

Abstract

The present study encompasses five distinct investigations to enhance various processes to valorize glycerol through innovative methodologies and catalyst development. In our first effort, for monostearin synthesis, a rotating batch reactor (RBR) is shown to outperform stirred batch reactors (SBR) under far infrared radiation (FIRR), yielding a remarkable $92 \pm 1\%$ monostearin, 40% higher than SBR within a reduced time frame. RBR operation under optimal conditions revealed energy efficiency and superior phase change material properties validated by FTIR, TGA, and DSC analyses. An intensified glyceryl monocaprin (GMC) synthesis protocol utilizing coactive electromagnetic energies (quartz halogen radiation) and ultrasonic cavitation achieved a $97\% \pm 0.5\%$ capric acid conversion employing an integrated rotating reactor. The hybrid reactor demonstrated enhanced energy efficiency and superior selectivity of glycerol monocaprate, (applied as a food additive), supported by Langmuir-Hinshelwood kinetics and reduced reaction activation energy. In another attempt, E-waste valorization yielded silica-supported layered double-oxide photocatalysts for glycerol carbonate synthesis. The photocatalyst displayed enhanced performance compared to conventional methods, with reduced environmental impacts and promising scale-up potential demonstrated through detailed life cycle assessment (LCA).

Moreover, autocatalytic esterification of methanol (produced as a by-product along with the product glycerol carbonate) with oleic acid for methyl oleate (biodiesel) production utilized a continuous flow rotating reactor under recycle mode, achieving maximum biodiesel yield under optimized conditions. The developed geometric-based COMSOL model validated reactor performance and kinetic modeling, showcasing energy efficiency and scalability through ASPEN PLUS simulation. Our final approach involves a novel barnacle-carapace derived chitosan-

supported nano aluminum-tungsten bimetallic-alloy electrocatalyst facilitated waste pork lard-derived glycerol electrolysis, yielding industrially important glyceric acid and formic acid along with hydrogen gas. The catalyst exhibited excellent stability, reduced energy consumption, and lower global warming potential than commercial glycerol electrolysis, showcasing its potential for sustainable glycerol valorization. Together, these studies offer innovative approaches toward sustainable chemical processes and catalyst development, addressing efficiency, environmental impact, and their efficacy toward scale-up studies.