

Crude Tall Oil-Based Renewable Diesel as a Blending Component in Passenger Car Diesel Engines

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ABSTRACT

The residue and waste streams of existing industry offer feasible and sustainable raw materials for biofuel production. All kind of biomass contains carbon and hydrogen which can be turned into liquid form with suitable processes. Using hydrotreatment or Biomass-to-Liquid technologies (BTL) the liquid oil can be further converted into transportation biofuels.

Hydrotreatment technology can be used to convert bio-oils and fats in to high quality diesel fuels that have superior fuel properties (e.g. low aromatic content and high cetane number) compared to regular diesel fuel and first generation ester-type diesel fuel. UPM has developed a new innovative technology based on hydrotreatment that can be used to convert Crude Tall Oil (CTO) into high quality renewable diesel fuel.

This study concentrated on determining the functionality and possible effects of CTO based renewable diesel as a blending component on engine emissions and engine performance. Tested fuels were Euro Stage IV diesel (CEC RF-06-03) as reference fuel and 30% CTO renewable diesel, blended with Euro Stage IV diesel.

The results showed that CTO based renewable diesel blend properties were comparable to those of the reference diesel and fulfilled the limits set by the EN590 diesel standard. The engine performance as well as the engine emissions was similar with both fuels.

For initial engine test, the renewable diesel was blended with RF-06-03 CEC reference fuel. During an intense test bench campaign engine load was varied from low load conditions up to full load. These tests revealed, that a blend of v./v. 30 % of the renewable diesel is perfectly suited for operation in a state-of-the-art diesel engine passenger car.

CITATION: Heuser, B., Vauhkonen, V., Mannonen, S., Rohs, H. et al., "Crude Tall Oil-Based Renewable Diesel as a Blending Component in Passenger Car Diesel Engines," *SAE Int. J. Fuels Lubr.* 6(3):2013, doi:10.4271/2013-01-2685.

INTRODUCTION

Limited sources for transportation fuels and the legislative decisions to increase the usage of renewable energy sources have pushed forward the development of transportation biofuels. Biofuels tackle the oil dependence of the transport sector, which is one of the most serious issues affecting energy supply security that the EU faces. During the past decades the biofuels, such as ethanol and ester-type biodiesels have been introduced to the existing fuel markets.

Demand for advanced biofuels will increase in the coming years as the EU's target cannot be reached with the current first generation biofuels alone. The commonly produced biofuels are also often competing with food production via excessive land use and edible raw-material. The European Commission is directing the biofuel production towards use of non-edible source materials, such as lignocellulose and other residues and wastes of existing industry, with subsidies and legislation. [1]

UPM, a forest industry company has started to build a biorefinery in Finland to produce biofuels from CTO, a residue of pulp making process, mainly generated in the production of sulphate cellulose from softwood. Using CTO to manufacture biofuels is an innovative way to use that residue without changing the main process, pulp and paper production. The technology that UPM uses for fuel production has been developed in-house collaborating with key partners. The biorefinery is a stepping stone in UPM's strategy to produce a line of new biofuels called *UPM BioVerno*. These renewable biofuels will be produced from various wood-based raw materials, such as forest residues, and like presented in this paper, crude tall oil. Producing biofuels from renewable raw materials in accordance with UPM's plans contributes to the European Union's long-term climate and energy targets.

Crude tall oil as feedstock does not compete with food chain, there is no indirect land-use change, and it is a residue of pulping industry. Tapping into underutilized lower grade material streams, the biorefinery is a minor addition to total crude tall oil demand. It will not affect demand-supply balance but is an important first step to drive development of wood-based biofuels and reach EU's renewable fuel targets in a sustainable way.

Hydrotreatment of CTO gives a diesel-like fuel which can be used as drop-in fuel in modern vehicles. UPM's crude tall-oil-based renewable diesel will be commercialized in the near future. The biorefinery will produce annually approximately 100,000 tonnes of renewable diesel for transport, equating to 120 million litres of diesel. The industrial scale investment is the first of its kind globally.

CRUDE TALL OIL

Extraction Process

Crude tall oil is a residue of chemical pulping process that contains natural extractive components of wood. It is currently extracted from the pulping process (Figure 1.) and distilled or burned for energy in boilers. An average yield of crude tall oil is 20-50 kilograms of CTO per ton of softwood pulp.

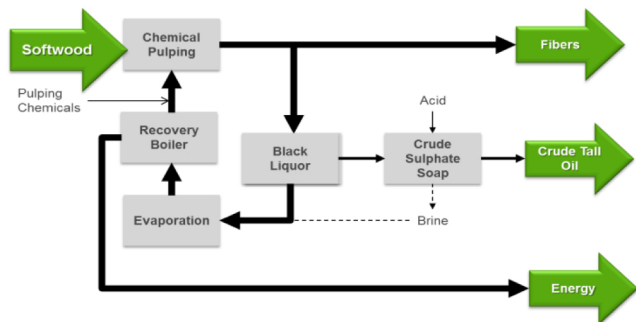


Figure 1. Schematic representation of a pulping process

The chemical pulping results “black liquor”, which is an aqueous mixture of lignin residues, hemicellulose and inorganic chemicals used in pulping process. Acids are converted into corresponding sodium salts by caustic conditions in kraft pulp cooking, and salts are suspended in spent black liquor from cooking resulting in crude sulphate soap. In other words, black liquor is let to settle and the top layer, known as the “tall oil soap” or sulphate soap is skimmed off. The soap generated in the pulping process must be removed from black liquor to avoid problems in evaporator operation and to guarantee good yield of pulp. The tall oil soap is then acidulated to form crude tall oil (CTO). The most commonly used acid is sulphuric acid (H_2SO_4). After the reaction the mixture is let to settle, various phases are being formed, and CTO separates to the top layer [2,3].

Composition

CTO is a mixture of 36-58% fatty acids with a hydrocarbon chain of 16 to 20 carbons being the dominant C18, 10-42% of rosin acids being abietic acid the dominant in this group and 10-38% sterols and neutral substances being β -sitosterol the predominant. However, its composition varies depending on factors such as specific tree species, time of year or growing cycle of the tree, age of the wood, the conditions of pulping and the geographic location. Table 1 presents the composition of CTO from three different regions.

Table 1. Composition of crude tall oil. [4]

	South eastern US	Northern US and Canada	Scandinavia
TAN ¹	172	135	155
Saponification number	172	166	142
Resin acids (wt%)	40	30	42
Fatty acids (wt%)	50	40	39
Unsaps (wt%)	8	15	10

CTO used in this study for biofuel production via hydrotreatment originated from UPM's own pulp mills in Finland. The composition of the CTO therefore resembled the “Scandinavia” quality presented in Table 1.

FUEL PRODUCTION PROCESS

The renewable diesel production process using CTO as raw material includes several production phases that are presented in Figure 2.

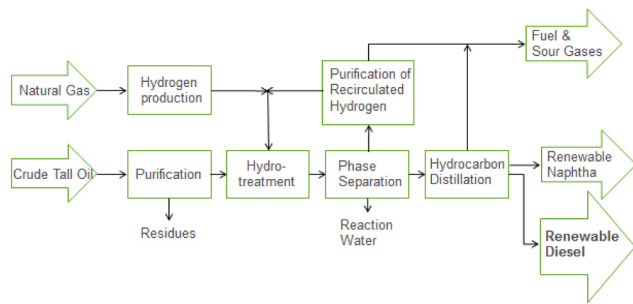


Figure 2. Schematic representation of CTO based renewable diesel production

Crude tall oil, an organic, water immiscible liquid, coming from a pulp mill has to be purified before it is in contact with hydrogenation catalysts. CTO contains large amounts of impurities, solid particles, elements and metals, that all have to be removed before introducing CTO to the hydrogenation reactor. The amounts of these impurities have to be decreased to ppm level or lower to ensure the functionality of the hydrogenation catalysts.

CTO used in this study was also purified and the actual hydrotreatment was carried out in a plug flow reactor. Commercial hydrotreatment catalysts capable of simultaneous hydrodeoxygenation, hydrodesulphurization, isomerization, hydrogenation and cracking were packed in the reactor. The hydrotreatment of CTO was performed at pressure range of 2-12 MPa and the temperature was in the range of 280-430°C.

The hydrotreated CTO “raw diesel” contains light components in addition to mid-distillate diesel components which have to be separated using commonly used fractionation methods. The CTO raw diesel was distilled according to the ASTM D 2892 method using 15 theoretical plates and the mid-distillate diesel was splash blended with RF-06-03 CEC diesel.

RESEARCH METHODOLOGY

In order to assess the potential of UPM's renewable diesel for utilization in conventional diesel engines, it was initially blended with reference diesel RF-06-03 CEC. The volumetric blend ratio was 30 % of UPM's renewable diesel with 70 % RF-06-03 CEC (in the following B30UPM).

As the quality of European diesel fuel is specified by the En 590 standard, prior to the test bench campaign at the single cylinder diesel engine, both the splash blend B30UPM and the reference diesel fuels were tested for all physical and the chemical limits stated in the EN590 regulation. The characteristics of both fuels are rather similar, except the slightly earlier start of distillation of the blend and its lower aromatic content. Both fuels meet the limits stated in EN590, as depicted by [Table 4](#) the appendix.

The single cylinder engine utilized in this study has been optimized for low engine out emissions while simultaneously feature a high efficiency. Therefore, the fuel injection

pressure was increased to maximum 2000 bar by using a Bosch CP 3.3 high pressure fuel pump and a CRI 3 injector. At the same both the charge air temperature and EGR is strongly cooled for sufficient cylinder filling.

The layouts of both the combustion chamber and the 8-hole nozzle have been optimized to feature the best possible air utilization. Due to the increased charge air pressures, the chosen compression ratio is 15:1 to still represent acceptable cylinder peak pressures. With this configuration, the specific power output is 80 kW/l with maximum cylinder pressures below 190 bar.

Reducing compression, using a higher maximum cylinder and rail pressure, as well as improved EGR cooling makes lowest particulate emissions possible, and as a result the research engine meets the Euro 6 standard with conventional diesel. Thus, the performance of the single cylinder diesel engine is top end of current production engines. [Table](#) summarizes the most important engine characteristics.

Table 2. Single cylinder engine characteristics

	Unit	Specification
Swept volume	cm ³	390
Stroke	mm	88.3
Bore diameter	mm	75
Valves per cylinder	-	4
Compression ratio	-	17:1, 19:1
Max. cylinder pressure	bar	220
Turbocharging	-	Max. 3.8 bar abs.
Fuel Injection Equipment	-	Bosch Piezo CRI 3 CP 3

More detailed information about the research engine can be found in [\[5\]](#).

All investigated load points are depicted in below [Figure 3](#). Three of these part load points are within the New European Driving Cycle (NEDC) reference area while the highest part load point at 2400 rpm and 14.8 bar IMEP is outside this range. This load point, as well as full load point, might become more relevant with future driving cycles, e.g. the Worldwide Harmonized Light Vehicle Test Procedure (WLTP). Engine tests were carried out with pilot injection and without pilot injection closed loop combustion control. The center of combustion (CA50) was chosen to maximize the engine efficiency while maintain low emission and combustion sound simultaneously. All tests at part load have been carried out as EGR-sweeps. Starting with pure air in the combustion chamber at start of injection, the EGR-rate was