engineering proceedings

MDPI

Proceeding Paper

Influence of a Bubble Curtain Device on Microplastics Dynamics †

César A. V. Santos [1,*], Emanuel A. R. Camacho [2,3], André R. R. Silva [2] and Cristina M. S. Fael [1]

1 Department of Civil Engineering and Architecture, University of Beira Interior, 6201-001 Covilhã, Portugal; cmsf@ubi.pt
2 Department of Aerospace Sciences, University of Beira Interior, 6201-001 Covilhã, Portugal; earc.aerog@gmail.com (E.A.R.C.); andre@ubi.pt (A.R.R.S.)
3 Department of Mechanical Engineering, Engineering School of São Carlos, University of São Paulo, São Paulo 13566-590, Brazil
* Correspondence: cesar.vaz.santos@ubi.pt
† Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: https://asec2023.sciforum.net/.

Abstract: Air bubble curtains have been applied to a wide range of situations, from the attenuation of underwater noise, debris control, and containment of suspended sediment to the reduction in saltwater intrusion. This work conducts a preliminary numerical study on the influence of a bubble curtain device on microplastic dynamics. Simulations are conducted with a two-phase unsteady model, and the trajectories of the microplastic particles are computed with the Discrete Phase Model (DPM). Particles are injected upstream of the bubble curtain, and their transport is analyzed under different flow conditions. Results show that the ratio between the water velocity and the air injection velocity can significantly impact the efficiency of the device in directing the particles toward the surface. Furthermore, a higher degree of turbulent mixing is seen for lower water velocities. This study highlights the intricate flow behavior, and the need for a deeper understanding of other variables such as the microplastic size and concentration and the geometry of the air injection system.

Keywords: microplastics; bubble curtain; numerical study; hydrodynamics

check for updates

Citation: Santos, C.A.V.; Camacho, E.A.R.; Silva, A.R.R., Fael, C.M.S. Influence of a Bubble Curtain Device on Microplastics Dynamics. *Eng. Proc.* **2023**, *56*, 81. https://doi.org/10.3390/ASEC2023-15317

Academic Editor: Simeone Chianese

Published: 26 October 2023

1. Introduction

Plastic materials have become ubiquitous in our lives due to their widespread adoption for convenience, cost, and benefits in terms of safety and energy saving. However, due to their widespread use and long decomposition time, we are currently facing a global plastic waste crisis [1].

One issue of particular interest is marine pollution by plastic debris. Around 10% of plastic waste is estimated to end up in the oceans [2]. Its effects threaten marine animals, in addition to being deposited in bed sediments and potentially impacting the animals that live and feed on the benthos [3]. Plastics can, therefore, play an important role in destroying habitats. While macroplastics are easily visible, and their social, economic, and ecological impacts have already been demonstrated, the same cannot be said for microplastics (MP), which consist of particles smaller than 5 mm.

Another issue of great concern is the ingestion of macroplastics and microplastics, not only by animals but also by humans through bioaccumulation [4]. Studies have shown that humans ingest up to 52,000 microplastic particles per year from food and drink [5]. Furthermore, since plastics can adsorb pollutants from their surroundings, they can act as efficient distribution systems for toxic pollutants such as heavy metals [6].

Considering the preponderant role of rivers in transferring plastic waste from terrestrial to marine environments, developing efficient solutions to reduce the amount of plastics in river systems is imperative. One solution, and the subject of this work, is the classic bubble curtain. This solution meets both ecological and navigational requirements, as it is fish-friendly and does not hamper the navigation of boats [7]. Simply put, the device consists of a perforated tube positioned along the channel bed, into which compressed air is injected, and a bubble curtain is generated. The current generated by the rising air bubbles drives the debris to the surface and directs it to a collection system [8].

Given the identified knowledge gap, this work conducts a preliminary assessment of the influence of a bubble curtain device on flow hydrodynamics, as well as its effects on the transport of microplastic particles. Ultimately, we intend to understand the feasibility of a bubble curtain device to retain microplastics in river systems.

2. Methodology

The present paper is built upon a numerical methodology that allows a controlled study of the influence of a bubble curtain device on microplastics dynamics. With that goal, a numerical study was prepared using Ansys© Fluent 19.2, following a Reynolds-averaged approach (RAS). Because of that, a turbulence model must be chosen, and for the present study, we select the $k - \varepsilon$ model. For the wall treatment, scalable wall functions are used. Regarding the water–air interaction, the commonly used Volume of Fluid (VOF) method is employed. To improve the method's accuracy, an adaptive mesh strategy is used which constantly refines the water–air interface. For the discrete phase modeling, which is responsible for determining the dynamics of the microplastics, the Discrete Phase Model (DPM) is used. The injection of particles is considered to not have any interaction with the continuous phase, following a one-way coupling strategy that is valid when particle concentration is fairly low. The computational domain designed for the present study is presented in Figure 1.

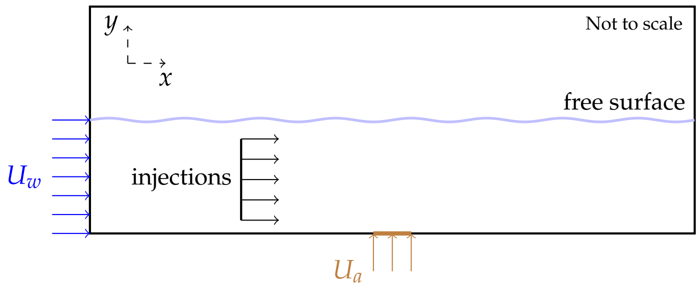

Figure 1. Computational domain.

As seen above, the domain has two inlets. At the water inlet, the velocity, U_w, is prescribed, as is the water level, h_w, through the open channel sub-model. The same height is used at the outlet, acting as a pressure outlet. At the air inlet, the velocity, $U_a = 0.2\,\mathrm{m\,s^{-1}}$, is also prescribed and kept constant for all the cases. Concerning the injection of the microplastic particles, these are inserted upstream of the air bubble curtain after 2 s of simulation with a duration of 2 s. Particles have a density of $1.04\,\mathrm{kg\,m^{-3}}$ with a diameter of 0.5 mm. This results in a mass flow of approximately $0.25\,\mathrm{g\,s^{-1}}$, which was selected based on very recent and preliminary experimental trials. Once again, it is important to mention that the particle concentration must remain low in order to guarantee that the one-way coupling strategy is valid.

3. Results

Figure 2 provides insight on the influence of the flow velocity on the bubble plume dynamics. As the U_w/U_a ratio increases, there is a higher downstream deflection of the bubble curtain, and thus, the bubbles reach the surface at a much later downstream position. On the other hand, as the U_w/U_a ratio decreases, the bubbles are more densely distributed throughout the water depth. Also, note the higher degree of turbulent mixing for the lower water velocities. This may be unfavorable since the turbulent mixing can pull the microplastic particles downwards, which may affect their efficient removal. This raises an important question on the importance of U_w/U_a, which must be thoroughly studied in order to identify its optimal value.

An analysis of the particle positions shows that the microplastic particles tend to stay at the surface and in the vicinity of the bubble curtain when the flow velocity is lower. As expected, for lower U_w/U_a values, the bubble barrier produces a strong enough uplifting current in order to drive the microplastic particles toward the surface. A higher concentration of particles close to the surface is particularly important for the subsequent removal process. This behavior is concurrent with preliminary experimental tests at lower velocities ($U_w = 0.05\,\mathrm{m\,s^{-1}}$), as the particles were effectively blocked by the bubble curtain and remained on the upstream side of the barrier.

Another important aspect is the shape of the bubble curtain device. In this work, the air is injected directly into the channel bed. However, in the previous work of Santos et al. [9] the device was simulated as a protruding body. This resulted in a distinct behavior close to the device, as the flow separated and a vortex was generated on the downstream side of the device. The combination of the protruding body (which reduces the longitudinal velocity on the upstream face of the device) and the downstream vortex (which tends to deflect incoming bubbles), meant that the bubbles had less downstream dispersion and were more evenly distributed along the water column. As such, the shape of the device itself is another variable that requires further study.

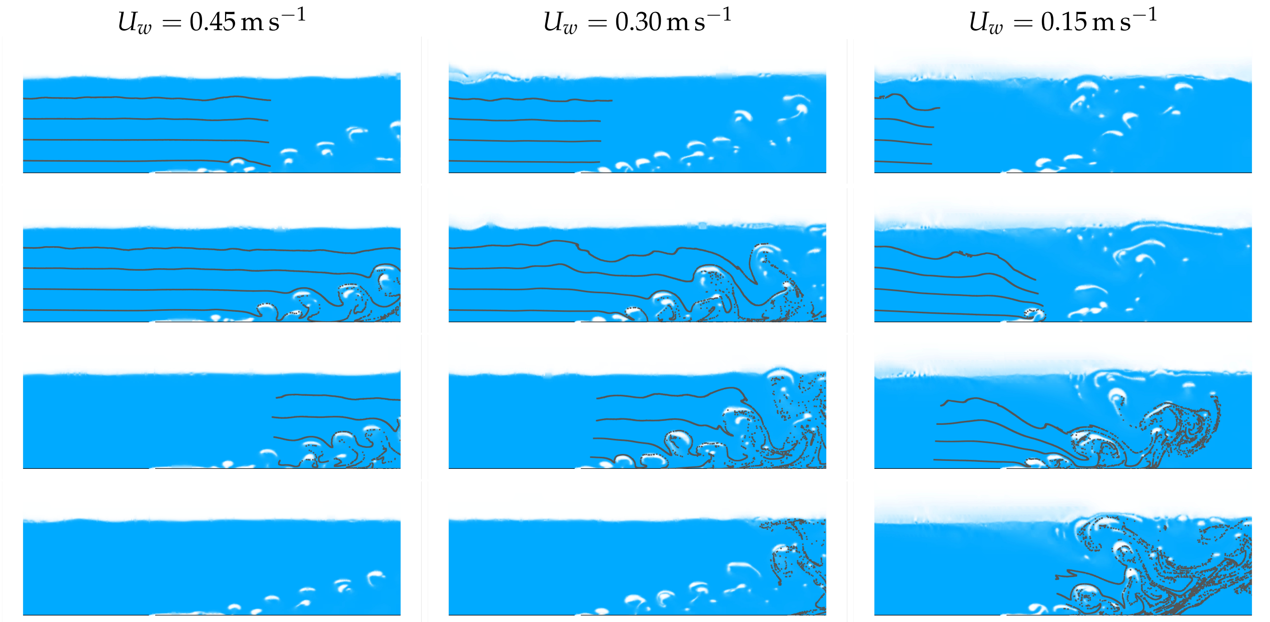

Figure 2. Air volume fraction and particle positions. Each column is for, respectively, flow velocities $U_w = 0.45\,\mathrm{m\,s^{-1}}$, $U_w = 0.30\,\mathrm{m\,s^{-1}}$, and $U_w = 0.15\,\mathrm{m\,s^{-1}}$. Each line matches instants, $t = 3\,\mathrm{s}$, $t = 4\,\mathrm{s}$, $t = 5\,\mathrm{s}$ and $t = 6\,\mathrm{s}$.

In Figure 3, the contour of the mean velocity magnitude is shown. Note the distinct flow behavior between each of the cases. For the slowest flow velocity, a vortex forms close to the surface on the downstream side of the bubble curtain device. In this case, the U_w/U_a ratio allows the generation of a strong enough uplifting current to drive the particles to the surface. In contrast, as flow velocity increases, the vortex is suppressed and the effect of the uplifting current becomes increasingly weaker. As such, determining the right U_w/U_a ratio is a critical task in order to increase the device's efficiency in retaining microplastic particles.

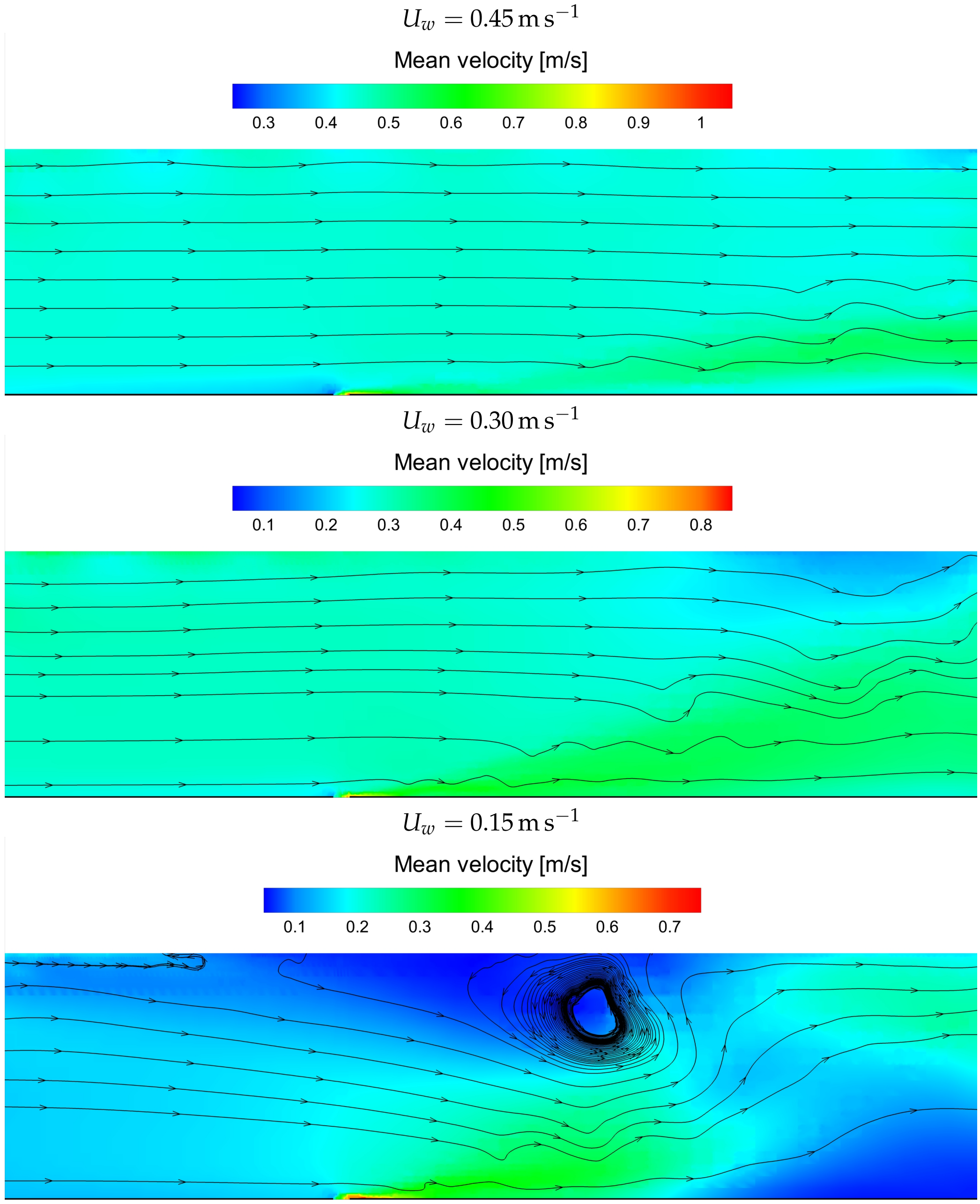

Figure 3. Mean velocity and streamlines based on a 10 s simulation. Top to bottom, each line represents a flow velocity of $U_w = 0.45\,\mathrm{m\,s^{-1}}$, $U_w = 0.30\,\mathrm{m\,s^{-1}}$, and $U_w = 0.15\,\mathrm{m\,s^{-1}}$, respectively.

4. Conclusions

The present work is an exploratory study of the behavior of a bubble curtain placed in a water channel with the purpose of removing microplastics. The study was conducted numerically and consisted of three conditions in which the water velocity was modified. By changing this parameter, the ratio between the water and air velocities was also modified. This ratio has a critical impact on the air velocity's dominance over the water flow. However, the results also indicated that as U_w/U_a decreases, the flow exhibits a higher turbulent mixing that may affect the ascent of the microplastics toward the surface. While this is an early study, the complex interaction between the two phases and how the particles behave under different conditions is already evident. Based on this study, future research will look into the air injector geometry, multiple air injection, the implementation of a collector system, and its efficiency regarding particle removal.

Author Contributions: Conceptualization, C.A.V.S. and E.A.R.C.; methodology, C.A.V.S. and E.A.R.C.; formal analysis, C.A.V.S., E.A.R.C., C.M.S.F. and A.R.R.S.; writing—original draft preparation, C.A.V.S. and E.A.R.C.; writing—review and editing, C.M.S.F. and A.R.R.S.; supervision, C.M.S.F. and A.R.R.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Fundação para a Ciência e a Tecnologia under grant numbers UIDB/04082/2020, UIDB/50022/2020, UIDP/50022/2020, LA/P/0079/2020, 2022.15387.CBM, 2023.03900.BD and 2020.04648.BD.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Schmaltz, E.; Melvin, E.C.; Diana, Z.; Gunady, E.F.; Rittschof, D.; Somarelli, J.A.; Virdin, J.; Dunphy-Daly, M.M. Plastic pollution solutions: Emerging technologies to prevent and collect marine plastic pollution. *Environ. Int.* **2020**, *144*, 106067. [CrossRef] [PubMed]
2. Thompson, R.C. Plastic debris in the marine environment: Consequences and solutions. In *Marine Nature Conservation in Europe*; Krause, J.C., von Nordheim, H., Bräger, S., Eds.; Federal Agency for Nature Conservation: Bonn, Germany, 2006; pp. 107–115.
3. Brandon, J.A.; Jones, W.; Ohman, M.D. Multidecadal increase in plastic particles in coastal ocean sediments. *Sci. Adv.* **2019**, *5*, eaax0587. [CrossRef] [PubMed]
4. Carbery, M.; O'Connor, W.; Palanisami, T. Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health. *Environ. Int.* **2018**, *115*, 400–409. [CrossRef] [PubMed]
5. Cox, K.D.; Covernton, G.A.; Davies, H.L.; Dower, J.F.; Juanes, F.; Dudas, S.E. Human Consumption of Microplastics. *Environ. Sci. Technol.* **2019**, *53*, 7068–7074. [CrossRef] [PubMed]
6. Turner, A. Heavy metals, metalloids and other hazardous elements in marine plastic litter. *Mar. Pollut. Bull.* **2016**, *111*, 136–142. [CrossRef] [PubMed]
7. Haberlin, D.; McAllen, R.; Doyle, T.K. Field and flume tank experiments investigating the efficacy of a bubble curtain to keep harmful jellyfish out of finfish pens. *Aquaculture* **2021**, *531*, 735915. [CrossRef]
8. Cheng, Y.; Zhao, N.; Zhang, K.; Wei, W. Research on the plume stability of air bubble curtains under low transverse flow velocity environment in dredging engineering. *Ocean Eng.* **2021**, *232*, 109133. [CrossRef]
9. Santos, C.; Taborda, C.; Fael, C. Effects of a bubble curtain device on flow hydrodynamics. In Proceedings of the 40th IAHR World Congress, Vienna, Austria, 21–25 August 2023.