SURFACE VEHICLE RECOMMENDED PRACTICE

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Emulsified Water/Fuel Separation Test Procedure

RATIONALE

SAE J1488 was revised to meet the SAE Five-Year Review requirements and includes improvements to the test method as defined by the SAE Filter Test Method Committee (FTMC). Changes made bring the document up to current practices and include experience gained since implementing the prior revisions. These changes include: the acceptable test fuel interfacial tension (IFT) range has been reduced, the test fuel pre-treatment procedure has been refined, water content measurements were further clarified to parts per million by volume (ppmv), and comments regarding the use of biodiesel test fuels have been added.

FOREWORD

Water in fuels is one of the major causes of diesel engine maintenance problems. The effects of water in fuel are characterized by corrosion of fuel system parts, plugging of filters and orifices and, in some cases, failure of fuel injection equipment. Water in fuel often dissolves sulfur compounds, becomes acidic, and enhances corrosion in fuel injection systems, as well as in the engine itself. The presence of water also encourages microbiological growth, which generates orifice and filter restricting sludge. Further, due to displacement of fuel lubrication in close tolerance injector parts, and rapid expansion of heated water at the fuel injector tip, galling and more serious failures may also occur.

During transportation, transfer, and storage of fuel, water may become entrained in a variety of ways. The mode and timing of water entry in the handling sequence before use, as well as the chemistry of the fuel itself (additives and surfactants), will determine what form the contaminant takes. In systems where water and fuel pass through high shear pumps, fuel/water interfacial tension is relatively low, and settling time is minimized, fine emulsions may predominate. In systems where water enters before or after low shear pumps, or where there is a prolonged settling time in high interfacial tension fuel, larger water droplets may predominate. In some systems, both fine emulsions and large droplets may be present simultaneously. Generally, fine emulsions are more likely to predominate on the pressure side of high shear pumps, whereas larger water droplets are more likely to predominate on the suction side of pumps. (A water removal test procedure designed for applications where large water droplets predominate is also recommended. This procedure is given in SAE J1839.)

The following test procedure is relevant to finely dispersed or emulsified water separation devices whether applied on the suction or discharge side of engine fuel transfer pumps. This procedure recommends pressure side location of the test unit for ease and convenience of testing only. The procedure is well suited to lower flow rates, although it may be applied with due caution to flow rates up to 100 L/min using parallel emulsion generating circuits. It has been designed to approximate field conditions in a practical manner. A 3500-rpm centrifugal pump is used to disperse water in the fuel, simulating most fuel loading pumps. The test fuel may be an actual fuel sample (with additives) that is to be used in the field, or it may be No. 2 fuel oil that has been clay treated (conditioned) so as to enable equal and reproducible laboratory comparisons of various test devices. Additionally, a fluid simulating a representative biodiesel is recommended, as biodiesel has been established as being particularly problematical for controlled water separation and water separation testing. Test fuel conditioning is recommended for laboratory comparisons only, as this treatment may yield water removal efficiency results, which are significantly different from those obtained using water separating devices in untreated fuel or biodiesel. Furthermore, testing unused “clean” water separators may provide water removal efficiencies that are far superior to those obtained from the same water separators after very short exposure to natural fuel and natural fuel contaminants.

1. SCOPE

To determine the ability of a fuel/water separator to separate emulsified or finely dispersed water from fuels. This test method is applicable for biodiesel fuel.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1839 Coarse Droplet Water/Fuel Separation Test Procedure

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D971 Test Method for Interfacial Tension of Oil Against Water by the Ring Method

ASTM D4176 Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedure)

ASTM D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration

ASTM D7261 Standard Test Method for Determining Water Separation Characteristics of Diesel Fuel by Portable Separometer

3. TEST APPARATUS

A test system, as illustrated in Figure 1. This system generates test emulsion populations in ultra-low sulfur diesel fuel (IFT 16 to18 mN/m). Test droplet size distribution in this procedure is controlled for changes in test flow rate at recommended interfacial tensions but may vary significantly in test fuels where interfacial tension is not controlled.

A test system, as illustrated in Figure 1, is to include:

3.1 A corrosion-resistant fuel container. If using a flat bottom container, ensure the fuel outlet is not less than 4 cm from the bottom of the container.

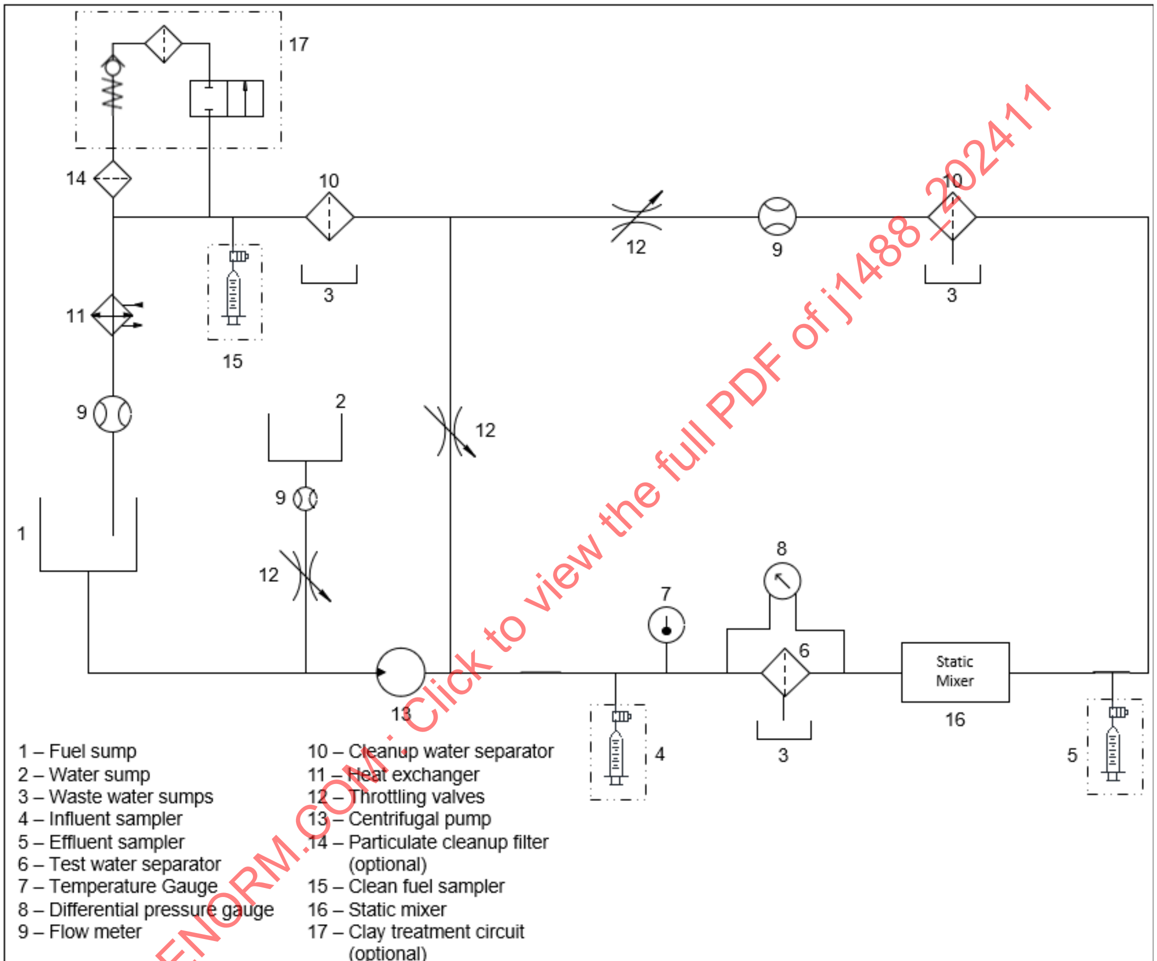

Figure 1 - Test system

3.2 A 3500 rpm ± 100 rpm, 1 hp centrifugal pump, Xylem Gould's model 1ST 1E_D4. The underscore represents the motor type. Motor type will have no effect on testing if it is operated at the specified 3500 rpm speed.

3.3 Fuel flow meter capable of measuring with an accuracy better than or equal to ±5% of the set flow rate.

3.4 Temperature indicator with an accuracy of ±1.5 °C.

3.5 A cleanup water separator assembly such that not more than 50 ppmv higher than beginning of test dissolved water (see Appendix B) concentration values is recycled on an average basis under test conditions.

3.6 A corrosion-resistant water sump with an approximate capacity of 19 L.

3.7 Water flow meter with a flow regulating valve or a pump capable of a range from 0 to 100 mL/min (or as required) with an accuracy of ±5% of the set flow rate.

3.8 Automatic Karl Fischer coulometric titration apparatus for water content analysis.

3.9 In-line system static mixer to ensure emulsification of test fluid prior to effluent water sampler. Full flow must pass through the mixer.

3.10 The fuel/water separation stand's pipe should create an average flow velocity equal to or greater than 0.72 m/s. Any non-rusting and non-reacting pipe material may be used.

3.11 A differential pressure gauge with an accuracy of ±5% and a resolution of 340 Pa is recommended.

3.12 Syringe sampler in accordance with Figure 2. Note that the influent sampler does not have an in-line mixer, while the effluent sampler does. This is because the water at the influent section is emulsified and an in-line mixer at this point is not needed. The syringe sampler may be replaced with a beaker or vial to collect the sample. The sample should be sealed and sonicated before Karl Fischer analysis.

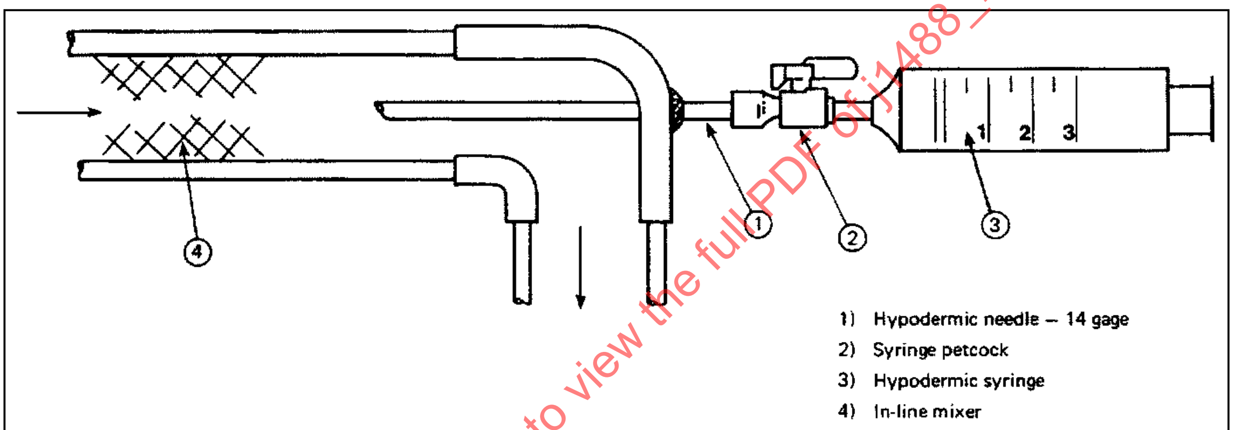

Figure 2 - Effluent sampler

3.13 Temperature control system capable of maintaining test temperature as specified in 5.2.

3.14 Double pipe heat exchanger (cooling and heating, if required) with fuel in the tube side. This should be a single pass, single tube, double pipe exchanger. If adequate cooling can be accomplished after the cleanup fuel/water separator (see Figure 1), then any type of heat exchanger may be used.

3.15 Fuel/water interfacial tension measuring device. A platinum ring detachment method (refer to ASTM D971) is recommended, although other correlatable methods may be used.

3.16 For testing at flow rates greater than 25 L/min it is required that separate emulsion generating circuit(s) with a common sump are connected in parallel to generate the emulsions for the test circuit.

4. TEST MATERIALS

4.1 Test Fluid

Since commercially available diesel fuel oil (particularly biodiesel) contains highly variable constituents that can significantly influence the outcome of emulsion removal testing, the test oil type should be categorized and recorded as one of the following:

a. A sample of the fluid used in the application, as defined by user, to include biodiesel fuels

b. Specially treated fluid, per Appendix A

For the most standardized laboratory comparisons, test fluid b is recommended as the least variable of the test fluids categorized above.

It should be understood that the results are relevant to each individual fuel and that significant variance in performance can be expected with different fuels, depending on the particular design of the test fuel/water separator and the chemical nature of the particular lot of fuel.

For the test fluid in item b, the IFT value shall be between 16 and 18 mN/m.

NOTE: Microseparometer (refer to ASTM D7261) results that show lower readings (full range is 50 to 100) may indicate poor water separation ability which implies the fuel contains a high amount of surfactants.

4.2 Clean, distilled, or deionized water with a surface tension of 72 mN/m ± 2 mN/m at 20 °C ± 1.5 °C.

5. TEST CONDITIONS

5.1 Volume of Fuel

Shall be 5X the flow rate per minute, with a minimum of 38 L.

5.2 Temperature

26.6 °C ± 2.5 °C measured at the test separator inlet or at a temperature agreed upon by the test requester and user.

5.3 Pressure

Pressure or vacuum operating parameters are set as required by the manufacturer, user, or application; otherwise, they are controlled by the fuel flow rate.

5.4 Flow Rate of Fuel

Rated flow of unit to be tested or as specified.

5.5 Water Flow Rate

0.25% of the emulsion generated circuit fuel flow rate.

6. TEST STAND VALIDATION

6.1 Determine the minimum and maximum flow rates at which the test stand is to be qualified, and test first at the minimum flow rate.

6.2 Install a straight pipe in the location where the test water separator would be located.

6.3 Adjust the emulsion generation circuit flow to 25 L/min using the throttling valves, while maintaining the minimum test flow rate in the filter test circuit.

6.4 Adjust the water flow rate to 0.25% of the emulsion generation circuit flow rate (0.25% of 25 L/min = 63 mL/min).

6.5 Run the validation test for 1 hour. Take samples from the influent, effluent, and cleanup sample ports at 20-minute intervals, starting 20 minutes after the water injection has been initiated.

6.6 Verify that the undissolved water content of all the influent and effluent samples is within the range of 2200 to 2800 ppmv, and the cleanup samples are less than 50 ppmv higher than beginning of test dissolved water concentration values.

6.7 The system is qualified if all the samples are within the required water content ranges.

6.8 Repeat the validation process, 6.3 to 6.8, for the maximum test flow rate for which the stand is to be qualified.

7. TEST PROCEDURE

NOTE: Fuller's Earth-treated fuel and non-Fuller's Earth-treated fuel (see 4.1.a. and 4.1.b.) may be used more than once for consecutive tests with or without re-treating, as long as the fuel meets the requirements of 4.1.

7.1 For every fresh batch of fuel, determine the water saturation level according to Appendix B.

7.2 Prior to using a new batch of test fuel, determine whether it has a reasonable contamination level and water concentration (indicated by a "pass" or "clear and bright" result in procedure 1 of ASTM D4176).

7.3 Install test fuel/water separator or filter on the discharge side of the emulsion generation pump circuit and in the filter test circuit (see Figure 1). Adjust the emulsion generation circuit flow to 25 L/min, using the throttling valves, while meeting the required test flow rate in the filter test circuit. Air should be bled from all filters in the system at this time. The systems should circulate for at least two turnovers to adequately coat test filter media. Take initial pressure drop reading across the test filter at the rated flow. To determine turnover time use Equation 1:

$$\frac{System\ Volume\ (L)}{Flow\ Rate\ (L/min)} = 1\ turnover\ (min) \quad \text{(Eq. 1)}$$

7.4 Adjust water flow rate to be 0.25% of the emulsion generation circuit flow rate (0.25% of 25 L/min = 63 mL/min). Start the clock at the same time water begins to flow and water flow rate is set. This point is zero test time. Water must be injected at the suction side of the pump.

NOTE: To ensure the proper water flow rate, the water line from water sump to pump should be free of air and completely full of water. Further, the water line must feed into the fuel line, as close to the suction line fitting of the pump as is practical.

7.5 Periodically, drain the water from the water collection sump of the unit under test and the cleanup water separator collection sump into a volumetric container. It may be necessary to bring the system under positive pressure to drain under suction applications. The amounts of water collected from the test can be used to obtain a water balance verification efficiency (see Appendix C). Manually draining may not be necessary if an automatic water-sensing switch/drain is available. Do not let water build up beyond the maximum recommended level of the water sump. DO NOT TAKE ANY SAMPLES WHEN ASSEMBLY IS BEING DRAINED.

7.6 At approximately 10 minutes, collect 50 mL of fuel sample from the petcock of the effluent sample port (see Figure 1) into any suitable vessel with a lid (use a beaker, vial or syringe). Record this sample time. Flush the vessel three to five times and slowly withdraw 50 mL of sample over a period of approximately 10 to 15 seconds. Ultrasonicate fuel sample before analysis. Analyze a portion of the sample using the Karl Fischer automatic titration apparatus. Determine water concentration in ppm by volume. Repeat this sampling procedure every 20 minutes thereafter, until termination of the test.

7.7 After approximately 10 minutes, take a 50 mL sample from the influent sampling port (see Figure 1), using the same technique as the effluent sample. Analyze approximately 0.5 mL of this sample using the Karl Fischer automatic titration apparatus. Record the exact sampling time and the water concentration. Verify that the concentration measured is within the designated range of 2500 ppmv ± 300 ppmv of water and is being injected into the fuel stream. Reconfirm this influent water concentration at approximately the same time as every alternate effluent sample (for example, take influent samples at 10 minutes, 50 minutes, 90 minutes, etc.; that is, every 40 minutes after the first 10-minute sample). Record the influent concentrations with respect to time.

Periodically (suggested 30-minute intervals), take cleanup water separator effluent samples at the cleanup sampling port (see Figure 1) to ensure that not more than 50 ppmv higher than beginning of test dissolved water concentration is being recirculated during the test. The cleanup water separator needs to be serviced if effluent water concentration exceeds the 50 ppmv.

7.8 Record the differential pressure across the test fuel/water separator at each effluent sample interval.

7.9 Terminate test if one or more of the following conditions is met:

a. Water concentration in effluent fuel is above acceptable level, to be specified by manufacturer or user.

b. An equilibrium pressure drop has been reached and a minimum of 2-1/2 hours of test time has been attained. Both conditions must be met. The pressure drop is said to have reached equilibrium if, after 2 hours, the pressure drop does not increase by more than 680 Pa over a 30-minute period.

c. Differential pressure exceeds an upper limit specified by the manufacturer or user for the element or application.

7.10 Upon completion of test, determine the IFT and micro-separometer (MSEP) values and record.

7.11 Take a final effluent sample for analysis at test termination.

8. PRESENTATION OF DATA

8.1 Plot concentration of undissolved water in effluent versus time (minutes) on a linear graph. Undissolved water = total water minus dissolved water (see Appendix B).

8.2 Plot of pressure drop (mm Hg or kPa) versus time (minutes) is optional. If plot is not presented, final pressure drop should be reported.

8.3 Note the test fluid(s), IFT, IFT method, MSEP rating, test flow rate, test temperature, total test time, equilibrium pressure drop, and dissolved water saturation level in the fuel at test temperature (see Appendix B). If the test was terminated early, state the reason for test termination.

8.4 Calculate and report the time average undissolved effluent water level (see Equation 2).

$$C_{av} = \sum_{i=1}^{n} c_i * \left(\frac{t_i - t_{(i-1)}}{t_{total}}\right) \quad \text{(Eq. 2)}$$

where:

c_i = effluent undissolved (free) water concentration, ppmv at time t_i, minutes

i = integer from 1 to n, where n equals the number of effluent samples taken

t_{total} = total test time, minutes

8.5 Calculate and report average dispersed water separation efficiency (see Equation 3).

$$\text{Average Efficiency} = \left(1 - \frac{C_{av}}{2500}\right) * 100\% \quad \text{(Eq. 3)}$$

8.6 Analyze the samples using the Karl Fischer apparatus, and report water content as parts per million by volume (ppmv).

Many Karl Fischer titration devices will determine the water concentration in terms of micrograms, or ppm by mass. To convert titration readings from parts per million by mass (ppm) to parts per million by volume (ppmv), use the following equation:

$$Titration\ Reading\big(in\ ppm\ (volume\ fraction)\big) = \frac{Titration\ Reading\ (in\ ppm\ (mass\ fraction)) * Fuel\ Density\ (g/l)}{Water\ Density\ (g/l)} \quad \text{(Eq. 4)}$$

9. NOTES

9.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE FILTER TEST METHODS STANDARDS COMMITTEE

APPENDIX A

A.1 FUEL TREATMENT TO OBTAIN FLUID AS SPECIFIED IN 4.1

A.1.1 Take the required volume of fuel oil and continuously contact the fuel with Fuller's Earth. This may be done by filtering the fuel through commercially available Fuller's Earth or clay cartridge filters. The test fluid sump should be used.

A.1.2 Periodically (about every 20 minutes, or two turnovers [see 6.3]), take a sample of the fuel in a beaker and measure the interfacial tension (IFT) with distilled or deionized water at 20 °C ± 5 °C. The platinum ring detachment method (refer to ASTM D971) is recommended, although other correlatable methods may be used.

A.1.3 If the IFT is above 20 mN/m, stop further contacting the Fuller's Earth or clay. Generally, two to four turnovers will more than adequately ensure that this condition is met. Report the IFT of the treated fuel.

A.1.4 Remove the Fuller's Earth filters from the test loop, or adjust valving to isolate them from the test loop.

A.1.5 Water wash the base fuel by adjusting water injection to a continuous water concentration of 2500 ppmv. Recirculate the fuel for three to five turnovers of the total fuel volume.

A.1.6 Monoolein is a pure compound composed of monoglycerides; it can be added to the test fuel to simulate biodiesel or ultra-low sulfur diesel fuel with low interfacial tension. At room temperature, monoolein is a solid and should be heated to convert it to a liquid. Add liquid monoolein to fuel (in the test sump) in a volume percent to reach the target IFT (between 16 and 18 mN/m). The modification of fuel/water interfacial tension and MSEP may have significant influences on test results.

NOTE: It is advisable to check the interfacial tension of this treated fuel (with monoolein) against distilled or deionized water (refer to ASTM D971). Figures A1 and A2 are graphical representations of IFT and MSEP values of one diesel fuel containing monoolein in different concentrations and are included for reference only. It must be noted that Figures A1 and A2 are representations of one diesel fuel. The amount of monoolein required to achieve the target IFT will be dependent on the chemical nature of the particular diesel fuel.

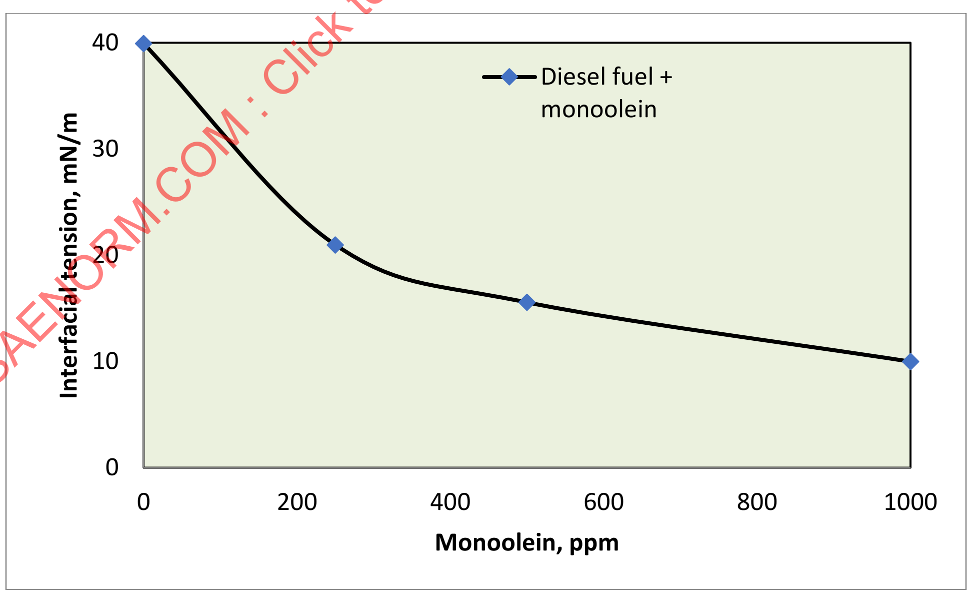

Figure A1 - Interfacial tension versus Monoolein, ppm