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From Plastic Waste to Environmental Pollutants: Elemental and Chemical Characterization of Microplastic Degradation Using µ-XRF and IR Laser Imaging Microscopy

AICHA EL KHARRAF JR.[1], MELANIE DAVRANCHE[2], MURIELLE RABILLER-BAUDRY[3] AND MARK WIESNER[4]

[1]University of RENNES
[2]Université de Rennes, Géosciences Rennes, UMR-CNRS 6118
[3]Univ Rennes, CNRS, ISCR (Institut des Sciences Chimiques de Rennes), UMR 6226, F-35000 Rennes, France
[4]Duke university

Plastics, particularly polyethylene (PE) and polypropylene (PP), account for over 50% of global plastic production. Upon disposal, approximately 3.25% of untreated plastic waste enters the environment [1]. Once in environment, plastics are subjected to weathering processes such as photodegradation, thermal oxidation, hydrolysis, and biodegradation, which facilitate their breakdown and fragmentation into smaller particles, including microplastics (<5 mm) and nanoplastics (<1µm) [2]. This research focuses on the environmental degradation (photooxidation combined with mechanical stress) of PE, examining how natural degradation processes and plastic intrinsic properties influence the polymer fragmentation and the release of harmful by-products, such as microplastics (MPs) and nanoplastics, that must further be treated for water decontamination and/or fresh water production.

To simulate environmental weathering, commercially formulated PE was subjected to UVC photooxidation (2.18 W cm^{-2} at 254 nm) and mechanical stress (shear stress of 0.00683 N m^{-2}) for 1000 hours in a custom-designed reactor.

Infrared laser imaging microscopy (Hyperion-ILIM) analysis was conducted to characterize the chemical composition of microplastics (MPs) generated during degradation. The results indicated significant oxidation, as evidenced by a substantial increase in the carbonyl index (from 0.002 for pristine PE-plastic to 3.496 for MPs-PE). A heterogeneous distribution of functional groups, including carboxylic acids (1717 cm^{-1}), was observed. Elemental mapping via synchrotron-based µ-X-ray fluorescence (µ-XRF) - further revealed the spatial distribution of additives within the MPs matrix. Contrary to previous assumptions, we demonstrated that small MPs can retain plastic additives within their structure. These findings underscore that UV degradation yields highly polar and crystalline MPs, which, due to their surface charge, act as vectors for contaminant transport (adsorption process) and pose potential hazards to human health.

References

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