

Abstract

The increasing prevalence of polymeric and composite waste from wind turbine blades (WTBs), personal protective equipment (PPEs) used in the medical sector, end-of-life photovoltaic (PV) panels, and municipal solid waste (MSW), necessitates the development of effective recycling technologies to uphold the principles of a circular economy. Traditional approaches, such as mechanical recycling, incineration, and pyrolysis, encounter challenges, including significant energy consumption, downcycling, emissions of pollutants, and suboptimal material recovery. This research thesis introduces oxidative liquefaction as a method to selectively degrade polymeric waste, facilitating the production of liquid chemical compounds and valuable secondary materials.

A systematic experimental matrix was established for each waste type utilizing a specific experimental design approach to assess the impact of reaction parameters, i.e., temperature, pressure, reaction time, oxidant concentration, and waste-to-liquid ratio on the degradation of selected waste types. After the oxidative liquefaction process, the total solid reduction (TSR), or total polymer degradation (TPD), was calculated for the obtained solid fraction, and the resulting liquid was subjected to analysis through gas chromatography with flame ionization detection (GC-FID) to identify the individual chemical fraction as well as to quantify overall yield of oxygenated chemical compounds (OCCs). Statistical modelling of obtained results and response surface methodology (RSM) were utilized to study the effect of each reaction parameter on overall process efficiency and to identify the optimal reaction conditions to enhance the resource recovery while reducing energy input. The inside reactor temperature profiles were drawn, and inverse analyses were performed to identify the reaction stages resulting in major waste degradation and determine the reaction's nature.

The investigation commenced with the detailed characterization of raw waste samples achieved through a series of analytical techniques, including ultimate and proximate analysis, Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and thermogravimetric analysis (TGA). The analyses indicated notable variations in composition, highlighting that PPEs are rich in polymers, MSW and WTBs display heterogeneity, and PV panels consist of a substantial proportion of inorganic residues. The TGA results validated single-stage degradation for PPEs, highlighting uniform composition, while the multi-stage decomposition behaviour was observed for remaining waste types.

In addition to producing OCCs, the successful recovery of glass fibers from WTBs highlights the potential of oxidative liquefaction as a viable method for material recovery, especially in the context of fiber-reinforced composites. The results highlight oxidative liquefaction as a practical and scalable approach to waste management, providing an alternative to traditional disposal methods and supporting circular economy principles. Nonetheless, additional investigation is necessary to improve process efficiency, refine reactor designs, and examine catalytic enhancements for applications on an industrial scale. This thesis aims to enhance sustainable waste-to-resource technologies, tackling significant environmental issues and facilitating the shift towards a more resilient and resource-efficient future.