Experimental research on pyrolysis oil rapid mixing and combustion in gas turbine engine

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Pyrolysis oil (PO) produced by thermal conversion of biomass is one of the most promising biofuels. Its energy density is several times bigger that the feedstock from which it was produced. Since it is in the liquid form it can be easily transported and stored. Unfortunately some of the properties of pyrolysis oil make it difficult for direct application in nowadays combustion engines and thus hindering its broad application for power and heat generation sector. The main obstacles are related to high viscosity, acidity, aging, solid content and non-miscibility of the PO with conventional fuels. Table 1 shows typical properties of woody-bases pyrolysis oil in comparison to conventional diesel fuel #2 and glycerine.

Table 1. Comparison of PO and Diesel #2 fuel properties [1-3]

Property	Pyrolysis oil	Diesel fuel #2	Glycerine
Density (kg/l)	1.1-1.3	0.8	1.3
Viscosity (cP @ 40 °C)	15-300	2-4	>600
LHV (MJ/kg)	13-19	43	17-21
pH (-)	2-3	-	8
Water content (wt.%)	15-30	<0.02	<0.5
Solid content (wt.%)	<0.5	<0.01	-

Some of the adverse parameters of the pyrolysis oil can be compensated by use of high quality materials for engine production (pH), increasing flow rates (LHV) or by additional filtering (solid content). Some other, like viscosity and miscibility with conventional fuels are very difficult to influence.

The effect of viscosity on the atomization and in consequence on the combustion process was studied by several authors, see [4-8]. The general conclusion was that the viscosity of PO can be slightly reduced by its preheating, however, preheating above 70-80 °C is not possible since at that temperature PO polymerization starts to being dominant process and leading to chocking of the fuel supply line. Thus without making major changes in the combustor design and in the atomizer itself, a direct combustion of PO is not possible.

Pyrolysis oil due its mainly polar character cannot be mixed directly with conventional fossil fuels (non-polar) and combusted in co-firing/mixing mode. Pyrolysis oil/diesel blends are stable only for very short time. After that separation of the heavy and light oil fractions occurs [9,10]. In order to mix both fuels for timespan of hours or days an additional tailor-made surfactants and alcohols have to be added to the blend increasing significantly cost of the fuel [9-13].

In this research a new approach for blending pyrolysis oil and diesel fuel for application in gas turbines (GT) for combined power and heat application is used. To avoid major changes in the gas turbine itself, which generate additional costs, a static mixer is added in the front of the nozzle. This SMX mixer is selected such that two fluids, one with very high and other with very low viscosity can be blended effectively for several seconds. Since the mixing occurs just in the front of the nozzle, this is sufficient to provide uniform emulsion, see Fig. 1 and generate spray droplets of the size acceptable for the gas turbine.

The elements of the static mixer together with an additional venturi tube were implemented in the fuel supply line of the 50 kWe multi-fuel gas turbine test-rig, see [4] and Fig. 2, as available in the Thermal Engineering Group at the University of Twente. The gas turbine test rig was equipped with pressure swirl RXT 0380 nozzle. The experiments were performed at the pressurised conditions; with pressure ratio of 2.5.

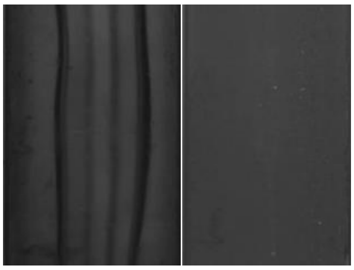

Fig. 1. Mixing of two flows: without (left) and with mixer (right)

Fig. 2. Gas turbine test-rig

The investigations were completed for various ratios of diesel/pyrolysis oil blends. Furthermore as an intermediate step a blend of diesel fuel #2 and glycerine was used. Glycerine is characterised by high viscosity, LHV and density similar to PO, however it does not contain any solid content and it is not acidic. Therefore, here serves as a precursor to the tests with PO blends. The investigated test cases were: (i) a reference case with diesel #2 without mixer, (ii) diesel #2 with mixer, (iii) glycerine/diesel blends with 20-35 wt.% of glycerine and (iv) PO/diesel cases with 20-50 wt.% of PO. For CO measurement, the RBR-ECOM-KD flue gas analyser was applied, whereas for NO, SO2 and O2 the ECOM J2KN Pro was used. The exhaust gas measurements were performed at steady state gas turbine conditions.

For all investigated cases, including 50/50 wt.% pyrolysis oil and diesel blends, a stable operational conditions were achieved without any symptoms of instabilities due to introduced pyrolysis oil. The exhaust gas measurements show, however influence of the fuel composition on the combustion efficiency, where glycerine and pyrolysis oil influenced the CO emissions. In case of the 50PO-50D blend, the CO emissions were doubled, in comparison to the reference diesel #2 case.

Based on the presented research it could be concluded that co-firing of renewable viscous fuels, like pyrolysis oil, with conventional low viscosity fuels in modern gas turbines is a feasible and viable option to increase the renewable fuel share in the power generation portfolio. However, an attention should be paid to the combustion efficiency and possible emission.

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