D3.16 Demonstration on application of methanol: compression ignited vs dual fuel

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

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Executive Summary

As part of Work Package 3 (WP3) of the SYNERGETICS project, SNAOS is tasked with demonstrating the performance of marine dual fuel and compression-ignited methanol engines. Deliverable D3.16 is a deliverable of type "demonstrator, pilot, prototype" (DEM). Demonstration for the consortium partners took place on June 14 in Gothenburg. This document provides additional information on the background, test setup and plans.

Methanol combustion engine technology in general is presented as part of Deliverable D1.1. Here the concept of compression ignited methanol engines and dual fuel methanol engines are covered. The particular planning and set-up of the test are described. Results, further testing, evaluation and comparison of the engines will be described in deliverable D3.17, with due date M24.

The compression-ignited engine technology, which utilizes an ignition improver, is currently available on the market through Enmar Engines, a sister company of SNAOS. To enable a comprehensive comparison of this technology with dual fuel system, the development of a dual fuel conversion kit for a similar engine is necessary. Dual fuel concept developed for comparison is one utilizing port injection. Once a dual fuel conversion kit is available, it is to be tested and compared on four characteristics: engine power, engine efficiency, Diesel replacement fraction and emissions.

Testing will be conducted in accordance with the ISO8178 standard, ensuring that the results are reliable and adhere to industry benchmarks. This comparative analysis will provide valuable insights into the viability and performance of methanol as a marine fuel, potentially guiding future advancements in sustainable marine propulsion technologies.

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1. | Introduction

1.1 Objective

Objective of this document is to describe test planning and test set-up for comparison of a compression ignited and a dual fuel methanol engine. Test results, evaluation and final comparison of engines will be described in the next deliverable D3.17, with due date M24. Brief description of the considered methanol combustion engine technologies is included here for context. Further technologies relevant for marine applications are included in deliverable D1.1.

1.2 Dual fuel port injection (DF-PI)

All major marine engine suppliers have dual fuel engines where methane gas (LNG) can replace a significant part of the HFO or MGO. The same concept can be used for methanol by replacing the gas valve with a methanol injector. This methanol injector is placed upstream of the inlet valve.

On diesel mode, the engine runs on normal diesel cycle. When switched to methanol mode, the engine runs on a dual combustion cycle. The main fuel is injected from the methanol injector and into the combustion chamber with intake air, and a burst of pilot fuel initiates the combustion at top dead centre (TDC).

Dual fuel engines normally operate on lean mixtures in methanol mode as the pilot fuel is sufficient to ensure combustion. This allows for higher compression ratio and thus higher efficiency, compared to a throttle SI engine.

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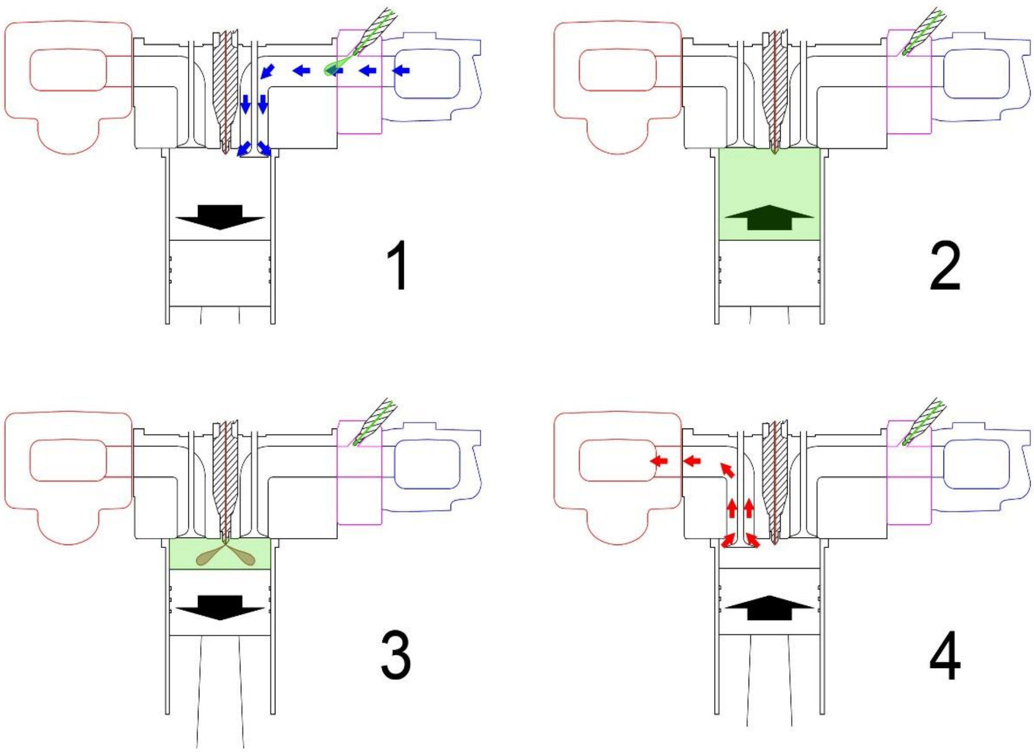

1 | The combustion principles of 4-stroke port injected engine with diesel pilot ignition

1. The piston moves down, methanol injects from the port into the inlet air
2. The piston moves up and compresses the air-methanol mixture, temperature and pressure are increased
3. Close to TDC the diesel is injected as pilot fuel and ignites the compressed methanol air mix in the cylinder. The piston is then pushed down by the expansion of the hot gases.
4. The exhaust gases are pushed out through the exhaust valve.

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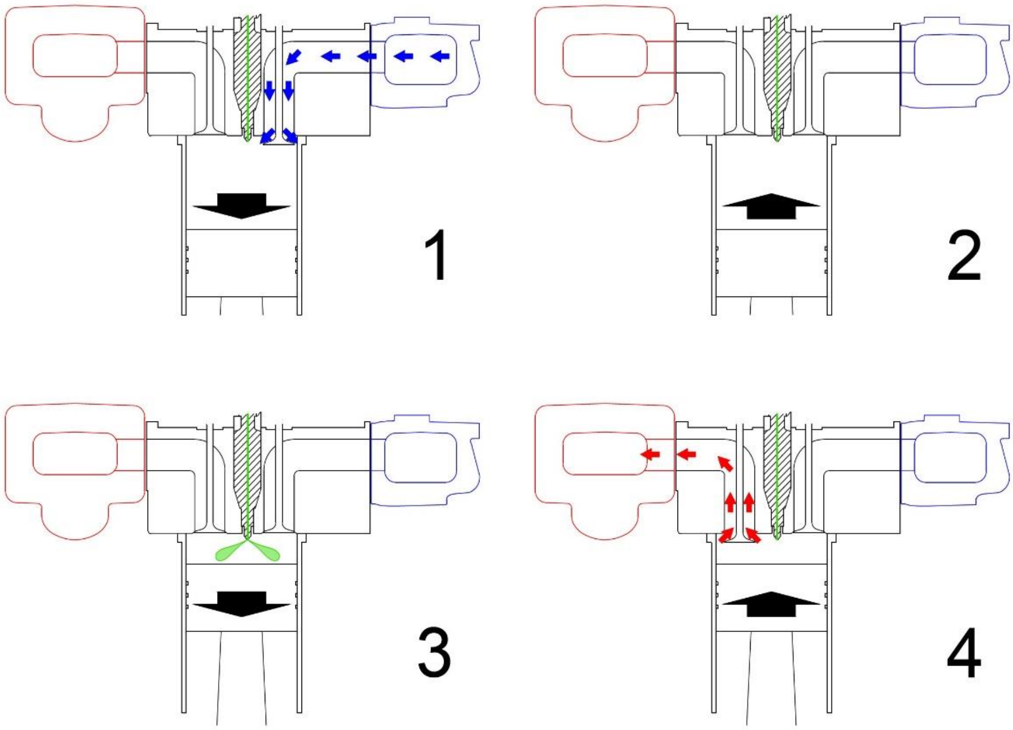
1.3 Compression ignited, with ignition improver (CI)

The low cetane number and high octane number of pure methanol makes it more suitable for spark ignited Otto combustion. However, by adding an ignition improver the characteristics of methanol are changed, so it can be used as single fuel in a compression ignited engine. Scania developed this concept for ethanol in the 1980s and has used it extensively for busses and trucks. Ethanol and methanol have comparable combustion characteristics and the concept has now been adopted for marine and industrial compression ignited methanol engines.



2 | The combustion principle of compression ignited methanol engine

The concept is based on the modification of Scania marine and industrial engines by using original Scania components from their ethanol (ED95) bus and truck engines.

1. The piston moves down, and air enters the cylinder
2. The piston moves up and compresses the air, temperature and pressure are increased
3. Methanol with ignition improver and lubricant are injected, piston moves down
4. The emission gases are pushed out through the exhaust valve.

Today Enmar Engines are selling compression ignited methanol engines that uses MD97 fuel. The fuel contains methanol and 3% Beraid ignition improver as well as a small fraction of lubricant. The engines are based on the Scania marine engines with several modifications, including alcohol fuel injectors and higher compression pistons. With the ignition improver, the engine can run on diesel cycle with methanol and provides similar performance as a diesel engine with high efficiency and fulfils IMO tier III NOx emission levels without after treatment system, according to the manufacturer.

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3 | Compression ignited methanol (MD97) engine 16LV8 415 kW at 2100 rpm, available from Enmar Engines AB

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2. | Methanol concepts compared in subtask 3.4.1

2.1 Introduction

Two similar high-speed methanol powered marine engines are being compared. One is compression ignited and the other is a dual fuel methanol diesel engine.

The compression ignited concept

The compression ignited concept is currently only available for Scania based engines. The reason is that only Scania has a high-pressure fuel injector developed for alcohol fuel.

Enmar Engines AB, a sister company of SNAOS, has developed and is marketing a compression ignited marine methanol engine. The engine is based on a Scania marine engine with hardware adopted from the Scania compression ignited ethanol engines that are available for trucks and busses. The engine control system is developed by and is the proprietary of Enmar Engines AB.

The dual fuel concept

The dual fuel concept is widely adopted for natural gas where most engine manufacturers today can offer a dual fuel gas-diesel solutions. Only few methanol-diesel dual fuel engines exist and none for the high-speed engine category.

In order to compare the performance of the Scania based compression ignited engine to a dual fuel engine of similar type, a dual fuel conversion kit had to be developed.

2.2 Development of a dual fuel conversion kit

To enable a larger impact from the development work, it was decided to make the conversion kit generic to the largest possible extent. This means that all parts, except the direct physical interface to the engine, can be adopted for any diesel engine.

The dual fuel conversion kit development can be divided in the generic part and the engine specific part

2.2.1 Dual fuel conversion kit development - generic part

The generic development was done on Volvo Penta 13L and Volvo Penta 16L engines which, from dual fuel perspective, are very similar to the Scania 13L engine. Thereby, the results are directly applicable to the subtask 3.4.1.

To ensure good performance and that each cylinder has similar operation conditions, a study of different positions, orientation, and spray angles of the fuel injectors had to be done. This effects the fumigation, i.e. how well the methanol mixes with the inlet air and how the methanol concentrations vary in the cylinder. This has in turn significant impact when knocking occurs. Knocking is typically one of the limits for how much diesel can be replaced with methanol.

CFD analysis was made to understand the behaviour in the inlet manifold and how the design can be improved. It could be seen that it is very important to get the injector to spray directly into the inlet port in order to avoid that the fuel/air blend gets richer and richer for the down stream cylinders.

The second task was to develop the methanol injection control system. The methanol fuel injectors are fitted in the modified inlet manifold. Multiple point injection has been chosen for more stable performance and even operation conditions. Diesel injection strategy is tuned for dual fuel application. The goal was to increase methanol energy fraction, reduce NOx and knock, while retaining efficiency. Tuning was done in an iterative manner for optimization. Results will be disclosed in deliverable D3.17.

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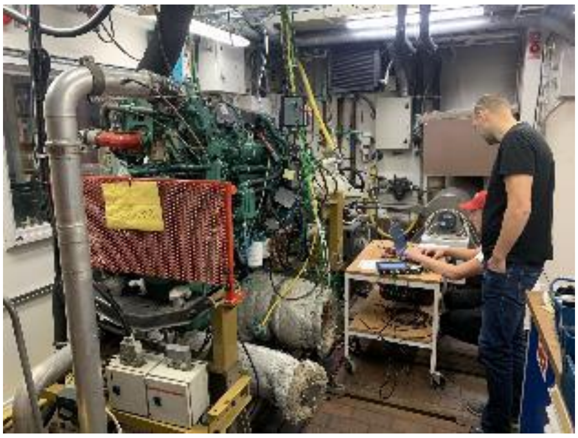
The injection timing is controlled by an add-on engine control unit, (methanol ECU). During operation the original ECU receives input from an external controller (i.e. the speed control handle at the operation station) which demands a certain engine speed (rpm). The signal is relayed from the original ECU to the methanol ECU. Within scope of engine, ECUs are be recalibrated for dual fuel. Outside of the scope of engine, the same performance will be retained regarding controllers. At idle speed, the engine runs on diesel only. At a certain engine speed, diesel injection is reduced and at the same instant, the methanol ECU activates the methanol fuel injectors to inject a sufficient amount of methanol to reach/maintain the rpm demanded by the external controller. The ECUs are communicating via the CAN-bus J1939 protocol. The development of the basic dual fuel functionality includes the handshake procedure, precise communication format, conditions for activating and deactivating the dual fuel mode. This is generic functionality for all future dual fuel engines.



4 | Development and testing of the methanol injection control system

2.2.2 Dual fuel conversion kit development – engine specific part

The engine specific part of the dual fuel conversion kit development contains two principal tasks.

1) Physical interface
2) Development of the methanol fuel map.

The physical interface includes a new air inlet manifold so that methanol fuel injectors can be fitted at the best location without interfering with fuel pipes and other equipment on the engine as well as to meet requirement of double boundary enclosure. A double walled fuel rail must also be fitted to feed the fuel injectors.

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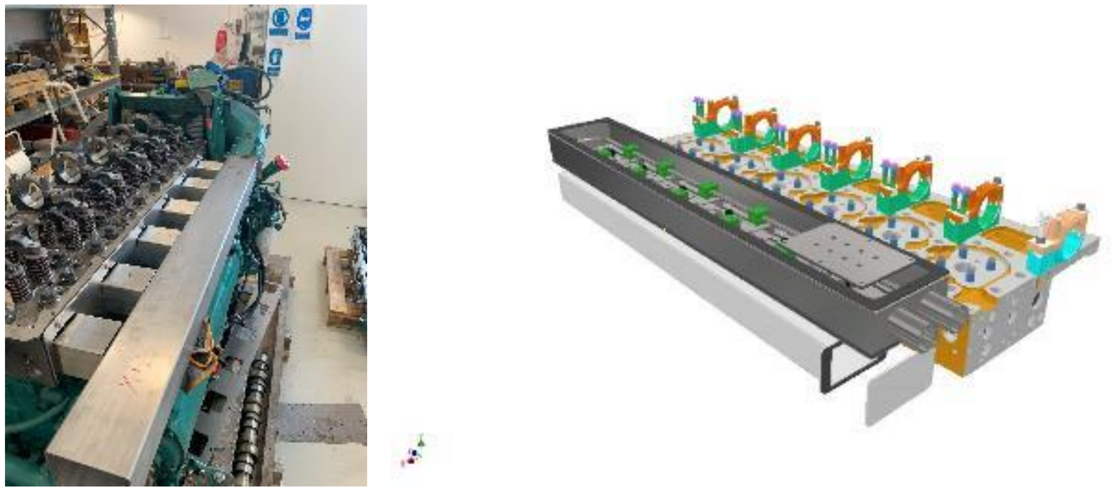

5 | New air inlet manifold

The development of a basic methanol fuel map requires about 50 – 100 hours on an engine dyno where the amount of methanol and diesel for each operation point is defined. For the comparison, only a few load points will be tuned in an iterative process to maximize methanol energy fraction, while retaining efficiency and stable combustion. The objective is to maximize the amount of methanol without occurrence of knocking while maintaining high engine efficiency and emissions below the defined limits. Peak pressure rise rate should be below 1.5 MPa/CAD and engine efficiency over 40%.

3. | Planning and set-up of the tests

3.1 Engine technology comparison

Two concepts are tested and compared within SYNERGETICS: MD97 (compression ignited, single fuel, methanol) and DF (dual fuel, port fuel injection, diesel-methanol). Note that MD97 is a developed product available on the market from Enmar Engines company while DF is in development phase.

3.2 Experiment set-up

Relevant characteristics to test and compare:

- Engine power (speed and load)
- Engine efficiency (fuel consumption)
- Fuel ratio (methanol fraction)
- Emissions

In the figure 6, a schematic set-up of engine test is shown. Engine power is measured by dynamometer, fuel consumption by AVL fuel balance systems. NOx, CO, CO2, O2 and HC are measured percentage-wise at the end of exhaust using HORIBA analyser and afterwards calculated according to IMO NOx technical code.

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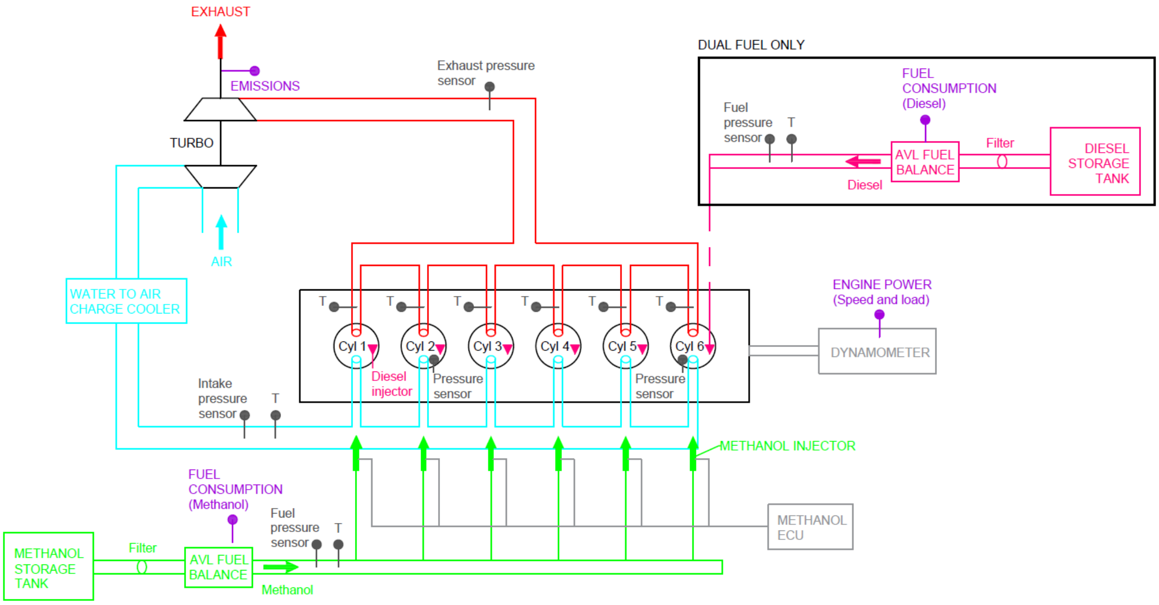

6 | Engines measurement points

Test on the dual fuel concept will be done with IMPCA methanol and Diesel MK1. Test on the compression ignited engine will be done with MD97 methanol fuel. MD97 test fuel characteristics can be found in table 1.

1 | MD97 Test fuel data

Fuel component	Target mix (w/w)	Acceptable mix (w/w)
Methanol (IMPCA)	96.9%	96.35-97.05%
Beraid 3555M[1)]	3.0%	2.90-3.50%
Armolube 211[1)]	0.1%	0.05-0.15%
Alt. Ethomeen O/12[1)] (Replaces Armolube 211)	0.1%	0.05-0.15%
Density	ISO 3675	0.795-0.810 kg/dm3

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3.3 Test programme

Test programme is set by ISO8178 – international standard for exhaust emission measurement. The standard includes collection of steady-state engine dynamometer test cycles. Test to be done is Type D2 – for constant speed, generating sets with intermittent load. Five test modes are defined, see table 2.

2 | Test modes definition as per ISO8178

Test modes, Type D2	Torque	Weighting factor
Mode 1	100%	0.05
Mode 2	75%	0.25
Mode 3	50%	0.30
Mode 4	25%	0.30
Mode 5	10%	0.10

All tests will be done at constant speed of 1500 RPM. This speed is chosen to enable comparison with generators that most often operate at 1500 rpm. Maximum specific engine power of MD97 and DF might differ, therefore test points for DF engine will be aligned with specific power of MD97. Results will be normalized.

3.4 Test results

Test results will be presented in D3.17.

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