- IDEALFUEL -

Lignin as a feedstock for renewable marine fuels

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Deliverable Report

D4.6 – Final Fuel system compatibility report

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Publishable summary

IDEALFUEL aims to develop an efficient and low-cost chemical pathway to convert lignocellulosic biomass into a Biogenic Heavy Fuel Oil (Bio-HFO) with ultra-low sulphur levels that can be used as drop-in fuel in the existing maritime fleet. It is also very important for any fuel to be drop-in capable so that the functionality of the current technology is not affected, and the fuel can be easily introduced into the market. In this regard, Tec4Fuels conducts the material compatibility testing in a Hardware in the loop testbench which consists of all the fuel system components of a 4-stroke Marine engine. CoCoS (Complete Common Rail System) is a hardware in the loop testbench in which all the fuel systems components are connected in series and the fuel can be circulated for a specified amount of testing period without combustion [1]. This helps in checking the compatibility of all the fuel components while stressing fuel leading to fuel degradation. This testing can be conducted at different conditions to obtain a detailed picture of fuel interaction with the fuel components. In this project the CoCoS test bench was adapted to the selected marine engine components and the compatibility testing was conducted.
The test bench is adapted to conduct the compatibility testing of the high-pressure pump with the IDEALFUEL. For benchmarking tests, the base line fuel (MGO) is tested, and the control is configured according to the fuel. Although the final Bio-HFO (IDEALFUEL) was not available at the end of project, surrogate mixture was developed from the lab scale samples that are produced at Vertoro, using the GC-MS results of the sample. The surrogate is mainly the worst-case test fuel with the components that are more relevant to component compatibility. This surrogate fuel was tested as a blend to MGO and no abnormalities were observed. Thus, the initial tests with surrogate prove that the Bio-HFO could potentially be a bio-component for MGO, and It is drop-in capable at 10 %V/V blending ratio.

Contents

Table of Figures

1 Introduction

IDEALFUEL aims to develop an efficient and low-cost chemical pathway to convert lignocellulosic biomass into a Biogenic Heavy Fuel Oil (Bio-HFO) with ultra-low sulphur levels that can be used as drop-in fuel in the existing maritime fleet. In this project, Tec4Fuels conducts the drop-in compatibility testing of the fuel using the Hardware in the loop method. As a part of the work package 4 and task 4.3.3: the compatibility of the IDEALFUEL and its blends with marine 4-stroke engine components were tested. This serves as one of the indicative input factors for the engine testing and infrastructure selection of the specified fuel. The current document serves as a follow up report for the deliverable D4.2 with results of surrogate Bio-HFO.

1.1 Drop-in compatibility

With the introduction of various renewable fuels, drop-in capability of the renewable fuels is of utmost importance, which implies, the fuel must be usable in the already existing technology without loss of efficiency and power output. In this regard, Tec4fuels will be conducting the hardware in the loop testing of these fuels and its blends in a complete common rail system (CoCoS) – test bench. This involves the testing of interaction of fuel injection system components of a 4-stroke marine engine with this new fuel [1, 2]. The hardware in the loop test bench was successfully adapted to the marine high-pressure pump operation and initial tests with the marine gas oil (MGO) were performed as benchmark.

2 Complete common rail system

Complete common rail system (CoCoS) is a hardware in the loop test bench which consists of all the fuel injection system components connected in a closed loop. The main difference to an engine testing is the avoidance of combustion which helps in recollecting the fuel back to the supply tank [1]. The closed loop of the test bench consists of a supply pump, fuel filter, high-pressure pump, rail, and the injector. The injector is then connected to a reactor with the help of heating block. The fuel is injected into the reactor, where the fuel spray is allowed to condense and collected back to the tank. Thus, by recollecting the fuel, it can be reused in the closed loop which helps in applying additional stress and eventually lead to fuel degradation. The testing parameters of the components are flexible to select rail pressures up to 2000 bar, and the injection timing are variable upon requirement. To emulate the real-life conditions of an atmosphere, the injector tip is heated up to higher temperatures such as 230 °C to 280 °C. Finally, the test cycle is flexing depending on the quality of the fuel or the requirement of the stress conditions on the components or the fuel [1, 2]. This flexible testing helps in identifying the compatibility of the fuel with the components which can act as a screening test before the Engine testing. The flexibility of the test to use smaller fuel volumes and quick testing times have the advantage over engine testing to save commissioning time, effort, and infrastructure requirements. Although until current project start, the testing was developed for passenger car technology and in the current project, the test method was adapted to marine 4 - stroke system and a new test bench was built for the dedicated testing in the IDEALFUEL project.

2.1 Adaptation to Marine fuel injection system

In the current project, the principle of the CoCoS is implemented to the marine engine components to check the drop-in compatibility of the IDEALFUEL. Thus, the CoCoS setup was built for the 4-stroke marine engine components. However, after contacting different suppliers regarding the criticalities of the 4-stroke engine fuel injection systems, it was concluded that most of the problems lie within the high-pressure pump such as cavitation, lubricity, etc. Thus, the CoCoS method has been adapted as a component specific test bench where the high-pressure pump will be tested under different conditions and an optimised test will be developed. The pump used in the current setup is Liebherr LP1 1.2-22 Gen2.1 (Max. 2 litre/minute). Figure 1 shows the P&ID of the test setup:

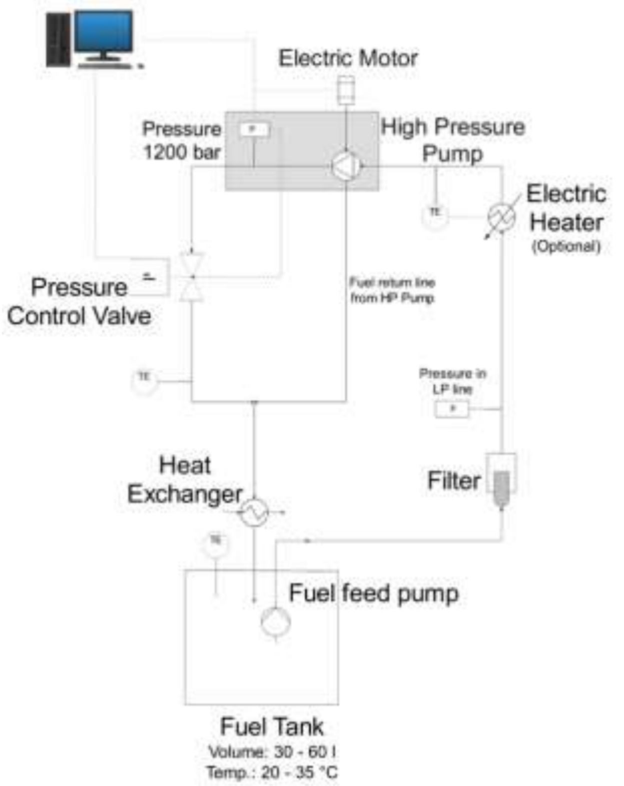

Figure 1: P&ID diagram of the IDEALFUEL test setup.

To adapt for the testing of high-pressure pump, the injector and the rail is replaced by a throttle valve and a pressure sensor. So, the fuel supply pump sends the fuel through the fuel filter to the high-pressure pump. The throttle valve generates the back pressure required for the high-pressure pump and the desired pressure is generated. This fuel is then expanded after the throttle and sent back to the tank along with the fuel return line of the high-pressure pump. The return lines are sent through a heat exchanger to keep the tank temperature below 50 °C. The compression and the expansion of the fuel generates high temperatures, and the influence of constant heat up and cool down of the fuel induces stress which lead to fuel degradation [1, 2]. Thus, the degraded fuel is also used to test the influence of degraded fuel on the components and observe the long-term compatibility of the fuel with the components. The test is also planned to run in cycles with constant ON and OFF phases to allow the cooling of tank to room temperature and, allow the high polymer molecules (formed due to fuel degradation) to sediment in the components. This could influence the functionality of the components. Thus, the method allows the use of as low as 30 litres of fuel sample per test and also helps in accelerating the testing time to nearly 100 h [2, 3]. Although further reduction of sample volumes and test times are possible with changing the experimental conditions upon requirement. Figure 3 shows the setup of the test bench: The grey high-pressure pump is attached to the motor with the help of an adapter. This adapter also helps in lubricating high-pressure pump. This high-pressure pump is then connected to the pressure sensor and then the throttle for the pressure and flow regulations.

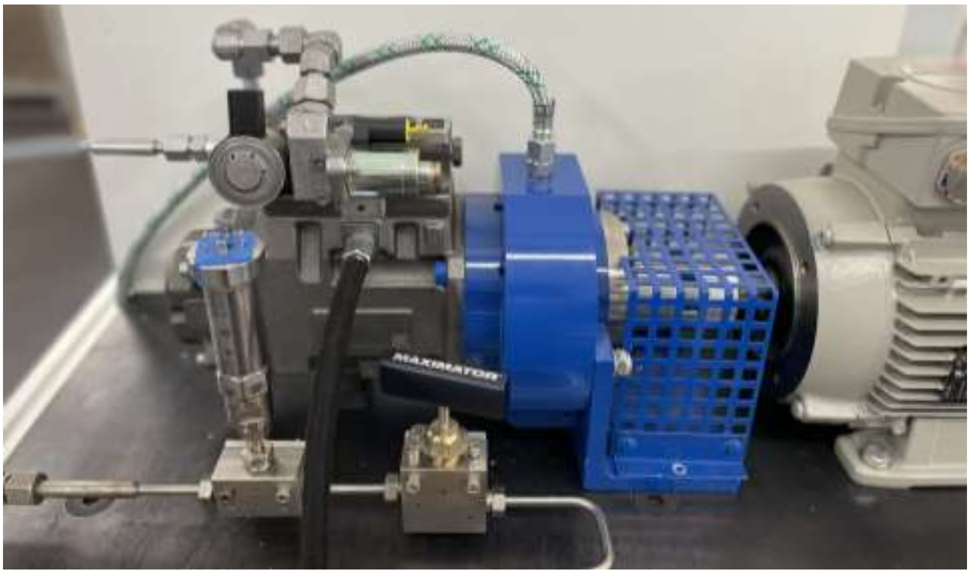

Figure 2: Test bench set-up with high-pressure pump connected to the throttle and a pressure sensor.

2.1.1 Operational safety

While handling these moderate fuel quantities (15 - 30 litres), the operational safety of the testbench is limited to a very few but important factors. Firstly, as the fuel is heated up to higher temperatures above the fuel's flash point, to avoid any possibility of flame/ignition in the fuel tank, it is placed below the testbench with enough distance away from all the electrical connections. The electrical connections to the in-tank pump are isolated from each other using a plastics holder to avoid any shortage. Also, the fuel tank is maintained at room temperature by cooling down the fuel return line from the high-pressure pump and fuel leak line. The high temperature fuel after throttle is directly sent to the heat exchanger where it is cooled to below its flash point. This avoids any fuel vapours in the fuel tank. Also, the hot fuel is contained completely in the fuel line with no access to the additional oxygen to avoid any ignition.

Secondly, all the high-pressure and low-pressure connections are fitted tightly to avoid any leakages. Especially leakages near the throttle are very critical as the temperatures exceed the fuel's flash and fire points. In this regard, the connections are sealed very carefully and monitored regularly for leakages. The hot fuel is then sent directly to the fuel tank where the fuel is directly quenched in the fuel bath which is maintained at room temperatures. As the test bench is allowed to run over night, to avoid any failure of fuel connections leading to fuel leakage, the

in-tank pump is inserted into the fuel tank only until a designated level, such that any leakage would stop only after the loss of few litres of the fuel.
Finally, failure of any component such as the pump can be identified by the sudden pressure variations, the cooling failure by fuel tank temperature, etc., by the online interface of the test bench control which immediately shuts down the entire testbench and avoids any critical issues. Also, for safety reasons the testbench is enclosed in a closed cabin which is also fitted with an exhaust system. These cabins are also fitted with the CO sensors to detect any harmful gases or flames in case of emergency.

2.2 Selection of testing parameters

For IDEALFUEL project, the test parameters concentrate solely on the high-pressure pump. The selected pressure for the high-pressure pump will be a medium load condition which is 1000 bar. As the surrogate Bio-HFO was also available in limited quantities the CoCoS testing is further simplified to adapt the test parameters for as low as 15 litres of test fuel when compared to standard 30 litres. Thus, the operating pressure have also been reduced to 600 bar, in order not to stress the fuel too much. The control was then configured to this pressure set point. The fuel volume was limited to 30 litres per test. Although, if necessary, the fuel volumes can be further decreased to induce more stress to the fuel and check its failure criteria. The tests are also run in a cycled operation with 2 hours ON phase and 45 minutes OFF for 8 cycles and 2 hours long break to finish a 24 h cycle. The constant pressurising and expansion after the throttle have led to a raise in temperature of the fuel in the return line to as high as 125 °C. This is then further cooled using heat exchangers. As features of security the following measures were installed in the control:

1. A drop of pressure by 200 bar from the setpoint will stop the test immediately.
2. The temperature of the fuel tank is always under 55 °C (below the fuel flash point).

3 Results and Discussion

3.1 Benchmarking

To initially configure the test bench, the setup is tested with a market available and fully compatible marine gas oil (MGO) as a base line fuel. The test bench control is configured using this base line fuel and an initial test is conducted to check the testing parameters effect. The results of this testing are mentioned in the Deliverable D4.2. Thus, the fully functional test method is applied on the IDEALFUEL to check the drop in compatibility of the fuel.

3.2 Surrogate Formulation

Due to the unavailability of final Bio-HFO (IDEALFUEL) in the necessary volumes for the CoCoS testing, a surrogate fuel has been formulated along with the support of consortium. The key components of the Bio-HFO has been determined using the GC-MS measurements from partner CSIC. Out of these components, the actual influential components for compatibility are selected and they are used to formulate the surrogate. For this formulation and the quantity of these components, their quantity in the actual Bio-HFO and Viscosity has been the key parameter of reference. The Table 1 shows the components for the surrogate formulation. This surrogate then in turn mixed with the standard Marine HFO (Heavy fuel oil) to complete the Bio-HFO recipe. Thus, the Bio-HFO is then used in the CoCoS test bench to check the compatibility of the fuel with the components.

Table 1: components for the surrogate formulation

Components for Surrogate	Density in kg/l	Flash point in °C
Ethers		
Trimethylene glycol monomethyl ether	1.026 (25 °C)	110
Esters		
Pentanoic acid, 4-oxo-, ethyl ester (Ethyl-Levulinate)	1.016 (25 °C)	94
Ketones		
2(3H)-Furanone, dihydro-5-methyl- (Valerolacetone)	1.05 (25 °C)	110,5
2,5-Hexanedione	0.974 (20 °C)	79
Aldehydes		
Furfural	1.16 (25 °C)	58
2-Furancarboxaldehyde, 5-methyl- (Methyl-Fufural)	1.107 (25 °C)	72
Acids		
Pentanoic acid, 4-oxo- (Levulinic Acid)	1.134	98
Alcohols		
2-Methoxy-4-Methylphenol	1.092 (25 °C)	99

3.3 CoCoS Tests

Figure 3 shows the 24 hour cycle of the initial test conducted with the 10 % blend of Bio-HFO in MGO. The test was conducted with 15 l fuel sample and for 100 h of effective run time. The components have successfully run for the testing time without any functional challenges. The pressure remained constant during the test time, no abnormalities have been observed in the functionality of the High pressure pump.

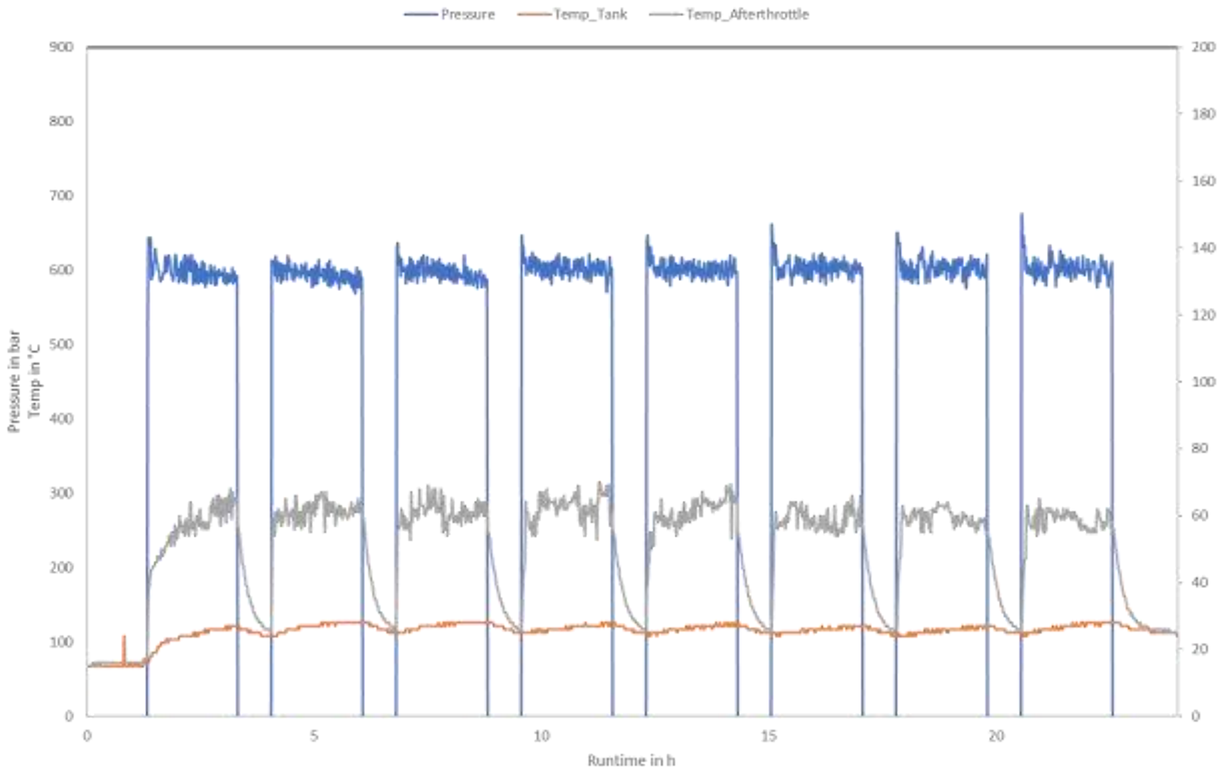

Figure 3: 24-hour test-cycle of the hardware in the loop test of the 10 % Bio-HFO blen in MGO.

3.4 Pump and Fuel Analysis

In the test with 10 % Bio-HFO blend, no significant abnormalities have been observed inside the high pressure pump, Figure 4. Thus, no functional problems have also been observed. Although in Figure 5, the fuel has shown sedimentation in the tank and on the low pressure pump. However, the sediments have been filtered out through the filter before the high pressure pump and no influence on the high pressure pump was observed. Thus in the final formulation T4F suggests the usage of additive to avoid the sedimentation in the tank.

Figure 4: The High pressure pump components from test run with 10 % Bio-HFO.

Figure 5: The fuel sediments in the tank and on the low pressure pump from test run with 10 % Bio-HFO.

4 Conclusion

In the task 4.3, T4F has successfully developed a methodology to investigate the component compatibility of Marine fuels in the 4-strocke high speed engine equipment. The test bench has successfully worked with the baseline MGO and also with the 10 % blend of Bio-HFO in MGO for 100 h test time. The testing will continue with 20 % and 30 % blends as well in the coming last days of the project and the results will be notified in the final report of the project. The key outcome for T4F is the usability of as low as 15 liters of fuel in the testbench which significantly reduced the necessity for high volumes in the future testing endeavors.

5 References

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[2] Hoffmann, Hajo. A Contribution to the Investigation of Internal Diesel Injector Deposits. Herzogenrath : Shaker Verlag GmbH, 2018. ISBN 978-3-8440-5953-3
[3] Hoffmann, Hajo; Sebastian Deist; Koch, Winfried; Lucka, Klaus; Development of a Non-Engine Fuel Injector Deposit Fuel Test: Results: TAE, Ostfildern 2015

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Project partners:

#	Partner short name	Partner Full Name
1	TUE	Technische Universiteit Eindhoven
2	VERT	Vertoro BV
3	T4F	Tec4Fuels
4	BLOOM	Bloom Biorenewables Ltd
5	UNR	Uniresearch B.V.
6	WinGD	Winterthur Gas & Diesel AG
7		(Formerly SeaNRG, is now GOODFUELS #12)
8	TKMS	Thyssenkrupp Marine Systems GMBH
9	OWI	OWI – Science for Fuels gGmbH
10	CSIC	Agencia Estatal Consejo Superior De Investigaciones Cientificas
11	VARO	Varo Energy Netherlands BV
12	GOOD	GoodFuels B.V.

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