ISSN 0554-6397
Prethodno priopćenje
(*Preliminary communication*)

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Analysis of Microplastic Particle Transmission

Summary

The progressive increase in the mass of microplastics in the ecosystem obliges us to urgently define measures to reduce its adverse effects, which primarily requires an understanding of the genesis of its presence and the dynamics of expansion through the biosphere. This paper aims to contribute to the understanding of the dynamics of microplastic particle motion, especially in the context of deposition rate with respect to microplastic material density, microplastic particle size and especially with respect to microplastic particle shape (which significantly affects shape resistance forces). For this purpose, an overview of existing works in the field of modeling the motion of microplastics is given, and a numerical model for modeling the transport of microplastic particles in an inhomogeneous fluid velocity field for laminar flow is formed. The proposed model is thus based on a system of two nonlinear ordinary differential equations.

Keywords: microplastics, precipitation, physical model

1. Introduction

Plastic is today one of the most important and most commonly used materials in the world. In the manufacturing process it is often a cheaper and lighter material than the available alternatives. However, increasing amounts of inadequately disposed plastic waste combined with an extremely long decomposition time have resulted in its increased accumulation in the environment.

According to the European Parliament [1], only 32.5% of plastic waste is recycled, 42.6% is incinerated, releasing significant amounts of toxins such as mercury and nitrous oxide, and carbon dioxide into the atmosphere with energy production, and only 24.9% are delayed. The data refer to plastic that has been adequately disposed of. Due to different parameters such as wind speed, temperature, earth rotation, salt concentration and the like, there are five main vortices in the oceans: North Pacific, North Atlantic, South Pacific, South Atlantic and Indian Ocean vortex. Sea currents collect plastic from the shores of continents and carry it towards the centers of the vortex, so there are huge amounts of plastic of different dimensions in the centers, which destroy flora and fauna. Plastic is so widespread in the seas and oceans due to currents, that it can be found in all parts of the world regardless of the presence of people in the area, so the parts have been found even in Antarctica.

The categorization of plastics accumulated in aquatic environments is defined according to sample size. The sample size is the maximum distance that can be measured between two points of the particle, which defines the characteristic dimension of the sample d_p [L]. Although there are different categorizations of plastics by size, in recent times the most common is the one in which samples are classified into 4 categories: (i) macroplastics for samples with a d_p greater than 200 mm, (ii) mesoplastics for samples with a d_p in in the range of 5 to 200 mm (iii) microplastics for samples in which d_p is in the range of 0.001 to 5 mm and (iv) nanoplastics for samples in which d_p is in the range of 1 to 100 nm.

In this paper, microplastics and its behavior in aquatic environments are considered. An overview of previous works in the field of modeling the motion of microplastic particles is given. Based on current knowledge about the behavior of microplastics in aquatic environments and the dominant forces influencing the process, a numerical model was formed and a simulation was performed for controlled conditions.

2. Previous achievements in modeling the movement of microplastics

Microplastic research is mainly related to the collection and analysis of particles, while a small number of papers deal with simulating the movement of microplastics due to very complex processes that cannot be unambiguously determined. Therefore, each survey contains a number of simplifications that allow the calculation of average values. The movement of microplastics can be horizontal due to winds and sea currents, and vertical due to the sinking of particles after their mass changes. In most cases, the particles move in both directions, and there is a vortex depending on the weather. Therefore, some of the works deal with one or both forms of movement.

Research [2] includes measurements and modeling of the vertical distribution of microplastics in the Atlantic Ocean. The collection was performed using a pump filtration device and then the particles were analyzed by Raman spectrometry. Concentrations ranged from 13 to 501 pieces per m^3. The largest number of particles had a size of 10 to

20 μm. The numerical model was made with polyethylene particles in the dimensions of 10, 100 and 1000 μm. The vertical distribution is based on an advective transport model that includes buoyancy and turbulent mixing forces that cause the microplastic particles to move. The vertical velocity depends on the difference in density of the polymer and seawater. The shape of the particles is assumed to be spherical. Particle distribution was calculated with a one-dimensional equation for depths up to 250 m. The results show that most particles are located in the upper layers, and indicate a correlation between particle dimensions and position in the water column.

As part of [3], simulations of the movement of microplastics on the ocean surface were made, based on satellite images and measurements, in order to place devices for removing microplastics from the sea in an appropriate place. The analysis was performed on the surface of all seas and oceans on planet Earth. The authors have placed 29 "sinks" for microplastics in the domain, which were proposed as part of the The Ocean Cleanup project. During the optimization process, the locations of the microplastic outlets were changed, in order to find the positions that would result in the largest amount of collected particles. The grid on which the search was performed was 1° × 1°. The amount of plastic that entered depended on the amount of poor waste management in each country based on previous research, taking into account the exponential increase in the amount of plastic over the years.

Paper [4] compares the results of modeling and collection of microplastics in the northern Italian part of the Adriatic Sea. In particular, the influence of the river Po is analyzed, which has a flow in the range of 100 to 11550 m^3/s and carries with it significant amounts of microplastics. The amount of microplastics from water at 24 locations and sediment at 9 beaches in the area of the tidal cycle was analyzed. Measurements have shown that the average amount of particles at sea locations is 84 particles per m^3 and 78 particles per kilogram of sediment on the beach. The model made in the ICHTHYOP program includes the movement of microplastics through particles in the Lagrange model, and includes a 3D model based on horizontal and vertical dispersion, advection and buoyancy force. Assumptions about particles that are spherical in shape, 1 mm in diameter and density 0.91 g/mL, and assumptions about the concentration of 10 particles per m3 in the amount of water coming with the river Po were used. The Po River itself is assumed in the model as a point source. ROMS, SWAN and COAWST programs were used to model the sea flow. The paper concluded that tourism is a significant source of plastic waste that is not included in the model, so the results do not match to a greater extent. In a scientific study [5], the concentration of plastic in the surface layer of the Adriatic Sea was calculated. Calculations include combinations of terrestrial and marine litter inputs, the Lagrange model MEDSLIK-II, AFS ocean current simulations, and ECMWF wind analysis. Rivers entering the Adriatic Sea and larger cities are taken as plastic entry points. This model allows the particles to remain on shore. The calculation was made so that 10,000 virtual particles are introduced into the model over a period of 10 days. Figure 1 shows the results obtained. This research covers all dimensions of plastic particles, not just microplastics.

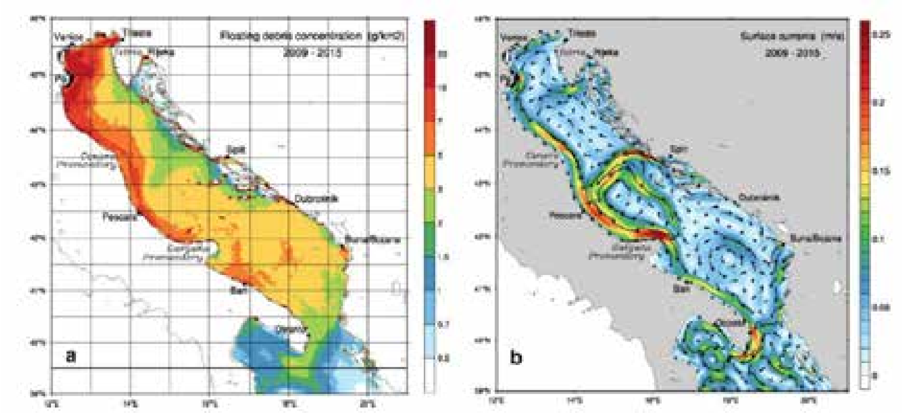

Figure 1. Expected average values of microplastics and sea speed for the period 2009-2015.

3. Numerical model of microplastic motion

When describing the vertical motion of microplastic particles, it can be found in conditions of sinking (negatively buoyant plastic) and conditions of emergence (positively buoyant plastic), which is predominantly influenced by the density of microplastics ρ_p and the density of the recipient ρ_f. The size and shape of the microplastic particle affect the amount of resistance force of the shape that occurs in the case of relative motion between the fluid and the particle itself. Challenges in modeling relate to defining shape factors for a randomly selected microplastic particle. For this purpose, the reduction principle is applied in which the shape of the particle is categorized according to the number of dominant dimensions. Based on this approach, we distinguish microplastic particles categorized as 3D, 2D, and 1D objects. Based on the above reduction approach, a mathematical and numerical algorithm for the integration of the equations of motion of microplastic particles of generalized shape was developed, taking into account the change in the resistance factor of the shape of the microplastic particles. This paper provides an overview of the model results for the described input parameters, but will not go into detail describing the model algorithm. Based on the above model, a numerical analysis of water flow and movement of microplastic particles in the experimental bed of the hydrotechnical laboratory of the Faculty of Civil Engineering in Rijeka was performed. The purpose of the analysis is to prepare an experimental procedure through which the different conditions of microplastic particle transport under open flow conditions will be investigated and the calibration of the numerical model will be enabled.

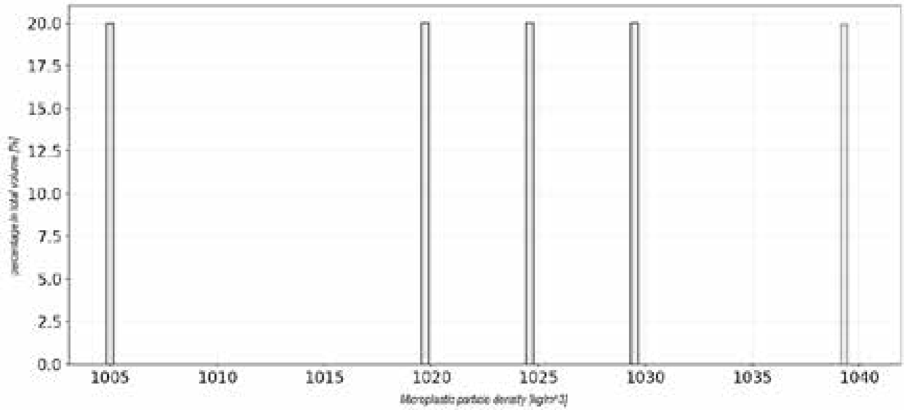

Figure 2. Microplastic particle density

A numerical model was performed for 2000 microplastic particles. The default particle density distribution is seen in Figure 2. The characteristic particle size is given by a uniform statistical distribution through which the characteristic particle size of the microplastic is given between the limits of 0.1 to 3.0 mm (Figure 3). The sphericity index of microplastic particles is defined in three categories: 3D, 2D and 1D samples. Water density is defined with an amount of 1000 kg/m^3. The spatial domain of the model was defined according to the dimensions of the experimental riverbed (length 12.5 m, width 0.309 m and height 0.45 m). An exponential velocity profile with a maximum velocity on the water surface of 0.3 m/s is given by the height of the cross section. The duration of the simulation is 60 s, and the time step is 0.5 s.

The spatial distribution of sedimented microplastic particles can be observed by applying statistical analysis [6] in a way that defines the probability of deposition for a particular group of microplastic particles or for particles that have the same or similar sphericity factor ψ . For these purposes, the bottom of the spatial flow domain is divided into 25 0.5 m segments in which the deposition of precipitated particles is performed. The sediment probability density function thus defines the probability that a particle from a particular grouping is located at a particular part of the bottom of the spatial flow domain. As 3 categories of shapes were considered, three separate density functions were defined.

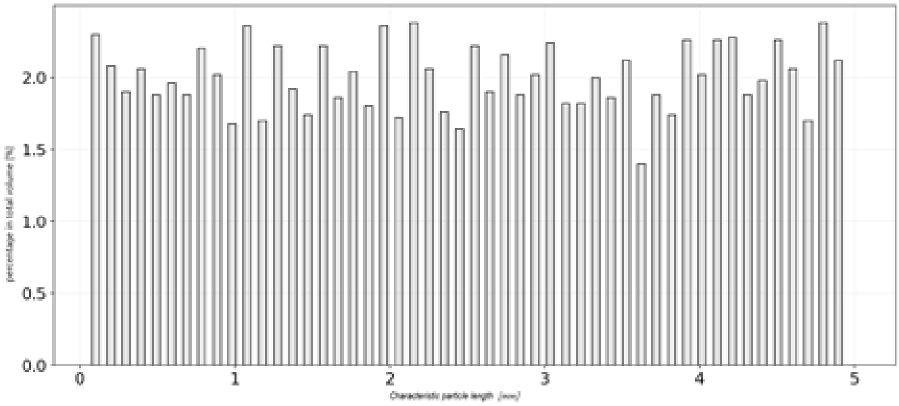

Figure 3. Characteristic particle length of microplastics

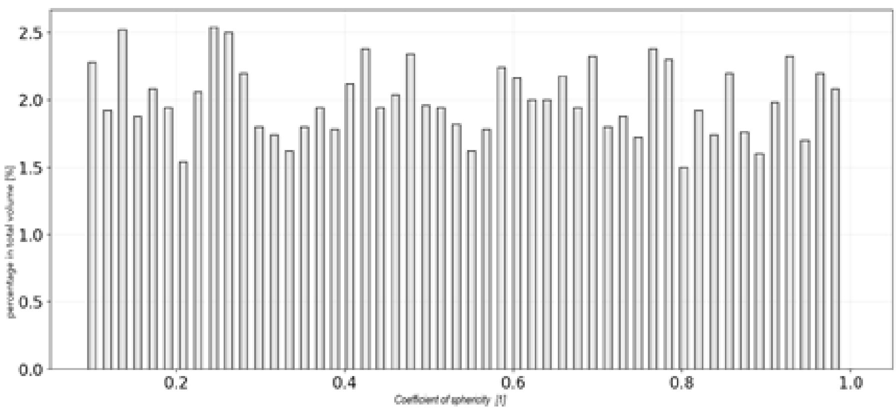

Figure 4. Coefficient of sphericity of microplastic particles

Figure 5 shows the results of the numerical analysis. The graph above shows the position of the particles for the final moment of the simulation t = 60 s, together with the flow velocity profile according to the previously defined model. The lower graph on the left ordinate shows the time to the moment when the particle touched the bottom of the spatial domain, and on the right ordinate there is the probability of deposition of three examined groups of particles according to the given sphericity index. On the graph, particles of different densities are shown in a different color. Particle density ranges from 1020 to 1100 kg / m^3.

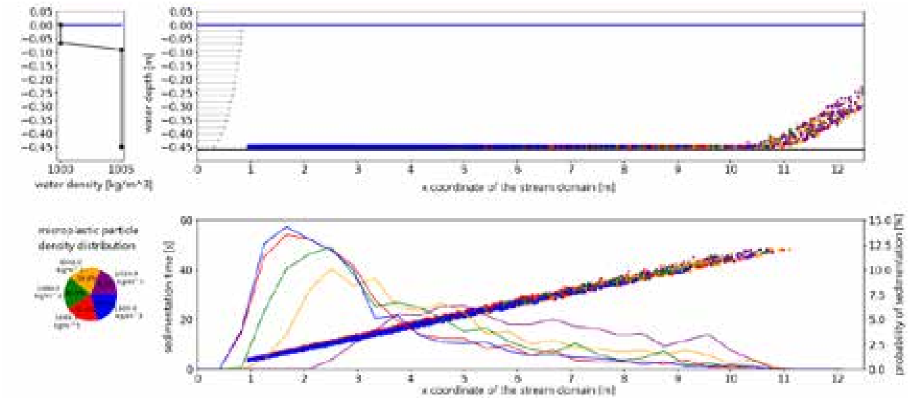

Figure 5. Results of the numerical model for t = 60 s

The particles with the highest density (blue color) precipitated the earliest, that's why their concentration is the highest in the first part of the spatial domain. The rest of the particles precipitated closer to the end of the spatial domain of the flow, which should be taken into account when defining the laboratory experiment in order to facilitate the monitoring of the results. Numerical results show the justification of the assumption about the possibility of spatial differentiation of particles through experimental analysis.

4. Conclusions

The paper briefly presents the global problem of microplastic accumulation in the environment, and especially in the seas and oceans. A presentation of some of the model tests of microplastic movement performed so far is given, and a numerical algorithm for the analysis of microplastic deposition in an open watercourse is proposed. The domain of the numerical model is given according to the parameters of the experimental channel located at the Faculty of Civil Engineering in Rijeka, and this choice is motivated by the planned experimental tests. The results of the numerical model confirmed the assumption about the possibility of spatial differentiation of the deposition of particles of different shapes. The proposed numerical model provides the possibility of modeling 3 dominant parameters that determine the dynamics of microplastic particle motion (density, size and shape). In the following research, it is planned to complete the development of the experimental channel and check the results of the model on real observations.

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