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COARSE DROPLET WATER/FUEL SEPARATION TEST PROCEDURE

Foreword—This reaffirmed document has been changed only to reflect the new SAE Technical Standards Board format.

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 failure 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 the 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 finely dispersed droplets predominate is also recommended. This procedure is given in SAE J1488.)

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SAE J1839 Reaffirmed JUN95

The following test procedure is relevant to coarsely dispersed water separation devices whether applied on the suction or discharge side of engine fuel transfer pumps.¹ The procedure is well suited to lower flow rates, although it may be applied with due caution to higher flow rates [up to approximately $1.6 \times 10^{-3} \text{ m}^3/\text{s}$ (~25 gpm)]. It has been designed to approximate field conditions in a practical manner. A water dispersing technique simulating the water droplet sizes experienced drawing fuel/water mixtures through fuel lines and fittings (180 to 260 μm mean droplet size), is used to reproduce field conditions where coarse droplets predominate. 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. 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. Furthermore, testing unused "clean" water separators may provide water removal efficiencies, which 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 undissolved water removal performance of a fuel/water separator under controlled laboratory conditions, using water droplets.

2. References

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1488—Emulsified Water/Fuel Separation Test Procedure

2.1.2 ASTM PUBLICATION—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM D 971—Test Method for Interfacial Tension of Oil Against Water by the Ring Method

2.1.3 ISO PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO R 760—Determination of water—Karl Fischer method (general method)

3. Test Apparatus—A test system, as illustrated in Figure 1, is to include:

3.1 Operating sump with a flat bottom. Material to be compatible with diesel fuel (polyethylene, etc.). Sump size to be adequate to hold test fluid volume under test conditions. Outlet to be 2.5 cm from bottom of tank or higher.

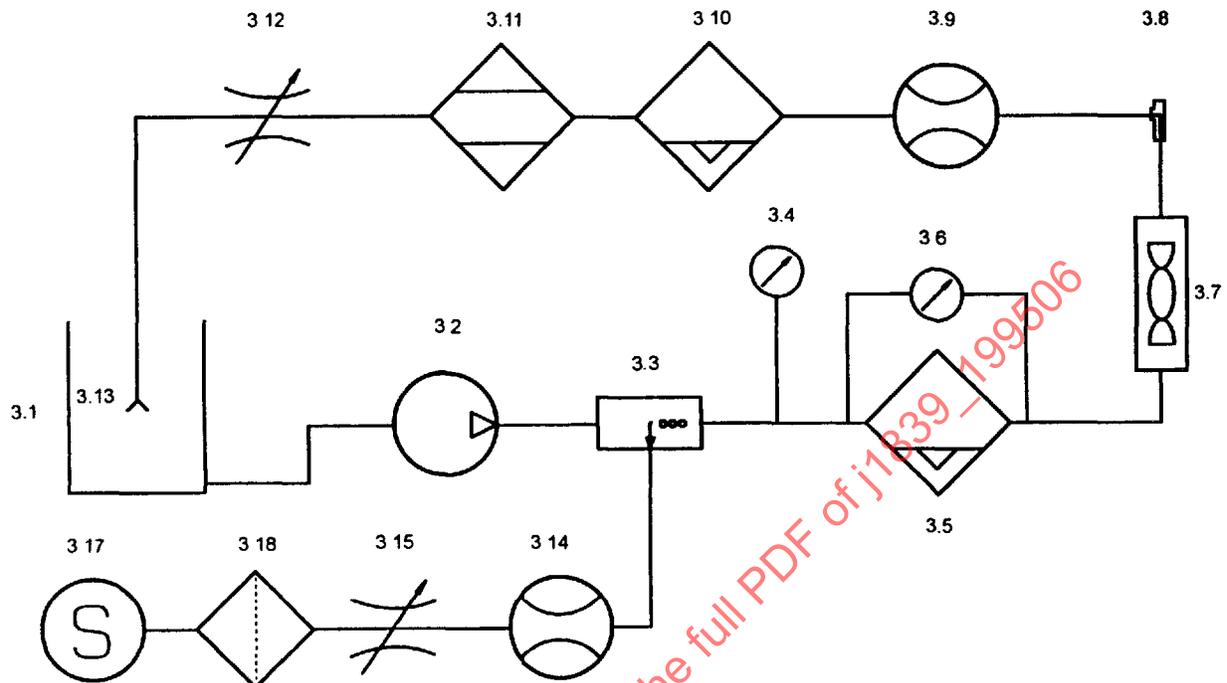
3.2 A pump, capable of providing test flow rate, under test conditions.

3.3 A water dispersing device, as described in Appendix A.

3.4 Thermometer or temperature readout accurate $\pm 2^\circ\text{C}$ under test conditions.

¹ This procedure recommends pressure side location of the test unit for ease and convenience of testing only. Modification of the procedure to place the test unit on the suction side of the pump should not alter test results as long as the water droplet size distribution remains unaltered.

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|---|--|---------------------------------|
| 3.1 Operating Sump | 3.6 Differential Pressure Gauge | 3.12 Flow Control Valve |
| 3.2 Pump | 3.7 Inline Mixer | 3.13 Diffuser |
| 3.3 Water Dispensing Device, Appendix A | 3.8 Sample Port | 3.14 Water Flow Meter |
| 3.4 Thermometer | 3.9 Fuel Flow Meter | 3.15 Water Flow Control Valve |
| 3.5 Test Fuel Filter/Water Separator | 3.10 Final Fuel Filter/Water Separator | 3.16 Water Filter/Deionizer |
| | 3.11 Heat Exchanger | 3.17 High Pressure Water Supply |

FIGURE 1—TEST SYSTEM

- 3.5** The fuel/water separator under test.
- 3.6** Differential pressure gauge or manometer with 1.0 mm Hg or 0.1 kPa subdivisions, or as required.
- 3.7** Inline static mixer with at least three internal mixing units, or similar, to provide a representative sample at the sample port.
- 3.8** Sample port. Provision must be made to allow adequate flushing, immediately prior to sampling.
- 3.9** Test fuel flow meter, flow range appropriate for the unit under test, accuracy $\pm 5\%$, repeatability $\pm 2\%$.

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- 3.10 A final fuel/water separator assembly, such that not more than 30 ppm undissolved water is recycled on an average basis under test conditions.
- 3.11 Suitable heat exchange and controls for maintaining constant test temperatures as specified.
- 3.12 Suitable valve or other control for adjusting and controlling test flow.
- 3.13 Diffuser, to promote uniform mixing in test reservoir.
- 3.14 Water flow meter with range to suit application capable of measuring flows of 0.25% of fuel flow rate, $\pm 5\%$ accuracy.
- 3.15 Suitable valve for adjusting and controlling water injection flow.
- 3.16 A supply of clean deionized or distilled water with a surface tension greater than 6×10^{-2} N/m (60 dynes/cm) at $20 \text{ }^\circ\text{C} \pm 1.5 \text{ }^\circ\text{C}$. Adequate pressure must be available to inject water on the high pressure side of the pump. (Use of a deionizing filter, for example, housed Barnstead D8901, will permit use of local water supply and pressure.)
- 3.17 Automatic Karl Fischer Titration Apparatus for water content analysis.
- 3.18 All interconnecting piping should be selected, sized, and oriented to prevent the separation of water and solid contaminants from the fuel or provide traps for these contaminants (13 mm PVC is recommended for 0 to 23 L/m flow rates).

4. Test Materials

- 4.1 **Test Fluid**—Since fuel oil contains various constituents, the test oil type should be categorized and recorded as one of the following:
- A sample of the fluid used in the application
 - No. 2 diesel fuel, locally available
 - Specially treated fluid, per Appendix B
 - A standard reference fluid to be specified

In all these cases, it should be understood that the results are relevant to this fuel and that some amount of variance in performance can be expected with different fuels, depending on the particular design of the test fuel/water separator.

- 4.2 Clean, distilled, or deionized water with a surface tension greater than 6×10^{-2} N/m (60 dynes/cm) at $20 \text{ }^\circ\text{C} \pm 1.5 \text{ }^\circ\text{C}$.

5. Test Conditions

- 5.1 **Volume of Fuel in the Test System (including filters, piping, etc.)**—Shall be five times the flow rate, per minute, with a minimum of $3.8 \times 10^{-2} \text{ m}^3$ (38 L).

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5.2 Temperature— $26.6\text{ }^{\circ}\text{C} \pm 2.5\text{ }^{\circ}\text{C}$ measured at the test separator inlet.

5.3 Flow Rate of Fuel—Rated flow of unit to be tested or as specified.

5.4 Water Flow Rate—0.25% of fuel flow rate.

6. Test Procedures

6.1 If clay-treated fuel (Appendix B) is not the selected fluid, use a fresh quantity of fluid. Retreat clay-treated fuel, if used.

6.2 Determine the water saturation level for each batch of test fluid:

- a. According to Appendix C
- b. By using tables or charts where available; see Appendix D

6.3 Install cleanup filter (95% efficiency at $5\text{ }\mu\text{m}$ or better suggested) in place of test filter; fill fuel tank; start circulation of fuel at cleanup filter flow rating. Continue system cleanup until a particulate contamination level of 5 mg/L or less and 30 ppm undissolved water or less is obtained. Low cleanup flow rates and/or lower efficiencies will require long cleanup times. The final fuel/water separator may be used as a cleanup filter if suitable.

6.4 Install test fuel/water separator to be tested (see Figure 1).

6.5 With flow set near zero, start pump, adjust to specified flow rate.

6.6 Bleed air from system if necessary, take initial (fuel only) pressure drop reading at the test flow.

6.7 Open the water valve and adjust water flow rate to 0.25% of fuel flow. Start the clock at the same time water begins to flow. Establish proper flow rate within 1 min.

6.8 Without interrupting test flows, periodically drain the water from the water collection sump of the unit under test. 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.**

6.9 Record test time for each drain.

6.10 After 10 min carefully withdraw a sample, being sure to flush the sample port thoroughly. Be sure that the sample syringe or container is thoroughly dry. Analyze the sample immediately using the Karl Fischer method (see ISO R 760), or similar. Record each reading. Additional sampling is permitted. Repeat this sampling procedure every 20 min thereafter until termination of the test.

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

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

- a. Water concentration in effluent fuel is above an acceptable level, to be specified by manufacturer or user
- b. 2 h and 30 min or more of test time has elapsed and an equilibrium pressure drop is attained. Equilibrium pressure drop has been reached when an increase of no more than 2.5 mm Hg (0.34 kPa) occurs during a 20 min interval
- c. Differential pressure exceeds an upper limit specified by the manufacturer or user

7. Presentation of Data

7.1 Plot concentration of undissolved water in effluent (ppm by volume)² versus time (minutes) on linear graph paper. Undissolved water = total water minus dissolved water (see 6.2). Indicate drain times on graph.

7.2 Plot pressure drop (mm Hg or kPa) versus time (minutes).

7.3 Record the following:

7.3.1 Test fluid viscosity, type, composition, specific gravity, and source.

7.3.2 Fuel flow rate.

7.3.3 Actual test temperature.

7.3.4 Total test time.

7.3.5 Equilibrium pressure drop.

7.3.6 Dissolved water saturation level, method used to determine level.

7.4 Calculate and report the average free water content of effluent by using Equation 1:

$$E_{av} = \Sigma E_i \times [(t_i - t_{i-1})^t \text{ total}] \quad (\text{Eq.1})$$

where:

E_{av} = Average undissolved water content of effluent, ppm by volume

E_i = Undissolved water content of the "i th" sample = Total water content of the sample-water saturation level (5.2), ppm by volume

$t_i - t_{i-1}$ = Time since previous sample, minutes

t_{total} = Total test time to final sample, minutes

² Many Karl Fischer titrators will determine micrograms. Convert this to ppm by volume.

$$\text{ppm by vol} = \frac{\text{Karl Fischer reading } \mu\text{gms}}{\text{Sample volume (mL)}} = \frac{\text{Karl Fischer } \mu\text{gms} \times \text{Fuel sp. gr.}}{\text{Sample Weight (grams)}}$$

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7.5 Calculate and report average undissolved water separation efficiency by using Equation 2:

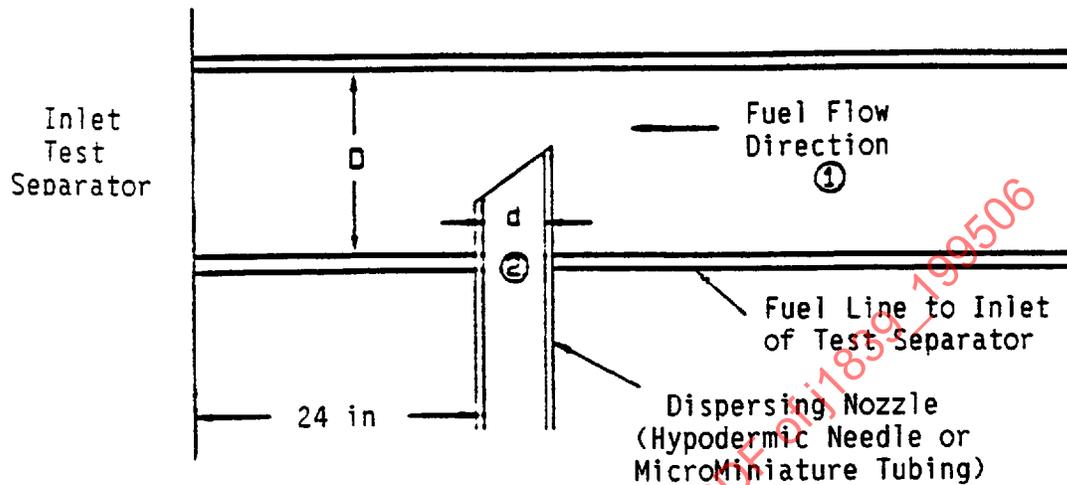
$$\text{Average Efficiency} = \left(1 - \frac{E_{av}}{2500}\right) \times 100 \quad (\text{Eq.2})$$

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APPENDIX A



- ① Fuel velocity past nozzle tip should be between 0.75 and 1.50 m/s.
- ② Water velocity through nozzle should be between 4.7. and 7.0 m/s.

where LPM = Test Flow Rate

$$D = \text{Maximum diameter (mm)} = 20\sqrt{\text{LPM} \times 0.07074}$$

for 0.75 m/s velocity

$$D = \text{Minimum diameter (mm)} = 20\sqrt{\text{LPM} \times 0.03536}$$

for 1.50 m/s velocity

$$d = \text{Maximum diameter (mm)} = 20\sqrt{\text{LPM} \times 0.000282}$$

for 4.7 m/s velocity

$$d = \text{Minimum diameter (mm)} = 20\sqrt{\text{LPM} \times 0.000189}$$

for 7.0 m/s velocity

(See Figures A2 and A3 for nozzle I.D. and gauge at various test flow rates.)

This water dispersing method has been found to produce dispersed phase droplet populations with mean diameters of approximately 180 to 260 μm .

FIGURE A1—WATER DISPERSING DEVICE

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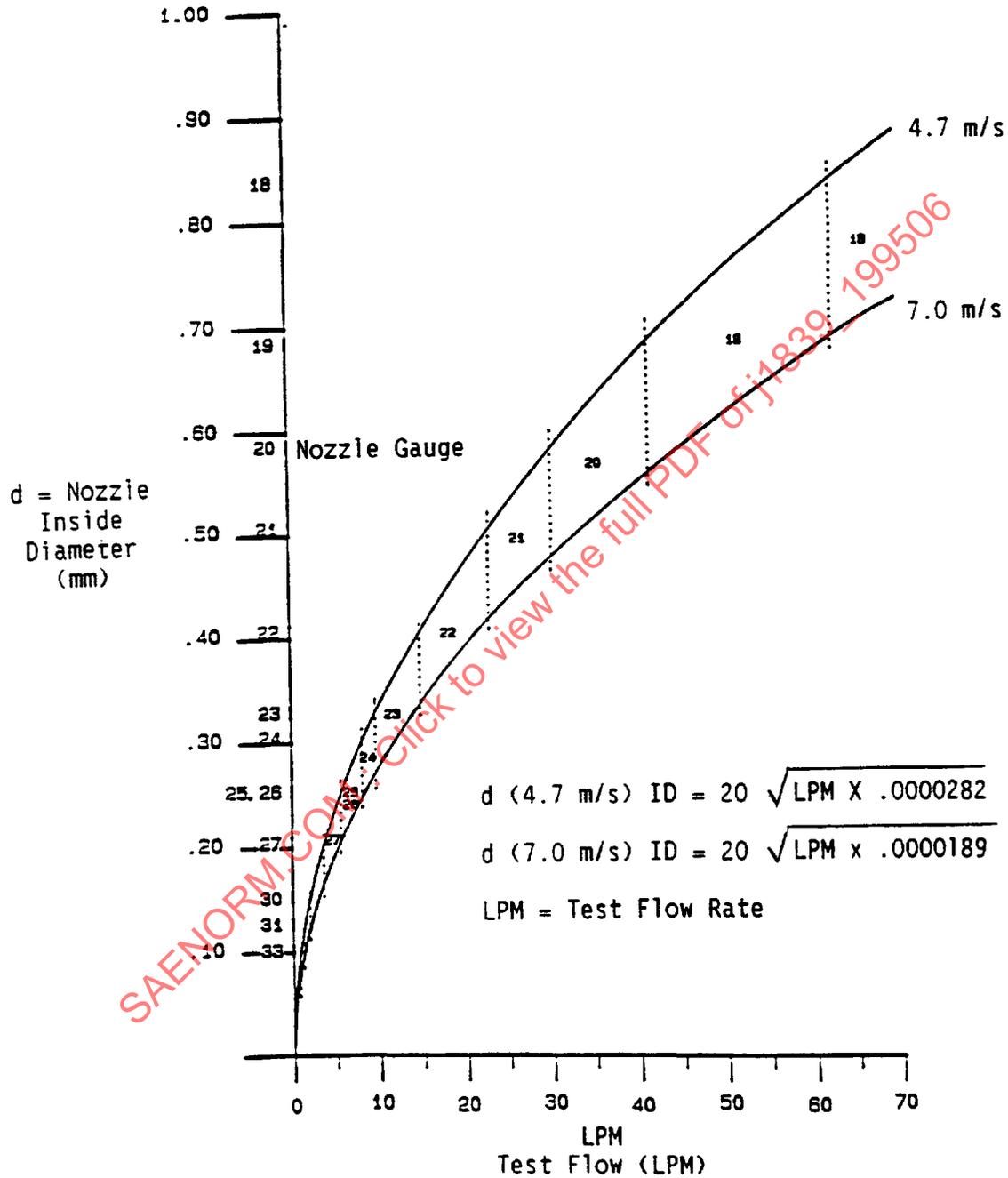


FIGURE A2—DISPERSING NOZZLE SIZE AND GAUGE FOR 0 TO 70 LPM TEST FLOW AT 4.7 TO 7.0 M/S VELOCITY THROUGH NOZZLE (ASSUMES 0.25% WATER ADD RATE)

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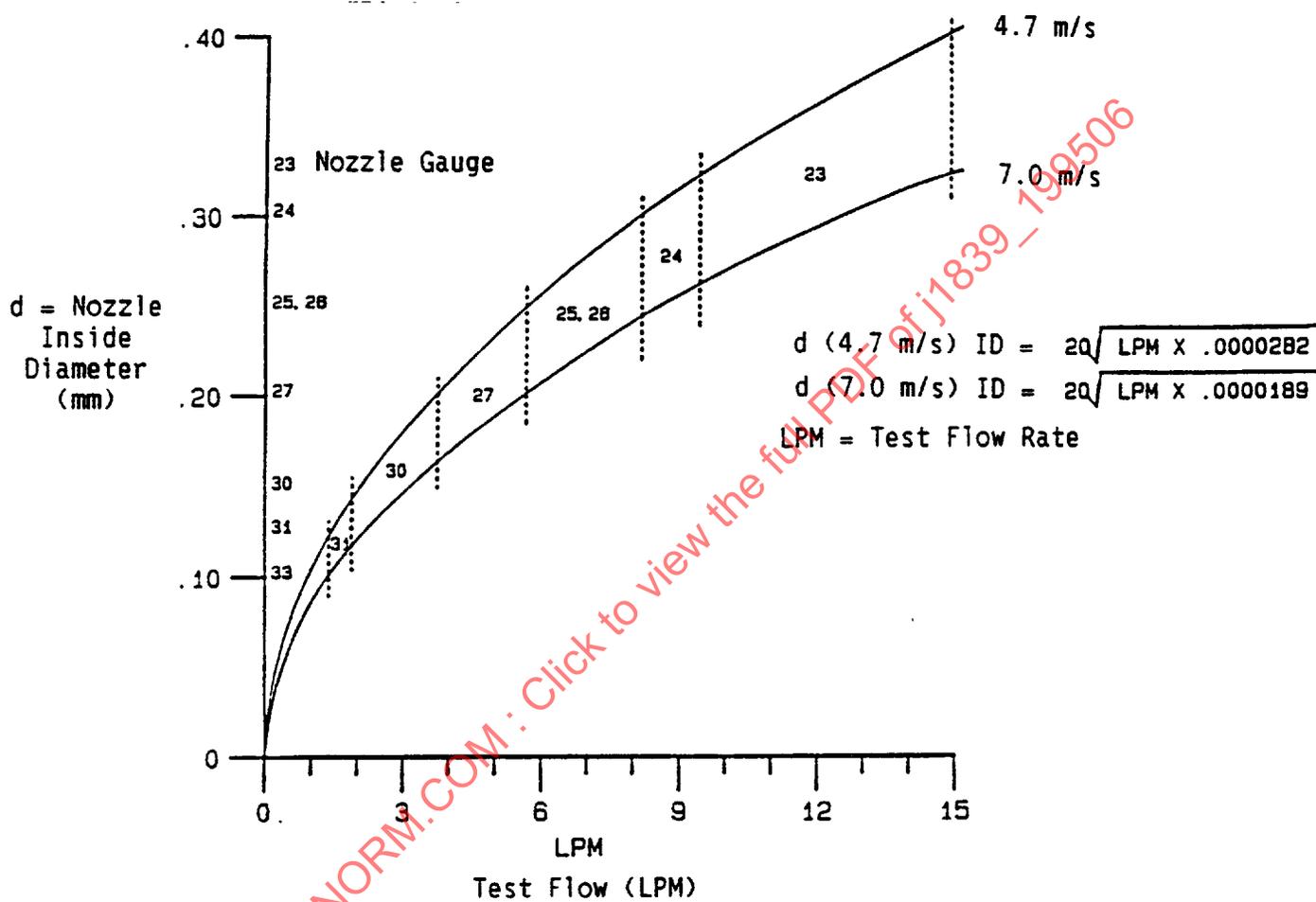


FIGURE A3—DISPERSING NOZZLE SIZE AND GAUGE FOR 0 TO 15 LPM TEST FLOW AT 4.7 TO 7.0 M/S VELOCITY THROUGH NOZZLE (ASSUMES 0.25% WATER ADD RATE)

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APPENDIX B

B.1 Fuel Treatment to Obtain Fluid as Specified in 4.1

- B.1.1** Take the required volume of No. 2 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 may be used.
- B.1.2** Periodically (about every 2 h) take a sample of the fuel in a beaker. Filter the sample through a 0.45 μm membrane and measure the interfacial tension (IFT) with distilled water at $20\text{ }^{\circ}\text{C} \pm 1.5\text{ }^{\circ}\text{C}$. The platinum ring detachment method (ASTM D 971) is recommended, although other correlatable methods may be used.
- B.1.3** If the IFT is greater than or equal to 27 to 35 dynes/cm (mN/m), stop further contacting with Fuller's Earth or clay. Generally 2 to 4 h of contacting will more than adequately ensure that this condition is met. Report the IFT of the treated fuel.
- B.1.4** Remove the Fuller's Earth cartridges from the test loop or adjust valving to isolate them from the test loop.
- B.1.5** Add to the Fuller's Earth treated fuel (in the test sump) 0.1% (1000 ppm) of cetane improver Ethyl DI13 (Ethyl Corporation). The additive is used to simulate additives normally found in diesel fuel which, through modification of fuel/water interfacial tension, may have significant influences on test results.
- B.1.6** Circulate the fuel with additive through the test system for 15 min or two complete turnovers of the fuel volume in the sump. The fuel treatment is now complete.

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