Automated, Continuous Pyrolysis Reactor for Process Research and Optimization

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Mainstream Engineering Corporation has been actively pursuing pyrolysis, hydrothermal liquefaction, and gasification research for more than 10 years. Mainstream currently operates a 1 ton/day (tpd) pilot-scale pyrolysis reactor, which generates commercially available bio-oil (Agrefine™) for research and testing. Pine bio-oil from the reactor is high quality and meets all the requirements listed in ASTM D7544 (*Standard Specification for Pyrolysis Liquid Biofuel*). The 1-tpd pyrolysis reactor was developed to be highly modular and scalable for remote locations and processing opportunistic fuels, such as lignocellulosic waste biomass, mixed waste, yard waste, and agricultural residues.

Mainstream optimized the pyrolysis reactor process conditions using a continuous, bench-scale fluidized bed reactor, which was designed to process up to 1 kg/h of pine biomass. We used pine sawdust with an average particle size of 250 µm and a bulk density of 0.34 g/mL as the reactor feed and the feed rate was maintained between 0.35–0.40 lb/h. To optimize the reactor, we varied temperature between 480 °C and 500 °C and residence time (τ) between 0.5 and 0.9

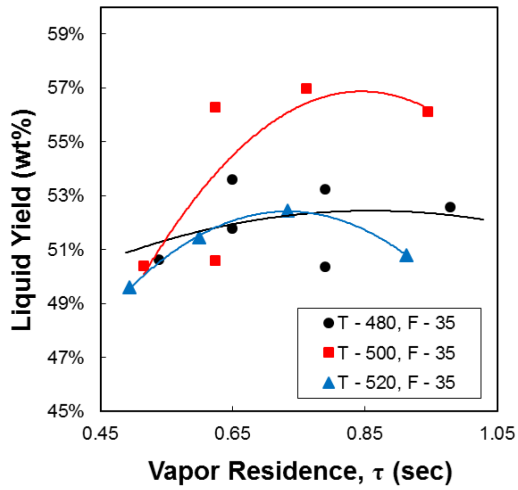

Figure 1: Optimization of the bench-scale pyrolysis unit.

seconds (Figure 1). Our testing revealed that a 0.8 s residence time at 500 °C maximized the reactor's bio-oil yield at approximately 57 % (dry mass basis). The patented reactor design minimizes secondary cracking reactions, which maximizes the yield of liquid bio-oil product.[1] Mainstream is currently manufacturing fully automated, continuous 1 kg/h pyrolysis reactors for researchers and educational institutions (Figure 2). The pyrolysis unit bridges the gap between fundamental research and real-world, large-scale systems. Mainstream's bench-scale pyrolysis unit provides an immediate method of testing new process conditions, catalysts for bio-oil upgrading, bio-oil collection methods, and testing a wide variety of feedstocks.

The system has a touchscreen human-machine interface (HMI) to control and monitor process conditions. A two-stage auger feeder can supply a variety of feedstocks (e.g., woody biomass, municipal solid waste, plastics, etc.) to the fluidized bed reactor. Volatile and gaseous products are separated from the pyrolysis char using two cyclone separators. Following char removal, the organic vapors are condensed using a multi-condenser system, which allows for fractional collection of the bio-oil. Following the multi-condenser system, an electrostatic precipitator collects any remaining bio-oil, while the fluidizing gas (N_2) and non-condensable gases (CO_2, CO, CH_4, etc.) are vented. Technical specifications for the bench-scale pyrolysis unit and properties of the bio-oil and char produced at 500 °C can be found on our website.

Our bench-scale pyrolysis unit has been optimized for a range of reactor temperatures and residence times. Mainstream has also used the bench-scale pyrolysis unit to co-

Figure 2: Mainstream's automated, continuous bench-scale pyrolysis unit.

pyrolyze biomass and plastics (e.g., polystyrene). Co-pyrolyzing oxygen-free plastics with lignocellulosic biomass increases the quality of the bio-oil by reducing the oxygen and moisture content, which increases the overall heating value.[2] Operating at optimal conditions for pine sawdust (500 °C and τ = 0.8 s), we observed that polyethylene and polyethylene terephthalate produced either a waxy solid or a char-like solid. In contrast, pyrolyzing polystyrene produced a liquid product. Based on these observations, we co-pyrolyzed polystyrene with pine sawdust. We found that just 10% polystyrene in the feedstock reduced char yields by more than 50%. Additionally, we observed that co-pyrolyzing polystyrene with pine produced significant amounts of styrene monomer that increased when more polystyrene was incorporated in the feedstock (Figure 3A).

However, increasing polystyrene in the feedstock also led to an increase in aromatic byproducts. Specifically, at 30% polystyrene in the feedstock, ethylbenzene became a significant product that was previously observed in trace amounts (Figure 3B). In addition to the development of our automated bench-scale pyrolysis unit, Mainstream is continuing to pursue

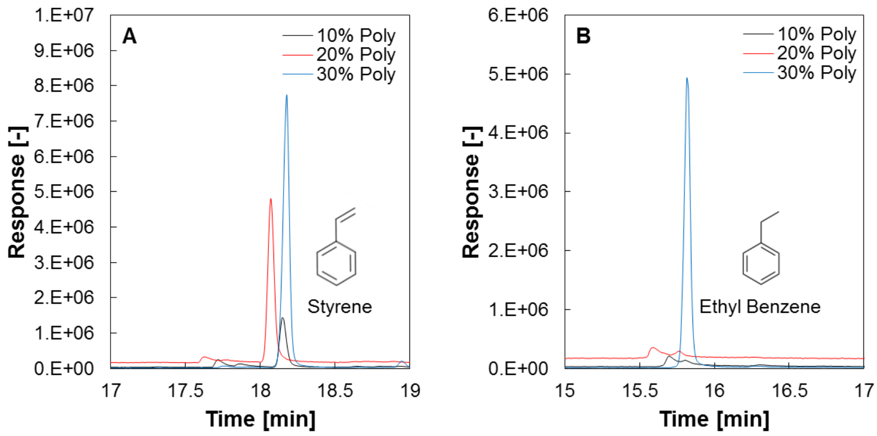

Figure 3: GC Chromatogram showing styrene and ethyl benzene yields obtained by pyrolyzing pine sawdust with varying amounts of polystyrene.

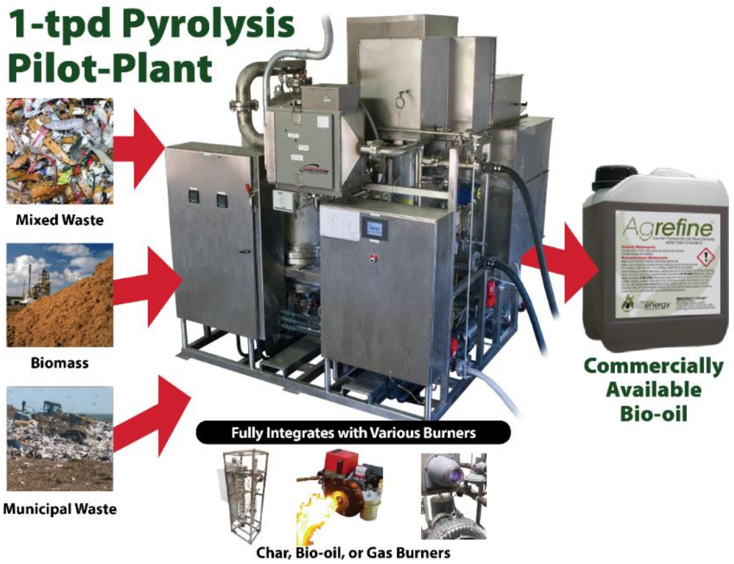

Figure 4: Mainstream's 1-tpd pyrolysis pilot-plant with bio-oil, pyrolysis char, and non-condensable gas burners used for converting byproducts to process heat.

transportable and modular solutions for pyrolysis of biomass and mixed wastes, hydrothermal liquefaction of food waste, torrefaction of municipal solid waste, and gasification for waste-to-energy applications. Mainstream has performed technoeconomic analyses for our 1-tpd pyrolysis system (Figure 4) and a 10-tpd, semi-trailer deployed pyrolysis system for converting waste materials into process heat and bio-oil.[3]

Dedicated burners have been demonstrated to convert pyrolysis products (bio-oil, pyrolysis char, and combustible gases) into process heat, which would allow the 1-tpd pyrolysis system to operate without external fuels. As Mainstream pursues production-scale pyrolysis, we are, and will continue to partner with university and government researchers to implement innovative technologies to make modular, transportable waste-to-energy systems feasible.

References

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