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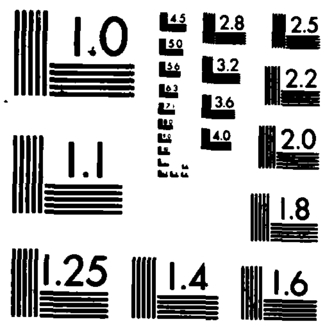

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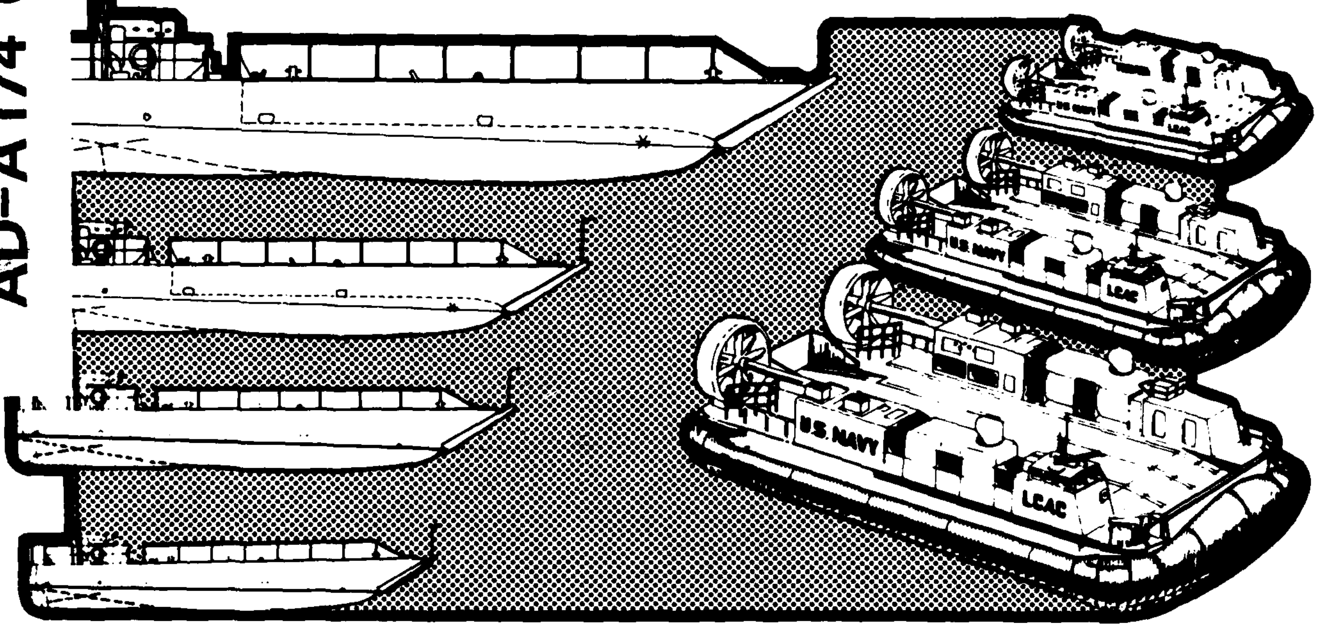

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SELECTION PARAMETERS FOR HYDRAULIC SYSTEM FILTERS WITH A COMPARISON OF AIRCRAFT AND MARINE APPLICATIONS

by: W. Wilcox

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SELECTION PARAMETERS FOR HYDRAULIC SYSTEM FILTERS

WITH A COMPARISON OF

AIRCRAFT AND MARINE APPLICATIONS

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ABSTRACT

Aircraft designers have been pioneers in the use of high
pressure hydraulic systems. Accordingly, hydraulic systems for
ships and their filters have often been based on aircraft compare
equipment and design practices. ~~In~~ this paper, the criteria for
design and selection of filters for aircraft and ships ~~are~~
~~compared.~~ By considering important parameters, the designer can selecting
make a more intelligent choice in ~~the selection of~~ filters for a
particular application. Parameters discussed include filter
location, essentiality and duration of operation, logistic
support requirements, and maintenance philosophy, including
costs. → [To p 12]

13

TABLE OF CONTENTS

TABLES:

FIGURES:

REFERENCES

SAE Aerospace Information Report (AIR) 887A "Liquid Filter Ratings, Parameters and Tests," 15 Sep 1985

Naval Ships' Technical Manual, NAVSEA S9086-S4-STM-000/CH-556 "Hydraulic Equipment"

MILITARY SPECIFICATIONS:

MIL-F-5504, Filter and Filter Elements, Fluid Pressure, Hydraulic Micronic Type

MIL-H-5606, Hydraulic Fluid, Petroleum Base, Aircraft, and Ordnance

MIL-F-8815, Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems, General Specification for

MIL-F-17111, Fluid, Power Transmission

MIL-L-17331, Lubricating Oil, Steam Turbine and Gear, Moderate Service

MIL-H-17672, Hydraulic Fluid, Petroleum, Inhibited

MIL-H-19457, Hydraulic Fluid, Fire-Resistant, Non-Neurotoxic

MIL-H-22072, Hydraulic Fluid, Catapult, NATO Code Number H-579

MIL-F-24402, Filters (Hydraulic), Filter Elements (High Efficiency), and Filter Differential Pressure Indicators

MIL-H-83282, Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft, NATO Code Number H-537

INTRODUCTION.

Many of the filters installed in hydraulic systems on U.S. Navy ships in the past have been inadequate. Common deficiencies have been:

- Short element life.
- Bypass reliefs lift even with new elements installed.
- Excessive pressure drop across the filter.
- Element collapse.
- Ineffective filtration efficiency.
- Element media incompatible with water in the fluid.

Some of the deficiencies appear to stem from the utilization of aircraft filters and design practices without careful evaluation of the differences in the applications. This paper will examine a number of parameters which must be considered in selecting filters and sizing filter elements for particular applications. Among the parameters which must be considered are:

- Fluid viscosity and flow rate.
- Location of filter assemblies.
- Essentiality of system operation.
- Duration of system operation.
- Required filtration level (efficiency).
- Maintenance philosophy.
- Logistic support requirements.
- Initial and operating costs.
- Filter size and weight.

Most of these parameters are interdependent and while each will be discussed separately one must not neglect their interrelationships.

FLUID VISCOSITY AND FLOW RATE.

Element Sizing. One of the most important considerations in filter selection is assuring that the element is sized to handle the flow and viscosity of the fluid to be filtered. The pressure drop across an element is a function of flow rate and fluid viscosity. Almost all losses across the element are viscous losses directly proportional to fluid viscosity. Therefore the safest practice is to assume that element pressure drop is proportional to fluid viscosity and flow rate. Flow rates are rather easily determined. Fluid viscosity however varies with the type of fluid, fluid temperature and pressure.

Comparison of Aircraft and Ship Fluids. Because of cold ambient temperatures for start-up and operation, aircraft hydraulic fluids have a relatively low viscosity. The fluids used on most ships tend to be considerably more viscous than aircraft fluids. See Table 1 for the viscosity of commonly used aircraft and ship hydraulic fluids. Too often in the past, the designer of hydraulic systems for ships has selected filter elements sized for the viscosity of aircraft hydraulic fluids. At 40°C (104°F) the viscosity of fluids used in ships may be up to seven times that of aircraft fluids.

Operating Temperature Range. Aircraft hydraulic fluids must usually operate over wider temperature ranges than the fluids used in ships. For aircraft operation, the ambient temperatures are usually very low while higher operating temperatures are permitted to minimize system weight.

Change of Viscosity with Pressure. Designers often are unaware of and ignore the change of fluid viscosity with pressure. Fluids whose viscosity varies significantly with temperature also are subject to viscosity variation with pressure. The viscosities of water base fluids change relatively little with pressure. For MIL-H-5606 aircraft hydraulic fluid the increase at 3000 psi and normal operating temperature is approximately 30% over atmospheric pressure, increasing to approximately 75% at -40°C (-40°F). For the more viscous fluids normally used in ship hydraulic systems, the increase is even greater as shown in Figures 1 thru 4. For example, Figure 3 indicates that the viscosity of 2135-TH fluid increases by factors of 1.65 and 3.0 at pressures of 200 bars (2900 psig) and 600 bars (8700 psig) respectively. For phosphate ester base fluids, the increase in viscosity with pressure is even greater than with petroleum base fluids.

FILTER LOCATION.

The number and location of filters within a system are dependent to a large degree on the size of the system, the number of actuators and pumps, and of the sensitivity of the components to contamination. Generally filters are installed in one or more of the following locations:

- Pump suction.
- Pump discharge.
- Pump case drain.
- Upstream of contamination sensitive components.
- Return lines.

To reduce system weight, space and cost it is necessary to minimize the number of filters. Filters are installed to protect components from damage and wear due to contaminants. Since the pump is the heart of most systems its protection is of primary importance. Therefore, filtration requirements for the remainder of the system must be integrated with pump protection in selecting the optimum filtration package.

Pump Suction vs Return Line Filters. Both pump suction and return line filters are used primarily to protect pumps. Pump suction filters are located closer to the pumps and can compensate for poor tank design but that is about their only advantage. Pump suction filters must operate at very low differential pressures. Consequently, they must be of relatively large size compared to return line filters of the same flow capacity. In addition, bypass relief valves are almost mandatory to prevent starvation and damage to the pump when the pressure drop becomes excessive due to contamination or cold fluid during system start-up. Return line filters can have higher pressure drops than suction filters. Bypass reliefs in return lines can be set at much higher pressures than in suction filters. However, in sizing return line filters, the designer must consider the peak flow rates that may occur, not just system pumping capacity.

Case Drain Filters. For pumps with case drains, a case drain filter should be considered. A considerable amount of the contaminant generated by the pump passes thru the case drain. A case drain filter can provide a warning of incipient pump failure. In some systems, the use of a case drain filter versus a return line filter can be considered. If the system is small and contamination generation within the system minor, the use of a pump discharge filter and a pump case drain filter can provide sufficient system filtration. A case drain filter can be much smaller than a return line filter because of the much lower flow rate. However, case drain filters are often used in a system with return line filters for the following reasons:

o Identification of incipient pump failures with case drain filters.

o Inability of pump shaft seals to withstand the higher differential pressures at which return line filters operate.

Pump Discharge Filters. One major U.S. commercial aircraft manufacturer minimizes the use of pump discharge filters; however, the general practice in both aircraft and ships is to install pump discharge filters. Return line filters are generally sufficient to maintain system cleanliness levels; however, they cannot protect system components from a catastrohphic pump failure.

Filters Upstream of Specific Components. Filters are often installed immediately upstream of critical components such as electrohydraulic servo valves, particularly in large systems where the servo valve is located a considerable distance from the pump discharge filter. When such filters are installed they should not provide finer filtration than the pump discharge or return line filters or they are apt to have short service life as they become the primary system filter. Filters in these locations should be minimized. For large servo valves, pilot stage only filters are sufficient.

Filter Location Comparison. Filter location requirements do not vary significantly between aircraft and ships. Due to weight considerations, more effort may be made to minimize filters on aircraft but minimizing the number of filters is important for all systems. Greater minimization is feasible in small systems than in large systems with several pumps and many actuators since a single pump discharge filter may be adequate in a small system.

FILTER BYPASS RELIEF VALVES, MISSION ESSENTIALITY AND MAINTENANCE PRACTICES.

One decision the designer has to make is whether or not to provide a bypass relief around the filter for the condition when pressure drop becomes excessive. A bypass relief jeopardizes the very protection which a filter provides. On the other hand, in many cases a bypass relief is necessary to prevent serious systems malfunctions. Therefore, system or mission essentiality and maintenance practices are important considerations in determining bypass relief valve selection. Whether or not to provide a by-pass relief needs to be evaluated specifically for each filter location.

Pump Discharge Filters. One purpose of pump discharge filters is to protect the system components from catastrophic pump failure. With a bypass relief, the filter may become loaded upon a pump failure and permit contamination to circulate through the entire system. In an essential system with a single pump this may be acceptable although cleaning the system after a pump failure may be costly. In a multiple pump system it is important that a pump casualty be limited to the failed pump and contamination isolated to prevent causing subsequent failure of other system components. A bypass valve is not recommended. When a bypass valve is not installed the effect of increasing differential pressure on system operation and maintenance philosophy must be considered. Elements may be able to withstand differential pressures greater than system operating pressure. Therefore, pressures in excess of system pressure may result if maintenance is neglected. Therefore, a pump discharge relief is often located between the pump and the filter to protect the pump, piping and filter from excess pressure. As this relief lifts, less flow passes thru the filter to the system. With proper maintenance requirements, this relief should lift only in event of catastrophic pump failure. If this is a multiple pump system, the relief valve should discharge into the return line upstream of any return line filter, not directly to tank. Under normal conditions, immediate change of an element is not required when the replacement differential pressure is reached. However, good maintenance practice is necessary since the rate of pressure build-up increases with time. Devices indicating the need for element change must be read frequently enough that element replacement can be scheduled before system operation and mission completion are jeopardized. Obviously, an aircraft element replacement is not accomplished while airborne. When periodic maintenance inspection for excessive pressure drop is infrequent, it may be necessary to have a remotely operated panel light to warn when element replacement is necessary.

Return Line Filters. Some commercial airliners use return line filters with bypass reliefs while others do not have reliefs. In U.S. submarines, where return line filters have been used extensively, a bypass relief is always installed. Without a bypass relief, the danger of excessive return line pressure causing inadvertent actuator operation must be carefully considered. If bypass reliefs are not installed, frequent monitoring of filter condition is essential and remote warning lights are often essential. Where timely maintenance cannot be assured, installation of bypass valves with relatively high settings should be considered.

Case Drain Filters. Case drain filters can be installed with or without bypass reliefs. If the filter discharge is direct to tank a relief should be avoided. If flow also passes thru the return line filter a bypass relief should be acceptable. The pressure rating of pump shaft seals may necessitate the use of a bypass relief.

Component Filters. Where filters are provided for specific components the preferred practice is to avoid bypass reliefs. U.S. submarine steering and diving servo valves were originally designed with pilot stage filters with bypass valves. Sailors often ignored maintenance and contamination resulted in degraded servo valve performance. Corrective action required both filter element and servo valve replacement. The bypass reliefs were later eliminated. Neglect of maintenance now results in high differentials across the filter and degraded performance of the servo valve which is similar to that expereinced with contamination at the servo valve. However, corrective action requires only filter element replacement.

FILTER ELEMENT EFFICIENCY AND DIRT CAPACITY.

Despite improved methods of specifying filtration efficiency (Beta ratios or percentage removal by weight of a specified contaminant) there has been a tendency in the aerospace and fitration communities to identify filter efficiency by rather meaningless nominal and absolute ratings. (See SAE AIR887A for a detailed description of liquid filter ratings.) Filter elements for ships have been to three military specifications as well as a number of proprietary commercial designs. Since two of these Military Specifications are also for military aircraft, a brief examination of the specifications is useful.

MIL-F-5504 Elements. This specification for replaceable (non-cleanable) elements has been in use for 35 years and covers both reservoir and line type elements. Characteristics of these inexpensive elements are identified in Table 2.

The relatively high dirt capacity at a low differential pressure makes the AN6236 reservoir elements suitable for pump suction as well as return line applications. Both the reservoir and line type elements require bypass relief protection because of low collapse pressure. The dirt capacity per gpm for the AN6235 line type element is relatively low, only 7 to 17% of that for the reservoir elements, with the lower flow elements being more adequately sized. When used in conjunction with the finer reservoir elements the dirt capacity of the line type element is probably adequate. Neither type element will perform adequately if used in ship systems with fluid more viscous than MIL-H-5606 unless the flow rating is significantly reduced. See Table 1 for viscosity comparison of ship hydraulic fluids with MIL-H-5606.

MIL-F-8815 Elements. MIL-F-8815 followed MIL-F-5504 by about 10 years and provided elements with 4500 psid collapse pressure suitable for use without bypass relief valves. Characteristics of the original configuration and widely used elements are identified in Table 3. While the specification permitted both cleanable and non-cleanable elements, woven wire mesh cleanable elements were predominately used at first. This specification also has a 15 micrometer absolute filtration requirement for removal of glass beads. The dirt capacity of the woven wire mesh elements is quite low, less than that of MIL-F-5504 line type elements even though the differential pressure across the element is over twice as high. The dirt capacity of the woven wire mesh MIL-F-8815 elements may be satistactory in aircraft, particularly if used in conjunction with MIL-F-5504 reservoir elements. However, when used in submarine hydraulic systerms, cleanable elements to MIL-F-8815 even with flow downrated to compensate for fluid viscosity, have had an unsatisfactory service life when they have been the only type elements used.

As advances were made in the design of disposable elements with non-metallic media it was found that additional dirt capacity could be provided. The dirt capacity requirements were increased by a factor three for the non-cleanable elements. Although not a speciication requirement, these elements usually have a much higher efficiency than woven wire mesh elements. They provide better filtration, higher efficency and at a lower cost.

At a time when the Navy was having hydraulic system contamination problems with Military aircraft, MIL-F-8815 was modified to include five micrometer absolute elements. While normally one would expect a finer element to have lesser dirt capacity the five micrometer elements per MIL-F-8815 actually have equal or greater capacity than the 15 micrometer disposable elements and more than three times the capacity of cleanable 15 micrometer absolute elements. This is a clear indication that the dirt capacity of MIL-F-8815/3B 15 micrometer disposable elements could be increased.

MIL-F-24402 Elements. This specification was devloped for submarine hydraulic system elements using MIL-L-17331 (2190-TEP) fluid at flows up to 50 gpm. Initially patterned after MIL-F-8815 it required a 95 percent removal of APM F-9 glass beads with a 25 micrometer absolute rating. It was subsequently revised to increase the efficiency to 97 percent removal of the beads and the absolute rating requirement eliminated. Current requirements are shown in Table 3. The dirt capacity is close to the maximum obtainable in the particular element configurations which were in use before the specification was issued. For size B the dirt capacity is over one gram of AC fine test dust per gpm of MIL-L-17331 fluid. Dirt capacity would be over six grams per gallon with MIL-H-5606 fluid flow.

Efficiency Recommendtions. Techniques have now been developed to determine the comtamination sensitivity of system components. Using finer filters than neccessary decreases filter life and increases filter element costs. While five micron absolute filters are being predominately used in military aircraft this does not appear to be the trend in commercial aircraft. In any event, high efficiency disposable elements appear to be the superior choice. If elements of different efficiency are used in a system, the highest efficency element should be used in return lines. Dirt capacity can be obtained at lower cost and weight in low collapse pressure elements and lower pressure assemblies.

Dirt Capacity Recommandations. In most cases, commercial aircraft manufacturers have not established requirements as to dirt capacity of elements. Criteria has not been established to size for a certain number of flight hours or provide specific amounts of dirt capacity per gpm of flow. Filter manufacturers indicate that there does not appear to be any consistent requirements identified for sizing elements for commercial airliners. A manufacturer may ask for dirt capacity considerably in excess of what the element configuration can provide while for another element the capacity requested is considerabley less than the manufacturer can provide. However, in many cases, airlines are achieving up to 5000 operating hours before element replacement. While no specific requirements can apply across the board it appears that some general guidelines may be applicable. First, the more locations in which elements are used, the less dirt capacity required on each element. If return line elements are installed they should have higher dirt capacity per gallon of flow than pump discharge elements. Case drain elements which are downstream of a primary dirt generator probably should have the largest dirt capacity per gallon of flow. Since case drain flow is relatively low, this is not difficult to achieve. In sizing filters, consideration must be given to system operating time, and the penalty for oversizing versus lower cost per gram of dirt removal for larger elements. For example, in a missile system operating life is short and weight space, and cost all dictate that the element be of minimum size. In Military aircraft, higher aircraft performance may justify small elements with higher operating costs than in commercial airliners. On ships, larger size elements not only have significantly lower cost per gram of contaminant removal but can contribute to lowering manning requirements by requiring less man-hours for maintainence. Since spare elements must be carried on board, smaller elements do not always result in space and weight savings as on aircraft.

ELEMENT OPERATING COSTS.

One factor that is too often neglected by the system designer in selecting filters is the operating cost. Emphasis is often placed on minimizing initial costs while operating costs which may be more significant are not considered.

Cost Per Gram of Element Dirt Capacity. Tables 2, 3, and 4 show the cost per gram of dirt holding capacity for various sizes of MIL-F-5504, MIL-F-8815 and MIL-F-24402 filter elements. Procurement quantities significantly affect costs and somewhat distort the data; particularly for the MIL-F-8815 elements. However, it is quite obvious that large elements cost less per gram of dirt holding capacity. This is perhaps best illustrated in Table 3 for MIL-F-24402 where the size A, B, and C elements are all rated for 50 gpm flow but have different dirt capacities. The cost per gram varies from $3.69 for the smallest (Size C) element to $0.90 for the largest (Size B) element. In comparing Tables 2, 3, and 4 remember that the MIL-F-24402 capacities are based on a more viscous fluid and will hold approximately six times more dirt with MIL-H-5606 aircraft fluid.

Maintenance Costs. In addition to the cost per gram of dirt removal being less with large elements, the frequency of maintenance is reduced. With the use of large capacity elements, the possibility of introducing contamination during maintenance is less and maintenance manpower and associated costs are reduced.

Logistic Support Costs. One factor often overlooked is the reduction of logistic support costs by minimizing the number of different elements used. This concept has been used by Douglas on the DC-9 and DC-10 aircraft and by the U.S. Navy on TRIDENT class submarines. In each case, the system was designed to use a single configuration element with multiple elements used in applications with high flow rates. One airline was impressed that an inventory of only $200 in elements was required to support a DC-9 versus several thousand dollars for a foreign competitor. For aircraft, spare elements are stocked at maintenance bases, whereas for ships, spare elements must be carried on board. Without the severe weight penalties faced by aircraft for oversized filter assemblies it would appear that standarizing on large dirt capacity elements in marine applications will minimize both maintainance and logistic support costs in addition to the storage space for spare elements.

Life Cycle Costs. Life cycle costs include the initial cost of the filter, replacement element costs, and maintenance cost to change elements. Operating costs are an important factor on aircraft but less important on most ships. On aircraft, larger and heavier filter assemblies reduce the payload which may be carried and increase the amount of fuel consumed to support the filter. Spare elements are not carried on aircraft but are usually carried on ships. Using large capacity filters reduces the number of spare elements required.

Table 5 shows a comparison of life cycle costs for a servo valve pilot stage filter on two classes of submarines. On SSN 688 class, a MIL-F-8815 aircraft filter was used. On SSBN 726 the largest MIL-F-24402 filter element was used throughout the ship even though it has a flow capacity 50 times that required for this application. While initial costs were comparable for the two filters, the life cycle cost for the small filter is nine times that of the large filter even when logistic support costs are neglected. The large element in this application essentially has negligible logistic support costs since it is used in other applications and additional spares are not needed for this application. In fact, the capacity of the large element may be sufficient for the life of the ship but the analysis is based on periodic replacement every five years. If the space and weight of larger filters is acceptable they will usually result in lower life cycle costs in marine applications.

MAINTENANCE PRACTICES.

There are several basic practices that can be employed in regard to filter element replacement/ renewal.

- o Replacement at specific intervals, i.e. six months, one year.
- o Replacement based on system operating hours
- o On-condition replacement (based on differential pressure.
- o Some combination of two or more of the above practices.

Each of these individual practices will be examined in more detail.

Periodic Element Replacement. Monthly, semi-annual or yearly replacement of filter elements is a relatively easy practice to implement. When used without on-condition replacement it results in low cost filter assemblies since no indicators are required. However, it is difficult to determine the proper replacement frequency. If elements are replaced too early, element and manpower costs are high. If the intervals between replacement are too long, the build-up of differential pressure will cause filter bypass reliefs to open. This permits contaminants to cause wear, jepordize component performance and perhaps even contribute to component failure. If bypass-valves are not installed, performance may degrade due to less energy being available. Continued operation may lead to unsatisfactory system performance. In most applications, periodic replacement alone is not a satisfactory maintenance practice. However, in systems or portions of systems that operate very infrequently and for which dirt capacity is more than adequate, periodic replacement may be suitable. For example, in system where handpumps are used only for emergency, replacement of handpump discharge filter elements every few years may be completely adequate. A case for periodic replacement could possibly be made in a system using inexpensive and considerably oversized elements. This should only be considered where neglect of replacement would not have significant adverse effects.

Element Replacement Based on Operating Hours. This maintenance practice presents some improvement over simple periodic replacement which does not take into account operating hours. However, if this is the sole maintenance practice it suffers from the same disadvantages as simple periodic replacement but to a lesser extent. The practice is widely used on commercial aircraft in conjunction with on-condition replacement. Replacement of elements is accomplished during scheduled major maintenance/overhaul periods for the aircraft based on operating hours. For most ship systems, operating hours are not recorded although this practice may become more common in the future.

On-condition Element Replacement. The most widely used maintenance practice on both aircraft and ships is on-condition replacement of elements based on differential pressure. Several types of indicators are available for monitoring element differential pressure build-up. The advantages and disadvantages of each type will be briefly examined.

ELEMENT CONDITION INDICATORS

Mechanical Pop-up Indicators. The most widely used indicator for element replacement is the mechanical pop-up indicator which is activated by differential pressure. Advantages of this device are that it is small, compact and relatively inexpensive. However, it does suffer from several disadvantages of which actuation under cold start-up conditions is very prevalent. Actuation under cold start-up conditions is often prevented by thermal lockouts which prevent actuation until a certain temperature is reached. Still, differential pressure across an element is a function of fluid viscosity. For fluids with a relative low viscosity, as usually used in aircraft systems, a pop-up indicator with a thermal lock-out can be successfully used. For example, MIL-F-8815 indicators do not actuate for fluid temperature below 100 $\pm$ 15 $^{\circ}$F. For MIL-H-5606 fluid viscosity varies from approximately 17 centistokes at 85 $^{\circ}$F (29 $^{\circ}$C) to 14 centistokes at 115 $^{\circ}$F (46 $^{\circ}$C), a change of 20 percent. On the other hand, over the same temperature range, 2190-TEP per MIL-L-17331 varies from approximately 150 centistokes at 85 $^{\circ}$F to 60 centistokes at 115 $^{\circ}$F. This large viscosity change at atmospheric pressure is even more pronounced at higher pressure and makes satisfactory use of a pop-up indicator more difficult with fluids subject to large changes of viscosity with temperature and pressure. Mechanical pop-up indicators require periodic visual inspection to determine if they have been activated, since once activated they remain so until reset. For many applications, particularly on aircraft, the filters may be located in areas which must be opened for access. In these applications, the pop-up mechanical indicator may be combined with a remote indicating device, usually a light. A single light is often used for all filters in a particular area or group to decrease cost, weight and space. On-site inspection is then required to determine the specific filter requiring service.

Mechanical Differential Pressure Indicators. These are similar to pressure gages in that a mechanical pointer is actuated by differential pressure to indicate filter condition. Words and colors sometimes used for indication are:

Clean or OK - Green
Caution - Yellow
Change or Bypassing - Red

Mechanical differential pressure indicators of this type are suitable for use where the indicator may be observed during system operation, a condition usually not practical on aircraft. The advantage over pop-up indicators is that false indications due to cold start-up can be eliminated. By making readings within closely controlled fluid temperature limits, adequate accuracy of readings may be obtained. However, if operating temperatures and fluid viscosity vary significantly the adequacy of the indicator may be marginal. At least one manufacturer makes a differential pressure indicator which not only indicates the current differential pressure but also indicates the highest differential pressure obtained.

Differential Pressure Gages. Differential pressure gages can be mounted directly on filter assemblies or at some distance from the filter assembly. For conditions in which viscosity and flow vary considerably, the gage can be used in conjunction with a chart to determine the need for element replacement under a wide range of conditions. Disadvantages of gages are that they are relatively expensive and are usually only suitable for monitoring current operating conditions.

Indicator Selection. The type of indicator selected must be matched to the application. MIL-F-24402, the filter specification for ship hydraulic systems, provides for three types of indicators:

Mechanical Pop-Up
Mechanical Pop-Up with Switch for Remote Indication
Gage Type

The specification standardizes the porting configuration for the indicators and thus all three types are interchangeable. Therefore, initial selection of the wrong type can be remedied with relative ease.

SUMMARY.

While most of the parameters for filter selection are similar for aircraft and ships there are important differences which must be considered. Dirt capacity requirements for military aircraft filters are generally inadequate for ship hydraulic systems as well as commercial aircraft. By considering the various design and maintenance requirements, improved filtration can be provided for ship hydraulic systems at lower life cycle costs than at present although initial costs may be slightly higher.

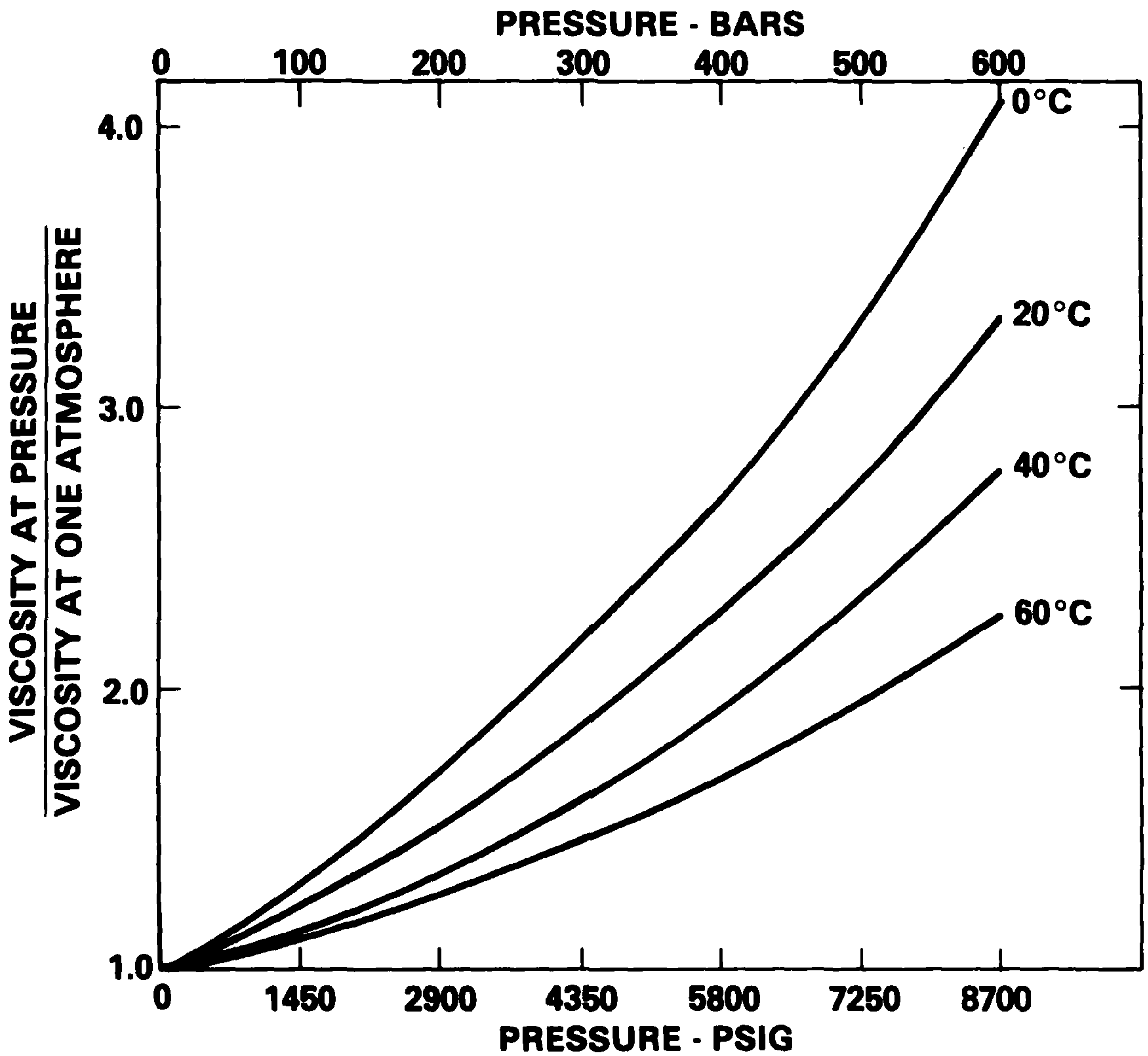

FIGURE 1
VARIATION OF VISCOSITY WITH PRESSURE FOR MIL-H-17672 2075-TH FLUID

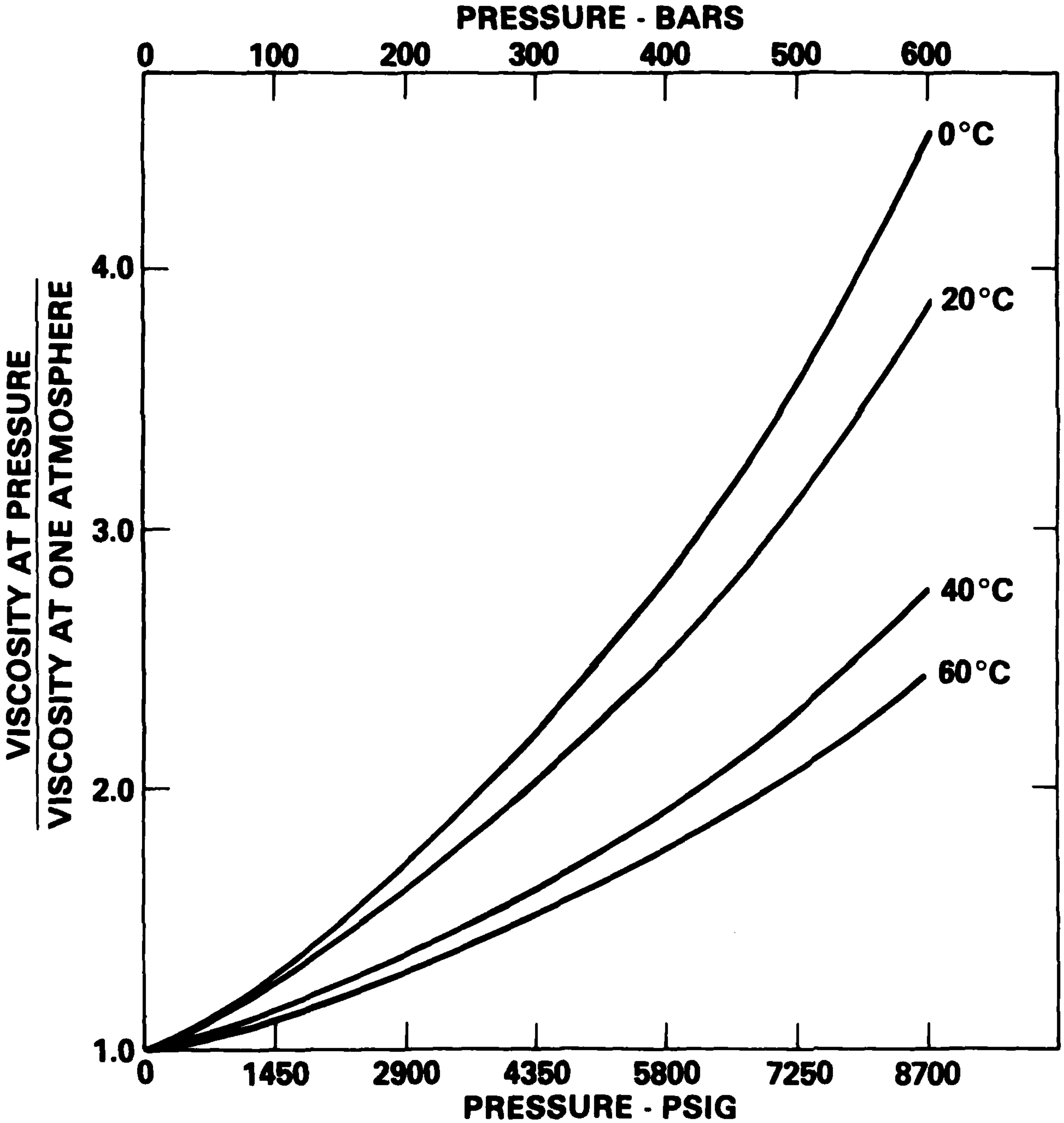

FIGURE 2
VARIATION OF VISCOSITY WITH PRESSURE FOR MIL-H-17672 2110-TH FLUID-NATO SYMBOL H-573

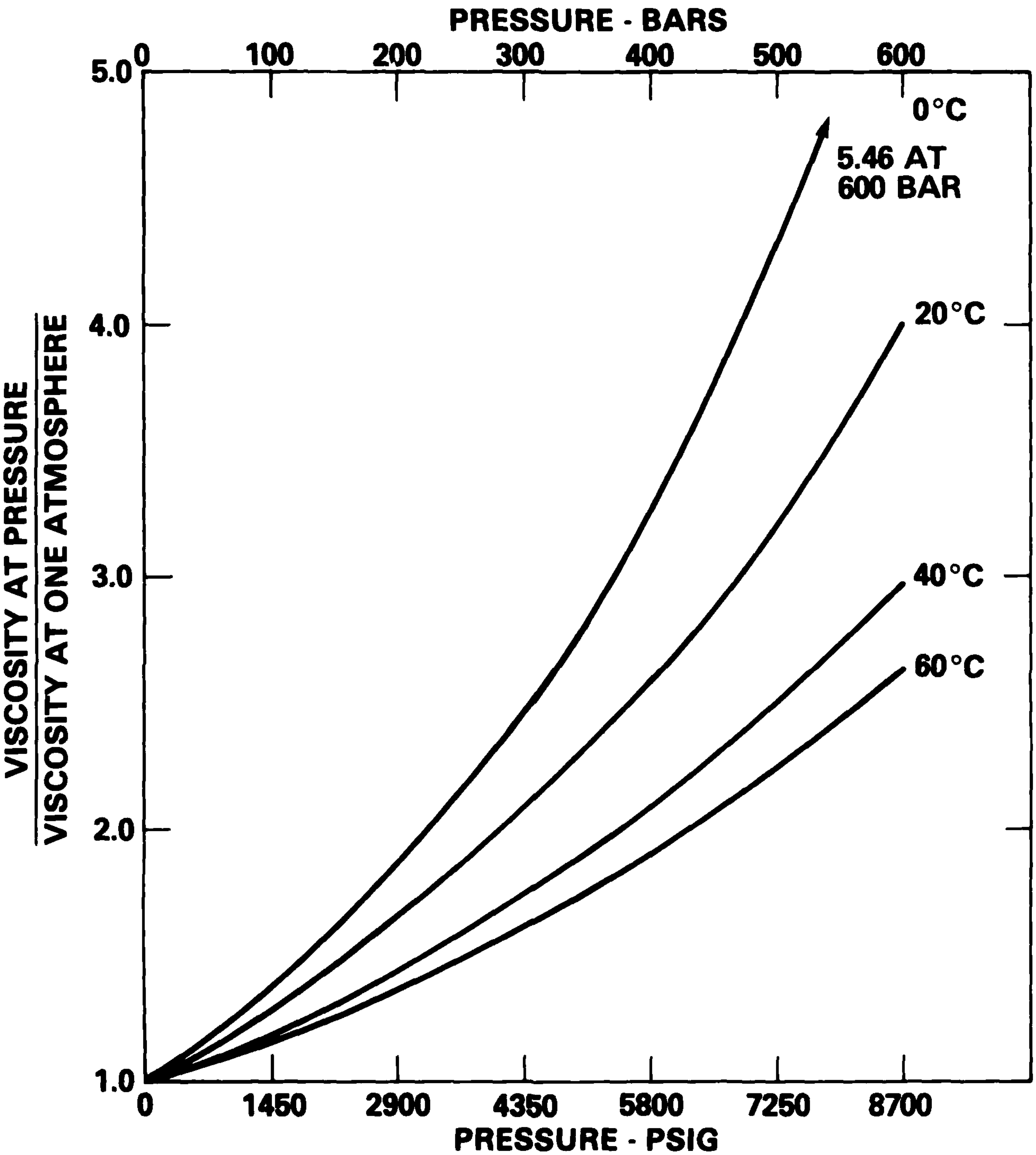

FIGURE 3
VARIATION OF VISCOSITY WITH PRESSURE FOR MIL-H-17672 2135-TH FLUID

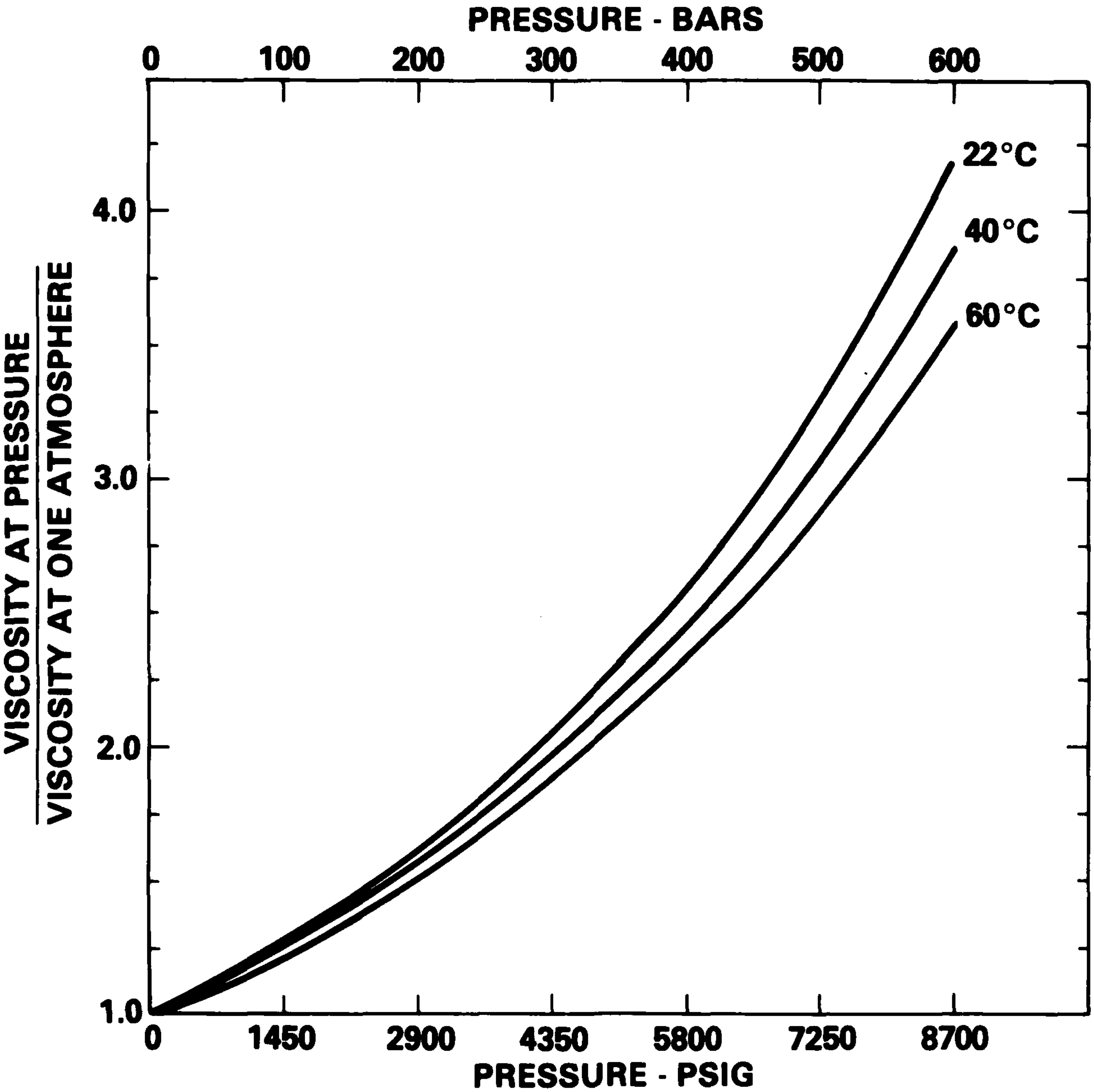

FIGURE 4
VARIATION OF VISCOSITY WITH PRESSURE FOR MIL-L-17331 (2190-TEP) FLUID-NATO SYMBOL 0-250

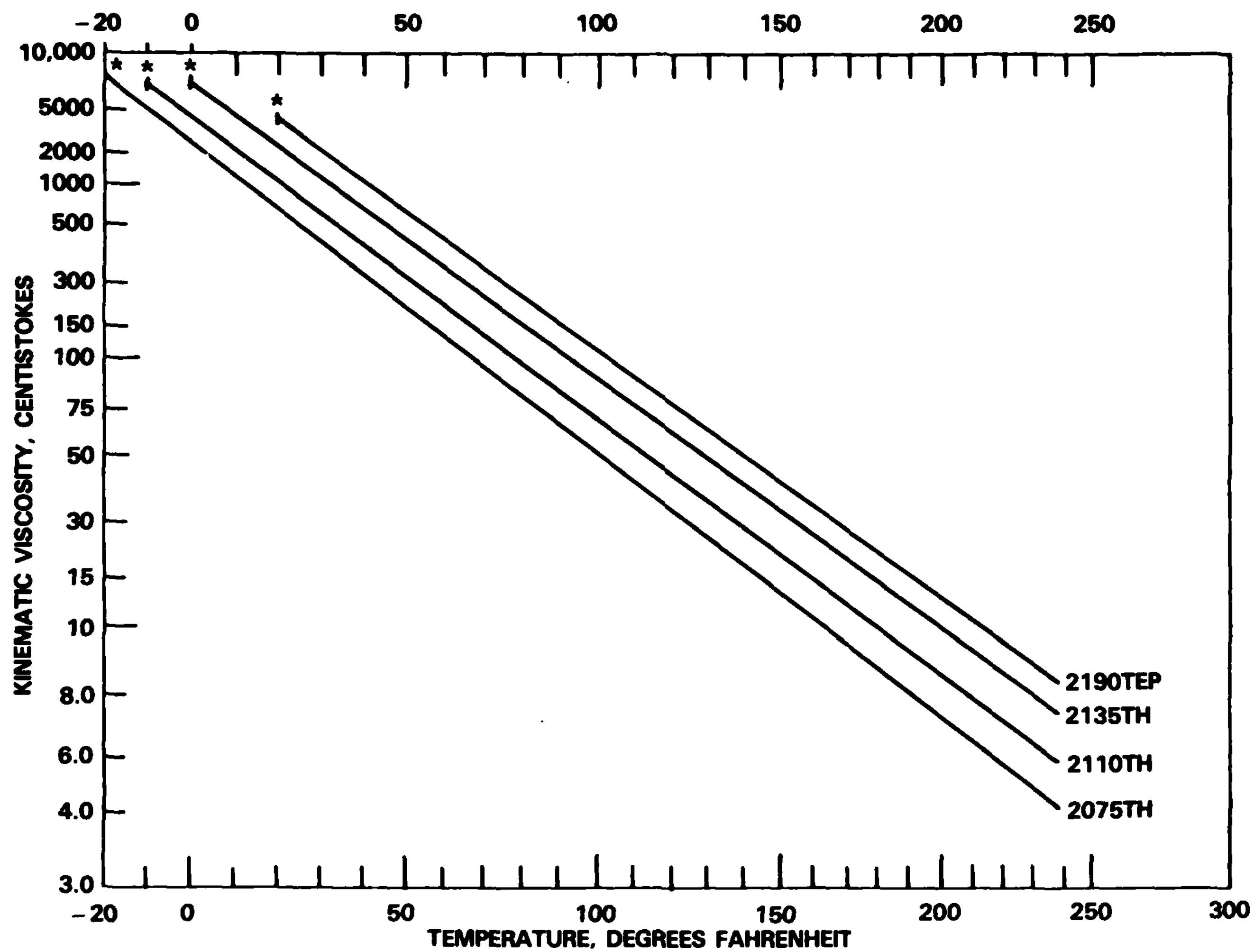

FIGURE 5. VISCOSITY-TEMPERATURE CHART FOR MIL-L-17331 AND MIL-H-17672 PETROLEUM BASE HYDRAULIC FLUIDS.

TABLE 1 - VISCOSITY OF COMMONLY USED AIRCRAFT AND SHIP HYDRAULIC FLUIDS

FLUID SYMBOL OR DESIGNATION	MILITARY SPECIFICATIONS	KINEMATIC VISCOSITY IN CENTISTOKES 40° C	0° C
	MIL-H-5606	14	45
FIRE RESISTANT SYNTHETIC HYDROCARBON BASE, AIRCRAFT NATO H-537	MIL-H-83282	14 MIN	90
NATO H-575	MIL-F-17111	27-30	
2075-TH	MIL-H-17672	32 ± 10%	150-200
2110-TH, NATO SYMBOL H-573	MIL-H-17672	46 ± 10%	275-300
2135-TH	MIL-H-17672	68 ± 10%	475-525
2190-TEP	MIL-L-17331	74-97	1000-2000
TRIARYL PHOSPHATE ESTER, TYPE 1, NATO H-580	MIL-H-19457	43-50	
WATER-GLYCOL	MIL-H-22072	36-43	

TABLE 2 - CHARACTERISTICS OF MIL-F-5504 FILTER ELEMENTS

FLUID: MIL-H-5606 VISCOSITY: 15 CENTISTOKES AT 100° F
COLLAPSE PRESSURE: RESERVOIR TYPE 75 PSID, LINE TYPE 150 PSID
REMOVAL EFFICIENCY RESERVOIR TYPE: 98% LINE TYPE 95%
(10-20 MICRON BEADS)

RESERVOIR TYPE	FLOW GPM	ACFTD DIRT CAPACITY	CAPACITY OF ACFTD/GPM	COST	COST/GRAM DIRT CAPACITY
AN6236-1	7½	9g @ 4 psid	1.2g	$8.66	$0.96
AN6236-2	15	18g @ 4 psid	1.2g	$5.01	$0.27
AN6236-3	30	36g @ 4 psid	1.2g	$7.61	$0.21
				AVG	$0.48
LINE TYPE					
AN6235-1A	½	.1g @ 40 psid	.2g	$2.17	$21.70
AN6235-2A	3	.6g @ 40 psid	.2g	$1.43	$ 3.22
AN6235-3A	6	.65g @ 40 psid	.108g	$2.08	$ 3.20
AN6235-4A	12	1.0g @ 40 psid	.083g	$2.22	$ 2.22
				AVG	$ 7.58

TABLE 3 - CHARACTERISTICS OF MIL-F-8815 FILTER ELEMENTS

FLUID: MIL-H-5606 VISCOSITY: 15 CENTISTOKES AT 100° F
COLLAPSE PRESSURE: 4500 PSID REMOVAL EFFICIENCY: 94% MINIMUM (APM F-9 BEADS

CLEANABLE ELEMENTS M8815/3	FLOW GPM	ACFTD DIRT CAPACITY	CAPACITY OF ACFTD/GPM	COST	COST/GRAM DIRT CAPACITY
−8C	6.0	.6g @ 90 PSID	.1g	$ 59.70	$ 99.50
−10C	10.5	1.05g @ 90 PSID	.1g	$234.00	$222.86
−12C	16.0	1.6g @ 90 PSID	.1g	$ 94.12	$ 58.83
−16C	29.0	2.2g @ 90 PSID	.076g	$393.63	$178.92
				AVG	$140.03

DISPOSABLE ELEMENTS M8815/3	FLOW GPM	ACFTD DIRT CAPACITY	CAPACITY OF ACFTD/GPM	COST	COST/GRAM DIRT CAPACITY
−8	6.0	1.8g @ 90 PSID	.3g	$ 19.41	$10.78
−10	10.5	3.15g @ 90 PSID	.3g	$112.80	$35.81
−12	16.0	4.8g @ 90 PSID	.3g	$ 94.88	$20.81
−16	19.0	6.6g @ 90 PSID	.228g	$ 44.55	$ 6.75
				AVG	$18.55

TABLE 4 - CHARACTERISTICS OF MIL-F-24402 FILTER ELEMENTS

FLUID: MIL-L-17331 (2190-TEP)
VISCOSITY: 100 CENTISTOKES
COLLAPSE PRESSURE: 4000 PSID
REMOVAL EFFICIENCY: 97% MINIMUM (APM F-9 BEADS)

	FLOW GPM	ACFTD DIRT CAPACITY	CAPACITY OF ACFTD/GPM	COST	COST/GRAM DIRT CAPACITY
SIZE D	20	15g @ 90 PSID	.75g	$109.46	$7.30
SIZE C	50	15g @ 90 PSID	.3g	$ 55.41	$3.69
SIZE A	50	21g @ 90 PSID	.42g	$ 44.65	$2.13
SIZE B	50	50g @ 90 PSID	1.0g	$ 45.23	$ .90
				AVG	$3.50

TABLE 5
SUBMARINE STEERING & DIVING SERVO VALVE PILOT STAGE FILTER LIFE CYCLE COSTS

SHIP:	SSN 688 CLASS	SSBN 726 CLASS
TYPE FILTER:	MIL-F-8815/2-8	MIL-F-24402, TYPE 1, SIZE B
DIRT CAPACITY (@ 1 GPM OF 2190-TEP FLUID)	.3 GRAM ACFTD	$\geqslant$50 GRAMS ACFTD
FILTER ASSEMBLY/ELEMENT COST	$1350/$19.41	$1100/$45.23
YEARLY ELEMENT COST*	$194	$9**
MAINTENANCE LABOR COST/YR	$200	$4**
TOTAL COST/YR	$394	$13**
30 YEAR ELEMENT & MAINTENANCE COSTS	$11,820	$390
TOTAL LIFE CYCLE COST	$13,170	$1490

* REMOVAL OF 3 GRAMS ACFTD PER YEAR

** BASED ON ELEMENT CHANGE EVERY 5 YEARS

END

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