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Review

Review of fuel oil quality and combustion of fast pyrolysis bio-oils from lignocellulosic biomass

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HIGHLIGHTS

- Review of state-of-the-art fast pyrolysis oil combustion in burner applications.
- Fast pyrolysis oil has been found to be suitable for industrial scale utilization.
- Curves for NO_x-emissions for air-assisted atomization burners are presented.
- Quality control, combined with standards and specifications is recommended.

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ABSTRACT

Fast pyrolysis bio-oils are completely different from petroleum fuels and other bio-fuels available in the market, as regards both to their physical properties and chemical composition. When the unusual properties of these bio-oils are carefully taken into account in system and burner design, their combustion without a pilot flame or support fuel is possible on an industrial scale. The aim of the paper is to review the work done on combustion of fast pyrolysis bio-oils and highlight the latest and most important findings of its combustion from laboratory fundamentals to industrial scale. The main focus of the paper is on the bio-oil burner applications.

In recent industrial scale bio-oil combustion tests, bio-oil has been found to be technically suitable for replacing heavy fuel oil in district heating. In addition, it has also been found out that limited possibilities for further lowering particulate emissions exist, since the majority of the particulates are typically incombustible matter. Curves for NO_x-emissions of fast pyrolysis bio-oil combustion for air-assisted atomization burners are presented in the paper.

Current burner designs are quite sensitive to the changes in the quality of the bio-oil, which may cause problems in ignition, flame detection and flame stabilization. Therefore, in order to be able to create reliable bio-oil combustion systems that operate at high efficiency, bio-oil grades should be standardized for combustion applications. Careful quality control, combined with standards and specifications, all the way from feedstock harvesting through production to end-use is recommended in order to make sure that emission targets and limits in combustion applications are achieved. Also the cost-effectiveness of the total package is extremely important.

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1. Introduction

Biomass fast pyrolysis bio-oils (also called biomass pyrolysis oils, and bio-crude oils) from lignocellulosic biomass are very different fuels from fossil oils with regard to both their physical properties (Table 1) and chemical composition. These liquids typically have high water content and may have substantial levels of suspended solids and also have a density higher than conventional fossil fuels. They are acidic, have a heating value of less than half of that of mineral oils, and they tend to polymerise when heated. Chemically, they are highly polar, containing about 35–40 wt% oxygen (dry basis), while mineral oils contain oxygen only at ppm levels. Hence, bio-oils are not soluble in mineral oils or other bio-oils, like biodiesels. The unusual properties of bio-oil must, therefore, be given careful consideration in a range of different applications [1].

To date, commercial operation has only been achieved for food and flavouring products [2]. A few companies are currently moving forward with commercialisation of bio-oil for energy applications. Forschungszentrum Karlsruhe (KIT), BTG, Fortum together with Metso and Green Fuel Nordic (GFN) probably have today the most advanced initiatives in pursuing larger scale operations in EU and KiOR, Honeywell's UOP with Ensyn/Envergent, in US [3]. The pyrolysis processes already in operation, commissioning or under design (2012) are listed with capacities and applications in Table 2. This is an indicative list compiled at authors' best knowledge, but not necessarily exhaustive and including all plants operating worldwide.

2. Properties affecting the combustion of fast pyrolysis bio-oil

2.1. Water

With regard to combustion applications of bio-oil, among the most relevant features in bio-oil composition is its high water con-

Table 1
Physical properties of wood fast pyrolysis bio-oils and mineral oils.

Analysis	Typical bio-oil	HFO 180/420	LFO Motor/heating EN590
Water, wt%	20–30	~0	~0
Water and sediment, vol%		0.5 max	0.02 max
Solids, wt%	Below 0.5		
Ash, wt%	0.01–0.1[a]	0.08 max	0.01 max
Nitrogen, wt%	Below 0.4	0.4	0.02
Sulphur, wt%	Below 0.05	1.0 max	0.001 max
Stability	Unstable[b]		
Viscosity (40 °C), cSt	15–35[c]	180/420 max @50 °C	2.0–4.5
Density (15 °C), kg/dm^3	1.10–1.30[c]	0.99/0.995 max	0.845 max
Flash point, °C	40–110[d]	65 min	60 min
Pour point, °C	−9–36	15 max	−5 min
LHV, MJ/kg	13–18[c]	40.6 min	42.6
pH	2–3		
Distillability	Non-distillable	Distillable	Distillable

[a] Note that metals form oxides during ashing, and may yield ash values that are larger than the total solids in the liquid.
[b] Polymerizes when heated and for prolonged periods of time.
[c] Depends on water content.
[d] Flash point method unsuitable for pyrolysis oils. Pyrolysis oils do not sustain combustion.