resistance genes to a wide range of species [29]. The HGT mediated by MPs occurs during the transit time and happens continuously in the aquatic environment since MPs are able to exist for a long period of time [30].

Horizontal gene transfer in MPs occurs in the absence of selective pressures by antibiotics which reveals the ability of MPs in accommodating the process. Plasmid transfer by conjugation is influenced by the composition of organic matters absorbed by the MPs [29]. A study showed that the weathering process (as mentioned above) predisposed the HGT mechanisms during microbial colonization [31]. The plastisphere community has been known to be more permissive towards plasmid transfer than aqueous phase-free living bacteria or bacteria on natural aggregates. The permissiveness of plasmid transfer towards distantly related taxa is also reported in MPs-mediated HGT [29].

3. Conclusion

This paper has summarized the microbiological perspectives related to the presence of MPs in the aquatic environment. The plastisphere is recognized for its important role in MPs biodeterioration whereas the biofilm formation hampers the abiotic pathway through UV light blocking. Biofilm formation also plays an important role in determining the fate of MPs; supporting the vertical transport and trophic transport as well as degrading the HCOs pollutants in the aquatic environment. The role of MPs in HGT and reserving the ARGs and MRGs reveals the potential risks of MPs towards other species, including humans.

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