FVTR GmbH | Whitepaper Series

EXPERIMENTAL ANALYSES OF MASH MAKES' POCC FOR USE ON MARINE ENGINES

INTRODUCTION

Marine industry is in transition. Due to oncoming regulations and demands, a reduction of vessels CO_2 footprint is necessary and mandatory. At present, the path that future propulsion systems will take and the fuel for them are not yet clearly defined. It will have to be low-carbon or carbon-free or utilise the carbon atom in a cycle. But there is still a lot of research to be done before then.

Drop-in fuels with a low carbon footprint are needed to take a step towards decarbonisation and thus achieve CO_2 reduction targets in the near future. They can be used to decarbonise existing systems. However, their availability is limited and new feedstocks for new drop-in biofuels must be found.

One of these new feedstocks is the waste product of the cashew nut. An oil-containing liquid (cashew nut shell liquid, CNSL) can be extracted from their shells, which can be used as a blend for diesel fuels. Currently, intensive research is also being conducted into the possible applications of POCC (pyrolysis oil cashew cake), which is obtained from the cashew shell press cake.

PYROLYSIS OIL CASHEW CAKE (POCC)

POCC is a pyrolysis derived product, produced from the cashew shell press cake (**Figure 1**), which is essentially a residue of another residue (cashew shell) from the CNSL production. The raw pyrolysis output is lightly upgraded to achieve the necessary stability under operational conditions. Furthermore, the co-product from the process is biochar, which is a known soil amendment product. Regarding the CO_2 footprint, a reduction by around 92% as ex factory rating compared to fossil fuels is possible (transport emissions related to taking the fuel to the destination port and bunkering it are not considered).

In the present study, the company MASH Makes provided their POCC material. This was processed into various test blends using a heavy fuel oil as a fossil blend base. As this new blend component is outside the standards, tests and analyses are needed to ensure its safe use as a fuel for marine engines.

Figure 1: Cashew shell press cake before further pyrolysis treatment (source: MASH Makes)

FUEL EVALUATION METHODOLOGY

… or how to test a new fuel with new challenges? FVTR gained experience with the most different bio grades over the past years, starting with the introduction of the first B100 products in on- and offroad applications – speaking about fuels which are clean and easy to handle. Later, introduction of different bio-grades from early-stage marine grade FAME via pyrolysis oils to HTLs for marine industry took place.

Testing all those oils either pure or as different blends with fossil components, such as MGO or residual fuels, new challenges were found. Even if a new blend is within the limits of e.g. ISO 8217, problems may occur due to its behaviour or properties. Whether it is insufficient ageing stability, fundamental incompatibilities with the blending partner, clogging of filters or problems with injection pumps due to the effects of temperature, pressure and shear forces - new potential drop-in candidates must be investigated well beyond the specifications and contents of existing standards in order to be able to exclude the above mentioned points.

Figure 2 shows the complete evaluation path for a new candidate before safe use or trial onboard of a vessel can be confirmed. This methodology starts with basic lab analyses, followed by different component tests before a first use in a single cylinder research engine allows insights in combustion behaviour, emissions as well as any other issues regarding the engine's hardware.

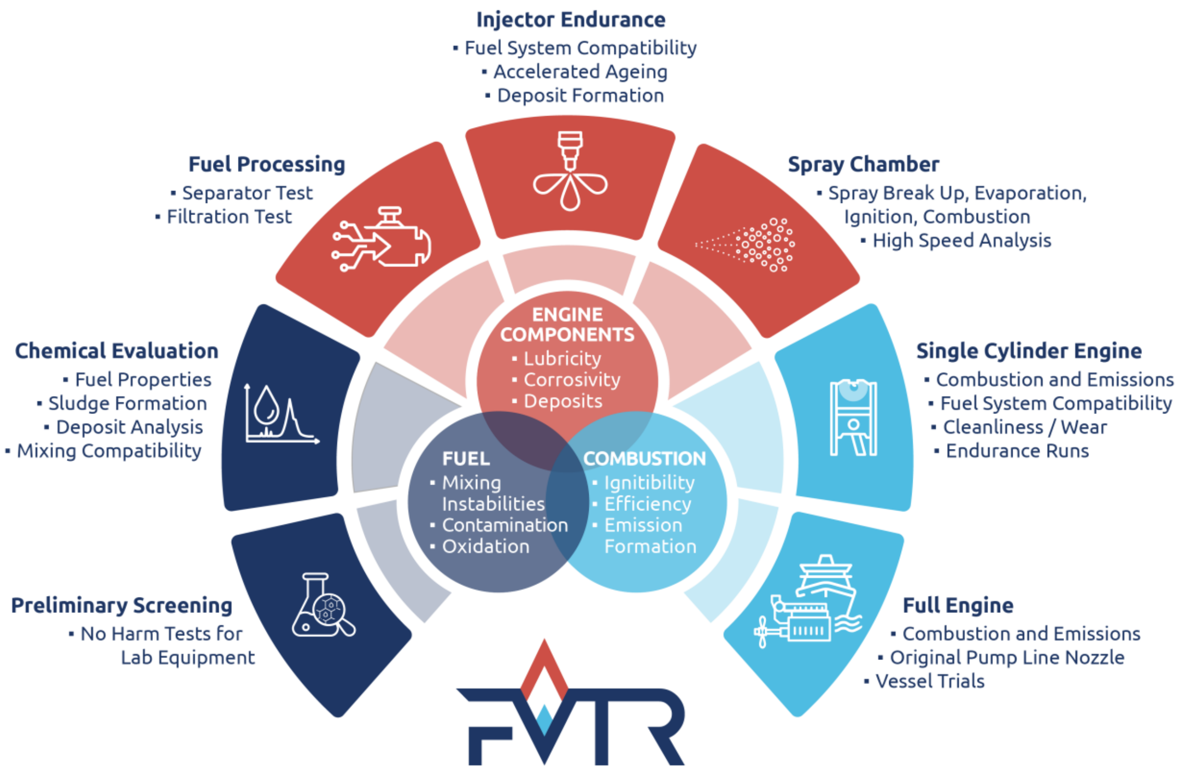


Figure 2: FVTR's fuel evaluation methodology: From basic routines in the lab to final full engine trials

LAB ANALYSES

The most important parameters of the basic lab analysis in terms of suitability to engine use are viscosity and density as well as tendency to sludge production or emulsification and mixing stability with the fossil blend partner. Furthermore, acidity is of interest to be sure having the correct materials.

ENGINE TESTS

A single-cylinder research engine (1VDS18/15CR) is used for comprehensive investigation of fuel impact on the fuel supply system, fuel injection system, engine performance, combustion, emissions and optionally exhaust gas treatment. The layout and size of the engine is representative for a marine medium speed engine.

On the SCE, the compatibility of the injection equipment is tested under severe but realistic conditions. As the common rail injector uses uncooled nozzles, the relatively high surface temperatures result in comparatively strong stress on the fuel. Because of the constant fuel pressure of the common rail system, power loss through deterioration of the nozzles is more easily detected compared to a mechanical injection system.

The test bed is equipped with a state-of-the-art pressure-trace indication system to calculate the rate of heat release as well as an exhaust analysing system using FTIR and particle analysis systems, e.g. for FSN or PN/PM. Engine tests are performed at steady-state operation points at rated engine speed and varying engines loads, rail pressures and injection timing.

The engine test is done according to scheme E2 of ISO 8178. This scheme is meant for highly stressed propulsion engines at constant engine speed. At 100%, 75%, 50% and, finally, 25% load, the engine parameters as well as the emissions are measured. Using the weighting factors one can calculate the corresponding emissions and compare, e.g. to IMO Tier limits.

At the different load points, the testing is started with the IMO Tier II level compliant operating parameters of the engine in terms of injection timing and fuel pressure. Furthermore, a rail pressure variation can be done, to analyse the influence and possibly even optimise combustion behaviour for this specific fuel blend. The testing is done first with the base fuel only (VLSFO) and repeated using the B20 blend. During both tests, the engine parameters are set to the same values. These parameters include charge air pressure, exhaust gas back pressure, injection timing and set injection pressure.

POCC TEST PLAN

For the investigations presented, a POCC B20 blend sample was prepared and a basic analysis for its parameter was done in our fuel's lab. Successfully passing those pre-tests, a larger quantity of the blend was produced and processed. This included homogenizing and purifying of the material. Then, the fuel was used on the single cylinder research engine. Fuel consumption, emissions, temperatures, pressures, ignition and combustion behaviour were monitored and recorded. After the testing, the injector was removed, and the nozzle was inspected, as were the fuel filters.

DISCUSSION OF TEST RESULTS

The processing of fuel in a vessel's fuel system, especially of a new drop-in fuel, is simplified if compatibility is given. Then, the new fuel can be handled as usual and as known from the previous fossil fuel. This includes all processes from bunkering to pumping, fuel treatment and finally standard-compliant use in the engine.Especially when blends are used and the base component is residual oils, the fuel must be treated accordingly. Water content, sediments, metals etc. must be removed using a separator.Some biofuels and oils tend to form an emulsion when they come into contact with water. This can already happen in the purifier and leads to a significant increase in sludge.

Figure 3 shows various organic oils that have been centrifuged with water. This represents the conditions in a separator. MASH's POCC (second from left) shows no emulsion formation. The emulsions are visible as a very thin separating layer between the bio-oil and the remaining water, so that after turning the sample vials upside down, the emulsion plug continues to trap the remaining water at the bottom of the bottle. The emulsion formation sometimes completely consumes either the bio-oil or the available water. Accordingly, if handled incorrectly, all of the bio-oil may be separated from the fuel blend and pumped into the sludge tank.

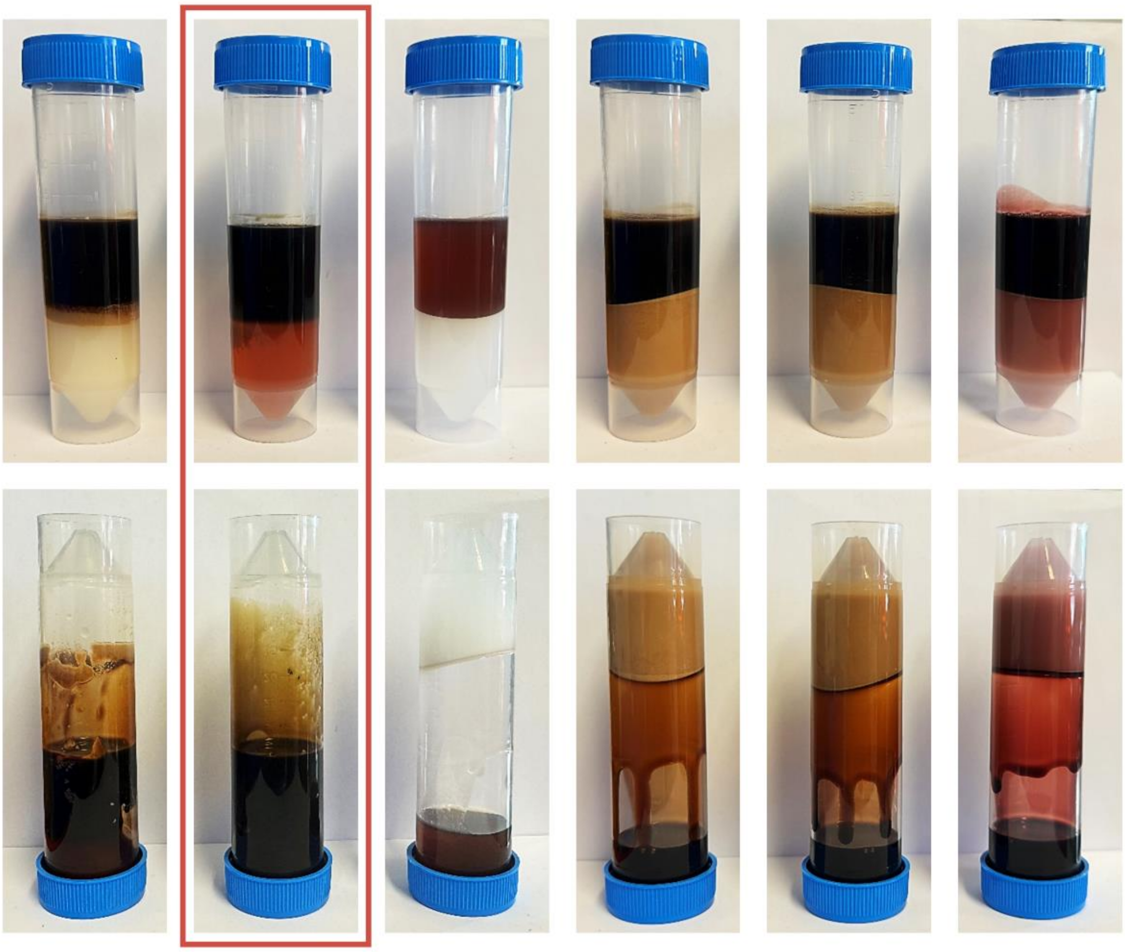


Figure 3: Sludge formation testing shows no interaction of MASH's POCC (second from the left) with water. The other cashew-based products show a gelification, creating increased amounts of sludge, probably causing issues in the purifier.

Finally, the tests show that the processing of MASH's POCC from the bunkering process via pre-processing in a marine fuel system can be carried out using conventional system settings without any problems being expected.

The next step is an engine test, in this case at the SCE, in order to evaluate combustion behaviour and emissions. An adapted E2 test is carried out for this purpose. Various load levels are tested at nominal speed. In addition, a rail pressure variation is carried out in order to generate a broader database. **Figure 4** shows the progression over time of some measured variables on the test bench for the reference fuel (VLSFO). The load levels of 25, 50, 75 and 100% engine load as well as the rail pressure variation are clearly evident. CO and NOx emissions as well as exhaust gas temperature and injection duration are also shown. The influence of the injection pressure on NOx emissions is particularly recognisable. The signals all show a smooth curve without major or obvious fluctuations.

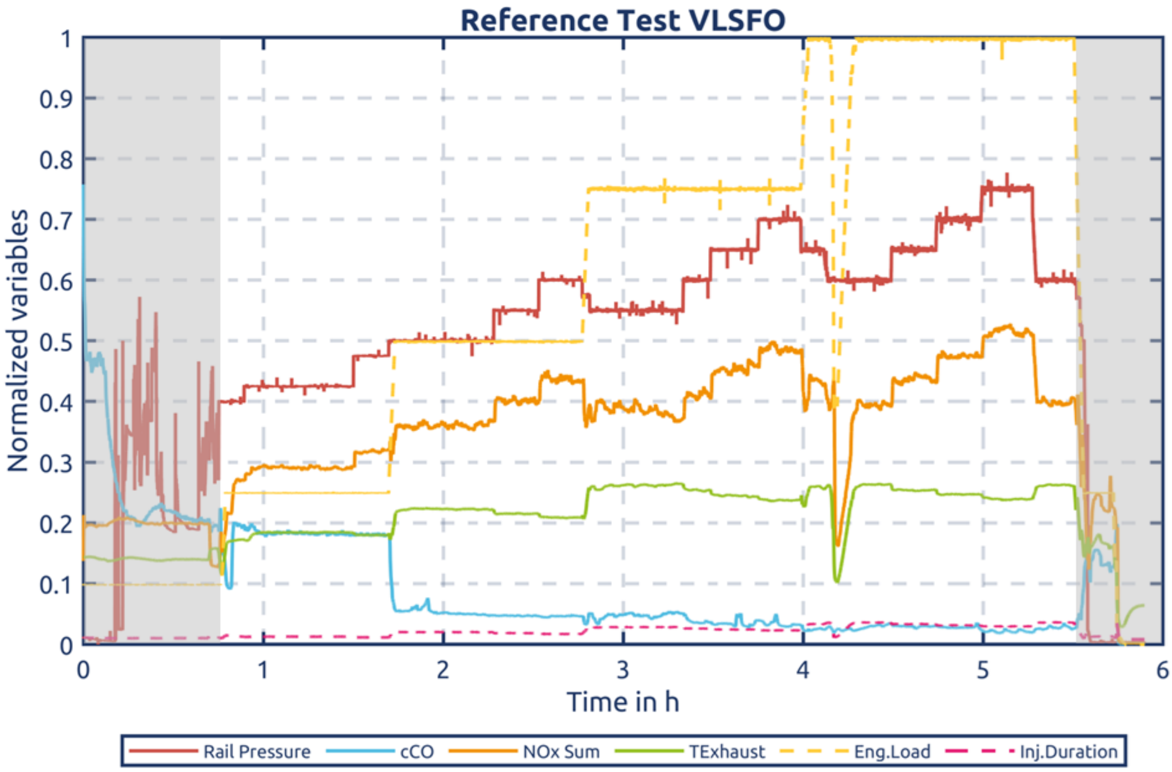


Figure 4: Time series of reference test using a conventional VLSFO

Figure 5 shows an equal test procedure using MASH's POCC B20 blend. The CO and NOx emissions shown in the diagrams are good indicators for upcoming issues with the combustion and the engine state itself. A possible bad fuel spray (droplet size, evaporation) will be visible in increasing CO and filter smoke number (FSN) as a sign for incomplete combustion. Due to decreasing efficiency with a delayed combustion, decreasing NOx would be visible, too. These effects are not apparent with the POCC blend. There are small effects visible in the 75% load data at the lowest injection pressure, but the behaviour of the NOx signal leads to the conclusion that any deposits flake off periodically. From the time series data averaged values are derived to compare reference test and B20 test more closely.

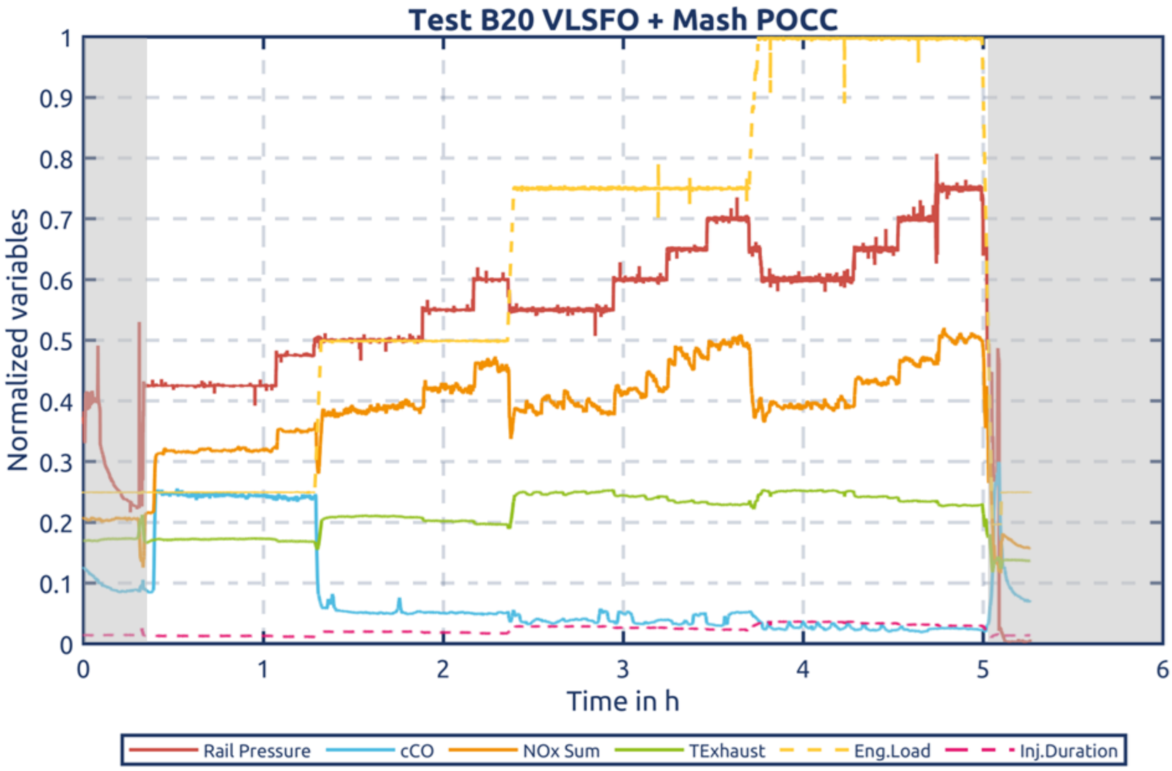


Figure 5: Time series of SCE test using a B20 blend of MASH's POCC with a VLSFO basis

Comparing MASH's POCC blend with the VLSFO base fuel, a slight increase in ignition delay is visible, see **Figure 6**. This is followed by an increased maximum pressure gradient at the start of the combustion. This effect is due to the increased amount of fuel at the ignition moment and therefore increased share of premixed combustion. So, combustion is slightly harder but very clearly within normal limits and still far off from bad fuel qualities. The increase is between 1 and 2 bar/°CA, depending on the engine load.

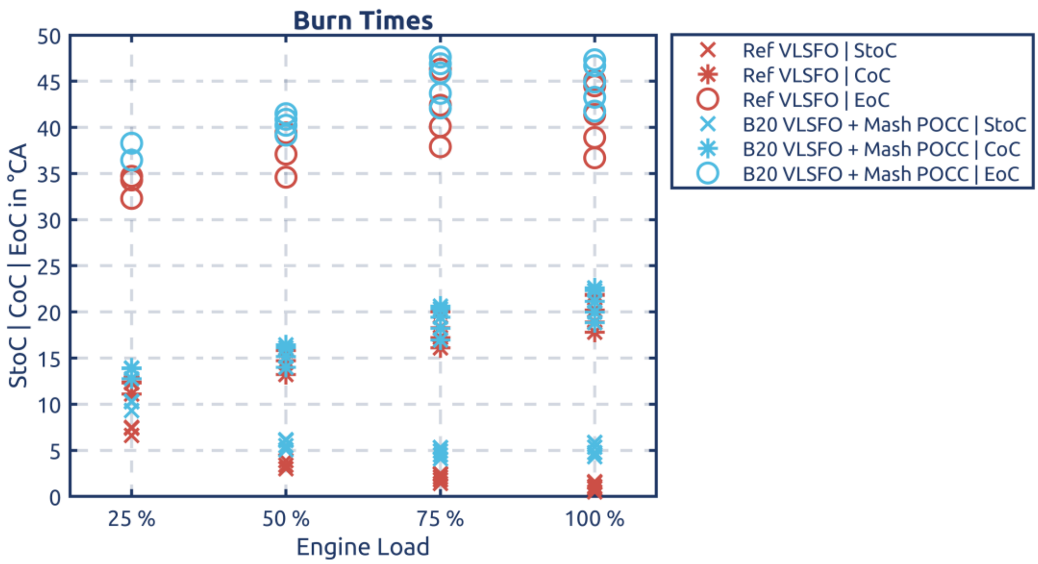


Figure 6: Averaged values of the combustion positions of the reference and POCC B20 tests

Furthermore, no significant differences were found between the blend and the reference fuel in terms of injection duration or specific fuel consumption (the calorific value of MASH's POCC is very similar to the one of the VLFSO).

As can be seen in **Figure 7**, apart from low-load operation, the use of the POCC blend even shows advantages over the reference VLSFO regarding FSN. The NOx emissions are slightly higher due to the higher pressure peaks and the oxygen content in the bio-component, but can still be kept within the IMO Tier limits.

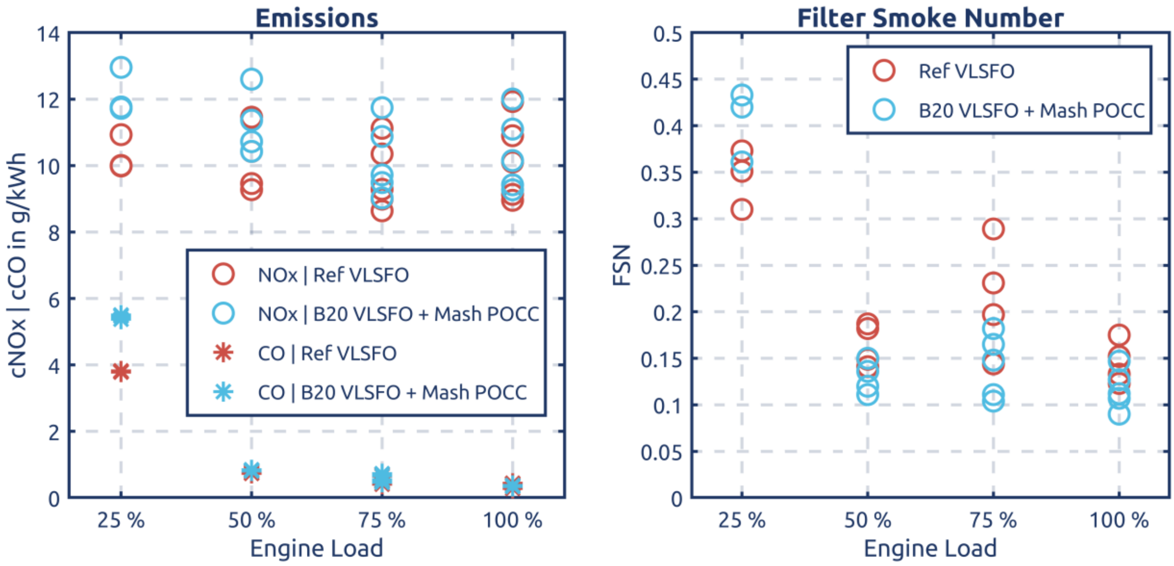


Figure 7: Emissions and FSN of the reference and POCC B20 tests

The engine test is followed by an optical analysis of the engine parts. After dismantling the injector, the nozzle is checked for external deposits. Furthermore, the inner parts such as needle, spacer and spring are visually inspected for any lacquer or deposits. Depending on the appearance, this is done via microscopy if applicable.

In case of the POCC B20 blend, there are nearly no external deposits on the nozzle tip, see **Figure 8**. Also needle, spring and spacer show no signs of degradation. The minimal build-up on the nozzle tip in the POCC B20 test could be easily removed.

After a rough base cleaning - from former testing, we know there is no influence or removal of the internal deposits - a high-definition silicone with a surface resolution of 0.1 µm is used on the nozzle itself and a very detailed imprint is produced. This imprint is analysed using microscopy. Deposits in the sac hole, in the spray holes as well as close to the needle seat become visible. Furthermore, extensive wear due to particles or sediment in the spray hole region or at the needle seat can also be detected.

Figure 8: Injector nozzle directly after dismantling (left) and disassembled nozzle incl. needle (right); from the test runs with POCC B20 blend (upper) and unsuitable bio-blend (lower)

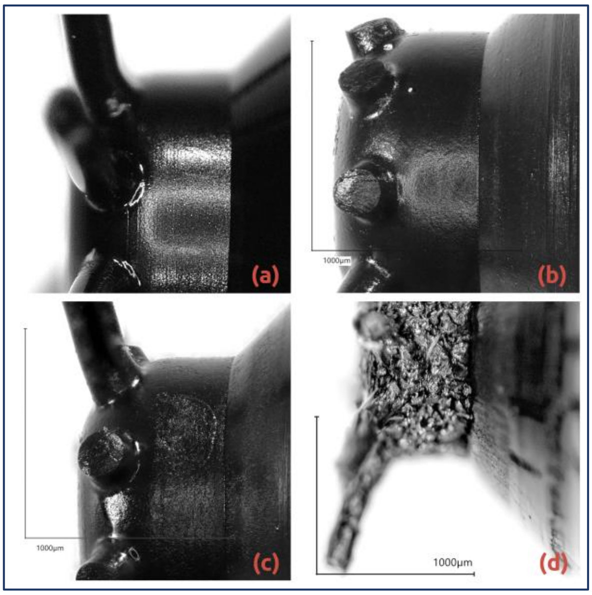


Figure 9: Imprints of injector nozzles in the microscopic analysis: (a) unused nozzle, (b) after operating on distillate fuel, (c) after POCC B20 blend, (d) after unsuitable bio-blend

Figure 9 shows the tip region of different nozzle imprints. Sac hole, spray holes and needle seat are visible. MASH's POCC blend (**Figure 9 (c)**) shows a still usable nozzle according to the imprint microscopy. This confirms the impression already made by the nozzle condition and measurement data from the test run.

As a comparison, the picture of the massive deposits from an unsuitable CNSL blend with a residual fuel can be used (**Figure 9 (d)**). Next to the deposits on the very tip and the spray holes, there are also deposits in the needle seat area. Whilst these will lead to injector leakage, the other deposits already cause increased injection duration due to bad spray formation and evaporation and therefore bad engine performance.

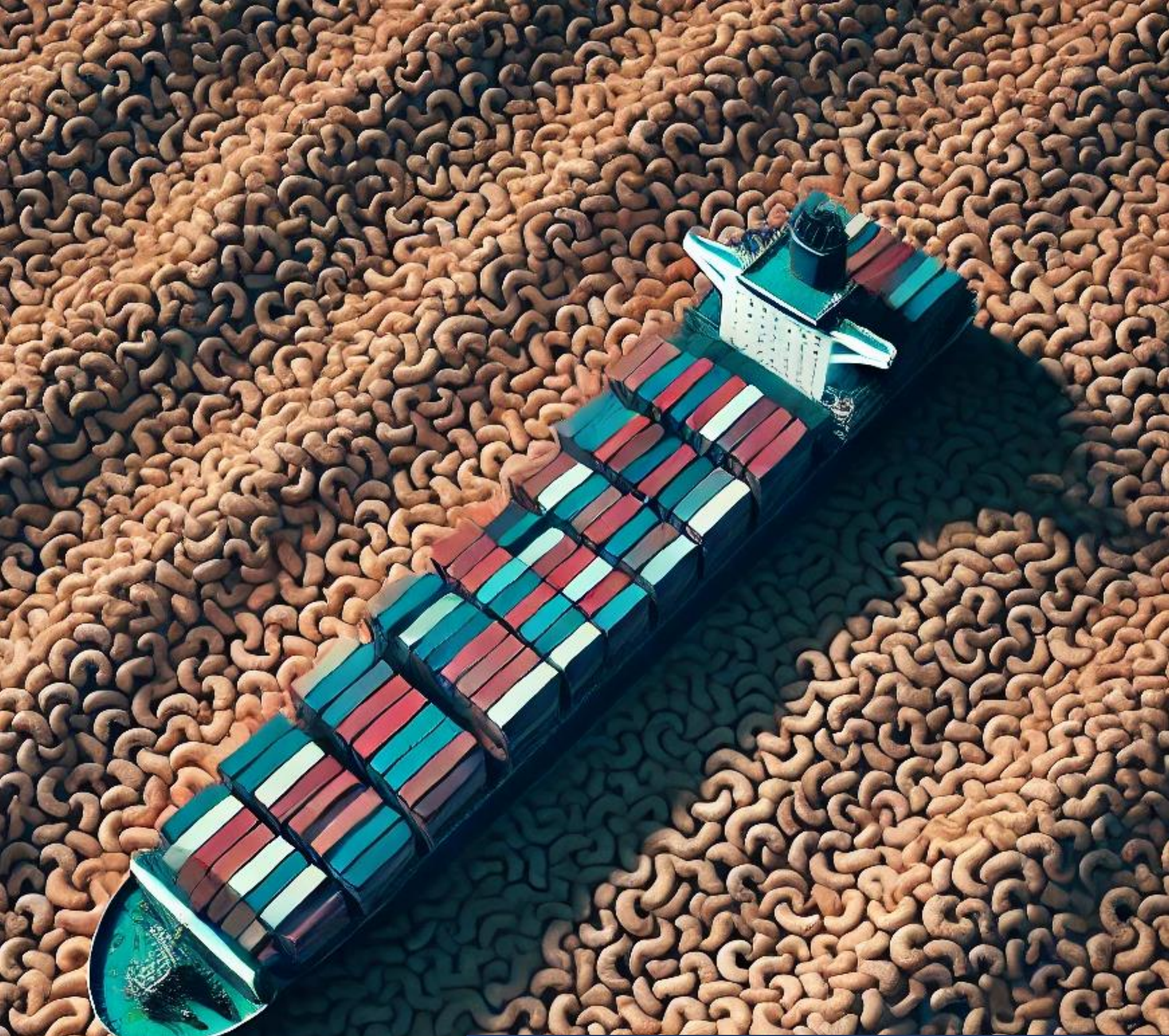
CONCLUSIONS

The POCC from MASH Makes is a promising approach of getting a suitable bio-component as a drop-in oil into the market for marine fuels.

The engine tests showed a good ignition and combustion behaviour. Even emissions stayed within acceptable limits and using a B20 blend should allow staying within IMO Tier limits without any changes in the engine setup or operational parameters.

Furthermore, the material is suitable to the state-of-the-art standard gear used on board of vessels. There are no issues to be expected from the test results – laboratory as well as component and SCE testing.

The next step should be made: A field trial on board of a vessel.



Author
Dr.-Ing. Robert Bank
robert.bank@fvtr.de

FVTR GmbH

Forschungszentrum für Verbrennungsmotoren und Thermodynamik Rostock GmbH

www.fvtr.de