Research on Converting Sewage Sludge Into Hydrochar: A Critical Evaluation of Hydrochar by Combined Hydrothermal and Biological Treatment.

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Abstract:

Hydrothermal carbonization (HTC) efficiently converts sewage sludge into hydrochar (HC) for energy, soil improvement, and environmental remediation. However, optimizing HTC is challenging due to the complex interactions of temperature and residence time. This study explores the application of machine learning (ML) techniques for predicting and optimizing HC yield and properties from the HTC of sewage sludge. The HTC processes were carried out at temperatures between 180 - 300 °C and residence times of 60 and 120 min in triplicate, while the pressure was generated autogenously. Fuel characterization results indicated that HCs exhibited higher heating values (HHV) reaching 11,645 J/g for HTC temperature at 220 °C and residence time of 120 min, suggesting that HCs can serve as a promising solid fuel. The energy yield and energy densification ratio decreased with increasing severity of HTC conditions, confirming that severe treatment promotes deoxygenation but reduces material yield. The distribution of acetic acid content decreased with increasing reaction temperature and residence time. As the temperature rose to 260–300 °C, acetic acid levels declined sharply, suggesting enhanced secondary reactions such as decarboxylation and polymerization, leading to the stabilization of carbon in the HC. Furthermore, heavy metal analysis revealed that elements such as Pb, Zn, and Cr were more concentrated in the HC compared to the raw feedstock, indicating the immobilization effect of HTC. Additionally, BET surface area analysis showed that HCs produced at lower temperatures (for example, at 180 °C, 60 min)

exhibited significantly higher surface areas (up to 417.85 m^2/g) compared to those produced at higher temperatures. The current study demonstrates the potential of ML-driven optimization for real-time control of HTCs, reducing reliance on trial-and-error experimentation and advancing sustainable waste-to-energy thermochemical conversion technologies.

Keywords:

Hydrothermal Carbonization, Hydrochar, Sewage Sludge, Machine Learning, Process Optimization, Volatile Fatty Acids.