NUMBER 5

HYDRAULIC FLUIDS SIMPLIFIED*

by C. R. Schmitt
Manager, Lubrication Sales Dept.,
E. F. Houghton & Co.
Philadelphia 33, Pa.

Mr. Schmitt graduated from Case Institute of Technology in 1934 with an M.E. degree.
He became associated with the Lubrizol Corporation and engaged in the promotion and sale of additives for industrial and automotive lubricants until 1942. At this time the Retail Division of Lubrizol Corporation was merged with that of E. F. Houghton & Co., and Mr. Schmitt joined Houghton. He was transferred from Philadelphia to Cleveland, remaining in Cleveland as Manager of the Lubrication Dept., Central Division, until April, 1951.
He is now manager of the Lubrication Sales Department of Houghton with headquarters in the home office in Philadelphia.
Mr. Schmitt is an active member of ASLE, having served in several official capacities with the Cleveland Section of the Society.

In arranging material for this article, I endeavored to bear in mind the underlying necessity of keeping it as non-technical as possible. In making this statement, I do not wish to create the impression that technical subjects are not acceptable. It is simply that I believe the subject of Hydraulic Fluids in general can best be covered by presenting ideas and facts rather than by the use of involved test results, graphs, charts, etc.

The word "Hydraulic" is defined as "pertaining to hydraulics, involving the movement of water, or force exerted by water." It is taken from the Greek words "Hydōr" meaning "water" and "Aulos" meaning "pipe." Today, of course, hydraulics applies to many other types of fluids besides water, chief among which is petroleum oil.

The principle of the utilization of fluids under pressure for mechanical motion is by no means of modern origin. We have only to read accounts of water powered machinery of the ancients to realize that, even then, its usage was understood, if somewhat crudely. The essential difference between today's hydraulics and those of the ancients lies in the complexity and severity of the modern circuit.

No truer fact was ever stated than that a chain is only as strong as its weakest link. This truism can be very aptly applied to the satisfactory performance of the hydraulic fluid in the hydraulic machine too.

The hydraulic fluid, or, since we are principally interested in petroleum oil, let us refer to it as hydraulic *oil,* has several functions to perform in the modern circuit.

1. It must protect the system against rust and corrosion.
2. It must adequately lubricate the hydraulic pump.
3. It must retain its original characteristics over a long period of service.
4. It must be capable of transmitting hydraulic power despite the presence of varying amounts of common contaminants.

*Sponsored by ASLE Technical Committee on Lubrication Economics.

At the recent ASLE Convention in Detroit, Mr. M. A. Hayden, Vickers, Inc., presented a paper entitled: "The Main-Ten-Ends in Hydraulic Maintenance." In his paper, Mr. Hayden makes the statement: "If there is still any doubt about the user's control of maintenance problems, here are the results of a recent analysis of service calls to customers' plants on hydraulic equipment, and of unit repairs. It shows the following approximate distribution of causes for such service:

70% due to improper condition of the hydraulic oil.
10% due to the improper diagnosis of the trouble or lack of "know how" in making repairs.
10% due to mechanical failures such as bearing failures from misalignment, seal failure due to dirt, etc.
5% due to operating units beyond recommended limits on speed, pressure or volume.
5% due to miscellaneous unclassified causes ranging from excessive packing friction on hydraulic rams to chatter resulting from inadequate way lubrication."

This analysis demonstrates emphatically the importance of the proper hydraulic fluid and its maintenance in the field. There are three things to consider in this respect:

1. The oil as received before service.
2. Maintenance of the oil during service.
3. Reconditioning of the oil following service.

Let us consider the first item, the oil as received before service. Unless this fluid is suitable for the application, troubles of several varieties can be expected to develop. For example, if the fluid tends to thin out excessively due to temperature rise during usage (low viscosity index), pump noise may develop with accompanying wear of pump parts. Such a condition can also result in pump slippage, pressure loss and sluggishness in machine functions.

Another example of trouble can occur from fluid breakdown. It may change chemically due to oxidation and form gummy residues which result in the retarding or complete halting of pilot and reversing valve actions.

This slows up production and, unless the circuit is carefully designed, can result in serious damage to both machine and work being produced.

These are but two general examples of the results of fluid breakdown in a hydraulic system. The task confronting the oil industry is to develop and market fluids capable of maintaining their original properties for prolonged service periods even under adverse operating conditions.

Secondary to this, but not less important, is the task of convincing the hydraulic machine user of the profit to him in terms of maintenance of production and lowering overhead costs, through the use of such fluids even though their first cost may be slightly higher.

In order to study the situation and arrive at a possible solution, let us first consider the essential properties desired in a hydraulic fluid:

1. Viscosity
2. Lubricity
3. Stability

You will note that I have listed only three requisites. There are other *desirable* properties worthy of mention but, for the sake of simplicity and getting down to fundamentals, let us, for the time being, consider only the three factors mentioned.

1. Viscosity

Regardless of what we think of the various superior properties of available hydraulic fluids, we must admit that, if the fluid does not flow properly through the system under pressure from the pump, it cannot be considered for use. It is analogous to considering the relative importance of food, drink, rest, clothing and shelter for the maintenance of life. While these are important, they are not comparable to the need for air, since lack of oxygen, even for a few moments, would result in certain death.

Viscosity, too, determines quickly whether a hydraulic circuit will operate or "die" due to lack of proper circulation. Other items, therefore, become secondary in importance.

It is essential to consult the oil supplier, or the machine builder, for information as to the correct viscosity of the hydraulic fluid to be used.

2. Lubricity

After the matter of fluidity is settled, comes the item of proper lubrication. Today's pumps are precision instruments of varying degrees depending upon the use to which they are put. Their rubbing surfaces are ground and lapped so that fluid leakage and loss in efficiency is held to a minimum. To protect these expensive surfaces, the fluid used must be a good lubricant. It is my belief, after considerable field observation, that they should be better than "good." Synthetic film strength and lubricity addition agents should be used to fortify the natural properties of the fluid.

Such so-called "EP" additives are now used and have demonstrated their stability and effectiveness over a period of years in many different kinds of service.

3. Stability

This property has been the most controversial subject, up until recently, of any to be discussed. Through the years, it has been alternately exalted and condemned. The reason for the fluctuations in opinion has been the means used to arrive at superior stability for petroleum fluids. Chemical additives used for this purpose are many and varied. Some of them have been used without careful consideration of *all* properties, resulting in failures other than those caused by oil breakdown. For example, a hydraulic oil was placed on the general market a few years ago which was supposed to incorporate high film strength with exceptionally great stability. It is quite possible that it did have the properties claimed and might still be available today had it not been for the fact that it clogged orifices, due to a gradual precipitation of part of the additive used. The oil was withdrawn from the market, additives in general were ostracized, and the cry—"Don't interfere with Nature" again underscored the sales efforts of most refiners. The pump manufacturers climbed down off the additive bandwagon and, from then on, were hard to convince. This, despite the satisfactory service record of other additive treated hydraulic oils extending back fifteen years or more.

Today, however, the picture has reversed, this time, it seems, permanently. Most pump and hydraulic machinery builders agree that additive-containing oils are beneficial and superior to straight mineral oils. With such agreement existing, there is every reason to expect hydraulic oil quality to keep pace with the ever accelerating design tempo of the hydraulic mechanism.

Before we leave the subject of the *new* oil properties completely, let us consider briefly some desirable qualities which are obtainable in certain hydraulic oils.

(A) Rust Protection

This feature is obtained through the use of suitable rust inhibitors which "plate out" on metal surfaces and thus protect them by insulating them against the action of moisture, mild acids, etc.

(B) Gum Solvency

Through the action of certain types of additives, the oil is given greater power to hold gums and resins in solution. Therefore, since even the finest oil will deteriorate in time, the products of such deterioration will be dissolved in the oil and prevented from dropping out onto valve and pump surfaces. For this reason, an oil having greater solvent power can be kept in service longer than one which permits such resinous compounds to drop out and interfere with proper machine action.

(C) Foam Resistence

Some oils tend to foam excessively during service if the return line to the reservoir is not kept below the surface of the oil at all times. This often happens when the oil supply is not replenished properly and the oil level drops. If the design is such that turbulence and mixture with air is unavoidable, anti-foam additives are available which, in as small proportions as one part to 100,000 parts of oil, will completely eliminate foaming.

(D) Miscellaneous Properties

Other properties, such as the following, associate themselves with one of the three basic requirements already discussed; namely, Viscosity, Lubricity and Stability.

1. Viscosity Index

Ability to maintain rated pressures and speeds throughout possible shop temperature changes. The higher the Viscosity Index, the more constant the body of the oil under temperature change. (Viscosity.)

2. Pour Point

Pump manufacturers usually recommend that the pour point be 15 F. to 20 F. below the lowest anticipated operating temperature. This is important to prevent starving of the pump on the suction side, commonly referred to as cavitation. (Viscosity.)

3. Neutralization (Acid) Number

This term formerly was used to predict the corrosive tendencies of a hydraulic oil. Today, however, so many things affect the magnitude of this number that it is seldom depended upon for this purpose. Instead, actual tests are run using the metals encountered in service to determine any corrosive effect likely to be had.

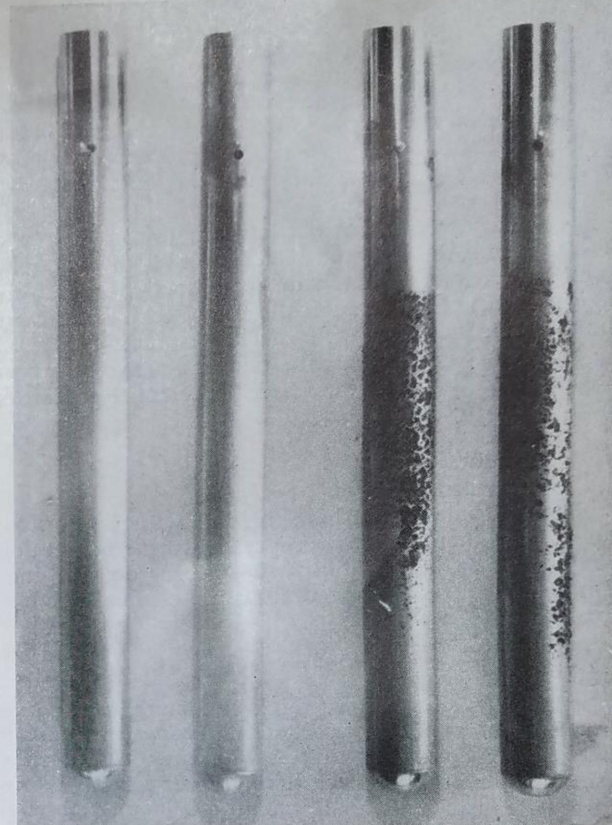
Neutralization Number, however, is often used as a rule of thumb test to determine the useful life of a hydraulic oil in service. Limiting values ranging from 0.5 to 1.0 have been used successfully to set up drain periods in the field. (Stability.)

4. Demulsibility

Because of the ever-present possibility of water contamination from condensation, particularly in humid climates, the oil must separate from it quickly. Otherwise, oil-water emulsions will form causing sluggish oil motion and reduction of lubriating effectiveness. Such oil-water emulsions are further aggravated when solids of any kind are present in the form of dirt, dust, metallic particles, plastic dust, lint, etc. Most of us at one time or another have seen this form of sludge inside automobile crankcases or valve chambers. The only difference is the black color imparted by soot produced through combustion in the engine. Hydraulic oil emulsions are usually brownish colored except where excessive heat has developed to turn them black.

We do not usually consider physical properties such as Gravity, Color, Flash, and Fire Points and Carbon Residue to be of importance in application of hydraulic oils. These properties originated in connection with crankcase oils but are of little or no significance in hydraulics.

In the foregoing, you have had a kind of Cook's Tour through the important points to be considered in selecting a hydraulic oil for your requirement. Of course, under each heading, there are other things to be discussed which are not within the scope of this paper. Furthermore, many of these points are clarified only on the basis of past experience and knowledge of the behavior of petroleum and petroleum-synthetic additive combinations. For this reason, it is well to select your oil supplier on the basis of confidence in his judgment and experience and permit him to guide you in the solution of hydraulic oil problems.



Test Pins—"Result of A.S.T.M. Test (D665-44T) showing pins at right corroded after run in straight petroleum oil. The pins illustrated at the left are unharmed after same time in rust inhibited oil."

Maintenance of System

Once the proper type and grade of fluid for the hydraulic system has been obtained, it becomes necessary to decide upon ways and methods for prevention of contamination. Since the oil reservoir level is constantly raising and lowering due to variation in the volume of oil flowing through the system, air is being drawn in and expelled at intervals. This breathing effect results in the possibility of contaminating the oil with whatever foreign particles form part of the surrounding atmosphere. If we are concerned with plastic moulding equipment, we shall very likely discover contamination in the form of plastic dust. If die casting machines are used, zinc or aluminum particles will probably be found in the oil reservoir.

Inlet Filters, Strainers

Having established the probability of outside contamination, prevention through the use of breather filters or strainers is in order. Such strainers are available either as original equipment or from any of the well-known filter or dispensing equipment manufacturers or distributors. Breather strainers must be watched carefully, especially in dusty atmospheres, since they may become loaded and plugged preventing free entrance and exit of air.

A strainer in the inlet pipe leading to the pump is highly recommended. This is usually in the form of a cylindrical wire mesh screen, fine enough to prevent solid contaminants from reaching the pump and valves, but capable of passing the proper volume of oil necessary for proper pump operation. Usually, 60-mesh screen will be satisfactory and the net area should be 3 to 4 times that of the inlet pipe. Some machines are now equipped with inlet filters of the mechanical type having spaces as fine as .001 inch.

It seems ridiculous, in view of the apparent common sense maintenance behind the use of such filters, to even caution against their removal. Still, I have seen many instances where filters and strainers were taken out because they became clogged too quickly and interferred with production. Such situations are usually discovered when the user is frantically trying to rebuild his machine after prolonged operation with hydraulic oil contaminated with a variety of abrasive materials. Moral—If the strainers clog too quickly, either get larger ones or set your cleaning schedule for more frequent attention.

By-Pass Filters

As we have seen, actual mechanical damage to the pump and other parts can be forestalled through the use of breather and suction pipe strainers. One thing further by way of maintenance of oil cleanliness remains, the installation of a by-pass filter for removing tiny particles such as oil sludge, lint, soot, fine dust, metallic particles too fine to be caught by the intake strainers and so on. Some filters of the Fullers Earth Variety are so constructed that they are said to remove water, acid and gummy particles.

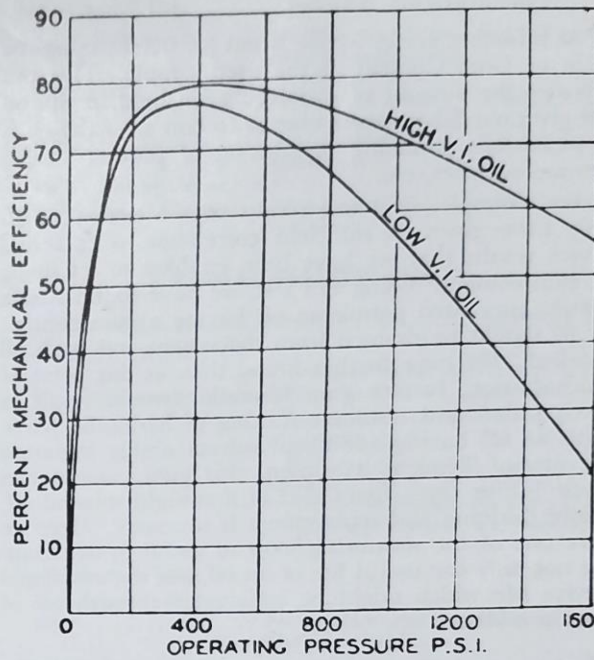
The contaminants of the above class are removed not only because of the damage they might do mechanically, but because some of them are destructive chemically. Altogether, they act to change the original properties of the oil until it is no longer fit for service. In other words, if systems were hermetically sealed, the oil would last indefinitely, as in the case of some of the well-known household refrigerator units which have been known to function for twenty years or more with the original charge of oil.

The matter of choice of filter should be discussed with the oil supplier, as well as the filter manufacturer, to see that the one is compatible with the other. For example, certain additives in oil are removed by particularly drastic filters.

A by-pass type filter is desirable since it does not interfere with machine operation and permits oil to be delivered to the pump at all times. It has been agreed that by-pass filters must be of sufficient capacity to filter the equivalent of all hydraulic fluid in the system within a period of eight (8) hours.*

Heat Exchange Units

The next important item following oil cleanliness is oil temperature. When hydraulic units are designed and tested, their performance is rated on the basis of oil viscosity within certain fluid limits. Designers must be practical about equipment and they, therefore, anticipate ambient temperatures normally encountered indoors in the average modern plant. There are times, however, when such conditions are not normal or average and ambient temperatures are either below or above these limits. Under such conditions, the oil in the system becomes too sluggish for proper pumpability or too thin to maintain pressure. Aside from effect on operation,



Graph showing efficiency vs. pressure—The above chart illustrates the effect of low VI oil on mechanical efficiency when operating pressures are increased. When oils thin out too rapidly loss in efficiency can result.

abnormal temperatures cause oil breakdown through formation of water-sludge from low temperature condensation, or thermal oxidation from elevated temperatures. The ideal operating oil temperature is about 125 F. with limits from 65 F. to 150 F. Opinions vary as evidenced by J.I.C. coverage of this point:

> "Under normal conditions of continuous operation, pump inlet temperature of the fluid shall not exceed 130 F."
>
> "In no case shall a sensitive temperature measuring device placed anywhere in the circuit indicate a local temperature above 250 F. (Petroleum fluids only. Other fluids require individual handling.)"

In selecting heat exchangers, several points should be considered:

(a) It must be accessible for servicing.
(b) It should be automatically controlled to provide fairly constant oil sump temperature.
(c) Exposed surfaces should be entirely compatible with hydraulic oil.

Despite the care exercised in the selection and maintenance of the hydraulic oil, it is nevertheless a fact that the time will come when the system should be drained, cleaned and fresh oil installed.

Service Period

Many attempts have been made to devise a yardstick by which useful service life of hydraulic oil may be

* Joint Industry Conference (JIC), Hydraulic Standards for Industrial Equipment, Detroit, Michigan.

measured. At the risk of becoming involved in strenuous argument, we are listing a set of limiting values of various physical laboratory tests on used oil samples which may be found useful.

Viscosity—allowable increase.......20%
Sludge (precipitation number) 2.0 Max.
Neutralization Number ....1.0 Max.

As a further guide, we use a test for determining the Resin or Gum Content of the used sample. This test indicates the amount of dissolved resin held in the oil and gives our laboratory a clue as to how near the oil is to permitting gumming or sticking of pumps, valves, pressure switches, etc.

For example, field test results over a period of 15 years have given us sufficient correlation with actual service results that we have been enabled to set limits on gum content. Using this test, we have found that a straight untreated petroleum oil having a gum content of .40 should be drained from the system and fresh oil installed. We have further found that, at this point of concentration, further gum formation would result in precipitation and resultant sticking of hydraulic parts. With an oil having additional solvent ability imparted by certain chemical treatment, this gum content can reach 1.0, or three times that of a straight mineral oil, before draining and replacement is necessary. Here we have one of the measuring tools so useful in determining not only the useful life of an oil, but the additional service life which might be anticipated through use of certain additive type oils.

Flushing and Cleaning Hydraulic Systems

In the past, many methods have been tried to maintain hydraulic systems in a reasonably clean condition. Such is particularly true when draining an oil prior to replenishment. Often such solvents as acetone, kerosene and various other petroleum solvents have been employed to remove sediment and oxidized oil from the system following the draining of the hydraulic oil.

Aside from the hazards connected with the use of certain inflammable solvents, such practices sometimes affect the metallic parts and packings adversely even though they remove the objectionable deposits. It is, therefore, much preferred to use a solvent which is compatible with all component parts of a system and, at the same time, affords lubrication protection to the pump. Such solvents are available for use either by themselves or in conjunction with the hydraulic oil.

In the former case, the oil should be drained and the system filled with the solvent flushing oil. The equipment is run under no load for periods ranging up to four hours. The solvent is then drained, the reservoir wiped dry and fresh hydraulic oil installed. Care should be taken to use lintless cloths such as cheesecloth or any hard fibered material.

The alternate method is to use a concentrated solvent which can be added to the hydraulic oil in the system in small percentages and the equipment run under normal conditions for a limited period of time. During this time, the added solvent dissolves the gummy and resinous deposits and, at the prescribed period, the unit is drained. This latter method has come into prominence during the past several years because of its time saving features as well as ease of use.

Reconditioning of Oil

Controversy has existed for many years regarding the pros and cons of the wisdom of attempting to reclaim petroleum oils for further service. Advocates of either side have certain arguments in their favor.

In our opinion, provided the right type of equipment is used, reclamation of oil resolves itself to a problem of economics. If the cost involved in the reclamation of used hydraulic oil is not considerably less than the cost of new oil, then the oil should be discarded and fresh oil supplied. If, on the other hand, atmospheric conditions surrounding the equipment result in premature contamination of large amounts of oil, then it would appear that frequent filtration or reclamation would be more economical than investment in new oil.

Several types of oil filters and reclaiming units are available, each of which has its particular advantages and disadvantages. If the hydraulic oil is used in large volumes, but contained in many small machine tools, then a unit of a portable nature should be used. Such a unit can be transferred from machine to machine and the oil reclaimed while the machine is being used.

If a large volume of oil is used in comparatively few units, then it may be less costly to use batch filtration wherein a portion of the oil is removed from the system and permitted to go through a reclaiming unit situated at a point some distance from the machine. Each type is available and care should be exercised to investigate the merits of each before a choice is made. Where Fullers Earth type filters are used, consultation should be had with the supplier of the oil to make certain that the additives in use in the hydraulic oil are such that they will be unaffected by such a filter. In cases where rust inhibitors are present, experience has shown that the new oil should be used for a minimum of 50 hours prior to filtration. This permits the anti-rust agent to plate out on the machine surfaces.

Summary

Summarizing, the characteristics to look for in hydraulic oils are these:

Of prime or absolute importance:

1. *Viscosity*
   Must be of correct fluid character to satisfy the requirements of the hydraulic mechanism under consideration.
2. *Lubricity*
   Must have sufficient lubricating value to amply protect the pump and other moving parts in the system.
3. *Stability*
   Must be highly stable in nature so that it can resist the destructive influences of heat, moisture, oxygen (air), metals, agitation, contamination, etc.

Of importance, albeit secondary importance:

1. Rust Protection.
2. Gum Solvency.
3. Foam Resistance.

PUMP MANUFACTURERS' RECOMMENDATIONS FOR HYDRAULIC OILS*

GEAR-TYPE PUMPS

Manufacturer	*Operating Temp.*	*Viscosity at 100 F.*
Brown & Sharpe Mfg Co. Spur, spiral bevel, herringbone gear pumps...	None Specified	150-300 S.U.S.
Gerotor May Corp. Gerotor external-internal gear pumps........	120-140 F.	250-300 S.U.S.
Hydraulic Press Mfg. Co. Hydro-Power gear pumps	——	950 S.U.S.
Northern Pump Co. Series 4000 pumps: Small	——	300 S.U.S.
Large	——	500 S.U.S.
Geo. D. Roper Corp. Series F and H rotary gear pumps.....	180 F. Max.	200-300 S.U.S.
Sundstrand Machine Tool Co. Type WX Rota-Roll Pump	120 F. Preferred	155 S.U.S.

AXIAL-PISTON PUMPS

Manufacturer	*Operating Temp.*	*Viscosity at 100 F.*
Denison Engineering Co. High-pressure, high-volume, constant-displacement Type 3500 series	Preferred: 110-130 F. Maximum: 150 F.	250-300 S.U.S.
LaPointe Machine Co. Variable and reversible discharge pumps	Preferred: 130 F. Maximum: 150 F.	200-210 S.U.S.
Northern Pump Co. Axial parallel-piston, Series 700	Maximum: 160 F.	450-650 S.U.S.
Vickers, Inc. Variable-delivery, piston-type fluid motor..	All Industrial Machinery	150-315 S.U.S.
Waterbury Tool Co. Variable-speed transmission and variable-stroke pump	Preferred: 120 F. Maximum: 150 F.	320 S.U.S.

VANE-TYPE PUMPS

Manufacturer	*Operating Temp.*	*Viscosity at 100 F.*
Racine Tool & Machine Co. Rotary-vane type, variable displacement...	Above 60 F.	200 S.U.S.
	Below 60 F.	75 S.U.S.
	Maximum operating temp.: 160 F.	

Vane-Type Pumps—(Continued)

(Industrial Machinery Installations; Ambient Temperature 50 F. to 90 F.)

Manufacturer	*Type of Installation*	*Viscosity at 100 F.*
Vickers, Inc. Vane type pumps......	Machine tools operating at pressures up to 1000 psi.	150-225 S.U.S.
	Presses and other heavy machinery.	275-315 S.U.S.
Piston type pumps.....	All industrial machinery.	275-315 S.U.S.
Piston type and gear type fluid motors......	All industrial machinery.	150-315 S.U.S.

RADIAL-PISTON PUMPS

Manufacturer	*Operating Temp.*	*Viscosity at 100 F.*
American Engineering Co. Hele-Shaw pump	Pressures below 1500 lb./sq. in. Below 100 F.	525 S.U.S.
	Pressures above 1000 lb./sq. in. Maximum: 100 F.	860 S.U.S.
	Pressures above 1500 lb./sq. in. Minimum: 100 F.	1250 S.U.S.
	Note: Minimum viscosity: 600 S.U.S. at operating pressure and temperature preferred.	
Hydraulic Press Mfg. Co. Hydro-Power radial pump	Preferred: 90-100 F. Maximum: 125 F.	850-1000 S.U.S.
Northern Pump Co. Series 5000	Maximum: 155 F.	650 S.U.S. 300-350 S.U.S. min. at oper. temp.
Oilgear Co. Variable-displacement pumps and motors:	Max. preferred operating tem.: 140 F.	
Type F-to 10 hp........	55 to 170 F.	550 S.U.S.
	40 to 70 F.	300 S.U.S.
Type C or D-100 or 150 hp.	55 to 170 F.	550 S.U.S.
	40 to 140 F.	300 S.U.S.
Type C or D-up to 60 hp.	40 to 160 F.	300 S.U.S.
	25 to 135 F.	150 S.U.S.
Superdraulic Corp. Constant and variable delivery pumps	Oil inlet temp.: Max.: 120 F. Optimum: 90-100 F.	150 S.U.S.

* Recommendations given above may vary somewhat from time to time depending upon manufacturers' experiences with pump in field.

The above recommendations are based upon information obtained by the author and represent average conditions. They are intended only as a general guide to the reader inasmuch as certain engineering changes in pumps or machine tools take place from time to time. For specific information consult the machine manufacturer or the oil supplier.

4. High Viscosity Index.
5. Pour Point.
6. Demulsibility.

The sole purpose of this article on hydraulic practices has been to depart, as far as possible, from the technical aspects of hydraulic fluids and, instead, supply facts which will be useful to those of you who have responsibility for hydraulic equipment.

We have found that the time to consider the *properties* of hydraulic oils is before they are purchased. This requires complete exchange of information between the user and the oil supplier.

Next, the *maintenance* of the purchased oil during service should be given the closest attention since the desirable properties of the new oil will be to no avail if contamination is permitted to continue.

Last, the *removal* and/or *reconditioning* of the oil should be given careful thought to permit an intelligent approach to the problem.

Attention to these functions will pay off in continuous, uninterrupted and efficient operation of your hydraulic machinery.