

Subject		Page
Test report after tests of 3 emulsified fuel oil and water mixture in boiler		1 of 6
Issued by	Department	Date
Lars Bo Andersen	Test Centre Aalborg	28 Dec 2023

Test of FOWE ECO Solutions in Alfa Laval Test & Training Centre, Aalborg, Denmark

Introduction:

This report describes the learnings from 10%, 15% and 20% emulsified fuel oil and water mixture tests in Alfa Laval Test & Training Centre Aalborg, Denmark

Overall test goal

The test-run was requested by FOWE to verify performance and emissions of boiler when combusting emulsified oil (eFO) prepared by FOWE CAVITECH device. The boiler should be kept, if possible, in "as-is" conditions to simulate an existing system.

Executive summary

Test was done with 3 fuels oil with different water content. A base test non-modified fuel oil and a 10%, 15% and 20% emulsion. Same test plan and measurements was used for all tests and comparison was made to the base test.

A scrapped 15% pre-test indicated that a rebuild of the return line to be pressurized to 2 barg was needed for handling the eFO in order to avoid evaporation.

Highlights from test on OS-TCi boiler with pressure atomizing burner and rebuild pressurized return line compared to base test:

- eFO with 10% water content: Steam output app. 10% lower than base test. No reduction observed in NOx emissions. The objective of the first eFO with 10% water content was to observe operation of the burner on emulsion and to verify if any further adjustments had to be done.
- eFO with 15% water content: Steam output app. 10% lower than base test. NOx in line with base test or a little higher, see appendix 1. The objective of this test was to verify potential fuel saving.
- eFO with 20% water content: Lower steam output compared to base test on same fuel input. NOx reduction was seen compared to base test. The objective of this test was to verify potential emissions reductions.

Short conclusion:

Expectation from FOWE was that fuel saving and emissions reduction would be seen during the test. The gathered test data indicates potential for fuel saving based on FOWE flowmeter equipment readings.

The 20% emulsion shows no improvement in fuel consumption but result on emission reduction. Generally, the 20% eFO was difficult to combust, and a break-away flame was seen where the flame leaves the swirler and combust further out in the combustion chamber. This causes lower steam production, which may have been enforced by the existing electrical fuel heater lacking capacity for handling 20% eFO.

Main equipment used during and prior to test:

- FOWE Solution CAVITECH installed to prepare the test oil.
- FOWE Flowmeter Bellflow-systems BFU-100 RF clamp-on on oil flow measurement
- FOWE Flowmeter Massflow Online – Magnetic Inductive flow Sensor MVM-060-PA measurement on water flow measurement
- Fuel Oil: 180 cSt VLSFO 0,5% delivered by BunkerOne
- 25m³ heated double walled HFO tank, 25m³ heated double walled stainless-steel tank, 2 m³ heated double walled day-tank.
- HFO Separator ALCAP S805
- Fuel supply system for 2t boiler with modified pressurized return line to 2 barg.
- Coriolis oil-flow meter type E&H Promass F on return line
- Coriolis oil-flow meter type Siemens FC430 on supply line.
- OS-TCi, 2 t/h steam boiler
- Multi Fuel Burner type MF PA 1.7 (pressure atomizing burner, max fuel flow 150 kg/h)
- Various equipment from Force Technology for emission measurement.
- Detailed boiler and burner performance scheme with flows, pressures, temperature, density, cSt. with more - measured during test.
- Handheld emission measurement device Testo 350,
- NO_x, CO₂ measurement in exhaust gas by Norsk Analyse

Preparation for test

The VLSFO was run through separator from and to HFO/ALT tank 2 times prior to each test. All systems were inspected and cleaning of relevant components in the fuel system was executed before the test run (e.g., FO filter, Nozzles, and valves)

The return line on the fuel supply system was modified to be pressurized to app. 2 barg pressure. Pressure on fuel line was increased with 2 bar to keep differential pressure over fuel nozzle the same.

Preparation of the eFO was made using the FOWE CAVITEC solution connected to the fuel tank system in the Test Centre. Various equipment was added e.g., booster pump with VFD, tracing and insulation of pumps with more to ensure a trouble-free operation.

Test run

- **VLSFO Base test (see attached test report under tab “Test 1 - HFO Base test”:**
 - The base test was obtained without modifying the return line thus the data obtained during test will be matching a potential retrofit application.
- **VLSFO Base test 1.1 (See attached test report under tab “Test 1.1 - HFO Base test”**
 - Same as above but with pressurized return line and extra measuring point, see steam measurement vs fuel consumption in appendix 1, figure 1.
- **Test 2.1 - Pre test 10%. (See attached test report under tab “Test 2.1 - Pre test 10%.”**
 - Test Day 1:
 - Production of emulsion oil
 - Boiler start-up/heat up on natural gas.
 - Prepare systems for 10% emulsion oil.
 - Test Day 2
 - Boiler start-up
 - Test with 10% FOWE oil emulsion on boiler
 - AL measurement at load points similar to base test
- **Test 3 - Test 15%. (See attached test report under tab “Test 3 - Test 15%”**
 - Test Day 1:
 - Production of emulsion oil
 - Boiler start-up/heat up on natural gas.
 - Prepare systems for 15% emulsion oil.

- Test Day 2
 - Boiler start-up
 - Test with 15% FOWE oil emulsion on boiler
AL measurement at load points similar to base test
- **Test 4 - Test 20%%. (See attached test report under tab “Test 4 - Test 20%”)**
 - Test Day 1:
 - Production of emulsion oil
 - Boiler start-up/heat up on natural gas.
 - Prepare systems for 20% emulsion oil.
 - Test Day 2
 - Boiler start-up
 - Test with 20% FOWE oil emulsion on boiler
AL measurement at load points similar to base test

Learning/observation during test

Disclaimer:

The learnings/observations during test can be interpreted in various ways depending on the measurement equipment used. Whenever indications are based upon a specific measurement device, the report will indicate this. Alfa Laval has facilitated a test in its test centre and does not warrant or take any responsibility in relation to the test results or the interpretation hereof. Particularly, Alfa Laval cannot and does not warrant any indicated fuel savings or emissions reduction stated in this report.

Test 2.1 - Pre test 10%.

- Steam production running on emulsified fuel app. 10% lower than base test. Adjusting for water content, which was measured by FOWE flowmeters to be 10%, the steam production is inline or vaguely better if instrument tolerances are considered, see Appendix 1, Figure 1 and 2.
- NOx level at level or higher than on the base oil test, see Appendix 2, Figure 1. Exhaust gas temperatures in line with base test.

Observations during test

- Ignition OK
- Brighter flame in combustion chamber.
- Flame has same size in combustion chamber as normally seen on FO.

Conclusion Test 2.1 – Pre test 10%

The 10% emulsion shows inline or slight improvement in fuel consumption based on FOWE flowmeter readings. No emissions reduction is seen. Reduction in exhaust gas temperature is not seen, so WHR would still be possible with emulsified fuel.

Test 3 - Test 15%.

- Steam production running on emulsified fuel app. 10% lower than base test. Adjusting for water content, which was measured by Fowe flowmeters to be 14.21%, the steam production is in line with what was theoretically expected if instrument tolerances are considered, see Appendix 1, Figure 1 and 3.
- NOx level at level or higher than on the base oil test, see Appendix 2, Figure 2. Exhaust gas temperatures in line with base test.

Observations during test

- Ignition OK, but one ignition fault seen.
- Brighter flame in combustion chamber.
- Flame has same size in combustion chamber as normally seen on FO.

Conclusion – Test 15%

The 15% emulsion shows potential improvement in average fuel consumption when FOWE flowmeter measurement is used. No emissions reduction was seen.

During test, we had to stop for filter cleaning. The fouling build-up in the filters was not believed to be due to the emulsion but instead coming from residues loosening in the day tank. The burner nozzle was changed to ensure best possible combustion.

Reduction in exhaust gas temperature is not seen, so WHR would still be possible with emulsified fuel.

Test 4 - Test 20%.

- Steam production significantly lower than on base test. Steam production running on emulsified fuel approx. 28% lower than base test. Adjusting for water content, which was measured by FOWE flowmeters to be 19.91%, the steam production is in line with what was theoretically expected if instrument tolerances are considered, see Appendix 1, Figure 1 and 4.
- NOx level significantly lower than on base oil test in all measurement points, see Appendix 2, Figure 3.
- Exhaust gas temperatures lower at low load but in line with base oil test for higher loads, see Appendix 2, Figure 3.

Observations during test

- Difficult to ignite, several ignition errors were observed, before boiler ignition was achieved.
- Brighter flame in combustion chamber.
- Break away flame from swirler with combustion taking place in the middle of the combustion chamber at max load thus minimizing the potential heat transfer consequently the steam production.

Conclusion – Test 20%

The 20% emulsion shows no improvement in fuel consumption but good result on emission reduction. Generally, the 20% eFO was difficult to combust, and a break-away flame was seen where the flame leaves the swirler and combusts further out in the combustion chamber. This causes lower steam production which was enforced by a lower fuel temperature due to a too small electric heater for heating up the emulsified fuel oil. A redesign of the fuel system might address these challenges.

3 different oil emulsion in boiler

Limited effects are seen when burning fuel oil with 10, 15 and 20% water content in a boiler with a pressure atomizing burner. Great care was taken to ensure correct handling of the eFO both during production, test run and when samples was taken out. Preparing the emulsified oil seems a controlled process with dedicated products and instrumentation for measuring the blend. It is therefore surprising that the laboratory results show such big deviation between what was produced and what was analysed.

Some fuel reduction was seen with 15% water content in the fuel oil if FOWE flowmeter was used for measurement. The steam production is in line with the emulsified fuel consumed and a theoretically calculation, where water is removed from the equation, demonstrates this in Appendix 1. Minor deviations are seen – but these are considered within the tolerances of the measurement instrumentations.

NOx reduction is seen on 20% water content but here steam production was very low.

For all emulsions, the exhaust gas temperatures remain in line with base test. This is a contradiction which has not been experienced earlier when water is in the fuel. Normally, a drop in exhaust gas temperatures are seen but with cavitation emulsified oil, this is not the case thus allowing for WHR as a potential energy efficiency increase solution.

It is expected that long time operation on emulsified fuel oil potentially could lead to a “cleaner” boiler with minor build-up of residues in piping and on heating surfaces. The short time test executed has not been able to verify that.

Conclusion

It seems possible to combust the emulsified fuel oil and water mixture if the fuel supply return line is pressurized and the water content is kept below 15%. This will minimize the struggle/number of needed fuels onboard a vessel in case the operator chooses to use eFO on ME or AUX.

A potential fuel reduction is seen on 15% eFO, when FOWE flowmeter is used for measuring. The potential emission reduction on 20% emulsion should be evaluated carefully towards the reduced steam production that follows by the relative high-water content needing evaporation in the fuel oil. Perhaps a reduced steam output is permissible in some use cases where NOx reduction is more important.



Appendix 1: Steam vs fuel consumption Avg. from AL datalog from FOWE tests

Water content in emulsion measured by FOWE flowmeters.

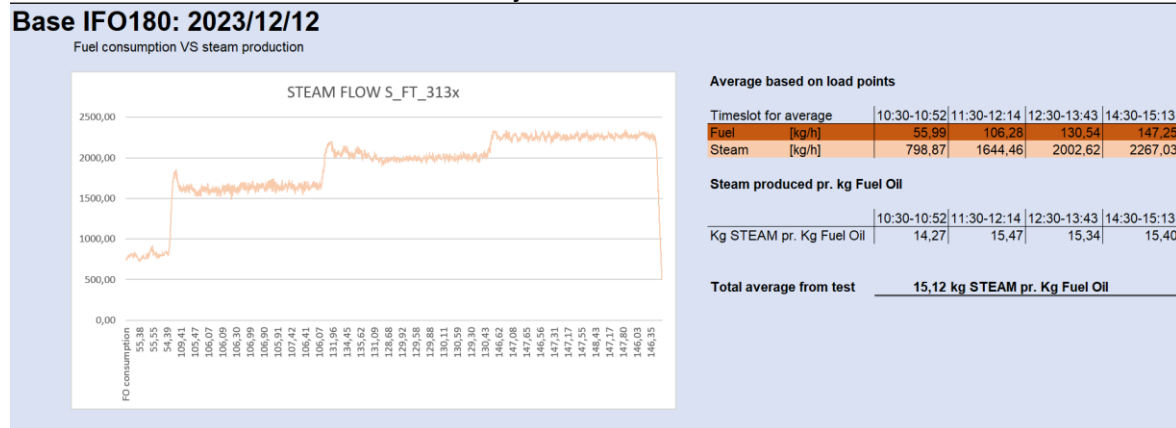


Figure 1 Base test

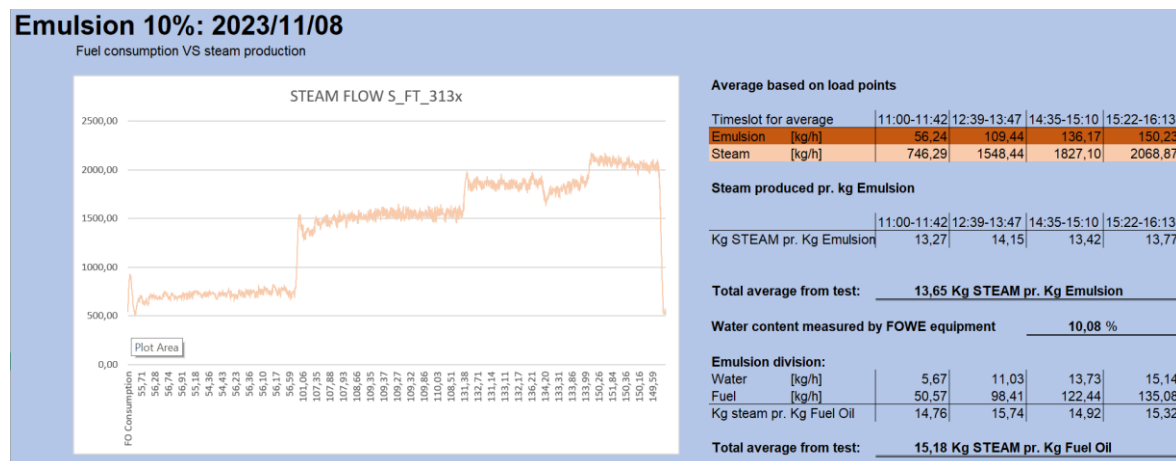


Figure 2 10% Emulsion

Appendix 1: Steam vs fuel consumption Avg. from AL datalog from FOWE tests

Water content in emulsion measured by FOWE flowmeters.

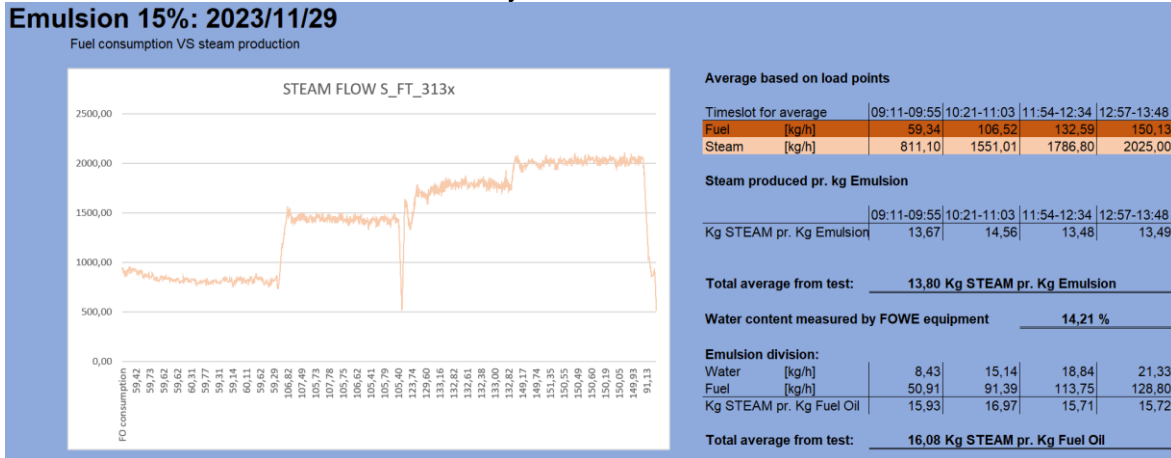


Figure 3 15% Emulsion

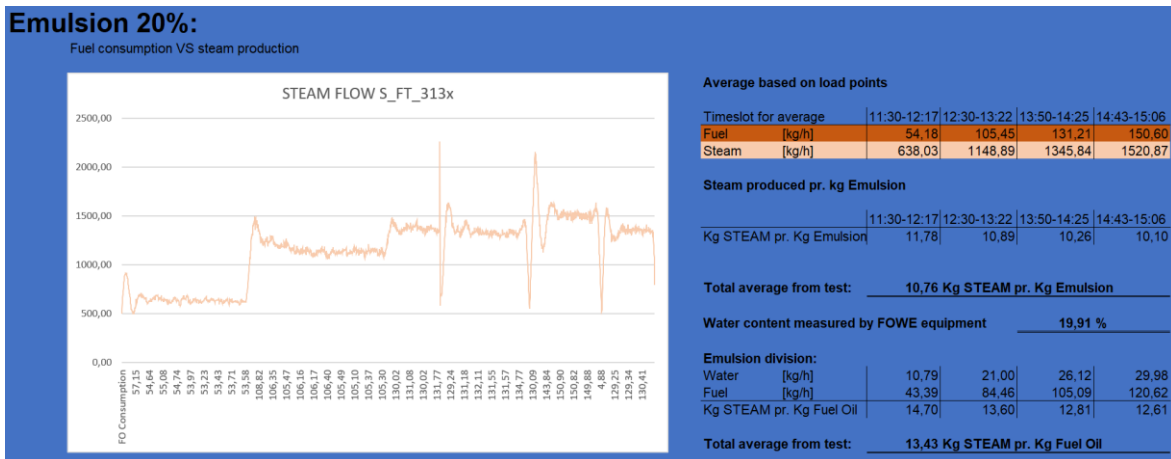


Figure 4 20% Emulsion

Appendix 2: NOx Emissions and exhaust gas temperatures Base vs Emulsions. Average measurements from test

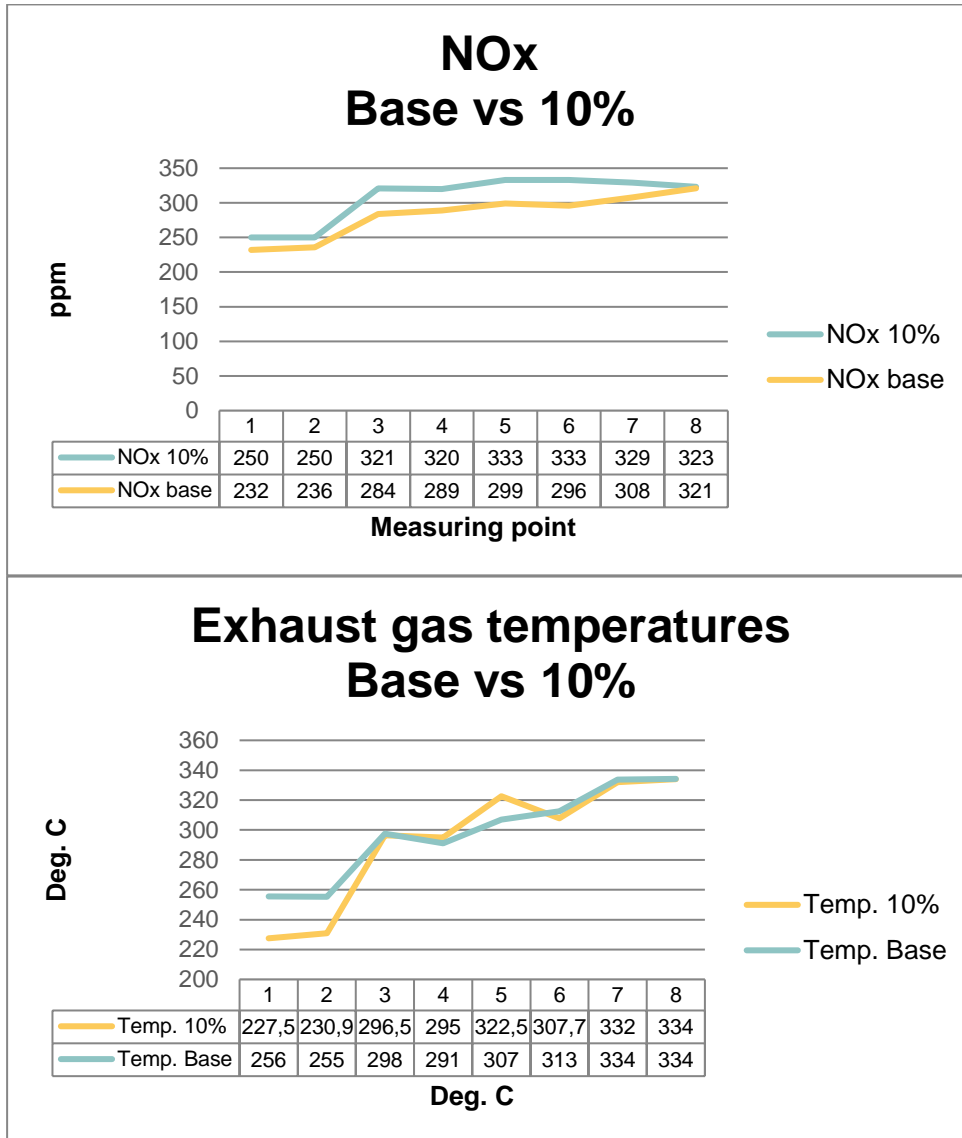


Figure 1 Base test vs 10% emulsion

Appendix 2: NOx Emissions and exhaust gas temperatures Base vs Emulsions. Average measurements from test

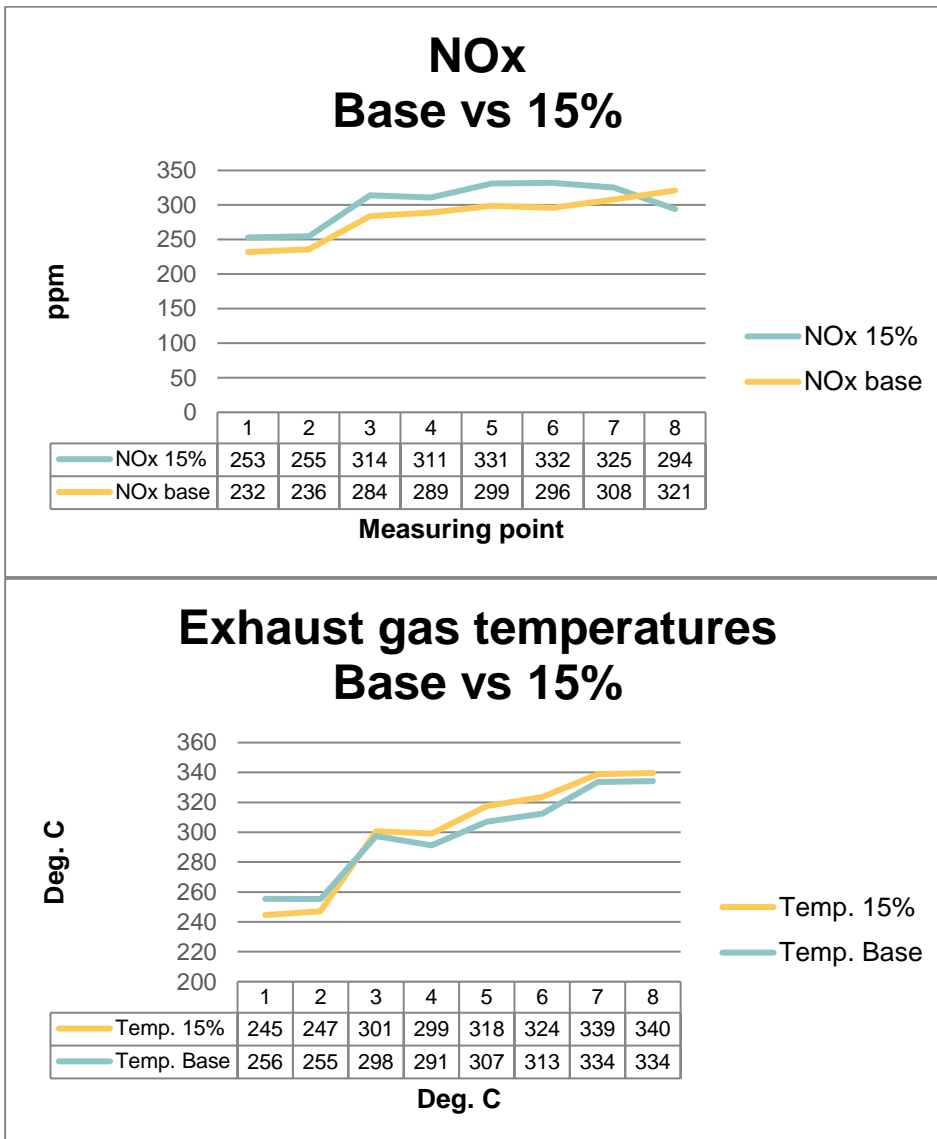


Figure 2 Base Test vs 15% Emulsion

Appendix 2:
 NOx Emissions and exhaust gas temperatures
 Base vs Emulsions. Average measurements from test

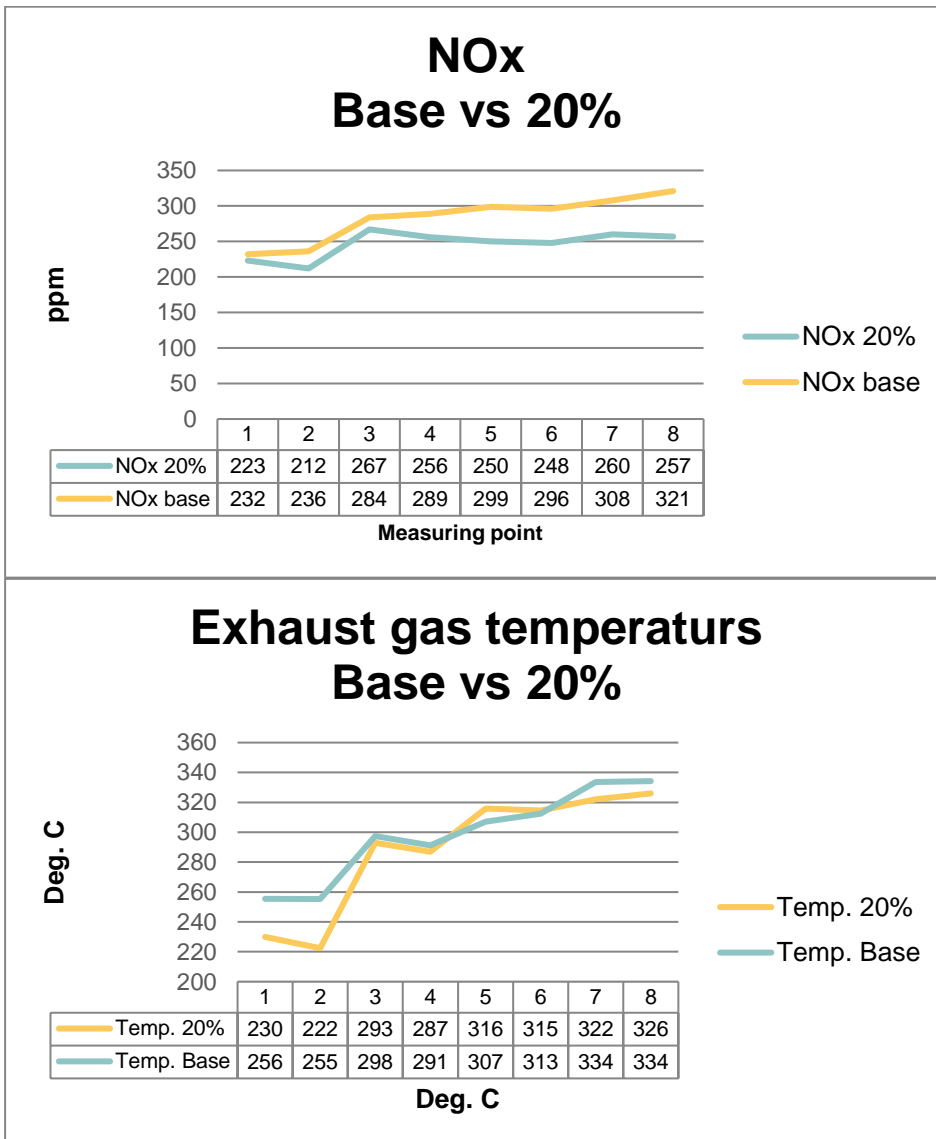


Figure 3 Base test vs 20% Emulsion

Letter regarding: FOWE ECO Solutions



Subject	Ref. No.	Page
FOWE ECO Solution test at Alfa Laval Aalborg Test Centre Denmark		1 / 2
Issued by	Department	Date
Lars Bo Andersen	Alfa Laval Aalborg, Test Centre	18-12-2023

Recipients

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To whom it may concern

This Letter is valid until 31/12-2025. Alfa Laval Aalborg A/S reserves the right to revise or withdraw this Letter if the applicability of the emulsified fuel oil and water mixture used on Alfa Laval boilers is considered to change during this time.

Test Certificate

Alfa Laval Aalborg Test & Training Centre conducted tests on emulsified fuel oil and water mixture on a boiler in the Test & Training Centre in Aalborg, Denmark from October to December 2023.

- A fuel oil, 180 cSt VLSFO 0,5%, was emulsified by FOWE with water using the FOWE CAVITECH product.
- The emulsified fuel oil and water mixture was combusted on a OS-TCi, 2 t/h boiler with Multi Fuel Burner type MF PA 1.7 test center version (pressure atomizing burner).
- The fuel supply system for the 2t boiler needed modification for handling the emulsified fuel oil and water mixture and a non-standard pressurized return line was established.

Several emulsified fuel oil and water mixture tests was performed on the test boiler and compared against a fuel oil without water mixture.

After establishing a pressurized return line, the boiler with the pressure atomizing burner, was capable, under constant operation by skilled boiler operators, to combust the emulsified fuel oil and water mixture up to and including 15% water content. Above 15% water content, we don't recommend using this type of burner.

Inspection and evaluation after test revealed no significant wear of components in contact with the emulsified fuel oil and water mixture but at this point, it is unclear what the longtime operation will cause of wear and/or problems on the boiler/fuel/exhaust gas system.

Since no significant problems were found regarding the inspected components. Alfa Laval does therefore not object to the usage of the emulsified fuel oil and water mixture prepared by FOWE technology under the conditions that were used during the test meaning same boiler and burner type and a modified return line.

Other boiler/burner types may require other arrangements to combust the emulsified fuel oil and water mixture. Consequently, the result of the test cannot be regarded as a generalized statement.

As the "fuel oil water mixture solution" is neither produced nor sold by Alfa Laval Aalborg, Alfa Laval Aalborg cannot be held responsible for any damage to the boiler or other components that may be caused by using the "fuel oil and water mixture".

Subject	Ref. No.	Page
FOWE ECO Solutions		2 / 2

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Best regards,



Lars Bo Andersen
Head of Test & Training Centre
Alfa Laval Aalborg, Denmark.