Combustion Emissions from Products of a Fast-pyrolysis Pilot Reactor

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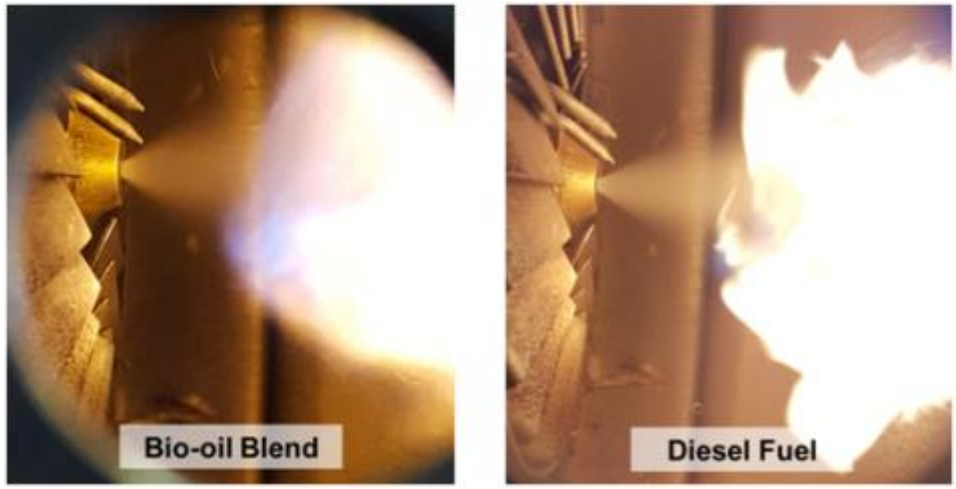

Figure 1. Burner flame on bio-oil (left) and diesel fuel (right)

Mainstream Engineering Corporation (MEC) is developing a transportable, small-scale pyrolysis reactor for the conversion of lignocellulosic waste biomass and mixed waste to pyrolysis bio-oil. The company operates a 1 ton/day (tpd) pilot reactor at its Rockledge, Florida facility. Funding for the work has come primarily from the US Air Force with additional funds provided internally and from the US Navy and the Department of Energy. The Air Force's interest arose from a desire to extend the lives of landfills at Air Force installations by diverting some of the incoming organic waste material. In addition, expanded on-site generation of renewable energy was seen as a way to improve energy security and help mitigate the risk of power outages. MEC is also targeting commercial applications—being a Florida company, initial waste biomass feedstock testing has focused pine logging residues from the northern part of the state.

MEC's focus has been on circumventing technical and cost barriers that have prevented small-scale pyrolysis from taking hold commercially, namely keeping the unit production costs low, finding a viable near-term offtake route for raw or mildy upgraded bio-oil, and demonstrating emissions compliance. The pilot reactor is fully operational and the company runs it approximately once per month as it works through various process improvements. The pilot reactor is described in more detail in PyNe 37 (June 2015).[1]

Recent additions and upgrades to the pilot reactor include on-stream regeneration of the hot-gas filter, a tunable high-voltage electrostatic precipitator, and an improved bio-oil collection filter media. The pilot-scale bubbling fluidized bed reactor (41 cm ID) was also recently outfitted with a high-temperature borescope to allow visualization of sand bed and screw feeder during operation. Wood-derived bio-oil from the pilot has been tested in-house and shown to comply with ASTM 7544-12 Grade D. The oil is particularly low in ash and solids because of the hot-gas filtration, making it attractive for bio-oil upgrading studies. For those interested, research quantities of bio-oil (2 L minimum order) are available for purchase from the email below.

Recently, MEC has focused on characterizing the combustion emissions from all three products of the fast pyrolysis process (bio-oil, biochar, and non-condensable process gas). Emissions measurements for bio-oil blends and the process gas have been taken at MEC. Bio-oil/ethanol blends (20%/80% by mass) were burned in a nominally 2 gal/hr (7.6 L/hr) modified fuel-oil burner. The bio-oil blend flame had similar stability and morphology as a baseline diesel flame (see Figure 1). The blending approach was adopted after attempts to burn neat bio-oil in this burner were unsuccessful. The process gas surrogate mixture was burned in a commercial burner designed for low-energy-content gaseous fuels. Emissions measurements for the biochar were taken as part of a project with the Energy & Environmental Research Center (EERC) in Grand Forks, ID using a pilot-scale fluidized bed combustor. For all three burners, measurements were made for CO, CO2, NOX, SOX, and particular matter (PM).

The emissions from the three burners were treated holistically to simulate a small, distributed, fast-pyrolysis installation where the bio-oil is used

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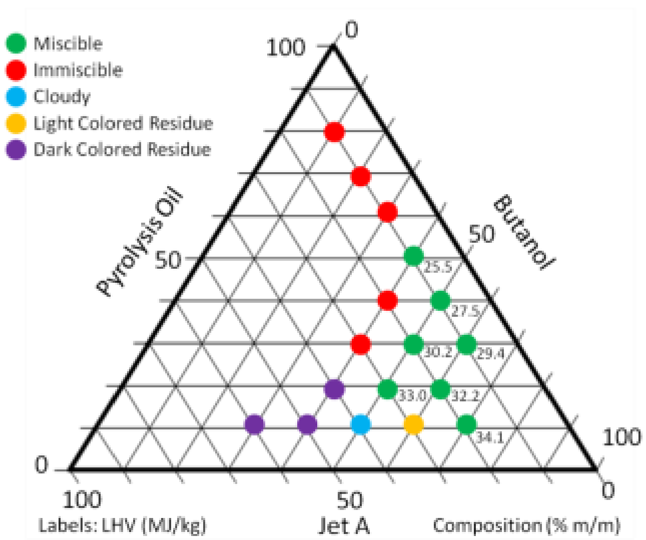
on-site. The emissions were compared to the Environmental Protection Agency's standard for Other Small Waste Incinerators (OSWI). The EPA OSWI standard includes limits for four common emissions species (CO, NOx, SOx, and PM) and five other air toxics (dioxins, cadmium, lead, mercury, and HCl). A combined emissions metric was calculated by weighting the emissions concentration of each burner by the flow rate of its exhaust stream, which is in turn related to the yield of each product and the amount of excess air in the burners. The combined emissions were corrected to a dry basis with 7% O_2 in the exhaust, as prescribed by the OSWI standard.



With a pine feedstock, the combined emissions of CO, NOX, and SOX were observed to fall below the EPA OSWI limit without any aftertreatment of the exhaust. PM was about twice the OSWI limit without aftertreatment suggesting that a baghouse filter should be used to meet the standard. Interestingly, the char burner and the bio-oil burner contributed nearly equally to the combined PM emissions. The char burner had a much higher PM emissions factor than the bio-oil burner, but its contribution to the combined emissions was weaker because the bio-oil yield is several times higher than the char yield.[2]

MEC has also been studying the blending of fast-pyrolysis bio-oil with jet fuel. Since jet fuel is not directly soluble with bio-oil, co-solvents are required to produce a single-phase blend including jet fuel and bio-oil. Unlike with diesel fuel and bio-oil blends, ethanol was not a good co-solvent for jet fuel. Butanol, on the other hand, was able to produce single phase blends with bio-oil and jet fuel when composing at least 40% (m/m) of the blend (see Figure 2). For a blend containing 50% (m/m) butanol, the fuels were miscible for bio-oil fractions ranging from 20 to 40%, with the balance jet fuel, allowing for some blending flexibility.[3]

In addition to blending, MEC is extracting bio-oil with supercritical solvents to study processing these extracts individually. Supercritical CO_2 at 60 °C and 2500 psig (170 atm) is able to extract over 10% (m/m) of the pyrolysis oil. Compared to the raw oil, the extract is characterized by lower water content, lower boiling range, and better solubility with butanol and jet fuel.[3] Future experiments will focus on treating this extract to produce value-added fuels and chemicals.

The long-term vision of the company is to commercialize small-scale pyrolysis reactors at the 1 tpd scale for military applications and the 10 tpd scale for commercial applications. It is envisioned that the 1 tpd unit would be packaged in a standard Tricon shipping container, and the 10 tpd unit in a standard semi-trailer. MEC is also interested in partnering with other researchers to evaluate innovative fast pyrolysis concepts in our highly instrument pilot facility.

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