AEROSPACE RECOMMENDED PRACTICE

ARP5891

Issued 2008-01
Reaffirmed 2014-05

Achieving Cleanliness Standards for Aircraft Hydraulic Systems During Manufacture

RATIONALE

ARP5891 has been reaffirmed to comply with the SAE five-year review policy.

TABLE OF CONTENTS

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) establishes the processes to achieve and maintain the required cleanliness levels in flight vehicle hydraulic systems during fabrication, assembly and pre-flight functional tests.

This recommended practice covers exclusion and removal primarily of solid contaminants that occur or are created during these successive steps. The flushing procedure for installed tubing is detailed. This ARP does not address contamination levels of hydraulic fluids as purchased, operation and maintenance of ground carts, details of component cleanliness or of contamination measurement.

This ARP applies to military aircraft and helicopters designed to AS5440, commercial aircraft hydraulic systems designed to ARP4752 and commercial helicopter hydraulic systems designed to ARP4925.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document 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 document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

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

ARP994	Recommended Practice for the Design of Tubing Installations for Aerospace Fluid Power Systems
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
AIR1362	Aerospace Hydraulic Fluids Physical Properties
AS4059	Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids
ARP4752	Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems
ARP4925	Aerospace - Design and Installation of Commercial Transport Helicopter Hydraulic Systems
ARP5376	Methods, Locations and Criteria for System Sampling and Measuring the Solid Particle Contamination of Hydraulic Fluids
AS5440	Hydraulic Systems, Aircraft, Design and Installation Requirements for

2.2 U.S. Government Publications

Available from Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft, Metric, NATO Code Number H-537
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile, NATO Code Number H-538
MIL-STD-419	Cleaning, Protecting, and Testing Piping, Tubing, and Fittings for Hydraulic Power Transmission Equipment

3. GENERAL

There are many steps in the fabrication and assembly of an aircraft hydraulic system. Tube extrusion requires lubricants for the dies. Tube bending requires lubricant for the bend mandrels. Cutting processes trim the tube stock to finished length. During many of the steps, solid contamination is created to some extent, affecting the cleanliness of the tubing or components in the system. Some processes produce no contamination; others create metal chips or expose the tube or component to the surrounding environment, which will affect the final cleanliness of the system.

This ARP outlines the major steps of the build process and makes recommendations which contribute to the achievement of the overall, final cleanliness level required.

3.1 Outline of Build Process

The following steps generally describe the fabrication, assembly and functional test stages for the aircraft hydraulic tubing system and prescribe steps for achieving a clean system.

3.1.1 Tube Fabrication

The stock tubing lengths are formed according to the defined bend data on applicable tube detail or assembly drawing for each tube assembly. Following forming, the tubes should be subjected to a cleaning process which removes solid contaminants and forming lubricants from the interior and exterior of the tube detail. The cleaning method varies, but usually involves a degreasing operation of the tube followed by a rinse operation to give a clean, non-tacky interior and exterior surface on the tube. Following the degreasing process, the tubes should be capped or bagged to maintain cleanliness for the next operation. MIL-STD-419 has detailed recommendations on cleaning of tubes.

3.1.2 Tube Assembly

Following forming, cleaning and degreasing, fittings are attached to those tubes as called up on the tubing assembly drawing. If required, tubes which have one or more permanent fittings will be trimmed to a length with allowance for final trim in preparation for final installation. The completed assembly is subjected to proof pressure test and identification and function tapes are applied. There are several points of quality inspection that may be applied during and following the prescribed steps:

1. The cleanliness of the fluid used for proof pressure testing should be controlled to one or two levels cleaner than the final system in order to help meet final cleanliness requirements.

2. The use of air or water for proof pressure test prevents the tube interior from becoming tacky and prone to pick up contamination. Either media should be cleaner than the final system as noted above to promote meeting delivered cleanliness level requirement.

3. Tube assemblies should be drained, dried and capped, bagged or plugged upon completion of this operation using fluid compatible materials for the caps and plugs.

3.1.3 Tube Installation

As the airframe subsections progress through their build process, the formed tubing is installed and clamped in accordance with released installation drawings. Usually the system components are in place to the maximum extent possible in order to use the components to establish the final, installed position of the tubing. During this stage, tubing which requires in-place permanent joints will be trimmed, deburred and joined. This operation can be one source of solid contaminant within the tube assemblies. Contamination generated by this operation must be removed by flushing as detailed in 3.2 of this specification, prior to operation of components, to avoid lodging contaminant within close tolerance parts in valves, actuators and other components. It will help to reduce contamination generation at the system level if the design of permanent joints between major airframe sections is such that no trimming is necessary.

3.1.4 Installation Leak Check and Pressure Test

Leak testing at this point allows easier access in event of a leaking joint. The assembled tubing, with pressure tight plugs at end points, will be subjected to a low-pressure nitrogen leak check. Leaks detected at this point are corrected. Once no leakage is ascertained, the tubing is subjected to the appropriate pressure for the prescribed time.

At this point, sections of tubing joined at this stage will receive a pressure test with the components removed. The tubing in major airframe sections may be pressure tested as an assembly prior to joining with other sections in final assembly.

3.2 System Cleanup

3.2.1 Tube Flushing

3.2.1.1 Need for Flushing

Flushing is used in order to remove the solid contaminants generated during the tube fabrication, installation, and assembly process with a high degree of confidence in the result. Unless verifiable Quality Control standards are used to guarantee that no contamination of a tube assembly has occurred during the previous processes, steps to eliminate any contaminant previously generated are needed. Once all tubing is installed and all tube joints completed, components must be removed and flushing of each tube path should be conducted to reduce any solid contamination to an established standard.

NOTE: For aircraft hydraulic systems, the flushing procedures of this document are more relevant than MIL-STD-419 flushing procedures and should be used in lieu of MIL-STD-419 procedures whenever possible.

3.2.1.2 Flushing Definition

Flushing is defined as the sequential application of sufficient flow through each tube circuit to produce turbulent flow in the circuit. For this document, a conservative Reynolds number value of 4000 is used.

3.2.1.3 Cleanliness Standard

A standard of at least one level cleaner than the final delivered cleanliness is recommended.

Example: If cleanliness of AS4059 Class 7 is required for delivery, Class 6 should be a goal during buildup. Components shall be sufficiently cleaned that a fluid sample taken from a filled component should meet AS4059 Class 5 cleanliness requirements. This tiered approach will simplify clean-up of the system in final stages when assembly of the system is complete.

3.2.1.4 Sampling Problems

Interim contamination testing on fluid samples at this stage for completed major sub-sections is conducted to verify cleanliness. The conditions for fluid samples are often not ideal at this stage of build-up. If care is not exercised in the processing of bottled samples the results may be one or possibly two classes dirtier than obtained with on-line sampling.

Taking of return fluid samples directly into sample bottles may be done, but does not always give a representative sample, as the initial discharge of fluid may contain higher levels of contamination. The practice of establishing a stream of fluid into a waste container, then switching to a clean sampling bottle without disturbing anything will improve sampling into a clean bottle.

The sampling process can be improved by use of a valve designed for sampling assembled to a clean hose that is connected to the return side of the section being flushed. A proper sampling valve installed in the return line from the aircraft system at the ground cart will aid in getting representative samples. Continuous on-line sampling of the return fluid going back to the ground cart is a time saving process, eliminating the time loop required for taking samples, submission to the lab for analysis and getting a report on results.

For additional discussion on sampling refer to ARP5376.

3.2.1.5 Flushing Tool Kit

Flushing of the aircraft hydraulic system should be supported by a defined “tool kit” consisting of a selection of hose sizes and lengths, and adapter fittings in the various tube sizes to accommodate each installation. The kit should include industrial ball or needle valves, and any special assemblies of hose, tubing, and valve(s) needed to flush dense, low access areas.

All fittings, hose, and valves in the kit should be rated for the highest pressure to be applied while installed. This would usually be proof pressure.

The jumper hose, shut-off valves and other tooling used in the flushing process should be drained and capped when not in use to help maintain cleanliness.

3.2.1.6 Flushing Power Source

Flushing of tubing is accomplished by using a ground cart or central hydraulic system with a high capacity industrial filter in the return circuit. The ground cart return filter should be rated to at least the level of the finest filter in the aircraft. Fluid used shall be the same fluid specification as approved for the aircraft hydraulic system.

It is essential that the fluid used for flushing be periodically checked for cleanliness and acceptable values for water content and acidity. The fluid should be maintained at one to two levels cleaner than the requirement for the aircraft system. Use of a commercial fluid purifier on the hydraulic power source used for flushing will reduce fluid waste and maintain high quality fluid for repeated usage.

3.2.2 Factors Which Effect Flushing

3.2.2.1 Generation of Turbulent Flow

For flushing, the ground cart pressure is raised just enough to force fluid through each circuit in the system at a flow rate which guarantees turbulent flow. Conservatively, a Reynolds Number of at least 4000 should be generated. Turbulent flow is absolutely essential to generate the flow forces at the tube wall to dislodge and carry off solid contaminant in the fluid stream. The flow rates shown in this specification are applicable for any stage of manufacture and build-up.

3.2.2.2 Time Required

The length of time to flush each circuit can be established with experience. The initial process can start with flushing each circuit for 10 min, then adjusting the time upward or downward as indicated by fluid sample results. This will establish a production process which gives the desired result with minimum time expended. The amount of time for effective flushing will be proportional to the volume of fluid to be cleaned, the efficiency of the ground cart return filter and the amount of contamination to be removed.

3.2.2.3 Fluid Temperature

Another factor, which aids in rapid clean up, is to conduct flushing at fluid temperature above 100 °F (38 °C). Fluid temperature of 120 to 140 °F (49 to 60 °C) temperature range is recommended. While the required Reynolds Number can be generated at lower temperatures, it has been found by experience that the higher temperature gives shorter flushing time.

With ground carts, warming the fluid to the required temperature is done by operating the cart in by-pass mode. The pump discharge is simply routed through the by-pass circuit back to the reservoir until the desired temperature range is achieved. With the thermal mass of fluid in the cart reservoir warmed to the required range, the temperature will remain within the required range during flushing operations, which generate heat as well. For a central hydraulic system, it may require use of a temperature control circuit, adjustment of cooling water rate, or limited by-passing of flow through the heat exchanger to achieve the minimum fluid flushing temperature.

3.2.2.4 Single Flow Path

It is essential that a single path be set up for each step in the flushing process. Parallel or multiple paths are not permitted. Figure 1 shows the use of valves used in conjunction with jumper hose to sequentially flush three circuits. If a circuit contains multiple tube sizes, the flow rate should be set for the largest tube in the circuit being cleaned.

3.2.2.5 Ineffectiveness of Low Flow Rates

It should be emphasized that flushing for long periods of time with laminar flow is not effective. Theoretically, with laminar flow, the fluid velocity at the tube wall is zero and insufficient force is generated to remove contaminant.

3.2.2.6 Length of Tubing

The length of tubing which may be flushed during each operation is limited by the pressure drop through the tubing.

The total length of the circuit which can be flushed can be estimated by proportioning the length of each tube size in the flow path and summing the pressure drop. The sum of the pressure drops shall not exceed the design operating pressure of the pressure, return or suction tube lines. Particular care is required when flushing high and low pressure lines at the same time.

3.2.2.7 Removal of Components

It is essential that no flushing be performed through components with close tolerance metal to metal clearances, dynamic sealing surfaces, or potential dead end passages which could trap particles. Therefore, disconnecting and jumpering around components is required.

Also, all flight-worthy system hoses should be removed or not installed until flushing is completed. The hose are delivered to an agreed cleanliness level, the same as any component, and meet cleanliness requirements as delivered. If hose are left installed without adequate support during flushing, the probability of exceeding the minimum bend radius and kinking or cracking the tetrafluoroethylene liner of the hose is high.

Removal of components such as manifolds, swivels, and flexible tubing assemblies should be considered on a case-by-case basis. Removal is not recommended.

Considerations are:

1. These components are usually delivered to an agreed cleanliness level.

2. They do not inherently have interior features that trap contaminant or inhibit flushing.

3. The action of removing and then replacing these components may introduce solid contamination.

3.2.2.8 Media Cleanliness

It is essential that all air, nitrogen and fluid used in the processes be maintained at cleanliness levels equal to or cleaner than the level established for the system being cleaned. Media maintained at one or two levels cleaner than the requirement will contribute significantly toward attaining the desired cleanliness.

3.2.3 Recommended Flow Rates

The flow rates recommended are based upon fluid properties at a supply pressure of 3000 psi. Minimum Reynolds number of 4000 will be met at supply pressures less than 3000 psi as well so long as required flow rate at a given temperature is met.

3.2.3.1 AS1241 Fluid

Figures 2A and 2B give recommended flow rates and maximum tube lengths for flushing for phosphate ester fluid. Also, Figure 2 illustrates the great variation in flow required with temperature and tube size. The required flow is approximately halved from 80 to 140 deg °F (27 to 60 °C).

3.2.3.2 MIL-PRF-83282 Fluid

Figures 3A and 3B illustrate the variation in flow required to generate turbulent flow and gives the recommended flow rates for flushing with MIL-PRF-83282 fluid.

3.2.3.3 MIL-PRF-87257 Fluid

Figures 4A and 4B illustrate the variation in flow required to generate turbulent flow and gives the recommended flow rates for flushing with MIL-PRF-87257 fluid.

3.2.3.4 Other Fluids and Tube Sizes

Flow rates for other fluids, tube sizes and wall thickness should be calculated to give a Reynolds number of not less than 4000 with viscosity corrected for temperature and pressure. AIR1362 is a good source for fluid property data for calculations. Appendix A has equations which may be used to compute the flushing flow rate required for other fluids.

3.3 Recommended Planning

3.3.1 Flushing Kit Definition and Procurement

The flushing kit described in 3.2.1 should be defined and procured early in the design cycle to allow the fittings, hose and valves to be available for flushing the first aircraft.

3.3.2 Establishing a Written Plan

The sequence of events should be documented in writing in a functional test procedure which is maintained and revised as the process matures and experience is gained on performing the operations in an efficient sequence. Throughout the process, emphasis should be placed on capping open lines and avoiding trimming or deburring of installed tubes in order to maintain cleanliness level.

By establishing and following a written plan, additional benefits are the verification that line connections are not crossed and that there are no obstructions in the tubing. There have been instances during flushing where it was discovered that fittings were not drilled through or that a ball mandrel from the bending operation had separated and became lodged within the tubing. Another instance discovered a drill bit broken off and blocking the flow path through a fitting.

The plan should include a procedure that personnel who have the responsibility of processes where good practice is required to maintain cleanliness, such as the taking of bottled samples, take an instructional course on acceptable procedure so that tasks related to contamination measurement use uniform procedures.

3.3.2.1 Basic Planning

The flushing plan is begun by a systematic study of the hydraulic system schematics to map out the plugging and jumpering of the tube circuits to arrive at a plan that flushes the outlying circuits with smaller tube diameters first and working back to the largest distribution lines in the system.

Flushing may be done by systems or by aircraft sections before they are joined, which ever works better with the aircraft build plan.

Because of the difficulty in removing and jumpering check valves, and the amount of clamp removal and disassembly required to get access, it is permitted that check valves be left in place during flush.

The flushing may start out with flushing of system extremities such as left wing, right wing, vertical stabilizer, empennage, center section. Or the plan may focus on subsystems, such as landing gear, brakes, flaps or thrust reversers. The completed plan will provide for the entire hydraulic system to be sequentially jumpered, plugged and flushed.

Flushing the tubing requires disconnection and often, removal of components, in order to attach jumper hose. The jumper hose used for each circuit should be at least the same tube size as the smaller diameter tube in the circuit being flushed. In some cases, a tube assembly made up for the purpose makes the process more efficient.

As illustrated on Figure 1, the jumper hose is connected, sometimes in conjunction with manual shutoff valves and/or a tee fitting to allow setting the valves to create a single flow path through one circuit and then resetting the valves to create a single flow path through another part of the circuit. As each circuit is flushed at the required rate, credit may be taken for completion of that circuit.

Upon completion of an airframe section or a subsystem, a representative fluid sample should be taken to verify the cleanliness of that section. Quality Control representatives can stamp off on each section completed of the flushing plan to provide accountability and verification of the operation.

NOTE: There is no requirement to flush the entire hydraulic system if all of the sections of the aircraft have been flushed previously.

3.3.2.2 Sequence of Flushing

The plan should start flushing the circuits with the smallest tube diameters and progressively work back to the central system with large diameter discharge and suction tubes which are flushed at the highest rate. The sequence can be organized by systems or sections of the airframe, so long as each flow path is flushed at least once.

When flushing a circuit with more than one tube diameter, the circuit must be flushed at the required flow rate for the larger diameter.

3.3.2.3 Reduction of Fluid Waste

In order to reduce fluid waste, it is recommended that the planning ignore very short lengths of tubing or where the location or density of the installation would only allow flushing into a waste bucket.

Every effort should be made to flush from the flushing pressure source back to the flushing source return filter.

3.3.2.4 Purging of Lines

Low pressure Nitrogen or clean, dry air can be supplied into the tubing to purge the lines of hydraulic fluid once the flushing and proof pressure testing of each section of tubing has been completed.

3.3.2.5 Completion of Flushing

Once flushing is complete, all jumper hoses are removed, components are re-installed and the tubes are reconnected.

3.3.2.6 Capping of Tube Ends

Capping and plugging of open tube ends is essential to retain the tube cleanliness. The plugs must be a material which is compatible with the hydraulic fluid and which minimize generation of solid contamination with application and removal.

NOTE: It is recommended that metallic plugs be used in order to prevent contamination from the plugs entering the hydraulic system.

3.4 System Fill

At this point, the system is ready to fill and bleed for operational use. This is usually accomplished by applying clean low-pressure fluid from a ground cart or central hydraulic supply operating in open loop mode. Open loop mode is defined as operation using the ground cart or fluid source reservoir, as opposed to use of the aircraft system reservoirs. All fluid entering the system must be filtered to maintain system cleanliness level.

Functional Test Plans should have previously been written for this stage, which give detailed instructions for excluding air from various portions of the system which are not self-purging. This may require loosening tube fitting nuts to allow air to escape with low pressure applied at the system fill point, then re-tightening the tube fitting nut once fluid appears at the connection.

Filling of engine driven pump case, suction and discharge lines may require pulling propellers through by hand, dry motoring of engines or use of manual crank rotation of the gear box to rotate engine driven pumps slowly to fill the pump lines at low pressure.

Once the system is substantially filled, electric motor powered pumps in the system may be turned on to pressurize the system and force air pockets to be dissolved in the fluid. This air should subsequently be removed by open loop operation of the system using a ground cart or central hydraulic system with non-separated reservoir allowing entrained and dissolved air to escape to atmosphere.

3.5 System Functional Checkout

At this stage the complete hydraulic system is subjected to a number of tests which establish that the various subsystems perform to standards established in functional test documents and that overall cleanliness levels of the complete system are met.

Fluid samples must be taken to verify that the fluid cleanliness meets or exceeds the level required for flight and delivery of the aircraft. ARP994 recommends a contamination check as part of Inspection, Checkout and Test Procedures.

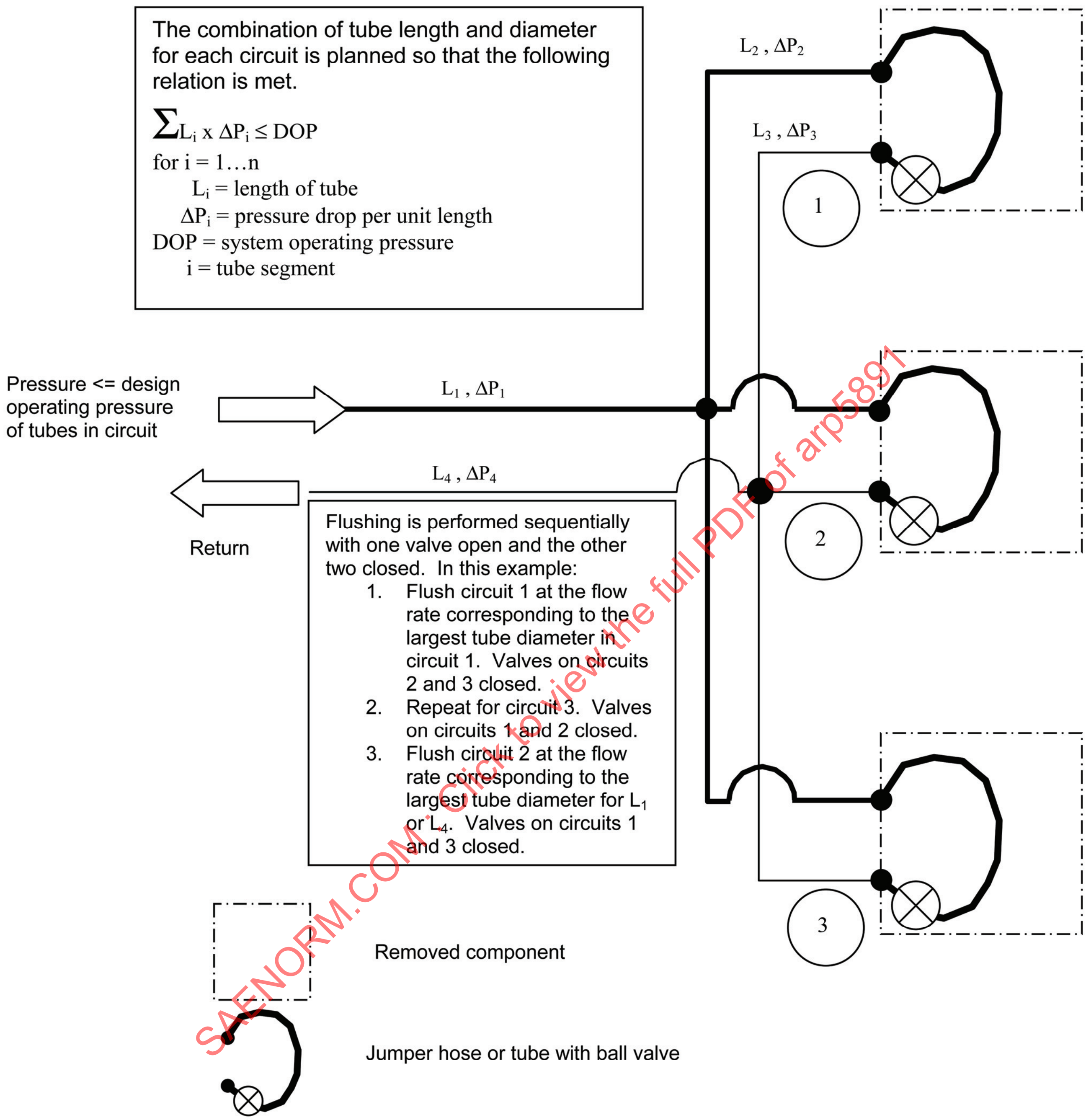
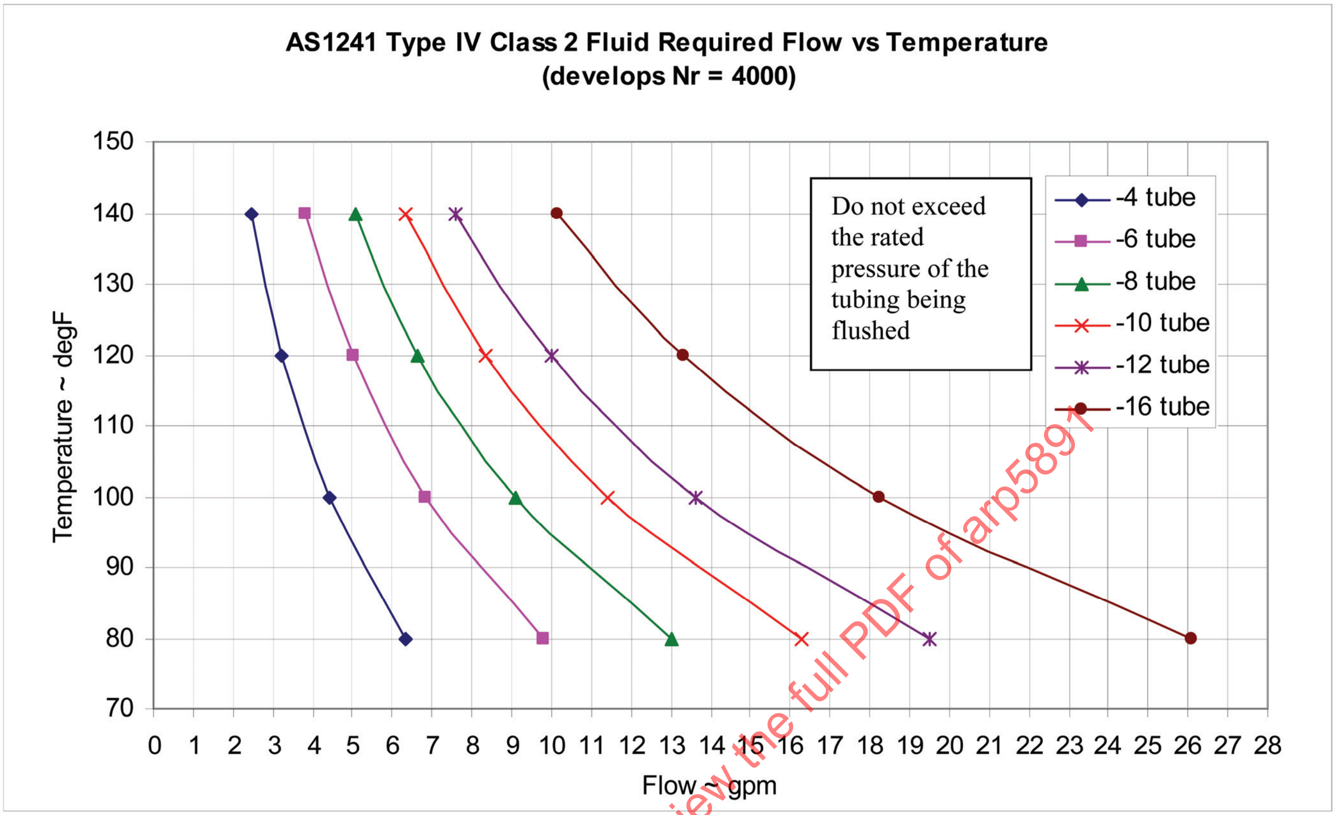


FIGURE 1 - EXAMPLE FLUSHING CIRCUIT

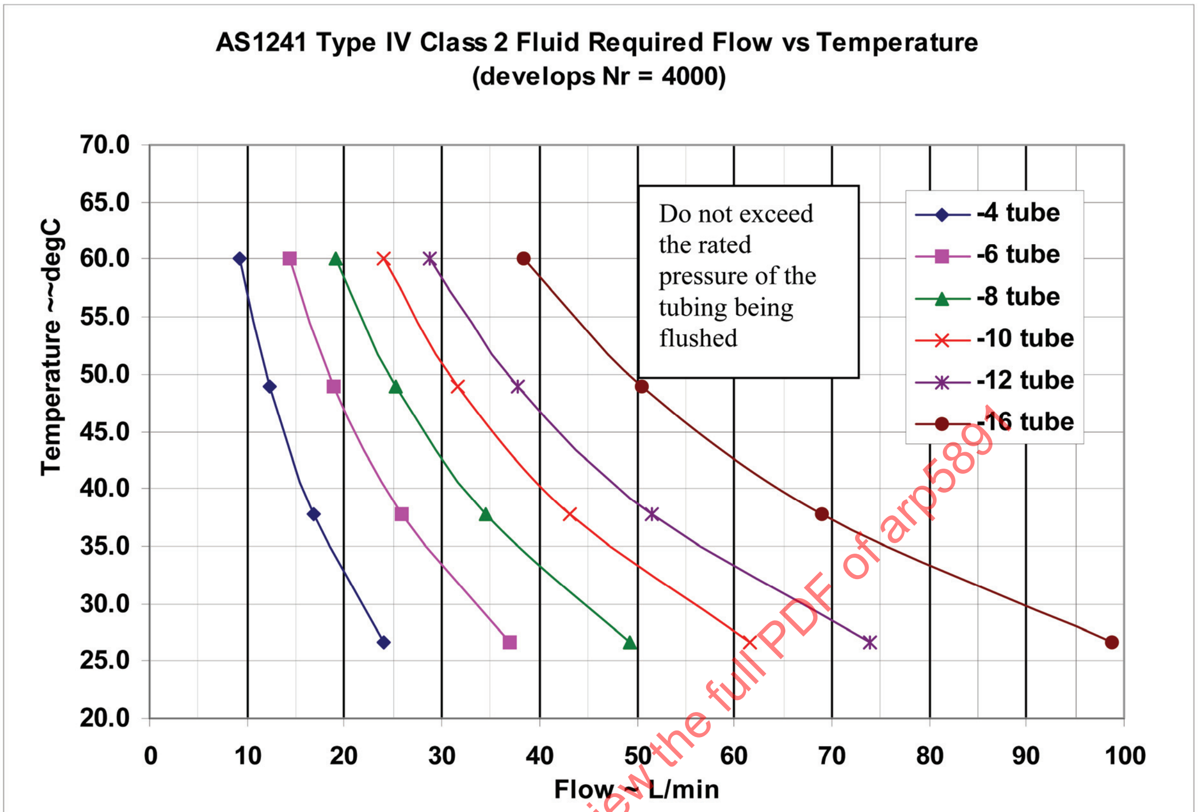


Recommended Flow Rates for 120 to 140°F Fluid

Tube Size Dash No.	Tube OD ~ in.	Wall ~ in.	Min Flow ~ gpm	Max Length for 3000 psi supply ~ ft
-4	0.250	0.016	3.2	201
-6	0.375	0.019	5.0	741
-8	0.500	0.026	6.7	1742
-10	0.625	0.032	8.3	3420
-12	0.750	0.039	10.0	5878
-16	1.000	0.051	13.4	14028

Note: These curves may also be used for AS1241 Type IV Class 1 and Type V fluid.

FIGURE 2A - RECOMMENDED FLUSHING FLOW RATES FOR AS1241 TYPE IV CLASS 2 FLUID

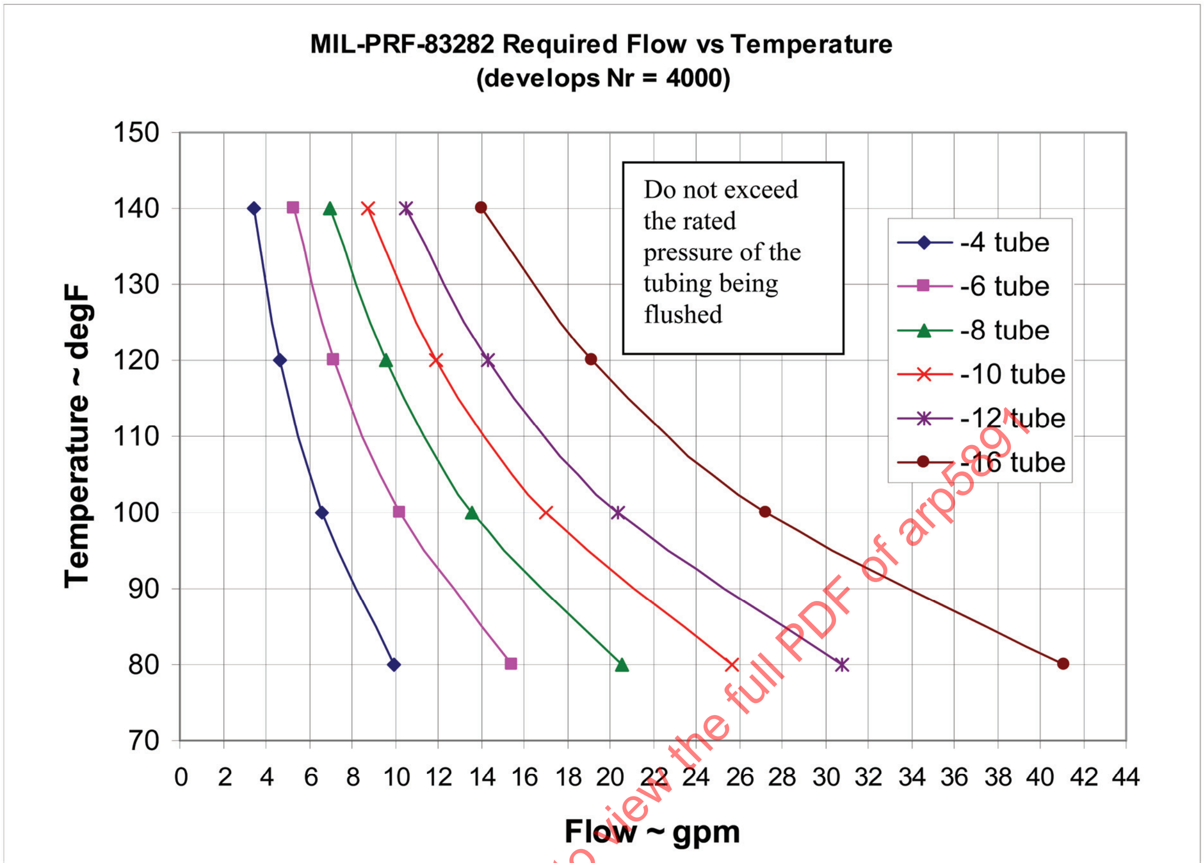


Recommended Flow Rates for 48.9 to 60°C Fluid

Tube Size Dash No.	Tube OD ~ mm.	Wall ~ mm.	Min Flow ~ L/min	Max Length for 20 MPa supply ~ m
-4	6.35	0.406	12.26	61.4
-6	9.53	0.483	18.96	226.6
-8	12.70	0.660	25.20	532.5
-10	15.88	0.813	31.56	1045.5
-12	19.05	0.991	37.80	1791.1
-16	25.40	1.295	50.52	4288.3

Note: These curves may also be used for AS1241 Type IV Class 1 and Type V fluid.

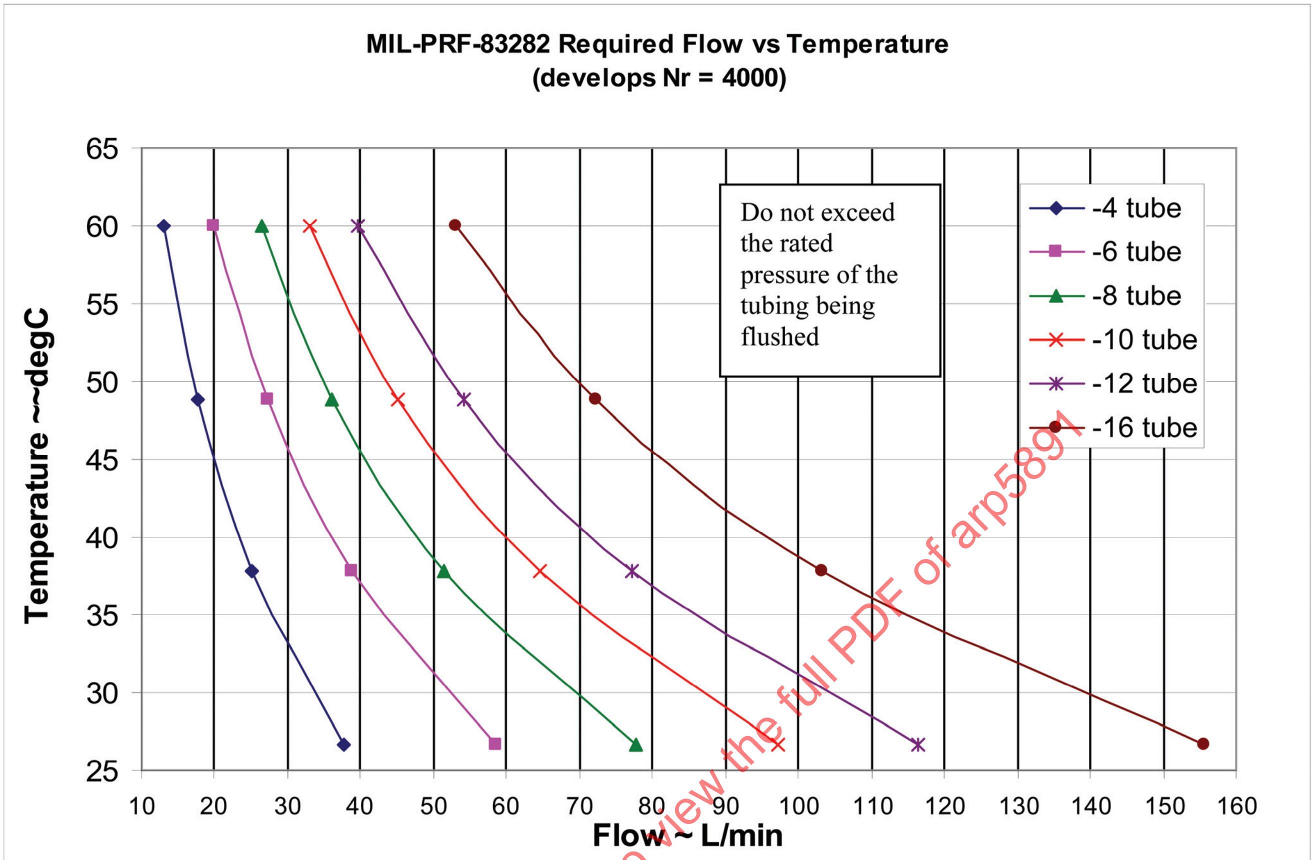
FIGURE 2B - RECOMMENDED FLUSHING FLOW RATES FOR AS1241 TYPE IV CLASS 2 FLUID (ISO UNITS)



Recommended Flow Rates for 120 to 140°F Fluid

Tube Size Dash No.	Tube OD ~ in.	Wall ~ in.	Min Flow ~ gpm	Max Length for 3000 psi supply ~ ft
-4	0.250	0.016	4.6	123
-6	0.375	0.019	7.2	455
-8	0.500	0.026	9.5	1070
-10	0.625	0.032	12.0	2101
-12	0.750	0.039	14.3	3611
-16	1.000	0.051	19.1	8616

FIGURE 3A - RECOMMENDED FLUSHING FLOW RATES FOR MIL-PRF-83282 FLUID



Recommended Flow Rates for 48.9 to 60°C Fluid

Tube Size Dash No.	Tube OD ~ mm	Wall ~ mm.	Min Flow ~ L/min	Max Length for 20 MPa supply ~ m
-4	6.35	0.406	17.6	37.68
-6	9.53	0.483	27.2	139.21
-8	12.70	0.660	36.1	327.04
-10	15.88	0.813	45.2	642.19
-12	19.05	0.991	54.2	1103.77
-16	25.40	1.295	72.4	2633.91

FIGURE 3B - RECOMMENDED FLUSHING FLOW RATES FOR MIL-PRF-83282 FLUID (ISO UNITS)