Performance and analysis of continuous reactor for hydrothermal carbonization

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Highlights

- Hydrothermal carbonization can convert wet organic wastes to solid fuel
- Data taken from a batch reactor were used to design a continuous reactor
- Performance of batch and continuous reactors are compared and analyzed

1. Introduction

Hydrothermal carbonization (HTC) is a method for processing diverse biomass, especially those with high moisture content. [1] Products of HTC include a carbonaceous hydrochar with potential use as a solid fuel, aqueous products (especially including sugars, sugar derivatives such as furfural, carboxylic acids, and ammonia), and a small amount of gas primarily consisting of CO_2. HTC has been applied to green waste, cow and pig manure, wastewater sludge, and food waste. [2-3] Until now, most studies reported are done in enclosed batch reactors. Full scale commercialization may benefit from processing in a continuous reactor, and there have been a few efforts reported. [4] Design of a continuous reactor for HTC is quite complicated and continuous control is complex. The feed includes a liquid / solid mixture, and must go against a substantial pressure, as much as 50 bar. The effluent includes gas, liquid, and solid, and must accomplish heat recovery while dropping the pressure for continuous operation with energy recovery. At the University of Nevada, Reno, we have designed, built, and operated a continuous reactor with feedback process control. The performance of the reactor has been analyzed and compared to that in a batch reactor. We have performed rigorous studies on the residence time distribution of both the liquid and solid phases to better understand reactor performance, and results of those investigations are reported here.

2. Methods

The continuous HTC reactoris designed to operate at temperatures between 180 °C and 250 °C, with a volumetric throughput of 5 ga h^{-1} (18.9 L h^{-1}). It has been operated to date processing cellulose and cow manure. Prior to feeding, manure is dried and milled to ensure homogeneity. A slurry with 3% solids is pumped to the reactor, designed as plug flow. The reactor is made from a stainless steel pipe 1.8 m in length and nominally 2-inch diameter. The reactor is heated with a 12-kW electrical heater, and is oriented so that flow is upward. Reaction time is nominally 5 minutes. Reactor effluent is cooled in a shell and tube heat exchanger, and reaction products are sampled as a cooled slurry periodically. We simultaneously control reaction temperature, reactor residence time by regulating pump speed. Our continuous reactor is designed as a plug flow reactor with residence time of 5 minutes.

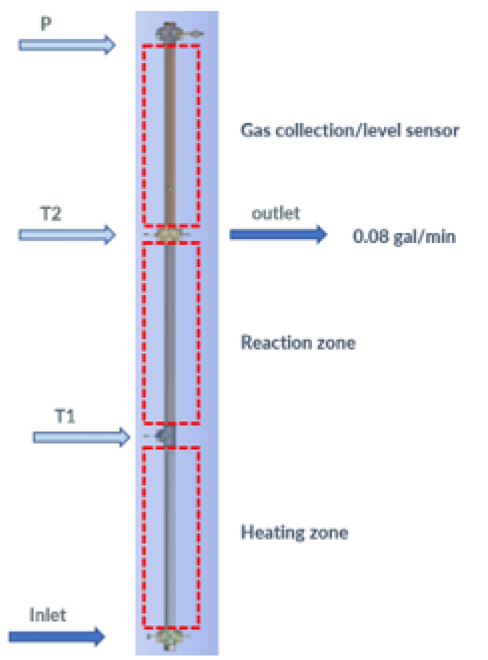

Figure 1. A schematic illustration of the continuous flow HTC reactor at the University of Nevada.

Solid yield is determined on a dry basis, and is measured by filtration to recover the solid reaction products, drying, and comparing the mass of the dry product with the mass of the feed. Hydrochar is analyzed by ultimate analysis, and carbonization is calculated from the carbon content.

Tracer tests of the continuous reactor without heating were done to analyze residence time distributions (RTDs) of both liquid and solid phases. A step function of methylene blue was used at the inlet to the reactor, and liquid samples were collected each 60 s, analysis of the MB concentration produced the F curve for the liquid-phase RTD. Milled cow manure was used as tracers for the solid phase. At time zero, the concentration of solids was increased from 0% to 3%. Analysis of the dried sample content of the reactor effluent produced an F curve for the solid-phase RTD.

3. Results and discussion

Preliminary tests of the continuous reactor established feasibility. The reactor was fed for 1 hour with a slurry of 3% solid manure and operated at 250 °C. From numerous experiments in a batch reactor, we expect that the yield of hydrochar at 250 °C is about 50%, but we found that the yield of hydrochar from the continuous reactor was 82%. Temperature monitoring and control of both batch and continuous reactors is well established, but the reaction conditions appear to be different between the two reactors.

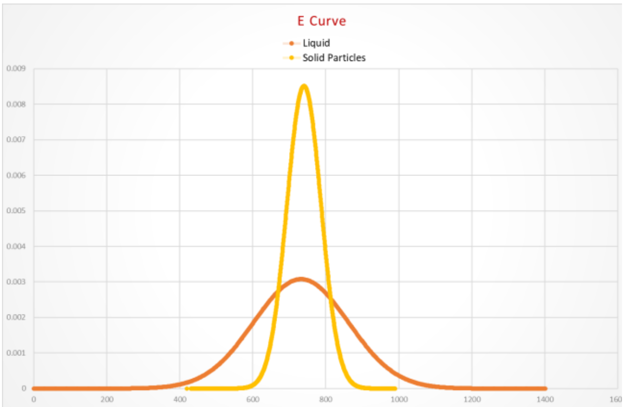

Figure 2. RTD of the solid phases through the continuous flow reactor.

Baffles were placed in the reactor to ensure plug flow in the continuous reactor, and the RTD of both liquid and solid phases were measured, with results as shown in Figure 2. The RTD of the liquid phase is showed substantial departure from plug flow, with a dispersion number of 0.0219. This may reflect laminar flow conditions of the reactor. The particles, however, were nearly in plug flow, with a dispersion number of 0.0029.

4. Conclusions

Performance of the continuous hydrothermal reactor was compared to the performance of a batch reactor. Under apparently identical conditions of average residence time and reaction temperature, the hydrochar yield was substantially different between the two reactors. Further analysis demonstrated that the reaction time in the continuous reactor was well controlled, but the reaction time in the batch reactor was in fact much longer than the reported reaction time. The reaction data taken from batch reactors can be used for design of continuous flow reactors, but must be done so very carefully.

References

The reference format is provided below [1 – 3]. [Times New Roman 10].

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Keywords

Residence time distribution; biomass; reactor scale up