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Catalytic Pyrolysis of Sewage Sludge for Upgrading Bio-Oil Quality Using Sludge-Based Activated Char as an Alternative to HZSM5

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Abstract : Due to the concerns about the depletion of fossil fuel sources and the deteriorating environment, the attempt to investigate the production of renewable energy will play a crucial role as a potential to alleviate the dependency on mineral fuels. One particular area of interest is the generation of bio-oil through sewage sludge (SS) pyrolysis. SS can be a potential candidate in contrast to other types of biomasses due to its availability and low cost. However, the presence of high molecular weight hydrocarbons and oxygenated compounds in the SS bio-oil hinders some of its fuel applications. In this context, catalytic pyrolysis is another attainable route to upgrade bio-oil quality. Among different catalysts (i.e., zeolites) studied for SS pyrolysis, activated chars (AC) are eco-friendly alternatives. The beneficial features of AC derived from SS comprise the comparatively large surface area, porosity, enriched surface functional groups, and presence of a high amount of metal species that can improve the catalytic activity. Hence, a sludge-based AC catalyst was fabricated in a single-step pyrolysis reaction with NaOH as the activation agent and was compared with HZSM5 zeolite in this study. The thermal decomposition and kinetics were invested via thermogravimetric analysis (TGA) for guidance and control of pyrolysis and catalytic pyrolysis and the design of the pyrolysis setup. The results indicated that the pyrolysis and catalytic pyrolysis contains four obvious stages, and the main decomposition reaction occurred in the range of 200-600°C. The Coats-Redfern method was applied in the 2nd and 3rd devolatilization stages to estimate the reaction order and activation energy (E) from the mass loss data. The average activation energy (Em) values for the reaction orders n = 1, 2, and 3 were in the range of 6.67-20.37 kJ for SS; 1.51-6.87 kJ for HZSM5; and 2.29-9.17 kJ for AC, respectively. According to the results, AC and HZSM5 both were able to improve the reaction rate of SS pyrolysis by abridging the Em value. Moreover, to generate and examine the effect of the catalysts on the quality of bio-oil, a fixed-bed pyrolysis system was designed and implemented. The composition analysis of the produced bio-oil was carried out via gas chromatography/mass spectrometry (GC/MS). The selected SS to catalyst ratios were 1:1, 2:1, and 4:1. The optimum ratio in terms of cracking the long-chain hydrocarbons and removing oxygen-containing compounds was 1:1 for both catalysts. The upgraded bio-oils with AC and HZSM5 were in the total range of C4-C17, with around 72% in the range of C4-C9. The bio-oil from pyrolysis of SS contained 49.27% oxygenated compounds, while with the presence of AC and HZSM5 dropped to 13.02% and 7.3%, respectively. Meanwhile, the generation of benzene, toluene, and xylene (BTX) compounds was significantly improved in the catalytic process. Furthermore, the fabricated AC catalyst was characterized by BET, SEM-EDX, FT-IR, and TGA techniques. Overall, this research demonstrated AC is an efficient catalyst in the pyrolysis of SS and can be used as a cost-competitive catalyst in contrast to HZSM5.

Keywords : catalytic pyrolysis, sewage sludge, activated char, HZSM5, bio-oil
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