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INTERNATIONAL
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AEROSPACE STANDARD

SAE AS4707

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Submitted for recognition as an American National Standard

TEST METHODS EVALUATION OF NONFLAMMABLE, CHLOROTRIFLUOROETHYLENE BASE HYDRAULIC FLUID

1. SCOPE:

This SAE Aerospace Standard (AS) covers laboratory test methods required to evaluate nonflammable hydraulic fluids. The methods of testing and description of the equipment have been used typically for evaluating chlorotrifluoroethylene (CTFE) base hydraulic fluids.

1.1 Classification:

Test methods are described in detail as follows:

a. METHOD 1 - Saturation Determination for Chlorotrifluoroethylene (CTFE) - Tests for Oxidizable Materials
b. METHOD 2 - Capillary Gas Chromatography - CTFE Fluid Analysis
c. METHOD 3 - Thermal Stability
d. METHOD 4 - Corrosion Rate Evaluation - CTFE Fluid
e. METHOD 5 - Bulk Modulus
f. METHOD 6 - Performance of Hydraulic Fluid in a High Performance Hydraulic Pump

1.2 Safety - Hazardous Materials:

While the materials, methods, applications, and processes described or referenced in this document may involve the use of hazardous materials, this document does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

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 applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this specification and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 5047	Steel, Sheet and Strip, 0.08-0.13C, Aluminum Killed, Deep Forming Grade
AMS 5567	Steel Tubing, Seamless or Welded, Corrosion Resistant, 19Cr - 10Ni (SAE 30304), Hydraulic, Annealed
AMS 5648	Steel Bars, Forgings, Tubing, and Rings, Corrosion and Heat Resistant, 17Cr - 12Ni - 2.5Mo (SAE 30316), Solution Heat Treated
AMS 5680	Steel Welding Wire, Corrosion and Heat Resistant, 18.5Cr - 11Ni - 0.40(Cb + Ta) (SAE 30347)
AMS 6440	Steel Bars, Forgings, and Tubing, 1.45Cr (0.98 - 1.10C), (SAE 52100), for Bearing Applications

2.1.1.1 Alloys Under the Unified Numbering System:

AISI 316	UNS S31600
AISI 304	UNS S30400
AISI 1010	UNS G10100

2.1.2 ASTM Publications: Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM D 445	Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)
ASTM D 664	Neutralization Number by Potentiometric Titration
ASTM D 1748	Rust Protection by Metal Preservatives in the Humidity Cabinet

3. ???

3.1 METHOD 1 - Saturation Determination for Chlorotrifluoroethylene (CTFE) - Tests for Oxidizable Materials:

3.1.1 Apparatus and Equipment:

3.1.1.1 Spectrophotometer Settings (UV Quartz Cuvettes Path Length 10 mm):

a. Slit: 1.0 nm
b. Absorbance scale for acetone (blank): 0 to 2.0
c. Absorbance scale for samples and standard: 0 to 1.0
d. Scan rate: 50 nm/min
e. Wavelength scanned: 650 to 425 nm

3.1.1.2 Recorder Settings:

a. 5 cm/min
b. Full scale 100 mv

3.1.1.3 Constant temperature bath set at 25 °C ± 1 °C.

3.1.1.4 Balance capable of weighing to ±0.0001 g.

3.1.2 Materials:

a. 10 mL pipet
b. Test tubes: 25 mm x 200 mm, Pyrex
c. Hamilton micro-syringe, type 710N or equivalent
d. Small flask
e. Reagent grade acetone, certified ACS (spectroanalyzed)
f. Double distilled water
g. Potassium permanganate, crystals, reagent grade, ACS
h. Standard CTFE test fluid (see 4.3)

3.1.3 Equipment Operation: Shall be as follows:

3.1.3.1 Turn on spectrophotometer and constant temperature bath and allow to warm up.

3.1.3.2 Rinse test tubes with distilled water, follow with a rinse using reagent grade acetone, and dry in an oven. Clean micro-syringe with acetone and dry under nitrogen.

3.1.3.3 Prepare a 1% solution of potassium permanganate with double distilled water and cover with paraffin film or stopper.

3.1.3.4 Clean four test tubes in accordance with 3.1.3.2. Add 1.0 g ± 0.05 g standard test fluid to two test tubes. Add 1.0 g ± 0.05 g sample hydraulic fluid to be tested to the two remaining test tubes and cover with aluminum foil.

3.1.3.5 Prepare a blank (10 mL acetone in test tube).

3.1.3.6 Using the micro-syringe, add 0.06 mL of 1% potassium permanganate to the blank (3.1.3.5), shake and swirl, record time and quickly transfer test tube to constant temperature bath set at 25 °C ± 1 °C (77 °F ± 2 °F).

3.1.3.7 Maintain blank in bath for 15 min minimum; add 10 mL acetone to standard, shake, and swirl; add 0.06 mL of 1% potassium permanganate solution, swirl, record time, and quickly place standard in bath.

3.1.3.8 After 60 min minimum, remove the first sample (blank), observe color, quickly transfer into a clean cuvette and place in the spectrophotometer. Check settings. Start the spectrophotometer and zero the recorder. Scan 650 to 425 nm, making certain that the blank run is set on absorbance scale (0 to 2.0). Measure and record absorbance at 528 nm. Stop at 425 nm, remove sample, clean cuvette, and prepare for next run. Set absorbance scale (0 to 1.0).

3.1.3.9 Remove the standard from water bath, observe color, quickly transfer to cuvette, and proceed as above (3.1.3.8). Record absorbance at 528 nm. Test other samples in the same manner.

3.1.3.10 Compare the duplicate standard's absorbance. Difference should not be greater than 0.04 absorbance units. If difference is greater than 0.04, repeat the test.

3.1.4 Acceptance Standard:

3.1.4.1 If the absorbance of the sample being tested is equal to or greater than the absorbance of the standard CTFE sample, the test fluid is acceptable.

3.1.4.2 If the absorbance of the sample being tested is lower than the standard CTFE sample, the sample is rejected.

3.2 METHOD 2 - Capillary Gas Chromatography Method (CTFE Fluid Analysis):

A candidate CTFE fluid and a standard CTFE trimer fluid are analyzed by a gas chromatographic system. The concentration of the peaks is calculated by taking the percent of the total area contributed by each peak. The total percent of the candidate sample peaks eluting earlier than the standard trimer are reported.

3.2.1 Apparatus and Equipment:

a. Hewlett Packard gas chromatograph, Model 5710 or equivalent, adapted for use with capillary columns with a flame ionization detector or equivalent

b. Fused silica capillary column, length 12 m, diameter 0.22 mm, methyl silicone, carbowax 20M deactivated stationary phase or equivalent

c. Chlorotrifluoroethylene trimer standard (see 4.2)

3.2.1 (Continued):

d. Syringe, 5 mL capacity

e. Linear recorder, 0 to 1 mV

f. Sample vials

g. Hewlett Packard Autosampler model 7671A or equivalent (optional)

h. Hewlett Packard 3354 lab automation system or equivalent for peak integration and calculation

3.2.2 Equipment Operation: Shall be as follows:

a. Equipment designation: See 3.2.1
b. Support: None
c. Split ratio: 100 to 1
d. Auxiliary gas: Helium, 40 mL/min
e. Carrier gas: Helium
f. Carrier gas flow rate: 1 mL/min
g. Chart speed: 0.66 cm/min
h. Detector: FID
i. Attenuation: 10 x 16
j. Temperature:
   (1) Injector: 250 °C (480 °F)
   (2) Detector: 250 °C (480 °F)
   (3) Column: 100 to 250 °C (212 to 480 °F)
k. Temperature program rate: 8 °C (15 °F) minimum
   Initial hold - 8 min
   Final hold - 8 min

3.2.3 Calculation of CTFE base fluid areas.

3.2.3.1 Sum all peak areas.

3.2.3.2 Express each peak as a percent of the total area.

3.2.3.3 Assume that the area percent is the same as the true composition.

3.2.3.4 Calculation results using Equation 1:

$$C_i = \frac{A_i \times 100}{n} \qquad \text{(Eq.1)}$$

where:

C_i = Concentration of component i
A_i = Area of component i in units of microvolt-seconds
n = Total area for entire run, microvolt-seconds

3.2.3.4.1 Assumptions used in this calculation are:

The detector responds quantitatively in the same way to all sample components; all response factors are the same.

All components are eluted from the column.

All components are detected and are represented as peaks.

NOTE: The Hewlett Packard 3354 Automation System carries out this integration.

3.2.4 Acceptance Standard:

3.2.4.1 New CTFE samples with less than 11% of the total concentration eluting before the trimer standard as measured (retention time 2.35 min for the above system) are acceptable.

3.2.4.2 Representative chromatograms are shown in Figures 1 and 2.

3.3 METHOD 3 - Thermal Stability Test:

3.3.1 Apparatus and Equipment:

Test cell equipment, material, and configuration is shown in Figure 3. The cell is fabricated from seamless tubing conforming to AMS 5567; fittings are fabricated from material conforming to AMS 5648.

Balls, 1.27 cm diameter, are fabricated from M10 tool steel, AMS 6440 bearing steel alloy, and naval bronze.

A suitable heat source with ±1 °C (1.8 °F) temperature control.

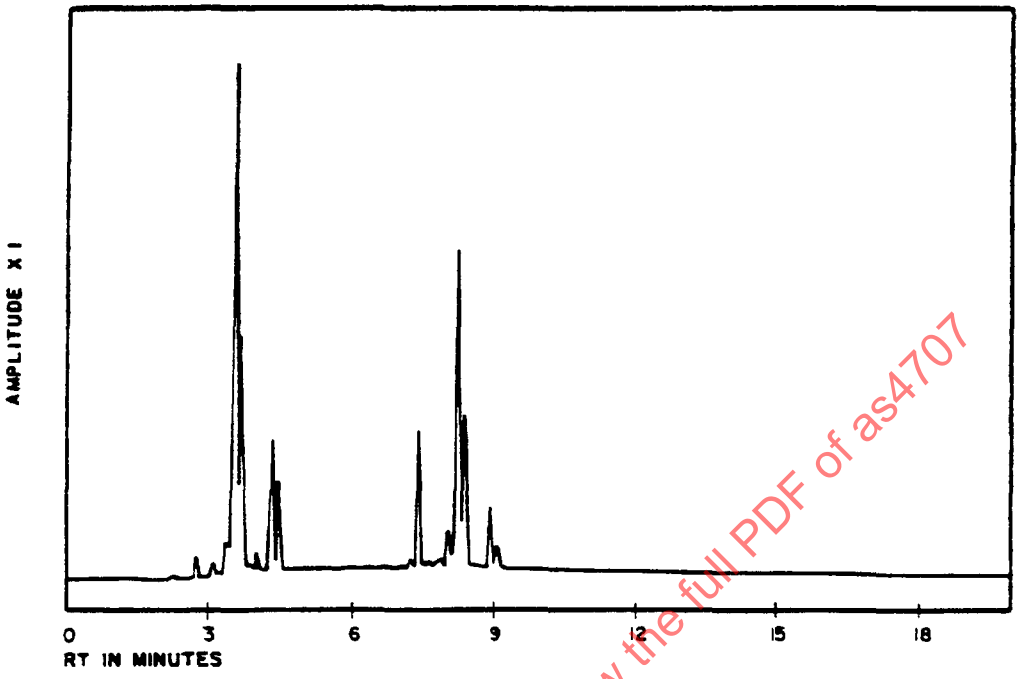

FIGURE 1 - Capillary GC of CTFE Base Fluid (Amplitude x 1)

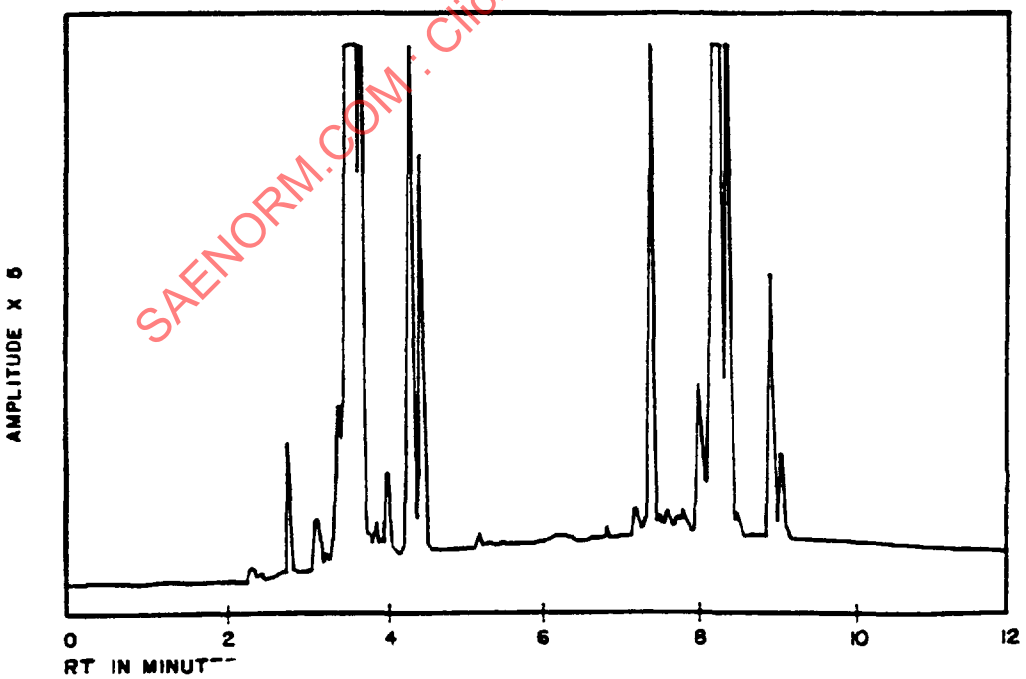

FIGURE 2 - Capillary GC of CTFE Base Fluid (Amplitude x 5)

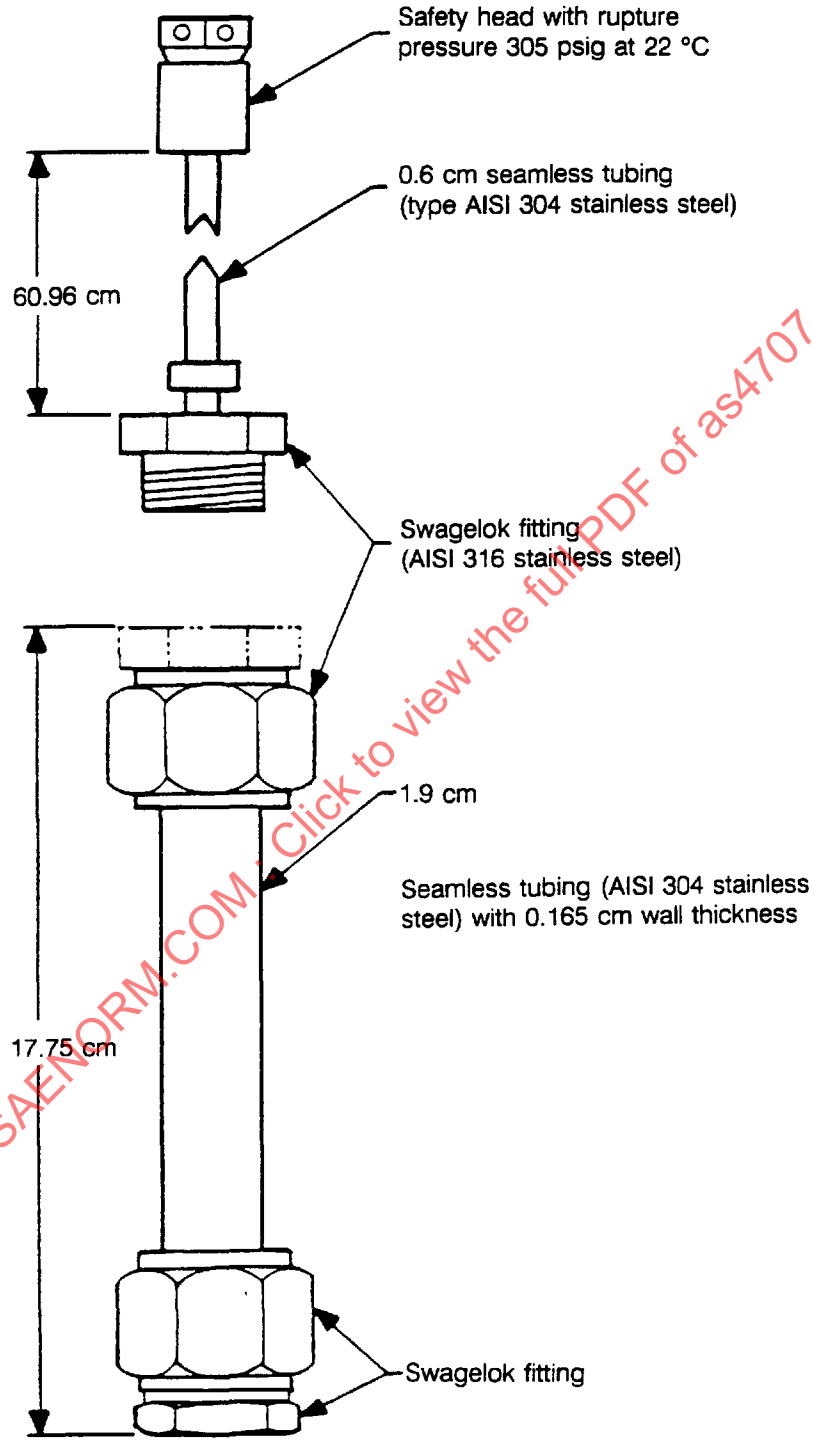

FIGURE 3 - Thermal Stability Test Cell

3.3.2 Pretest Procedure:

a. Clean balls and test cell with suitable solvent in an ultrasonic bath for 5 min. (Duplicate analyses shall be made.)

b. Repeat cleaning step two more times using fresh solvent each cleaning operation.

c. Dry test cells in an oven at 100 °C (212 °F) for 1 h ± 5 min.

d. Wipe balls dry with lint-free tissue.

e. Weigh balls to nearest 0.0001 g and record. Repeat cleaning operation and weighing until weight change is less than 0.0001 g.

3.3.3 Test Procedure:

a. Place balls in test cells with tool steel (M10) on bottom and bearing steel (AMS 6440) on top.

b. Add 20 mL ± 0.1 mL test fluid in each cell.

c. Bubble nitrogen through fluid for 5 min and quickly cap test cells.

d. Weigh test cells and record to the nearest 0.1 g.

e. Place test cells in the heat source for 72 h minimum at 135 °C ± 1 °C. The entire 1.9 cm tube section of the cells shall be heated. The safety head must be out of the heated zone.

3.3.4 Posttest Procedure:

a. Remove test cells from heat source and cool in air.

b. Weigh cells and record to nearest 0.1 g.

c. Clean balls and weigh as in 3.3.3.

d. Determine percent viscosity change at 40 °C (104 °F) and total acid number on fluid in accordance with ASTM D 445 and ASTM D 664, respectively.

3.3.5 Acceptance Standard:

Test cell weight loss shall be less than 0.5 g for acceptance. Test results shall be considered unacceptable if loss is greater than 0.5 g.

3.4 METHOD 4 - Corrosion Rate Evaluation Procedure for CTFE Hydraulic Fluids:

3.4.1 Equipment, Materials, and Reagents: This test requires the use of the following equipment and materials:

1. Reaction kettle: PYREX, 2000 mL capacity, complete with cover having a finely ground flange for a tight seal. Cover has one standard taper 34/45 female joint in the center and three standard taper 24/40 female joints spaced 120° apart with centers 50 mm ± 2 mm from the center of the cover.
2. Bushing type reducing adapter, standard taper 34/45 male outer joint, standard taper 24/40 female inner joint
3. Allihn condenser, water cooled, 400 mm ± 5 mm jacket length, with standard taper 24/40 male joint to match female joint of standard taper 34/45 to 24/40 bushing type reducing adapter
4. Ace-thread offset adapter, with a No. 7 ace-thread or equivalent, a threaded nylon bushing, and a Buna-N O-ring
5. Air injection tube, borosilicate glass, 850 mm ± 5 mm long and 6 mm ± 1 mm outside diameter with one end flared from 6 to 12 mm ± 1 mm over a distance of 30 mm ± 1 mm at one end of the tube
6. Glass stopper with glass loop; hollow pennyhead stopper with glass loop fabricated from 30 mm ± 1 mm OD glass rod. Distance from base of stopper to base of glass loop shall be 0.09 mm.
7. Perforated teflon splash suppressor, fabricated from 3 mm teflon sheet stock. Splash suppresser disk is 127 mm ± 5 mm diameter and perforated with 6.4 mm diameter holes in seven equally spaced rows, with the center row passing through the diameter.
8. Suspension wire conforming to AMS 5680, 20 gage, cut and formed to the required geometrical configuration.
9. PYREX boiling beads, 3 mm diameter
10. Hot plate, electric, Thermolyne Model SP-13115, or equivalent
11. Airflow meter, Matheson mass flowmeters or rotometers, or equivalent
12. Metering valve for airflow control, Whitey Model 22rS4, or equivalent.
13. Compressed dry air, Size A cylinder, with two stage regulator
14. Laboratory timer, Model 171 Universal, or equivalent
15. Analytical balance, readability to 0.1 mg
16. Desiccator
17. Wiping tissues
18. 240 and 320 grit silicon carbide paper
19. Distilled water
20. Scaled-down box in accordance with ASTM D 1748, Appendix A1.13, or equivalent to provide a coupon draining chamber for dust free environment for oil draining cycle
21. Camera, Polaroid, or equivalent
22. Die set for coupon identification
23. Laboratory aluminum foil

3.4.1 (Continued):

24. Steel test coupons shall be fabricated from AMS 5047. Coupon dimensions shall be 51 mm x 13 mm x 1.6 mm (2 x in 0.5 in x 0.6 in), with one hole 2.4 mm (0.09 in) diameter drilled 3.2 mm (0.13 in) from one end of the test coupon and centered across the width. All surfaces and edges of the test coupons shall be polished to 10 to 20 µin finish; faces shall be completely free of pits, scratches, or other imperfections. Surface grinding shall be in direction parallel to the coupon length. Coupons shall be coated with a nonvolatile, water insoluble rust preventative and packaged in a moisture proof package for shipment and storage prior to being used. Specimens from Metaspec, Box 27707, San Antonio, Texas 70227 have been found to be satisfactory for these corrosion tests.
25. Toluene, reagent grade
26. Acetone, reagent grade
27. Methanol, absolute, reagent grade
28. Dow Corning High Vacuum grease, or equivalent
29. Standard Reference Fluid A = Formulated CTFE (0.05%, 3M FL1478 and 0.5% barium dinonlynaphthalene sulfonate)
30. Standard Reference Fluid B = CTFE (A02) base stock

3.4.2 Specimen Preparation:

1. Each test requires six coupons (see item 24 above).
2. Identify each coupon using die-cut 3.2 mm (0.13 in) numbers positioned immediately below the suspension hole.
3. Rinse coupons with distilled water, air dry, and store in a solution of 50 parts toluene and 50 parts absolute methanol until final cleaning.
4. Final clean by immersing each coupon in boiling toluene, flash drying, and immersing in boiling acetone, followed by flash drying.
5. Store coupons in a desiccator for 30 min minimum to equilibrate to ambient temperature; weigh to five decimal places.
6. All handling shall be with forceps, or equivalent. Do not touch with bare hands.

3.4.3 Test Apparatus Assembly: Two identical setups are required to obtain duplicate results.

1. Glassware must be carefully cleaned and dried. Place reaction kettle on the hot plate and add approximately 10 boiling beads to the kettle to preclude bumping and splashing of the distilled water.
2. Place the teflon splash suppresser in the kettle; it should be loosely seated against the kettle base.
3. Coat the ground glass flange of the reaction kettle with a thin film of silicone grease to prevent condensate leakage and center the cover on the reaction kettle.
4. Fit the center female joint with a standard taper 34/45 to 24-40 reducing type bushing adapter.

3.4.3 (Continued):

5. Insert male joint of the Allihn condenser into the bushing adapter; insert the male joint of the threaded offset adapter into the female joint at the top of the condenser. Condenser must be supported.
6. Insert the glass air inlet tube through the center of the Allihn condenser and offset adapter; seal with an O-ring in the threaded bushing of the adapter. Position the air inlet tube so the flared end is 51 mm (2 in) above the kettle base.
7. Place glass stoppers with glass hooks in the remaining three female joints of the cover.
8. Form the coupon suspension hooks (shaped from AMS 5680 20-gage stainless steel wire), so the bottom edge of the test coupon is approximately 110 mm (4.3 in) from the base of the kettle.
9. Prepare the regulated dry air source using the micrometer valve for flow control and the calibrated flow meter for airflow measurement.

3.4.4 Test Procedure:

1. After assembling test apparatus, remove the reaction kettle and cover from the hot plate, leaving the condenser and airflow assembly attached to the support stand.
2. Preheat hot plates; allow to equilibrate at the highest setting.
3. Start water flow through condenser.
4. Add 10 mL distilled water to the reaction kettle and reassemble apparatus on the equilibrated hot plate.
5. Establish airflow rate of 500 cc/min to the reaction kettle before the water starts to boil. (Temperature around coupons will be approximately 92 °C (198 °F).
6. Equilibrate for 60 min minimum before inserting test specimens.
7. Wrap the kettle and glassware before the condenser with aluminum foil to avoid cooling.
8. Immerse two of the prepared coupons in each of three fluids (i.e., test fluid, standard reference fluid A, and standard reference fluid B for 5 min).
9. Remove coupons and suspend vertically in a dust free environment for 15 min.
10. Remove excess oil at the bottom edge of the specimens by light, quick dabbing with a wiper.
11. Suspend the test coupons (one coated with each fluid in each reaction kettle) by the wire hooks from the glass stoppers and insert in the reaction kettle for 60 min.
12. Remove test coupons from the reaction kettle at the end of the test and photograph before cleaning.
13. Numerically rate the appearance of the coupons immersed in the fluid being evaluated in regard to the degree of corrosion comparing them to the coupons that were immersed in standard reference fluids. Coupons tested in Standard Reference Fluid A are rated 10. Standard Reference Fluid B coupons (base stock) are rated 0. Visual ratings are based on a linear interpolation of the sample coupon compared to the two reference coupons.
14. Remove all loose material from the coupons by wiping with a paper tissue or laboratory wiping material.

3.4.4 (Continued):

15. Immerse the coupons in boiling toluene for 5 min, followed by boiling acetone for 5 min. Flash dry and place in desiccator to equilibrate to ambient temperature.
16. Wait 30 min and weigh test coupons to five decimal places; calculate weight change.

3.4.5 Evaluation: A weight change of greater than 20 mg shall constitute a failure. A visual rating of less than eight shall constitute a failure.

3.5 METHOD 5 - Bulk Modulus:

3.5.1 Apparatus and Equipment: Bulk modulus of hydraulic fluid shall be determined using a calibrated precision capillary pycnometer similar to Figure 4 (modified 21 F 50 Jersuson or equivalent instrument). A pressure vessel and auxiliary equipment that has proven satisfactory for this determination is illustrated in Figures 5 and 6.

3.5.2 Procedure: The pycnometer volume to capillary diameter ratio shall be chosen to provide a precision of measurement for liquid density of ±2 parts in 10 000. The pycnometer shall be charged with candidate fluid to the top of the capillary at 40 °C ± 1 °C (104 °F ± 2 °F) constant-temperature bath; allow equilibrium to be reached. Take volume reading at atmospheric pressure.

NOTE: Since the precision of the unit depends on visual readings, care must be taken to avoid errors due to parallax and distortion in the pressure vessel window and the walls of the constant-temperature bath.

3.5.2.1 Increase nitrogen pressure to a new level and read volume and after a 1 h soak, take a third reading. For any pressure range, the secant bulk modulus is defined by Equation 2:

$$\text{Bulk modulus} = \frac{V\ (\text{delta P})}{V + (\text{delta } V_g)} \qquad \text{(Eq.2)}$$

where:

V = the original volume of the fluid
delta V = the observed volume change due to P increase in pressure
delta P = the pressure change between the two measurements in kPa
delta V_g = the correction factor

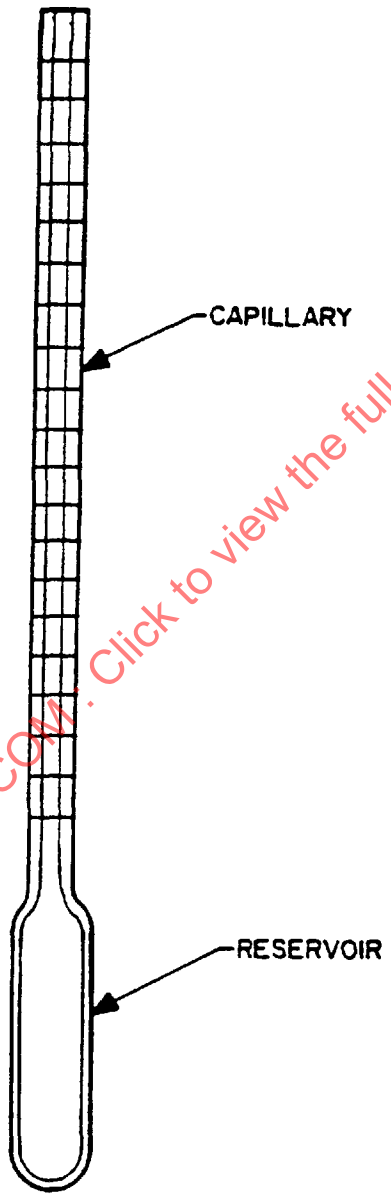

FIGURE 4 - Precision Capillary Pycnometer

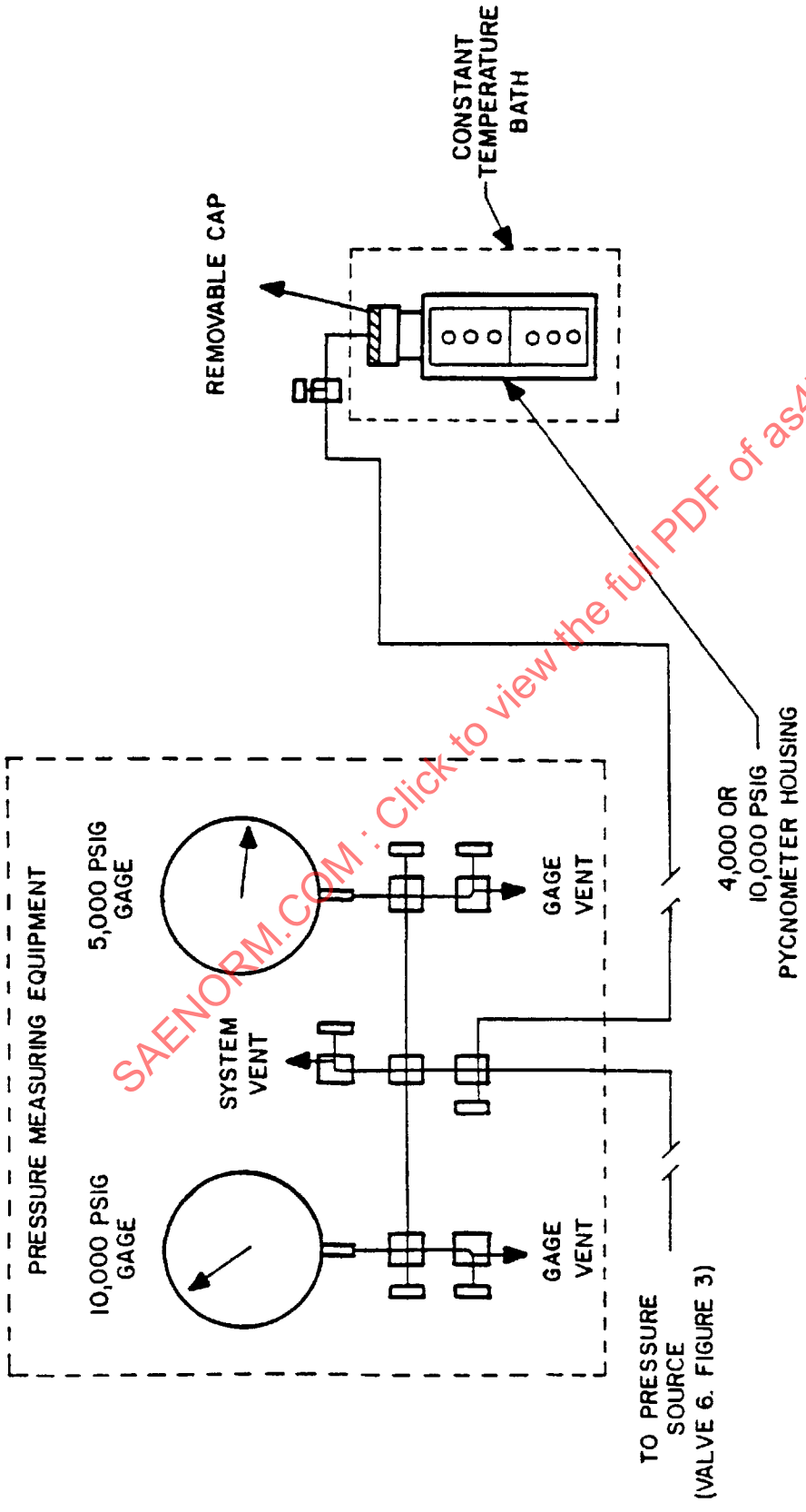

FIGURE 5 - Diagram of Bulk Modulus Equipment

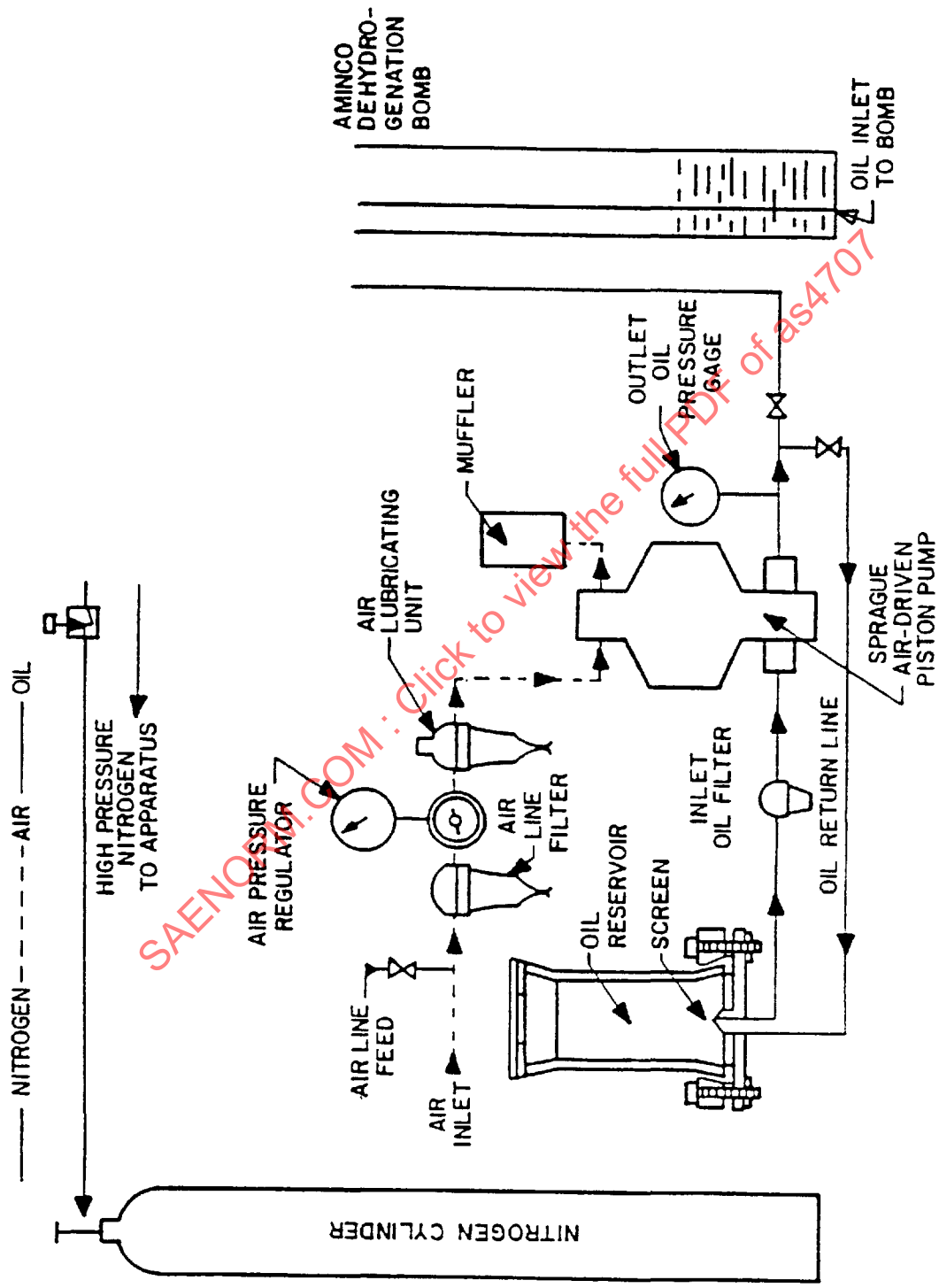

FIGURE 6 - Auxiliary Equipment

3.5.2.1.1 The correction factor (V_g) considers the bulk modulus of glass in determining the true volume of the pycnometers at pressures above atmospheric. The bulk modulus of Pyrex glass is 3.28×10^7 kPa (4.77×10^6 psi). Calculate the correction factor using Equation 3.

$$\text{delta } V_g = \frac{V \text{ (delta P)}}{3.28 \times 10^7} \qquad \text{(Eq.3)}$$

3.6 METHOD 6 - Test for Performance of Hydraulic Fluid in a High Performance Hydraulic Pump:

3.6.1 Method Summary: This test involves the cyclic operation of a hydraulic pump in a closed loop test stand for a total of 500 h.

3.6.2 Test Fluid Required: 15 L, minimum

3.6.3 Test Pump Description: 'VICKERS' inline type, pressure compensated pump model PV3-075-15 has been used for this type of testing and found to be satisfactory.

3.6.4 Test Stand Description: A schematic diagram is shown in Figure 7. The test stand consists of a drive motor, throttling valve, heat exchanger, reservoir, filters, pressure relief valve, check valve, hand pump, and instrumentation. The throttling valve serves as a flow control device. Working volume of the fluid in the test loop should be between 3 and 3.8 L (0.8 to 1 gal). The reservoir is not in the test loop, but provides makeup fluid only when fluid samples are taken or leakage occurs. All lines, fittings, and other metallic components shall be made of stainless steel (such as AISI 316) or materials compatible with chlorotrifluoroethylene (CTFE) base hydraulic fluids.

3.6.5 Instrumentation: Location of thermocouples is noted below. Total system accuracy shall be calibrated to ±1 °C (±1.8 °F) to measure test fluid temperature. Thermocouples shall be shielded and unless otherwise specified by purchaser, shall be immersed to the midstream and located as close to the components as practical.

a. Pump inlet temperature: In pump inlet line
b. Pump outlet temperature: In pump outlet line
c. Throttling valve (T/V) outlet temperature: In T/V outlet line
d. Case drain temperature: In case drain line

3.6.5.1 Flow Measurements: Fluid flow in the pump outlet and case drain line shall be measured. Fluid flow measurements shall have a resolution of ±0.4 L/min (±0.1 gal/min).

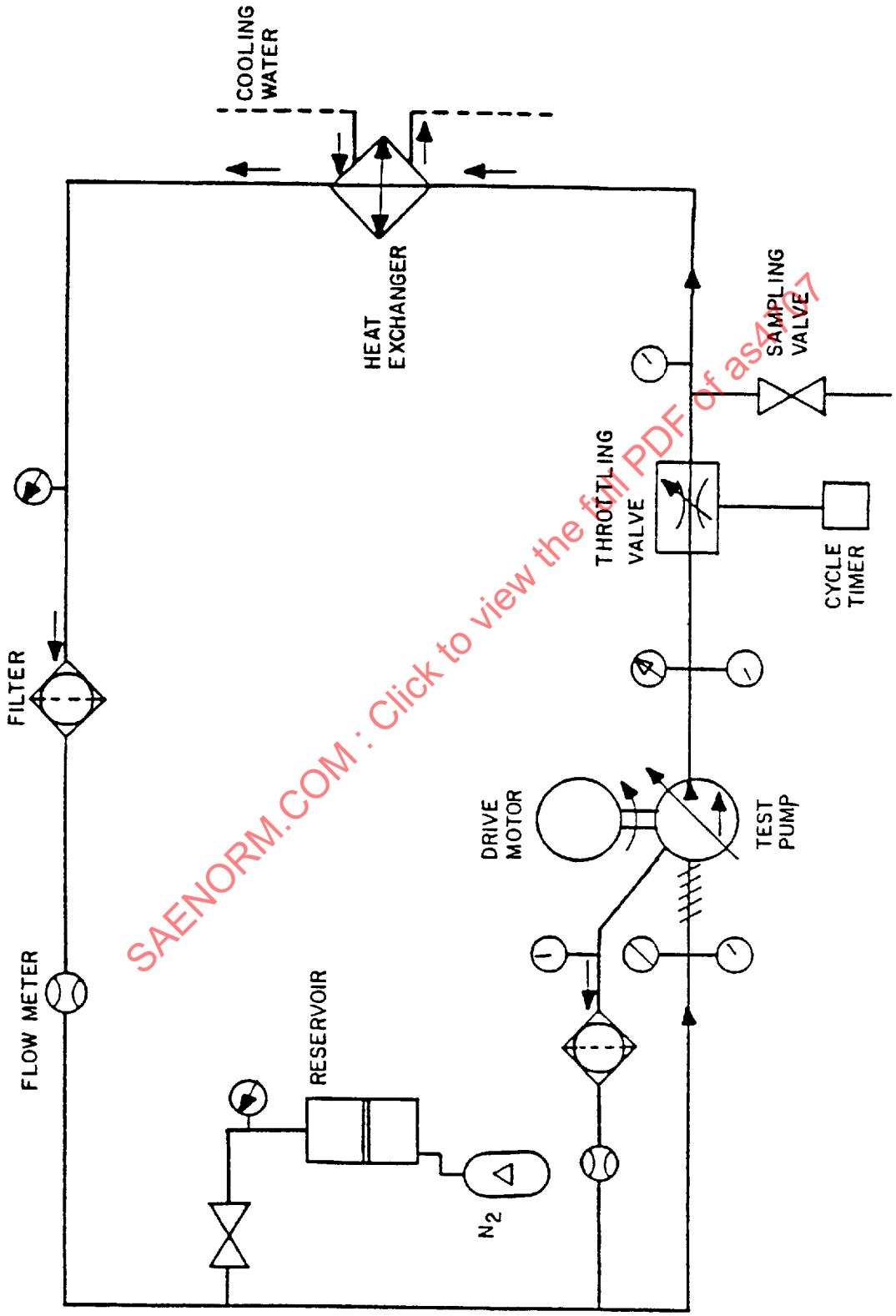

FIGURE 7 - Schematic of Aircraft Hydraulic Pump Test Stand

3.6.5.2 Pressure Measurements: The following values shall be monitored with appropriate pressure sensors. Measurements shall have a resolution of ±6.9 kPa (±1 psi).

a. Pump outlet pressure
b. Pump inlet pressure
c. Case drain pressure
d. Main filter pressure drop
e. Case drain filter pressure drop

3.6.5.3 Pump Speed Measurement: Pump shaft speed measurement shall have a resolution of ±10 rpm.

3.6.5.4 Torque Measurements: Measurements of torque on the pump shaft shall have a resolution of ±0.6 N-m (±5 in-lb).

3.6.6 WARNING: Some of the materials used in this test method are toxic and hazardous. Careful handling is required.

3.6.6.1 Cleaning Solvent: Heptane may be used for part cleaning. Chlorinated solvents must not be used for cleaning.

3.6.7 Test Procedures and Preparation of Equipment: Shall be as follows:

3.6.7.1 Pump Preparation: A new pump shall be used for every test. Preservative fluid from the pump casing shall be drained. Pump shall be completely disassembled, cleaned thoroughly with heptane, blow dried with nitrogen, and placed in an oven at 66 °C ± 6 °C (151 °F ± 11 °F) for 30 min. All elastomeric seals shall be replaced with 'VITON' seals. Pump shall be assembled and the casing filled with the test fluid. During disassembly and reassembly, care must be taken to install the pistons in their original cylinder bores.

3.6.7.2 Test Stand Preparation: Test stand shall be completely disassembled and thoroughly cleaned by spraying heptane on all parts. All fittings, lines, and other components shall be cleaned to remove any residual metal and fluids from previous tests. If necessary, a clean cloth (cheesecloth or equivalent) shall be run through the tubing for cleaning. Parts may be blow dried with nitrogen and placed in an oven at 66 °C ± 6 °C (151 °F ± 11 °F) for 30 min to remove any solvent left on the parts. All elastomeric seals shall be replaced with new 'VITON' seals. Test pump, prepared as in 3.6.7.1, shall be mounted on the drive motor/torque sensor assembly. Splines on the pump shaft shall be adequately lubricated with a fretting-corrosion resistant grease. Test stand shall be filled with 9 to 11 L (2.4 to 2.9 gal) of the test fluid. Any air in the system shall be removed to avoid cavitation damage to the components. Since air bleeding procedure may vary from one test stand to another, one method that has proven satisfactory is presented in 3.6.7.2.1.