Chemical Depolymerization of PET Waste Using Sodium Ethoxide as Catalyst: Five-factor Optimization Using Response Surface Methodology

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Abstract

Polyethylene terephthalate (PET) waste is mounting up in the environment due to its poor biodegradability and low recycling rate. Glycolysis of PET is a promising chemical recycling technique to convert it into its monomer bis(2-hydroxy ethylene terephthalate) (BHET). In this work, sodium ethoxide (NaOEt) as a low-cost and novel glycolytic catalyst to depolymerize post-consumer PET waste is presented. The BHET monomer was confirmed by gas chromatography-mass spectrometry (GCMS), Nuclear Magnetic Resonance (NMR) Spectroscopy, and High-performance liquid chromatography (HPLC). Response surface methodology (RSM) based on Box-Behnken design was applied to study five independent factors, namely reaction temperature (160-190 ^{o}C), the molar ratio of PET: NaOEt (50-150), the molar ratio of ethylene glycol to PET (EG: PET) (3-7), reaction time (2-6 h) and particle size (0.25-1 mm). Based on the experimental results, regression models as a function of significant process factors were obtained and evaluated by analysis of variance (ANOVA) to predict the depolymerization performance of NaOEt in terms of PET conversion and BHET yield. Coefficient of determination, R^2 of 92% indicated the adequacy for predicted models. Afterward, both models were validated and optimized within the design space. PET conversion of 77% and BHET yield of 68% was obtained at the optimum conditions demonstrating a deviation of less than 5 % from predicted performance. Analysis of the response surface indicated that the upper region of the design space favors the catalytic performance. For this purpose, performance was investigated beyond the upper limits of design space, and an extraordinary PET conversion of 98% and BHET yield of 76% was achieved at 197 ^{o}C. The depolymerization performance was also compared under similar conditions with widely studied zinc acetate (PET conversion 97%, BHET yield 75%) and cobalt acetate (PET conversion 93%, BHET yield 70%). Hence, NaOEt is a promising catalyst for PET depolymerization that has the potential for complete PET conversion, additionally, its low cost will make it economically feasible for the large-scale process.