Abstract

Tires have become an essential component of every automobile wheel and they are expected to increase in coming years. The continuous growth of tire consumption poses significant environmental challenges, particularly in terms of waste management. Sustainable development emphasizes the necessity of recycling and reusing resources to combine economic expansion with global supply chains. Traditionally, tire waste has been either dumped in landfills or incinerated, leading to severe environmental pollution, as well as, these processes do not promote the circular economy concept. This work involves alternative recycling techniques such as pyrolysis and devulcanization to treat waste tires. The pyrolysis method is capable of extracting valuable chemicals by thermally treating the scrap tire products in gas, oil, and solid char in an oxygen-free atmosphere. Due to stringent environmental emission protocols, the liquid oil is refined to diesel-like fuel oil. Moreover, pyrolytic char is incorporated in rubber formulation to examine its upcycling potential. On the other hand, the devulcanization process breaks down the cross-linked sulfur bonds in vulcanized tires, enabling the devulcanized rubber to be reprocessed. The chemical devulcanization is regarded as a "green" recycling process for efficient waste tire treatment, which utilizes supercritical carbon dioxide ($scCO_2$) and a decrosslinking agent. This research work involves a pilot-scale $scCO_2$ extraction equipment for devulcanizing scrap tires. Furthermore, the product circularity of devulcanized rubber is explored for newer rubber product manufacturing. This thesis also includes a comparative study on the environmental implications and economic feasibility of pyrolysis and $scCO_2$ devulcanization processes to choose better recycling techniques for tire waste management. Environmental sustainability by life cycle assessment (LCA) found that the pyrolysis process has less ecological impact than the devulcaization process. However, economic viability by techno-economic analysis (TEA) revealed that both processes have the potential to be financially profitable with less than 2.5 years of payback time.

Keywords: Scrap Tire Recycling; Pyrolysis; Alternative Fuel Oil; Devulcanization; Product Upcycling; Life Cycle Assessment; Techno-Economic Analysis