HYDRAULIC SYSTEM CLEANLINESS

STP 491

ASTM

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HYDRAULIC SYSTEM CLEANLINESS

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Foreword

The Symposium on Hydraulic System Cleanliness was given at the Seventy-third Annual Meeting of the American Society for Testing and Materials held in Toronto, Ont., Canada, 21-26 June 1970. The symposium was sponsored by Committee D-2 on Petroleum Products and Lubricants. J. J. Weaver, Shell Oil Company, presided as symposium chairman.

Related ASTM Publications

Significance of ASTM Tests for Petroleum Products, STP 7-B (1957), $3.50

Contents

Introduction

Experience in the hydraulic industry indicates that there is a need for test methods to deal with problems caused by dirt in hydraulic systems. Representatives of industry have asked Technical Division N to consider the possibility of developing applicable test methods. To achieve a better understanding and definition of the problems, we have organized our symposium to discuss the various aspects of industrial hydraulic system cleanliness. We planned the symposium to include contributions from a wide range of interested parties. Our authors represent users of hydraulic systems, equipment manufacturers, filter manufacturers, technical societies, and educational institutions.

We believe that the authors have done an excellent job for us. Their papers show the benefits and problems associated with hydraulic system cleanliness and demonstrate the need for test methods to evaluate filters and measure contamination. It is hoped that Technical Division N will undertake the development of these test methods. Our symposium and the following list of D-2 Committee, ASTM Standards are suggested as guides for such an undertaking.

ASTM Standards Relating to System Cleanliness

Sampling

- D 2388 Field Sampling of Aerospace Fluids in Containers
- D 2407 Sampling Airborne Particulate Contamination in Clean Rooms for Handling Aerospace Fluids
- D 2429 Sampling Aerospace Fluids from Components
- D 2437 Open-Bottle Tap Sampling of Noncryogenic Fluid Systems
- D 2535 Sampling for Particulates from Aerospace Components with Convolutes
- D 2536 Sampling Particulates from Reservoir Type Pressure-Sensing Instruments by Fluid Flushing
- D 2537 Sampling Particulates from Storage Vessels for Aerospace Fluids by Vacuum Entrainment Techniques (General Method)
- D 2542 Liquid Sampling of Noncryogenic Aerospace Propellants

Sample Processing

- D 2391 Processing Aerospace Liquid Samples for Particulate Contamination Analysis Using Membrane Filters

Tests for Contamination

D 893	Test for Insolubles in Used Lubricating Oils
D 1404	Estimation of Deleterious Particles in Lubricating Grease
D 2273	Test for Trace Sediment in Lubricating Oils
D 2276	Test for Particulate Contaminant in Aviation Turbine Fuels
D 2387	Test for Insoluble Contamination of Hydraulic Fluids by Gravimetric Analysis
D 2390	Microscopic Sizing and Counting Particles from Aerospace Fluids on Membrane Filters
D 2430	Tests for Identification of Metallic and Fibrous Contaminants in Aerospace Fluids
D 2546	Test for Identification of Solder and Solder Contaminants in Aerospace Fluids

Filters

D 2499	Method of Test for Pore Size Characteristics of Membrane Filters for Use with Aerospace Fluids
D 2767	Test for Liquid Flow Rate of Membrane Filters

Acknowledgment

I wish to thank K. G. Henrikson, Mobile Oil Corp.; R. C. Givens, Texaco Inc; P. K. Schacht, Rex Chainbelt Inc.; R. H. Schmitt, Mobile Research and Development Co.; and W. M. Schrey, U.S. Steel Research, for their work and guidance in organizing the symposium.

J. J. Weaver
Shell Oil Company;
symposium chairman.

O. H. Arndt[1]

Hydraulic Oil Cleanliness: A Key to N/C Machine Maintenance

REFERENCE: Arndt, O. H., "**Hydraulic Oil Cleanliness: A Key to N/C Machine Maintenance,**" *Hydraulic System Cleanliness, ASTM STP 491*, American Society for Testing and Materials, 1971, pp. 3–17.

ABSTRACT: High uptime on numerical control (N/C) machining centers is the result of correcting any condition that may ultimately lead to some component failure. This requires an intimate knowledge of the machine hydraulic system and components, and that rare sense of what is right (or wrong) in the entire operation of a machine. A measurement of oil cleanliness can be most helpful.

A remarkable increase of N/C machines in manufacturing industries presents a challenge to develop personnel for proper care of these installations. Development of this skill in machine maintenance is the users' achievement.

Present day machines, with improved components and hydraulic systems, are less sensitive to hydraulic problems. Several years of experience has provided technical knowledge in the art. This information can be passed on by a machine builder to a user, or from one user to another, in symposiums such as this.

KEY WORDS: failure, clean oil, contaminants, filters, lubrication, manuals, oil tests, oil coolers, particle size, numerical control, machine tools, hydraulic systems, servomechanisms, maintenance, cleaning, preventive maintenance, temperature control, education, varnishes, evaluation

All our problems have a beginning some place. When high pressure hydraulic servo systems and numerical controls were married to machine tools, a new family of problems appeared. But thanks to the progressive nature of our industries and the ingenuity of people associated with them, many new fields of adventure and accomplishment developed.

I like to think that the pioneer in this story was a revolutionary new machine with an automatic tool changer and numerical control of the late fifties, Kearney and Trecker's Milwaukee-Matic Model II Machining Center, Fig. 1. In a few years, many of these machining centers were serving industry throughout the country.

Various other models of the Milwaukee-Matic Machining Center followed, along with a variety of profilers, and an assortment of special numerical

[1] Senior mechanical engineer, Kearney and Trecker Corporation, Milwaukee, Wis. 53214.

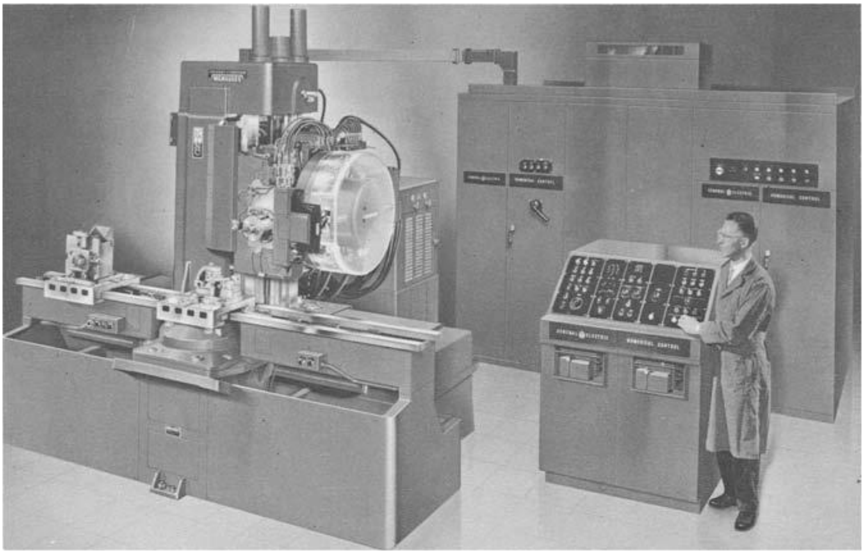

FIG. 1—*Early Milwaukee Matic Model II Machining Center.*

control (N/C) machines developed by Kearney and Trecker, Figs. 2 to 5, as well as similar machines of many other machine tool manufacturers.

The very fact that industry absorbed all this new equipment is a monumental credit to the men who accepted such a challenge. No doubt, the pioneers in programming, operating, and maintaining these earlier machines

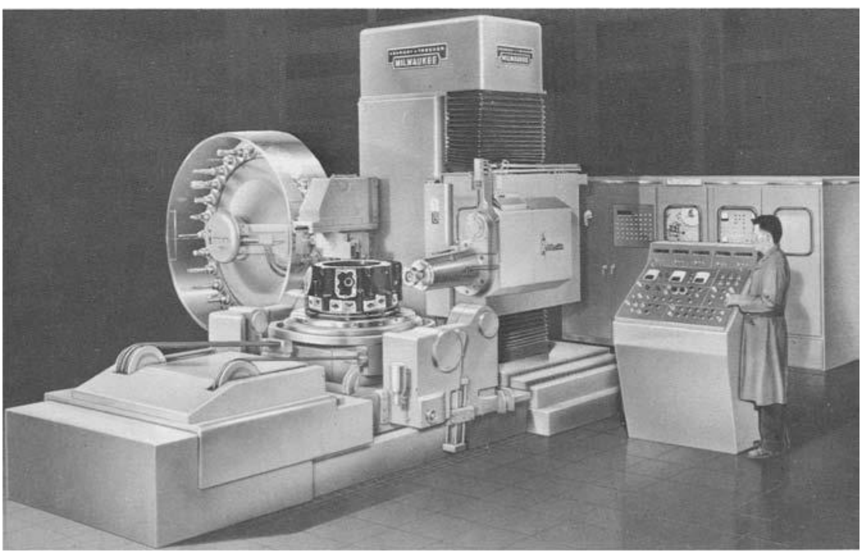

FIG. 2—*Milwaukee Matic Model III 5-Axis Machining Center.*

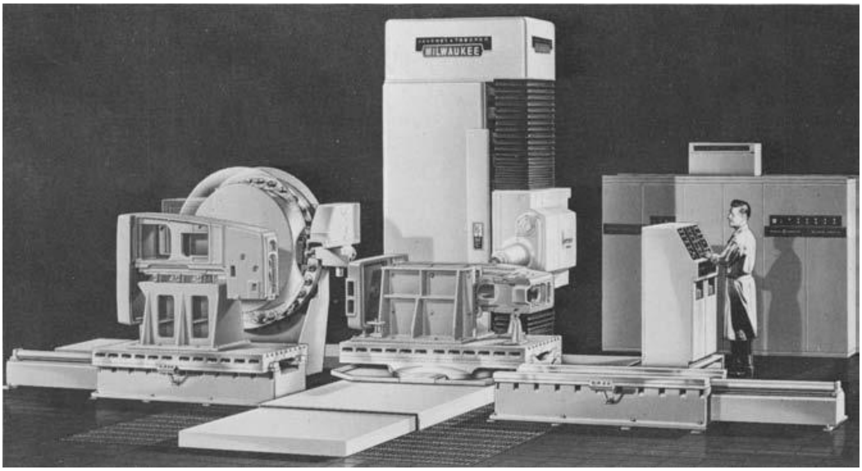

FIG. 3—*Milwaukee Matic Model V 5-Axis Machining Center.*

were rewarded with more responsible positions and may even have directed more N/C acquisitions.

So now we have more of these sophisticated machines in our shops and relatively less help qualified to service them. Fortunately, development progressed on a broad front, providing solutions as quickly as complications appeared. Pump and servo valve manufacturers developed products for N/C machines that were more reliable and less vulnerable to contaminants. Hydraulic oils were adapted specifically to servo systems and are provided by suppliers to meet certain standards of cleanliness. A variety of filters are available to meet the needs of N/C servo systems.

New technology, developed and disseminated by the oil companies and the many component suppliers, has enabled machine tool builders to manufacture machines that are less sensitive to contaminants and capable of giving longer trouble free service. Helpful as these improvements were, industry still had a new line of machines to become familiar with. This brings us to the problem of N/C machine maintenance. The general principles of plant maintenance apply to machine tool maintenance, and it would be well to mention them here.

The primary objectives of maintenance are:

1. To maintain machines in an adequate operating condition.
2. To keep down time to a minimum.
3. To keep break down costs to a minimum.

To attain these objectives, it is first essential to have an adequate staff and appropriate supervision, an effective preventive maintenance program, and a thorough knowledge of the equipment.

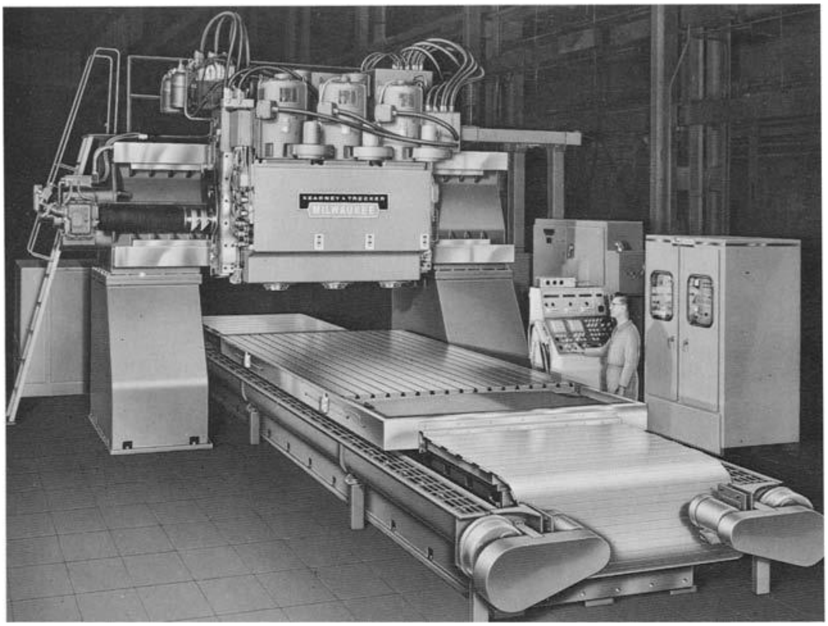

FIG. 4—*3 spindle profiler.*

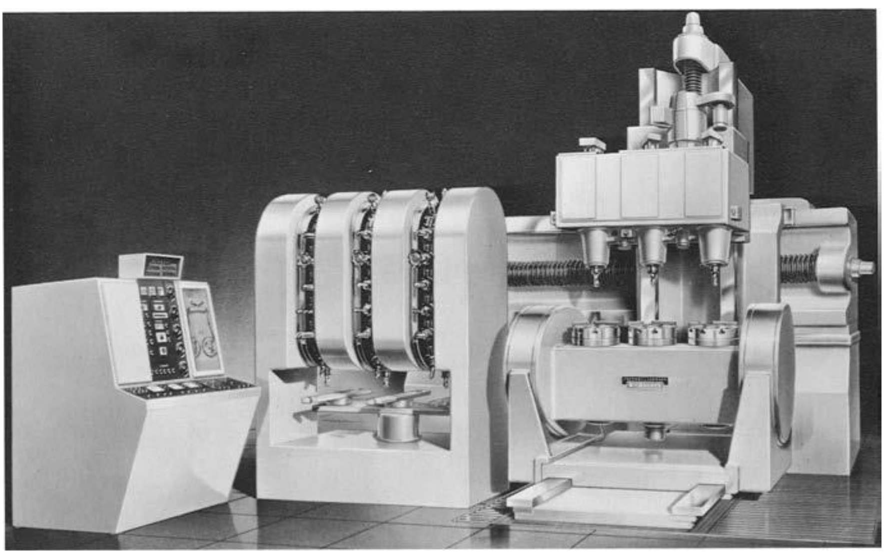

FIG. 5—*3 spindle, 5 axis N/C machine with tool changer.*

Cooperation between production and maintenance is of prime importance. Each must have a realistic appreciation of the other's role in the profit picture. Preventive maintenance must be provided for in the production schedule. Preventive maintenance work must be conscientiously completed on time. Good service records must be *kept–available–and used!* These records establish the characteristics of a machine and how it is used (or misused). A review of the records can show where more or less attention is required or what special work may be necessary. This can then be scheduled for the convenience of both production and maintenance. Even the competence of the operator may be reflected in such records, especially where a number of similar machines permit comparison.

Follow-up on breakdowns is valuable, too. Could this break down have been prevented? Was it forecast in the pm check? Analysis of a failure may show the cause and thus prevent a recurrence. Preventive maintenance work must be organized around the skills of the personnel and facilities existing in the plant as well as the requirements of the machines to be serviced.

Skills of personnel can be developed [*1*].[2] Training programs at the machine builder's plant are conducted under ideal conditions with good facilities and qualified instructors available. Component suppliers offer similar opportunities or may even bring their "school" to your plant. Technical schools often provide special courses if requested when the required courses are not already part of the regular curriculum. Home study courses and seminars, like this, provide other sources of upgrading the individual. The will to learn can be stimulated and is contagious once begun in a plant. The added knowledge also brings with it a new pride and satisfaction for the workman in his job. He has become more involved through his own personal efforts.

Now a word for the man who services the machine [*2*]. He is as important as the operator or the millwright. He must know the importance of guarding against contamination and following the lubrication schedule. The cost of the oil or coolant he handles may be small, but if he does not handle it properly, a quarter million dollar machine tool may be out of production. That can run into real money. The machine serviceman must be properly oriented for these responsibilities.

This is where the maintenance manual comes into the picture. A machine tool manufacturer provides instructions and recommendations for proper care and servicing of the equipment he builds. We should like to center our discussion from here on, on the "Contaminants in the Hydraulic System" section of a *Milwaukee-Matic Machining Center Maintenance Manual* [*3*]. In preparing this section, we learned:

1. Well written material on contamination for a maintenance manual was hard to find.

[2] The italic numbers in brackets refer to the list of references appended to this paper.

2. Few people had a full appreciation of what was involved in a servo hydraulic system [*4*].
3. Among knowledgeable persons, there is general concurrence on most principles involved in the design of a good servo hydraulic system.
4. There was a real need for some simple explanation of the hydraulic system for the maintenance man.
5. The big question was: What is clean oil?

It was decided to very briefly cover the main points concerned with the hydraulic system, so that everyone would be more likely to read this section. A skilled technician would readily get the picture. It is hoped one less knowledgeable would be alerted to things requiring special consideration and would realize when additional information or help should be obtained.

Perhaps the manual itself can best illustrate our approach.

Contaminants in the Hydraulic System

The hydraulic system (see Fig. 6) is designed for accurate performance and long troublefree service of a fine precision machine tool. Certain special features play important roles to this end. Understanding their function will help the maintenance personnel minimize service work and machine down time.

Coolers and temperature controls maintain hydraulic oil operating temperatures between 110 and 135 F. This temperature range gives ideal servo performance, is high enough to free water in the system, and yet not high enough for rapid varnish formation. A separate circuit with a low volume pump continuously circulates the oil through a large capacity filter and the cooling system. This filter is not subjected to the surges in the operating circuit of the hydraulic system. Each axis servo valve is preceded by a filter in the hydraulic circuit.

Effects of Contamination

Contamination in a hydraulic system causes corrosion, erosion, and accelerates wear, reducing the useful life of all components. Pump slippage and system leakage gradually increase until the system is no longer able to perform the job it was designed to do. Components must be overhauled or replaced.

The sharp metering edges in servo valves are especially vulnerable to erosion that reduces accuracy and impairs performance. Silting decreases system resolution and accuracy, and can result in system "hunting." Clogging of servo valve orifices can result in a "hardover" valve condition. Tests indicate that an absolutely clean system would almost eliminate all component wear.

Systems completely free of contaminants never can be attained; however, a good testing program can help keep contaminants to a practical minimum. To help the reader visualize the microscopic size of contaminants, the following chart is presented:

Particle Size
1 micrometer = 0.001 millimeter
25 micrometers = 0.001 inch

	Microns	Inches
Smallest particle visible to the naked eye	25 to 50	0.001 to 0.002
Table salt	100	0.004
Human hair	75	0.003

Contaminants in a hydraulic system are generally smaller than a grain of salt. Visualize these particles traveling at 200 to 300 ft/s, as the fluid flows through restricted passages of pumps, motors, and valves. The ballistic impact of microscopic particles becomes measureable and the frequency of impact is high, even at acceptable levels of contamination. The picture of erosion becomes quite realistic.

Sources of Contamination and Steps of Prevention

1. Contaminants in new oil and equipment used in adding oil.
   (*a*) Store oil drums on sides.
   (*b*) Clean top of drum before opening for pump or suction lines.
   (*c*) Use only clean transporting containers.
   (*d*) Filter all oil added through a 5-μm filter.
   (*e*) Keep reservoir filled at proper level to prevent formation of moisture and rust.
2. Leakage of water, coolants, lubricants, etc., into the system.
   (*a*) Keep all line connections tight.
   (*b*) Keep all seals in good condition.
   (*c*) Avoid improper use of coolants and lubricants that may cause system contamination.
3. Infiltration of gases, fumes, and dust through breathers.
   (*a*) Clean air breathers regularly.
   (*b*) Provide special filters or duct in a clean air supply for severe conditions.
4. Contaminants introduced while replacing filters, valves, pumps, etc.
   (*a*) Break lines only when absolutely necessary.
   (*b*) Cap all line openings.
   (*c*) Install replacement parts immediately or protect opening from airborne particles.
   (*d*) Use only a solvent and lint-free wipers for cleaning.

5. Varnish or scale forming from deterioration of oil.
   (*a*) Check operation of temperature controls.
   (*b*) Check effectiveness of cooling system.
6. Particles resulting from wear and erosion.
   (*a*) Check filters and change as required.
   (*b*) Sample oil for analysis regularly. Particle identification can pin point an impending failure, if wear or erosion becomes abnormal.

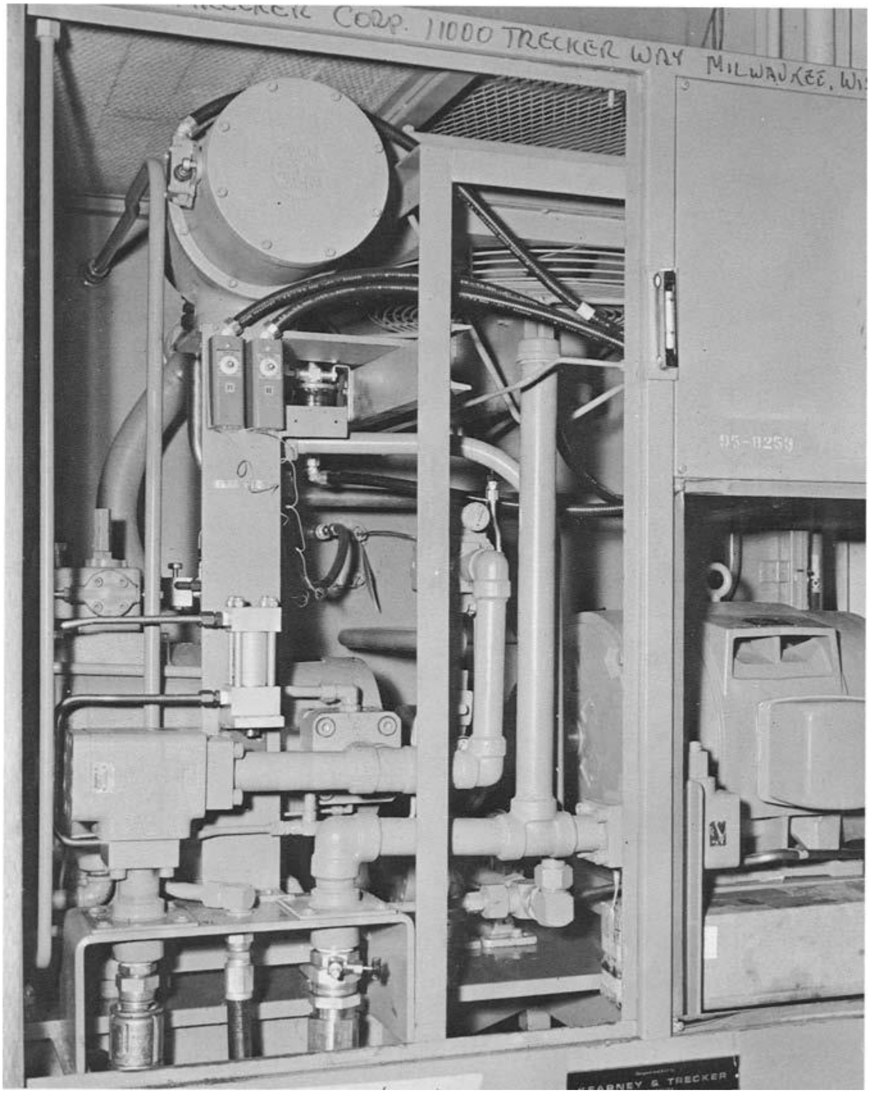

FIG. 6—*Hydraulic power supply unit.*

Filters

Filters are provided throughout the hydraulic system to remove solid contaminants from the system. The hydraulic power supply unit has a filter that will light the "oil filter clogged" light on the power distribution panel when the cartridge becomes clogged. Each axis drive hydraulic circuit has a filter with a replaceable cartridge.

The spindle drive hydraulic circuit has a filter with a pop-up indicator to show the condition of the filter cartridge. When this filter cartridge is replaced, each axis drive filter is also to be replaced, since the spindle hydraulic circuit is set up as the "control circuit" for axis filter replacement.

The following observations on filters are general in nature and are applicable to all filters:

(*a*) The best available filter *will* pass many particles larger than its rated pore size.

(*b*) The quantity and size of particles passed by a given filter is dependent on how the filter is used. The cause of unusual virbration, excessive pressure changes, and flow surges should be checked and promptly remedied.

(*c*) Filter elements must be replaced, as required, to maintain their effectiveness.

Fluid Analysis

Samples of oil taken from the hydraulic system and analyzed according to standard ASTM procedures adequately reveal the condition of the oil and its suitability for servo machine tool service. The degree and nature of contamination indicate what corrective steps may be necessary. A sample of oil may be used to determine the *specific gravity*, *viscosity*, *water content*, and *neutralization number*. A change in any of these from normal indicates dilution or contamination by water, coolant, lubricants, or other fluids. The *neutralization number* also indicates any increase in acidity of the fluid due to a breakdown of the oil. These contaminants are more of a "chemical" nature, and cannot be easily removed, as particles are by filtration. If tests show a high degree of such contaminates, the oil must be changed.

Foreign particles in the oil can usually be removed by filtration. This is a continuous process as long as the filters in the system are functioning properly. External filtration may be necessary to clear up an excess condition of particle contamination and bring the system back to a safe operating level.

A Particle Count—to show the extent of such contamination, is obtained by passing a known quantity (100 ml) of this sample through a filter. The particles left on the filter are counted by size groups and also may be identified as to their origin. Such particle identification can help pin pointing trouble, with filters, seals, motors, pumps, etc., that may be averted by prompt attention.

From the particle count, the *class of contamination* is determined. Class 0 through 4 oil is considered to be satisfactory for further use; sampling again at the regularly scheduled time. For Class 5 (or dirtier) oil, all filters must be checked, and changed, if necessary. Careful examination of each filter should be made to identify the type of contamination. External filtration also is recommended, especially if contamination is worse than Class 5. Anything that appears to contribute to the contamination should be corrected, and after 16 h of operation another sample should be taken for analysis.

A particle count is practical on oil samples of Class 6 or cleaner. Gravimetric analysis test provides a useful measure of contamination for Class 6 and worse, but particles are not identified easily. Silt index shows up an excess of particles below 5 μm and also varnish formation in the oil. For a high count of particles smaller than 5 μm, or a high silt index, external filtering with 2 μm, or finer, filters is recommended.

When the benefits of clean oil and the potential problems of contaminants are realized, the value of a regular oil sampling program becomes quite obvious. It is recommended that samples of oil be taken, see Fig. 7, and analyzed as follows:

First—Upon completion of installation.

SAMPLING PROCEDURE

Take samples of fluid from the hydraulic system as follows:

a. Take fluid samples while the machine is in operation and has been running 15 minutes or more.

b. Always take sample at same place, specified by manufacturer of machine.

c. Clean the area surrounding the sampling valve on the hydraulic system with a filtered solvent, such as Freon TF.

NOTE: Rags should not be used for cleaning, because the lint they leave contaminates the oil. When wiping is necessary only lint free wipers, such as KIMWIPES, should be used.

Keep the sampling bottle absolutely clean and free of any additional contaminants at all times.

d. Open the sampling valve and flush a quart or two of fluid into a pail, fill the 1000 ML shipping bottle with fluid, remove the bottle and then close the valve. (Discard the fluid in the pail; do not return it to the hydraulic system).

e. Place a 3" square of "Saran" or similar material over the shipping bottle to seal the opening and screw the cap on tightly over this seal for shipping.

f. Identify each sample with date taken and machine serial number. Give name and address of person who is to receive the reports and the returned bottle.

g. Place the bottle with the sample of fluid in the plastic bag and seal it. Prepare it for shipping by wrapping with corrugated paper and placing in corrugated paper container and seal. (Do not pack in saw-dust.)

h. Label package "Hydraulic Oil Sample".

FIG. 7—*Recommended sampling procedure.*

ROSAEN FILTER DIVISION
PARKER HANNIFIN
1776 E. Nine Mile Road, Hazel Park, Michigan 48030

Phone: 313-566-4778

FLUID ANALYSIS REPORT

No. ____________

Company ____________________

Address ____________________

City & State ____________________

Attention ____________________

From Machine No. ____________________

Sample Received ____________ (Date) Analysis Made ____________ (Date)

TYPE OF TEST	READING	*CONDITION A	B	C
Specific Gravity				
Viscosity				
Silt Index				
Water Content				
Gravimetric				
Neutralization No.				
Particle Count				

SIZE RANGE	SAMPLE RECEIVED	0	1	2	3	4	5	6
5-10 µm		2,700	4,600	9,700	24,000	32,000	87,000	128,000
10-25 µm		670	1,340	2,680	5,360	10,700	21,400	42,000
25-50 µm		93	210	380	780	1,510	3,130	6,500
50-100 µm		16	28	56	110	225	430	1,000
>-100 µm		1	3	5	11	21	41	92
Fibers		Hydraulic Contamination Standards – Particles Per 100 ml by Class of System						
Amount of Sample								

This sample is: ☐ Better ☐ Worse ☐ Same as the previous sample

analyzed on ____________ (Date) (See remarks)

* Conditions:
A. Oil is satisfactory for further use. Test at regular schedule.
B. Oil condition is poor. Replace all filter elements and submit another sample for analysis after 16 hours of operation.
C. Change oil and flush system. Readings are not within safe limits.

REMARKS:

FIG. 8—*A typical fluid analysis report.*

Second—After first 160 h of operation.

Third—After 480 h of operation and every 480 h thereafter.

These are recommendations for normal operating conditions. Where unusual conditions exist, the schedule may be modified to suit. Should it be necessary to change the oil, or some major component where the cleanliness of the oil may be affected, a sample analysis should be made.

ROSAEN FILTER DIVISION
PARKER HANNIFIN ® TRADEMARK
1776 E. Nine Mile Road, Hazel Park, Michigan 48030

DO NOT OPEN BAG UNTIL READY TO SAMPLE

RECOMMEND NEXT SAMPLING ______________________

PLEASE COMPLETE AND FORWARD WITH SAMPLE:

MACHINE SERIAL NUMBER ______________________

DATE OF SAMPLING ______________________

HOUR METER READING ______________________

LAST SAMPLE TAKEN ______________________

OIL ADDED OR CHANGED (DATE) ______________________

RETURN REPORT TO ______________________

____

____

ATTENTION ______________________

REMARKS ON MACHINE OPERATION * ______________________

____

____

____

____

____

*Please note failures and causes, if known.

FIG. 9—*Sample data sheet.*

Oil sample reports, Fig. 8, should be filed, together with service work records, for a convenient reference book of the machine. Comparing successive reports helps to establish the characteristics of the machine, and variations from normal then can be readily detected.

Measuring Contamination

Measuring contamination by fluid analysis is a laboratory procedure with standards established by American Society for Testing and Materials (ASTM) and Society of Automotive Engineers (SAE) in general use in industry. Plant laboratories with competent personnel can carry on an excellent oil sampling and analysis program. When there are no such facilities, the sampling can be assigned to a responsible person or made part of the preventive maintenance program. Oil samples are then sent to a laboratory providing an analysis service, see Fig. 9.

Companies supplying hydraulic oils also provide testing services; however, the important particle count is generally not included. The economics of component replacement costs and lost production time that may be avoided, not only justify a good hydraulic fluid testing program, but indicate that the best is required.

External Filtration

When the particle count shows contamination of the hydraulic oil to be up to Class 6, it is advisable to use an *external filtration unit*, Fig. 10, in addition to changing the spindle and axis filters. Various portable units are available with excellent filtering capabilities, 1 μm range, that can clean a hydraulic system up overnight.

Conclusion

All our discussion up to this point, still leaves us with a dire need for a simple, fast, and reliable means of determining the cleanliness of hydraulic oils. This remains the key to effective N/C machine tool maintenance.

Acknowledgments

The author wishes to thank Kearney and Trecker Corporation for making this presentation possible. The help of many co-workers, especially William Bartz and Robert Sedgwick gratefully is appreciated. The technical assistance of F. S. Stilwagner of Rosaen Filter Division and M. O. Thommesen of Mobil Oil Corporation in preparing the *Maintenance Manual* is also appreciated.

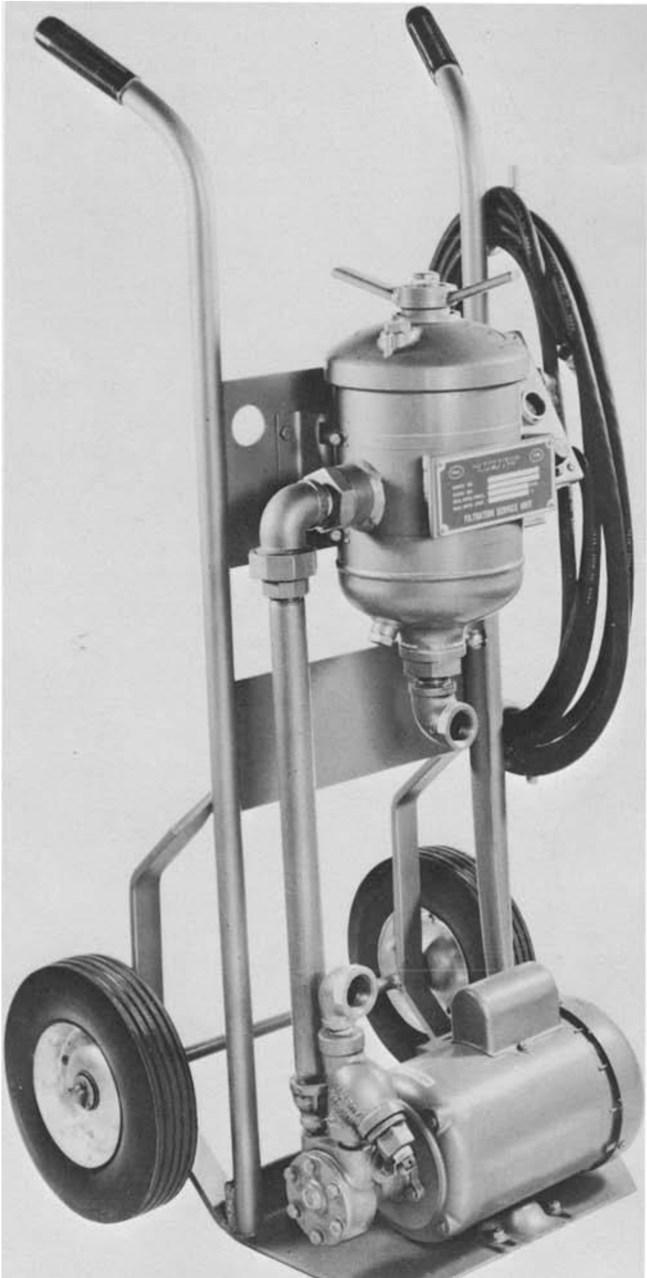

FIG. 10—*A portable filtration unit.*

References

[*1*] Bachmann, R. W., "Personnel Selection and Training for Numerical Control."
[*2*] *Maintenance Engineering Handbook*, Morrow, L. C. ed., McGraw Hill, New York, 1966.
[*3*] "Maintenance Manual Milwaukee-Matic Model III," Kearney and Trecker Corporation.
[*4*] Sedgwick, R. K., "Hardware for Applications of Hydraulic Servo Systems to Machine Tools."

L. B. Baranowski[1]

Maintenance of Cleanliness of Hydraulic Fluids and Systems

REFERENCE: Baranowski, L. B., "**Maintenance of Cleanliness of Hydraulic Fluids and Systems,**" *Hydraulic System Cleanliness, ASTM STP 491*, American Society for Testing and Materials, 1971, pp. 18–28.

ABSTRACT: The cleanliness of a hydraulic system and its fluid is an important factor in the proper operation of such a system and its components. The sources of contamination and prevention of it are discussed. Types of contaminants are classified as particulate matter or liquids and gases in both free and soluble phases. Their effect on systems and components are discussed briefly. The methods for measurement of contaminants are reviewed with special attention to water and gas content. Techniques and practices for contamination prevention and control are described. Applications of filtration, dehydration, and degasification of hydraulic fluids in hydraulic systems are suggested, including totally enclosed circuits.

KEY WORDS: hydraulic equipment, hydraulic fluids, filtration, oil filters, vacuum, degassing, dehydration, contamination, purification, maintenance, cleaning, diluents, exhaust gases, particle size, grit, evaluation, tests

There is a growing awareness of the importance of cleanliness in the hydraulic fluids and systems.

A survey of the articles published in *Hydraulics-Pneumatics* in the two nine-year periods clearly indicate the trend [*1*][2] as shown in Table 1. The rate of innovations dealing with contamination control and related subjects increased from 10 in 1948–1957 to 48 in the 1958–1967 period.

This trend originated in aerospace industries, due to the critical nature of hydraulic applications, and later spread into earth-bound industries, which, prior to that time, were reluctant to accept higher standards for contamination control. The reasons for adaptation of this philosophy are mostly economical: to reduce maintenance costs and to increase reliability and accuracy.

During a recent 25th Annual Meeting of the American Society of Lubrication Engineers (ASLE), the Machine Tool Committee held a panel discussion "Solving the Problem of Clean Fluids for Machine Tool Hydraulics." Also,

[1] Manager, system application engineering, Fluid Handling Division, Keene Corporation, Cookeville, Tenn. 38501. Member ASTM.

[2] The italic numbers in brackets refer to the list of references appended to this paper.

TABLE 1—*Filtration innovations.*[a]

Subject of Articles	Feb. 1948 through Dec. 1957		Jan. 1958 through Oct. 1967	
	Number of Articles			
	Total	Aerospace	Total	Aerospace
Contamination control, filtration, particle counting, dehydration and deaeration, etc.	10	1	48	29
Leakage control	42	7	32	7

[a] From: *Hydraulic and Pneumatics,* Nov. 1967.

a special ASLE/FPS Symposium was held on Hydraulic Fluids and Fluid Conditioning [*2*].

The panel members reported that by proper filtration, the life in mobile hydraulics increased as high as 100:1 ratio. A numerical control machine builder reported improvement in cleanliness level from 4 to 8 down to 0 through introduction of a 3-μm filtering system.

Sources of Contamination

There is always some residual contamination left in the system after assembly or overhaul. Even by application of the most careful flushing procedures, it is difficult to attain a low level of contamination in the flushing fluid.

Contamination may enter the system with hydraulic fluid when filling the system or when adding make-up oil. Checks of oil at the refineries frequently indicate a very high level of contamination in 5 to 10 μm range prior to filtration. Additional contamination is picked up during transfer and from the shipping containers.

During the operation of the system, contamination can enter with atmospheric air or be generated within the system. Air breathing reservoirs collect atmospheric dust and moisture which condenses as the temperature changes.

System generated contamination consists of rust and products of corrosion due to the presence of water and oxygen. Decomposition of hydraulic fluids in the presence of water, oxygen, and catalytic effect of metals results in the formation of sludge. High temperatures accelerate decomposition, resulting in the generation of gums and varnishes.

Seals and gaskets also may contribute to contamination due to wear or incompatibility with the fluids.

Last but not least are the accumulating particles of wear of the system, which in turn breed more wear.

Particulate Matter

A great deal of attention is being paid to the particulate matter contamination and the cleanliness levels, which are, in a way, the reciprocals of contamination.

I would like you to refer to a paper by J. A. Briggs on "Determining Contamination Levels in Hydraulic Systems" [3]. Table 2 shows a tentative SAE standard based on particle count. It illustrates a particle population explosion. There are several other competitive systems of classification; for example, Cincinnati Milling Machine Company with classes from 00 to 10 overlapping the SAE standard.

TABLE 2—*SAE-A-6D tentative.*

Size Range, μm	System Class							MIL H 5606B
	0	1	2	3	4	5	6	
5 to 10	2 700	4 600	9 700	24 000	32 000	87 000	128,000	2 500
10 to 25	670	1 340	2 680	5 360	10 700	21 400	42 000	1 000
25 to 50	93	210	380	780	1 510	3 130	6 500	250
50 to 100	16	28	56	110	225	430	1 000	25
>100	1	3	5	11	21	41	92	0

The paper by J. A. Briggs contains ample bibliography on contamination level. A very commendable effort is conducted by the National Fluid Power Association to establish a uniform method of reporting data on contamination levels by the Hydraulic Filter and Separator Group.

For this reason, and to avoid being repetitious, I would like to deal in more detail with contaminants other than particulate matter, which are frequently overlooked and underestimated.

Water as a Contaminant

Water is always present in hydraulic fluids. This water may be present in its free form or as water dissolved in the fluid, mostly in both forms. Free water may appear in a precipitated form, separated from the fluid by difference in specific gravity. Thus in phosphate esters and chlorinated hydrocarbons free water will appear on top of fluid. In some silicone type fluids, free water will remain in oil in a state of weightlessness as their specific gravity is close to 1.00.

The other form of free water in oil is emulsion. When thoroughly dispersed by the mechanical action of pumps, or by passage of oil, the emulsions may be more or less permanent. Less permanent emulsions, given time, will separate by gravity or by a centrifugal force, provided a difference in specific gravity exists.

In general, oils containing surface acting additives or contaminants tend to form tighter emulsion with water. Tighter emulsions are characterized by smaller water particles and a slower rate of separation. Some emulsions do not separate at all.

While most additives and inhibitors are put in oil for a specific purpose, their presence frequently has an adverse effect on the water separating properties of the oil. The presence of soluble oxidation products and particles of rust tend to stabilize emulsions still further.

In addition to free water, oils contain water in solution. Figure 1 shows maximum water content in its soluble phase for petroleum oils. Curves *A* and *B* show the relationship between oil temperature and soluble water content for a typical light viscosity oil. Curve *A* shows a transformer oil, Curve *B* oil with high aromatic content.

Air as a Contaminant

Hydraulic systems are highly sensitive to the presence of free air or gas. Gases are highly compressible and dissolve easily in fluids; therefore, they affect the operation of a hydraulic system in many ways. Cavitation of the pumps, erosion of the valves and orifices, and mushy operation are credited to the presence of gas in hydraulic systems. Rapid compression of free gas generates heat, which in the presence of oxygen can scorch or oxidize the oil. Foaming is another ill effect of gas in a hydraulic system.

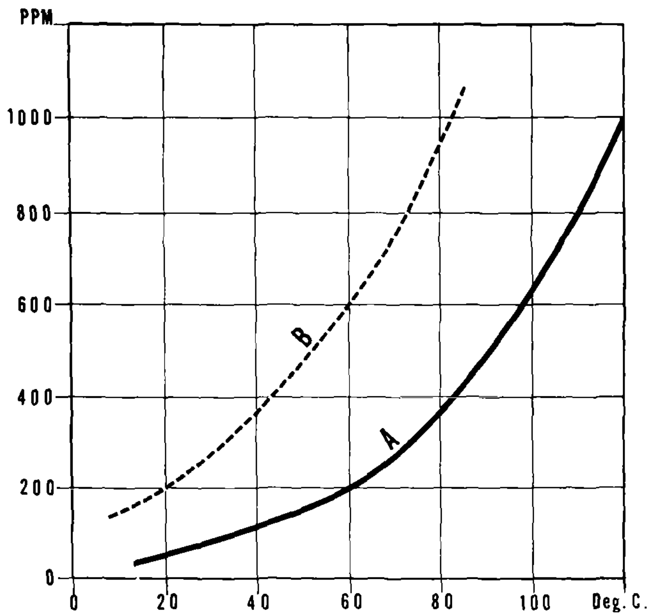

FIG. 1—*Maximum water solubility in petroleum type oils.*

Gases are soluble in oils in quantities depending on the type of oil and gas. Air is soluble in mineral oil to approximately 12 percent by volume at atmospheric pressure. A silicone type oil will dissolve approximately 20 percent of air under the same conditions.

Solubility of gases in fluids changes only little with the temperature, but is affected greatly by pressure. At twice atmospheric pressure, the total possible soluble gas content is double that at atmospheric pressure, while at full vacuum, the theoretical gas content is nil. This shows almost a linear relationship between pressure and soluble gas content.

The reverse process to solubility is evolution of gas from the fluid, caused mostly by the reduction of pressure. There are additional factors involved, including time, for complete solution or evolution of gas from liquid [*4*].

The measurements of the dissolved gas can be accomplished by one of the following methods: ASTM Test for Gas Content of Insulating Oils (D 831–63) or ASTM Test for Gas Content (nonacidic) of Insulating Liquids by Displacement with Carbon Dioxide (D 1827–64). First, the gas is evolved in a vacuum chamber and its contents calculated from the increase in pressure. The second is by displacement of air by carbon dioxide and is suitable for nonacidic oils or nonreactive with strong caustic solution.

Other Contaminants

The other intangible contaminants are some things that sometimes are lumped under the heading of surfactants, or sometimes suspected as bacterial contamination. It interferes with super-fine filtration and the coalescing action of filters. They plate out as a slimy coating on the filter fibers causing premature plugging of the filter. We have observed this phenomenon on some new rust and oxidation inhibited turbine and hydraulic oils. One of the plausible explanations is that in the presence of water, some rust inhibitors plate out on the porous filter media.

Effects of Contaminants

While effects of the contamination by particulate matter are publicized widely, the effects of water and gas, present in hydraulic oils, are not fully appreciated.

With the reduction of pressure, dissolved gas evolves from fluid in the form of bubbles. This gas in a free state may cause cavitation of the pump, erosion of the components, oxidation and deterioration of oil, overheating, foaming, and resulting loss of lubricity.

The other detrimental effects of air in oil were described in the June 1968 [*5*] and November 1969 [*6*] issues of *Hydraulics and Pneumatics* magazine.

While the effects of gas or water contamination on a hydraulic system are considerable, the combined effect of both is still more damaging. Oxygen from air and water causes corrosion of both liquid and gas space of the hydraulic system, thus generating contaminant right within a system and even the best micronic filters cannot prevent it.

Rust inhibition of oils is one of the preventive measures designed to form a barrier to water and oxygen on ferrous surfaces of the system. The presence of water causes this inhibitor to plate out the unprotected surfaces. Too much water, however, causes inhibitors to precipitate from oil, clog fine filters, and to deplete the inhibitor. Too much inhibitor reduces the ability of water to separate from oil.

In active hydraulic systems, water alone does not affect system operation as it forms a water-in-oil emulsion, and has no opportunity to wet the ferrous surfaces. In stagnant or intermittently operated systems even a trace of water may cause a great deal of trouble. A small water particle resting in a fine clearance of a spool valve may start a rusty spot. Larger water drops may shorten the life of a pump due to its poor lubricity.

Rust inhibitors and oxidation inhibitors are added to the hydraulic oils to counteract or prevent effects of water and oxygen. In absence of water and oxygen hydraulic oils can be run at higher temperatures without the varnishing effect. It follows that the ideal operating conditions of a hydraulic system are a complete absence of gas and water contamination in their free and soluble forms.

Synthetic Fluids

Perhaps we should mention briefly other types of hydraulic fluids such as synthetic fluids which for our purpose may be defined as nonmineral fluids.

For some of the synthetic fluids, water could be a component, not a contaminant.

The popular fire resistant phosphate esters become frequently corrosive due to development of acid in the presence of water and exposure to high temperature [7]. Dehydration and corrective adsorptive filters are used to maintain condition of the fluid and stop erosion occurring in the system.

Water is a contaminant for automotive brake fluids. These are mostly a mixture of glycols, polyglycols, polyglycol esters, lubricating additives, inhibitors, and some castor oil. In modern brake systems, particularly disk brakes, higher temperatures are encountered and the boiling point must be in the 460 to 550 F range. Water lowers the boiling point considerably. The brake fluid is highly hydroscopic and mixes with water in any proportion. Only one half percent of water in fluid can reduce boiling point by approximately 50 F.

Mineral oils are also contaminants for brake fluids, as they affect the rubber parts of the system.

Solvents, fuels, and other types of fluids also may contribute to contamination. Proper separation of the fluids in handling and maintenance will prevent accidental mixing.

Detection and Measurement of Contamination

Although this is not in the scope of this paper, the measurements and monitoring of the system fluid contamination is very important for the proper maintenance of hydraulic systems.

It is done mostly on a periodic basis by sampling. It is possible that in the future a continuous monitoring method will be applied to some larger or more critical hydraulic applications.

The prevailing methods of contamination detection and measurement are as follows:

1. *Particulate Matter*

1.1 Gravimetric—by weight in milligrams of contaminant per 100 ml of fluid

1.2 By particle count—using microscope or automatic optical or capacitance counters.

1.3 By changes in turbidity of fluid.

2. *Water Content*

2.1 Centrifuge for free water.
2.2 Karl Fischer for total water content.
2.3 Boiling point for brake fluids.
2.4 Optical—by turbidity change.
2.5 Water in oil meters, conductivity type.

3. *Gas Content*

3.1 Vacuum decay in vacuum chamber.
3.2 Direct reading method—gas content meters.
3.3 Oxygen content monitor.

4. *Other Contaminants*

4.1 Acidity by neutralization number.
4.2 Surfactants by interfacial tension.
4.3 Dilution by distillation.
4.4 Chemical by infrared spectrometry.

Purification Practices

Contamination control can be exercised as preventive or corrective measures.

Table 3 shows purification methods. Table 4 shows most common practices in maintenance of cleanliness of fluids and systems.

Figure 2 shows the usual locations of the filters and other purification devices in a typical hydraulic system. Each location has some advantages and some limitations.

TABLE 3—*Purification methods.*

	Removes							
	Solids		Water		Gas		Other	
Method	h	l	Free	Sol	Free	Sol	Dil	Add
Settling	×		×		×			
Centrifuge	×		×					
Filtration	×	×						
Coalescence	×	×	×					
Absorption			×[a]	×[a]				
Adsorption			×[a]	×				×
Vacuum			×	×	×	×	×	
Air drying			×	×			×	
Vacuum filter	×	×	×	×	×	×	×	

[a] Limited.

TABLE 4—*Purification practices.*

1. *Prior to operation:*
   - 1.1 System flushing
   - 1.2 Filtration of fluid at the source
   - 1.3 Filtration and purification while filling the system
2. *During the operation of the system:*
   - 2.1 Suction filters
   - 2.2 Pressure filters
   - 2.3 Bleed filters
   - 2.4 Discharge filters

   Mode of operation is intermittent
3. *Continuous operation on bypass:*
   - 3.1 Fine and superfine filtration
   - 3.2 Dehydration
     - (a) By dry air or gas
     - (b) By blotter media
     - (c) By vacuum
   - 3.3 Degasification
   - 3.4 Corrective treatment

The changing filtration requirements of the last 15 years indicate a trend towards better degree of filtration or fine filtration in the micrometer range 1 to 5 μm.

This in turn imposes some limitations on the flow rates through the filter and may lead to a relatively short life of the filter element.

With a fine filter located in high pressure part of the system, Location 2, the cartridge changes become very inconvenient and cause introduction of hard to displace air into the system. This location, however, is ideally suited for protection of the servo valve from the effects of pump erosion.

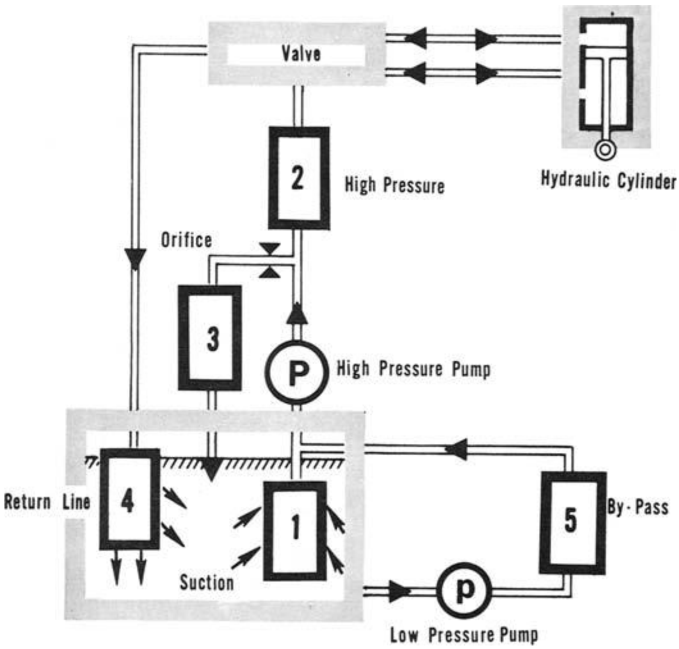

FIG. 2—*Location of filters and purifiers in hydraulic systems.*

Further limitations are imposed on the size of the filter housing due to high pressures.

The discharge filter, Location 4, is not the best location. It is subjected to sudden return flow, and hydraulic shocks operate only part time of the work cycle.

The suction filter on the pump intake, Location 1, is advantageous for the protection of the hydraulic pump. There are, however, severe limitations. Fine filtration media cannot be used, as the restrictions of the flow cause cavitation of the pump. A coarse inlet filter will protect the pump only from larger particles, which, any way, should not be present in a clean system.

Orifice or bleed type filters, Location 3, can be of a low pressure case design; however, they operate only when the system is running and take only a small percentage of the pump flow.

These limitations do not apply when the filter is located on the bypass loop, Location 5. The filter housing on the separate low pressure circulating pump 25 to 50 psig can be considerably larger and carry more filter cartridges.

Filter elements can be changes at any time without interference with the operation of the hydraulic high pressure system. Also, air introduction into the system is eliminated.

Furthermore, the purification devices for water removal, degasification of fluid, and a corrective filter also should be installed on a separate loop on the fluid reservoir.

The ultimate results can be obtained by continuous filtration or purification or both on a bypass loop at a flow rate slightly greater than that of the main hydraulic pump or pumps.

The discharge from the purification loop into a hydraulic pump suction manifold would assure 100 percent purified and filtered fluid supply to the pump and eliminate the need for the suction filter.

In some instances a central purification system may serve the reservoirs of several hydraulic systems, using the same fluid.

The use of a continuous purification device on the bypass from the reservoir and the protection of the air space above the fluid in the reservoir will result in cleanliness of both.

To enlarge the scope of this paper, I would like to show a system used for dehydration and degasification of the brake fluid used in the automotive industries. The brake lines are evacuated by vacuum and filled with degassed and dehydrated fluid under vacuum in order to eliminate the possibility of air pockets and mushy operation of the brakes (Fig. 3).

Perhaps vacuum bleeding and filling could be a good practice to follow in other types of hydraulic systems.

Recently a central single point evacuation and fill system is considered for the automotive assembly lines. High vacuums applied at the master cylinder will remove air. The void will be filled with dehydrated and degasified brake fluid in the upright stages of car assembly in a 1 to 2 min automated cycle.

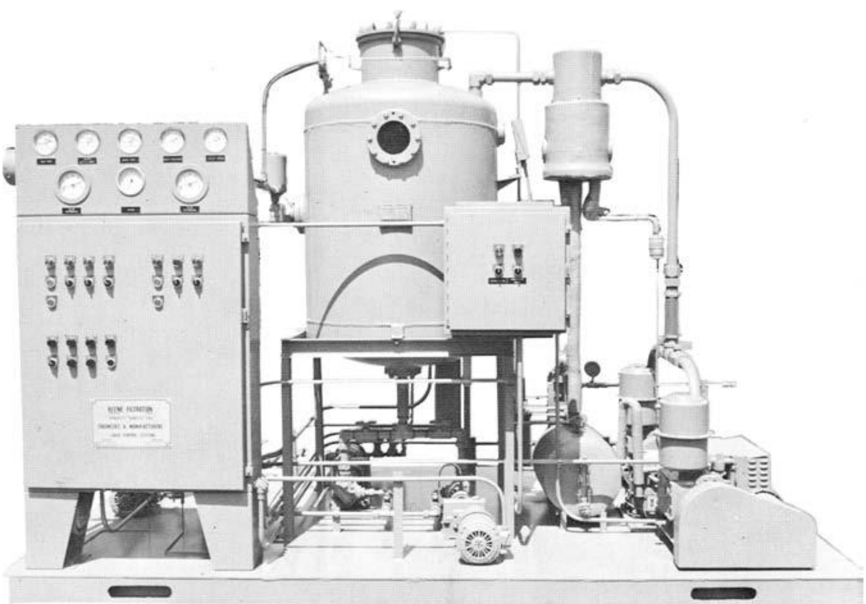

FIG. 3—*System used for dehydration and degasification of the brake fluid used in the automotive industries.*

Conclusion

Hydraulic systems and fluids can be kept clean, dry, and free of dissolved and entrained gases.

Proper maintenance of hydraulic fluids should start at the refinery and continue during the storage and transfer to its destination.

Once in the system, the hydraulic fluids should be maintained at the lowest possible contamination level by fine filtration.

Additional means of purification should be provided if water and entrained air or chemical deterioration are present.

The advantages of a continuous bypass filtration and purification should be considered as means to assure a constant level of cleanliness, independent of the operating cycle and frequency of the system activity.

Closed systems, vacuum fill, and degasification of hydraulic fluids are predicted as an ultimate target in hydraulic system design and maintenance [*8*].

References

[*1*] Jacobs, Edwin, assistant editor, "Is Contamination Control Possible?" *Hydraulics and Pneumatics*, Nov. 1967, pp. 128–129.

[*2*] Twenty-Fifth Annual ASLE 1970 Meeting Program, 4–8 May 1970, American Society of Lubrication Engineers, Chicago, Ill.

[*3*] Briggs, J. A., "Determining Contamination Levels in Hydraulic Systems," Annual Meeting, American Society of Lubrication Engineers, Philadelphia, 5–9 May 1969.

[*4*] Bucher, L. T. and Beerbower, A., "State of Art of Gas-Liquid Solubility Experiments," Annual Meeting, American Society for Testing and Materials, 21–26 June 1964, Chicago, Ill.

[*5*] Magorien, V. G., "How Hydraulic Fluids Generate Air," *Hydraulic and Pneumatics*, June 1968.

[*6*] Magorien, V. G., "What Is Bulk Modulus and When Is It Important?" *Hydraulic and Pneumatics*, Nov. 1969, Chicago, Ill.

[*7*] Wolfe, G. F., Cohen, M., and Dimitroff, V. T., "Ten Years Experience with Fire Resistant Fluids in Steam Turbine, Electrohydraulic Controls," *Lubrication Engineering*, Jan. 1970.

[*8*] Baranowski, L. B., "Degasification and Dehydration of Hydraulic Fluids and Systems," National Conference on Fluid Power, Chicago, Ill., 20 Oct. 1967.

J. N. Coroneos[1]

Fluid Conditioning for Servo Systems

REFERENCE: Coroneos, J. N., "**Fluid Conditioning for Servo Systems,**" *Hydraulic System Cleanliness, ASTM STP 491*, American Society for Testing and Material, 1971, pp. 29–33.

ABSTRACT: In the design of hydraulic servo system filtration systems, the designer must be aware of the effects of contamination in a servo system. The tolerance level of a system will be affected by the physical characteristics of the servo components. The designer must take into consideration the critical clearances, type of force motor, and whether valve dither is used. When all the component facts are known, the proper filtration system can be designed to provide the required reliability and component life.

KEY WORDS: servovalves, servomechanisms, filtration, contamination, particles, hydraulic equipment, hydraulic fluids, clearances, tolerances (mechanics), silts, agitation, evaluation, tests

In the design of electrohydraulic systems, a major factor in ensuring its success will be a properly designed and maintained filtration system. Without proper attention given to the fluid conditioning, all system components will experience shortened service life. The servo valve itself, in addition to shortened life, will more than likely cause lowered system response and reduced system accuracy. The filtration system must eliminate to an acceptable level, the foreign materials such as metal particles and airborne dirt which may enter or are generated by the hydraulic system itself.

A starting point in the process of designing the filtration system is to determine the critical clearances of the selected servo valve. Since 1 μm is equal to 1×10^{-6} of a meter or approximately 0.00004 in., the critical clearances, therefore, can be related to the micronic filtration rating required for the system.

Typical critical clearances of servo valves follows:

Servo Valve Type	Typical Critical Clearance
Medium pressure sliding plate	0.0008 to 0.001 in. = 20 to 25 μm
High pressure sliding plate	0.0002 to 0.0004 in. = 5 to 10 μm
Flapper nozzle between flapper and nozzle	0.0008 to 0.0020 in. = 20 to 50 μm
Typical servo valve orifice size	0.004 to 0.30 in. = 100 to 7,500 μm
Spool clearance	0.00004 to 0.00016 in. = 1 to 6 μm

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The critical clearances normally decrease as the system requirements progress from single stage medium pressure sliding plate to multistage high pressure spool valves. In order to ensure proper attention to the filtration requirements, an appreciation of the effects of contaminants within a servo system should be understood by the designer.

When contaminants become lodged between the torque motor clearances in the flat plate valve or between the flapper and nozzle in the first of a two stage valve, the total servo system response will be lowered. In the single stage valve the maximum valve flow rate will be decreased due to restricted valve opening. The response time of a two stage servo valve will be reduced since the flow from the first stage determines the speed of response of the second stage spool. Because most servo systems are designed for the normal valve flows and response rates, this type of contamination usually results in lowered system accuracies. This contamination, if allowed to proceed, will result in the single stage valve becoming inoperative at one flow rate and the two stage valve failing at its maximum flow rate in one direction or the other. Sudden and complete failure can occur when a particle large enough to completely block spool or plate motion enters the valve. This happens when the particle is just the proper size to enter the critical clearance between the moving parts. Small particles will pass through the valve, whereas the particles larger than the critical sliding clearance will be prevented from entering between the moving parts.

When servo valves contain internal filters these filters may become contaminated at different rates. This is especially noticeable in valves with parallel filters in spool end cavities. When filter differential contamination rate occurs, an increase in the pressure differential between spool ends shifts the spool gradually according to supply pressure changes. This type of valve is pressure sensitive, and the condition will gradually worsen as the filters plug until complete loss of control occurs.

Silting is another condition which can occur when the servo valve is maintained near its null position for a length of time. It is most common in the second stage of spool type servo valves or high pressure sliding plate valves where close tolerances are held to minimize valve leakage. Minute particles are introduced by the fluid leakage between the mating parts, and these close tolerances act as a very fine filter increasing the total valve friction characteristics. Silting increases the valve hysteresis which can greatly reduce system response especially at low amplitude input signals. If for example, the servo valve gain normally is set at 500 psi/mA, a 1-mA signal could produce a net change of 500 psi. The effect of silting can be seen if the friction level on the spool is increased by a force equal to 10 lb. Assuming a $\frac{1}{4}$-in.-diameter spool, a differential pressure equal to 200 psi would be required to overcome this increased frictional force. This would be equal to an input signal in the magnitude of 0.2 mA before any valve response would be seen.

Contaminants within any electrohydraulic servo system can cause increased wear in which degradation of the system occurs over a relatively long term period but at a rate above the normal design life of the components. Particles larger than the critical clearances normally do not cause wear problems since they are too large to pass through the components. Particles substantially smaller than the critical clearances, however, will accelerate the wearing rate of the valve as they strike orifices, nozzles, and flapper surfaces, causing the edges and surfaces to become galled and misshaped. Particles of the approximate size as the critical clearances cause the greatest and fastest wear rate. As they move through the moving members, they act as a lapping compound wearing away the two mating parts. This action increases clearances between the spool or sliding plate and the valve body which increases the leakage rate and wears the metering edges causing lower system response.

On many servo valves dither is required to maintain the system resolution. Resolution is the maximum increment of input current required to produce a change in the valve output flow. Dither is an a-c input current superimposed on the servo valve input. This small amplitude signal maintains spool motion at all times considerably reducing the effects of slip-stick friction. This continuous motion also minimizes the effects of silting which occurs when the system is such that the valve remains near its null position for any length of time. In many servo systems proper fluid filtration can reduce or eliminate dither requirements and still provide the required response rates.

Metal contamination normally is generated within the hydraulic system by moving parts such as hydraulic motors, pumps, valves, and actuators. These particles are normally ferrous and have been shown to be one of the greatest contributors to servo system failures since they are normally heavy, jagged particles that tend to retain their shape. Also many of the single stage flat plate type servo valves are designed to operate with the force or torque motor immersed within the operating fluid. Since these devices normally contain a very strong magnet it is the natural place for these ferrous materials to accumulate, preventing full movement of the torque motor reducing maximum valve opening. System performance is reduced as the amount of contaminants increases until eventually complete failure takes place.

One way to reduce this problem, other than removing the motor from the fluid, is to provide a shield around the torque motor. Normally this is not designed to seal the force motor push rod which would decrease the resolution of the valve but to provide an enclosure to prevent circulating fluid from passing across the torque motor. Because the material is normally ferrous a high efficiency magnet filter ahead of the valve inlet can be used to remove most of the detrimental portion of the contaminants smaller than the designed filtration.

Once the overall system requirements are known, the properly sized servo valve with the required characteristics can be selected. It is then possible to determine the critical clearances and to proceed with the filtration system design.

Starting with the system supply pump, the most common placement of the first system filter would be in the pump suction line. These are normally rated from 10 to 144 μm with the most common being from 74 to 144 to prevent cavitation. The inlet to any pump must not be restricted; therefore, most filters of this type are provided with bypass arrangements to allow fluid to enter the pump in the event the filters become clogged before they are changed. In order to prevent dissolved air from being released from the fluid due to the vacuum in the filter housing, the submerged type units which are serviceable from the exterior of the reservoir are preferred.

Another common placement of filters is in the system return lines. In this location it is possible to remove contaminants that are generated by the system components. This arrangement also protects the pumping equipment once the system is in operation, assuming the pump case drain lines also are interconnected through the filters. It is important, however, to make sure all components can tolerate the increased back pressure as the filter differential pressure increases. For this reason, filters used in the return lines normally are provided with a bypass to prevent damage in the event they become plugged. Since it is usually possible to maintain some nominal back pressure on a system, the filter ratings are normally in the 3 to 25 μm range.

Separate pump return line filters also are commonly used to prevent contaminants from entering the system from the pumping mechanism itself. Again, however, it is normal to use bypass filters to prevent damage to the pumping equipment in case of a clogged element. Because normal return flow from pumping equipment does not exceed 10 percent of the rated output, it is possible to install filters with 3 to 10 μm in these lines at reasonable cost.

Main line pressure filters directly before the servo valve are the surest protection that can be provided. It should be selected with its micronic rating compatible with the smallest critical clearance of the component it is to protect. The system should be designed to locate this filter with minimum line length between it and the servo valve to decrease the possibility of contaminants being introduced into the servo valve during the initial startup. These contaminants take the form of loose dirt, chips, and scale which may be present in the original installation. Maintenance of long pipe runs also can cause problems if reasonable care is not used during repair or replacement. In the case of the servo valves with small critical clearances, it is advisable to use filters without bypass relief valves to prevent contaminants from entering the system if the filter is allowed to reach its clogged condition, and to avoid filter bypass under cold starting conditions due to the larger pressure drop caused by increased fluid viscosity.

In many servo systems where down time is critical, it is advisable to use dual filter arrangements in the pressure lines. Each filter should be capable of full system flow with manual or automatic valving arrangements to allow changeover and element replacement during operation. Most filters today can be provided with both visual and electrical indication for use in determining filter change requirements. In all nonbypass filters a relief valve arrangement or filter elements designed to withstand full system pressure without rupturing should be used to prevent contaminants from entering the system. Many filters also can be provided with magnetic rods to help collect ferrous materials smaller than the micronic rating.

The hydraulic reservoir should be designed in a manner to prevent the introduction of unfiltered air during operation. All air entering the reservoir should pass through a minimum of 10-μm air breather. By preventing unnecessary foreign material from entering the reservoir filter element life can be greatly increased and failure rate of the servo equipment reduced.

Selection of the filters with properly selected micronic ratings, dirt holding capacities, and differential pressure drop indicators together with their proper placement will prevent many of the hydraulic failures seen in today's servo valve system. The fluid conditioning system should be a major consideration in designing any hydraulic system to ensure the life expectancy required by the industrial user.

J. P. Duncan[1]

Improve System Contamination Control and Increase System Efficiency

REFERENCE: Duncan, J. P., "**Improve System Contamination Control and Increase System Efficiency,**" *Hydraulic System Cleanliness, ASTM STP 491,* American Society for Testing and Materials, 1971, pp. 34–38.

ABSTRACT: This paper presents a manufacturer's view of the critical areas regarding contamination control based on our experience with both hydraulic components and systems. Fluid contamination is a leading contributor to reduced system efficiency, and its control should be given consideration during system design. Contamination sources and the acceptable contamination levels are presented in addition to the types of contamination normally encountered. The ratings and location of filters in the system are discussed, and a brief outline for a maintenance program is included at the end of the paper.

KEY WORDS: hydraulic equipment, maintenance, decontamination, hydraulic fluids, oil filters, contaminants, cleaning, efficiency, evaluation, particle size

This paper is presented from the viewpoint of a manufacturer of hydraulic components. It is intended to point up some of the areas that are critical regarding contamination control. These comments are based on our experience with both individual components and total systems. Most manufacturers and users will agree that contamination in hydraulic systems should be avoided, but our problem is what degree of contamination can be tolerated (no system will ever be or need to be free of all contamination) and how to effectively control contamination. As we have striven to gain system efficiency we have learned that it is necessary to employ a sound program for system contamination control.

Importance of System Contamination Control

Hydraulics are being put to a wide range of uses, varying from applications requiring sophisticated and complex controls to systems that are very basic in function. Demands are increasing for components with improved reliability, efficiency, and lower maintenance costs. The efficiency of a component, in particular a pump, is critical to the overall system performance whether it is used on a Lunar module or your neighborhood garbage truck. Degradation

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of performance results in time and money lost and in certain applications threat to human life.

Hydraulic pumps and controls are devices requiring close tolerances, controlled wear surfaces, accurate finishes, and an *adequate* supply of *clean hydraulic fluid* with the proper characteristics. The lubrication of moving parts in a hydraulic pump or motor is a prime function of the hydraulic fluid, and fluids that are contaminated will not provide satisfactory lubrication with the result that critical parts in the system will deteriorate causing an inefficient and malfunctioning system. *Fluid contamination* is a leading contributor to reduced efficiency, excessive down time, and increased maintenance costs in hydraulic systems. The dependence of the system on the hydraulic fluid has increased greatly in the last few years as demands for small, high horsepower packages, at low cost, have resulted in operating at higher speeds and pressures, in turn producing more friction requiring better lubrication.

Sources of Contamination

System contamination control should be given the same considerations as component selection and maintenance to help ensure that a hydraulic system will provide the desired performance and reliability. System contamination control means very simply, to be sure the system is clean when assembled and to be sure it stays clean. There are three major sources of contamination that must be considered.

1. Contamination at assembly due to the condition of parts and components and contamination introduced from sources such as rags, welding, threading, etc.

While it is not necessary to maintain a "clean room" assembly operation, some basic precautions will help avoid premature system malfunctions.

(*a*) Keep all openings into the hydraulic system adequately covered.

(*b*) Take steps to ensure that pipe and fittings are free from rust, scale, and dirt.

(*c*) Remove burrs from parts prior to assembly.

2. Contamination which is introduced into the system after assembly from the environment or human sources.

The human element can be a source of many contamination problems due to a lack of education regarding the system (not usually a lack of formal education). The following are common findings.

(*a*) Fluid added to a system which is of unknown origin and condition.

(*b*) Filter elements removed from filters entirely to reduce the frequency of maintenance.

(*c*) Filter elements "cleaned" in solvent which is heavily contaminated.

3. Contamination generated internally due to wear of a component or a malfunction generating metal particles or fluid breakdown due to excessive temperature or improper maintenance.

Acceptable Levels of Contamination

The level of contamination control required varies with the application, and each system should be evaluated using its specific requirements. There is some correlation between operating pressure and the allowable contamination level; however, each application should be reviewed from an overall standpoint. It is generally true that a 2000-psi system can tolerate more contamination, therefore wear, than a 5000-psi system before appreciable efficiency losses are noted; however, if a servo control is used in this 2000-psi system, a high level of cleanliness is necessary to ensure proper valve operation. Servo components (valves, motors, etc.) require 3 to 5-μm nominal filtration with an overall system contamination level not more than a Class 6 [National Aerospace Standard (NAS) 1638, see Fig. II]. Other components generally should have 10-μm nominal filtration with a system contamination level not over a class 8 (NAS 1638). Filtration systems larger than 10-μm nominal ratings can be used with discretion but do not provide the optimum in system cleanliness for most hydraulic components.

Filter Ratings

It is recommended that the micronic rating of the system filter elements be selected based on the finest filtration required. If there is a servo valve in the circuit then the filters should be sized at 3 to 5 μm. Even though only a small percentage of the total system flow may pass through this valve during a given time (flow rate), the entire volume of system fluid (capacity) will eventually pass through it during operation. If a small capacity 3-μm filter were installed for this valve and a 10-μm filter used for the remainder of the system, the 3-μm filter would actually become the prime system filter which would result in excessive maintenance costs for the system as the small filter could not handle the large volume of contaminants from 10 to 3 μm.

Critical Period

The hydraulic system sees a critical period regarding contamination during the first few hours of operation. There has been a relatively large amount of contamination put into the system as it was assembled due to scale on metal, small burrs being chipped off, residue from assembly functions such as welding and pipe threading, dirty materials, and numerable other sources. These contaminants will normally pass through the filtration system during the first few hours of operation and be trapped by the filter elements; therefore, it is necessary to replace all filter elements after the first few hours of system operation.

Types of Contamination

There are many different types and classes of contamination that can seriously damage hydraulic components. We normally visualize the large particle type when discussing contamination as we can see most of these pieces either with the naked eye or low power magnification. These particles are too large to pass through the clearances in the components and can become wedged between parts resulting in galling, excessive heat, and usually a basket case failure. A more subtle problem is caused by the contaminants under 25 μm which require high magnification to detect. These particles tend to embed themselves into soft or porous materials forming an abrasive surface which steadily wears away moving parts. The end result of this wear will be a steady loss of performance until an unacceptable level is reached and premature repair or replacement of parts or components is necessary. Chemical contamination of the system always should be considered. This can range from an accidental mixture of a foreign substance (such as water) to the hydraulic fluid to improper maintenance of the hydraulic fluid itself. Certain chemical combinations that have been formed in hydraulic systems which attacked the base material of critical parts. Some hydraulic fluids should not be mixed even though their functional characteristics are similar because of possible acid formation. A source of contamination that is often given too little consideration is the operating environment of the equipment. An environment involving heavily polluted air may require a sealed system. The selection of air breathers for open type systems is extremely important in a contaminated environment. It would be of little value to install a 10-μm fluid filtration system but use a 100-μm air breather in a coal mine where abrasive dust is present.

Placement of Filters

The placement of filters and their design is, of course, up to the discretion of the equipment manufacturer; however, there are certain areas that always should be given careful consideration to ensure contamination control and prevent component damage. Suction strainers are a risk and should be used with caution. These devices must be installed in the inlet line causing an increase in the work load of the pump at a critical point. It is generally not possible to place strainers where they can be conveniently serviced so that the strainers plug up causing an excessive pressure drop in the inlet line resulting in cavitation and probable pump damage due to a lack of fluid. It is more desirable to establish a system to control the reservoir cleanliness and to monitor the fluid cleanliness before it is put into the system. Reservoirs should be designed with contamination control in mind so that the accidental entrance of foreign material is less likely to occur. Locating access covers somewhere other than the top of the reservoir is recommended. The selection of filter flow capacity should be done with the knowledge that as the filter element becomes contaminated, its surface openings are reduced resulting in increased pressure drop. Premature bypassing of the filter or excessive pressure drop through the filter negates an otherwise sound filtration system.

It is desirable to filter the drain oil from all pumps and motors in a system to protect the system from contamination generated from the pump or motor due to heavy wear or a malfunction. In most instances this contamination washes out with the drain oil rather than with the main system fluid and can be readily removed with drain line filtration. This can be usually accomplished with low capacity filters or by using an existing filter, providing the resulting case pressure does not exceed the pump or motor capability.

Maintenance Program

System contamination control programs are never complete unless adequate maintenance is performed during the life of the equipment. Filter elements are made to deteriorate (become contaminated); therefore, they must be replaced on a regular basis. Fluids deteriorate due to thermal and stress cycles, and need replacement on a scheduled basis. The items are considered necessary for establishing a sound maintenance program.

1. Monitor the hydraulic fluid before it enters the system as well as during the life of the system on a regulated basis.

(*a*) Check contamination level by millipore patch and particle count (Reference NAS 1638).

(*b*) Check chemical composition.

(*c*) Check viscosity index.

2. Regularly replace all filter elements including air breathers, if applicable.
3. Keep adequate records of the maintenance performed and the results.

E. C. Fitch, Jr.[1]

Requirements for an Effective Program in Fluid Contamination Control

REFERENCE: Fitch, E. C., Jr., "**Requirements for an Effective Program in Fluid Contamination Control,**" *Hydraulic System Cleanliness, ASTM STP 491,* American Society for Testing and Materials, 1971, pp. 39–49.

ABSTRACT: Contamination control in a hydraulic system means that the filtration equipment of a system has established a fluid contamination level which is within the contaminant tolerance specifications of the hydraulic components. Such a control condition is not beyond the realm of practicality and must be achieved if hydraulic systems are to function in an optimal manner. Sufficient technology has been developed to permit the specification of the requirements for achieving, maintaining, and appraising contamination control conditions.

This paper reviews the present status of the various factors which are involved in achieving contamination control conditions. A general discussion is presented of such details as sample bottle cleaning, fluid sampling methods, fluid contamination analysis, component tolerance profiles, and filtration performance specifications.

KEY WORDS: hydraulic equipment, hydraulic fluids, filtration, tolerances (mechanics), cleaning, maintenance, contaminants, concentration (composition), particle size distribution, gravimetric analysis, cleaning

The purpose of this paper is to review the requirements for establishing contamination control in hydraulic systems and to present a method for achieving a control condition. The basic requirement for establishing contamination control is simple—the contamination level of the fluid must be less than the contaminant tolerance of the operating components. In practice, the main problem is knowing what conditions should be specified and how to physically implement the system to obtain the conditions.

It should be recognized that the contaminant sensitivity of the operating components must dictate the maximum levels of contamination which can be tolerated in a given hydraulic system. A subtle fact is that these maximum levels are not the same for all hydraulic systems even though the same components may be used. The contaminant tolerance of components depends upon such factors as operating speed, temperature, and pressure as well as the hydraulic fluid. In addition, the requirements regarding component life and

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reliability are important in establishing the maximum contamination level of a system.

Once the maximum contamination level of a system has been defined, the selection of a system filter is of paramount importance. The filter not only must ensure that the contamination level of the system will be maintained below the tolerance level of the components but also must exhibit sufficient capacity to provide a reasonable operating life. In a properly designed system, the life of a filter will depend almost entirely upon the rate of contaminant ingression.

Techniques are currently available for establishing the contamination tolerance level of components and for appraising the ability of a filter to maintain a prescribed contamination level in a system. However, if the established limits of the components and the capability of the filters are not expressed in terms which can be compared with the contamination level of the operating system, contamination control is a meaningless concept.

The method presented in this paper was developed at Oklahoma State University and has been employed successfully to establish contamination control in operating hydraulic systems. The method correlates all control factors in a manner which can be interpreted easily and quickly by the hydraulics engineer.

Particulate Contamination Chart

The basis of the contamination control method reported in this paper is the particulate contamination chart shown in Fig. 1. The chart was developed to give an added dimension (gravimetric level) to cumulative particle size distributions of hydraulic system fluid. The particulate contamination chart is a log-log^2 graph (a graph having a logarithmic ordinant (log y) and an abscissa of (log x)^2) which contains superimposed lines of constant gravimetric levels. The gravimetric lines were derived on the premise that the ratio of the contaminant specific gravity to the contaminant shape factor is equal to one. This assumption has been shown to be quite valid, since the average density and the shape factor of particulate matter found in hydraulic systems will both range between 2.5 and 3.5. The log-log^2 model proposed by Cole [*1*][2] in 1966 has been widely adapted throughout the fluid power industry and provides the best method to date for linearizing cumulative particle size distributions from hydraulic systems.

The particulate contamination chart was designed in such a manner that a distribution drawn on the chart will exhibit a gravimetric level corresponding to the value of the gravimetric line with which it is tangent. The actual distribution is identified uniquely and rigorously by the extrapolated number of particles per milliliter in the distribution greater than 1 μm and its gravimetric

[2] The italic numbers in brackets refer to the list of references appended to this paper.

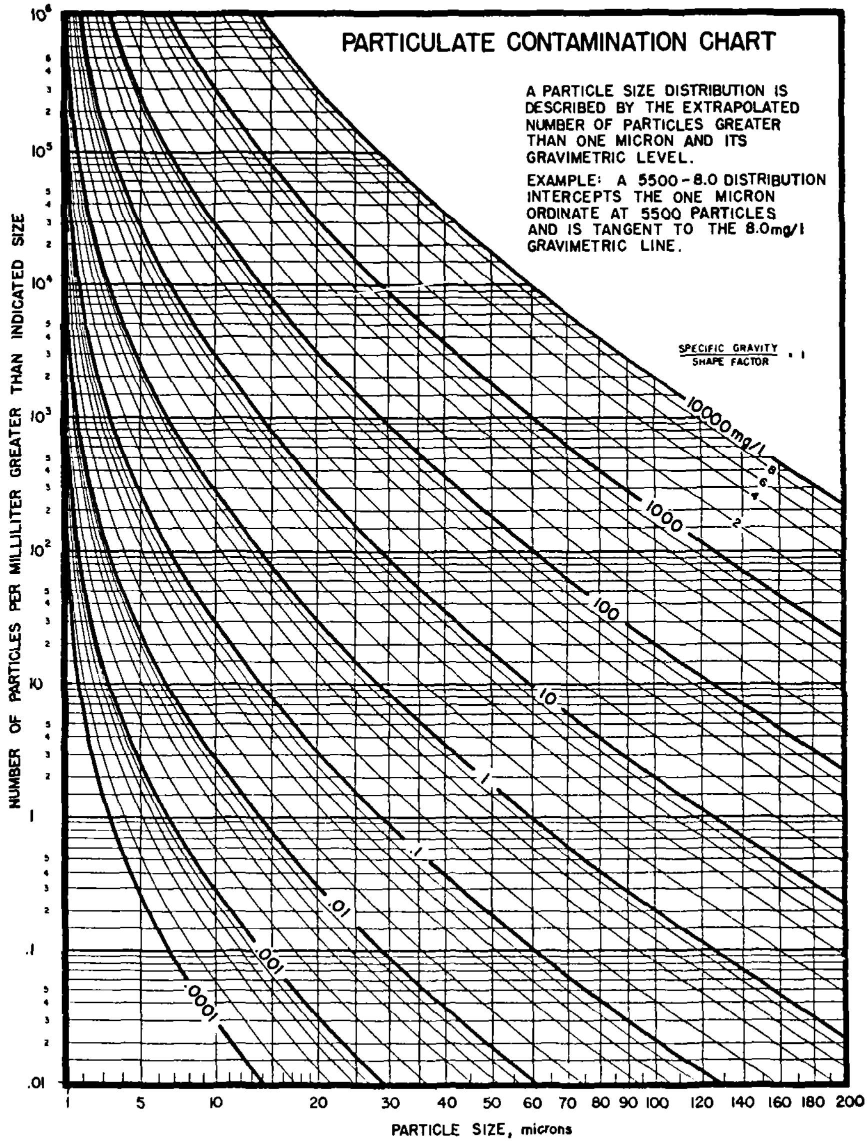

FIG. 1—*Particulate contamination chart.*

level. For example, a 9500–2.0 distribution shown in Fig. 2 statistically contains 9500 particles per milliliter greater than 1 μm and exhibits a gravimetric level of 2.0 mg/liter.

The accuracy of the chart in predicting the gravimetric level of a system fluid has been shown to depend almost entirely upon the amount of deviation of the actual particle size distribution from the extrapolated straight line

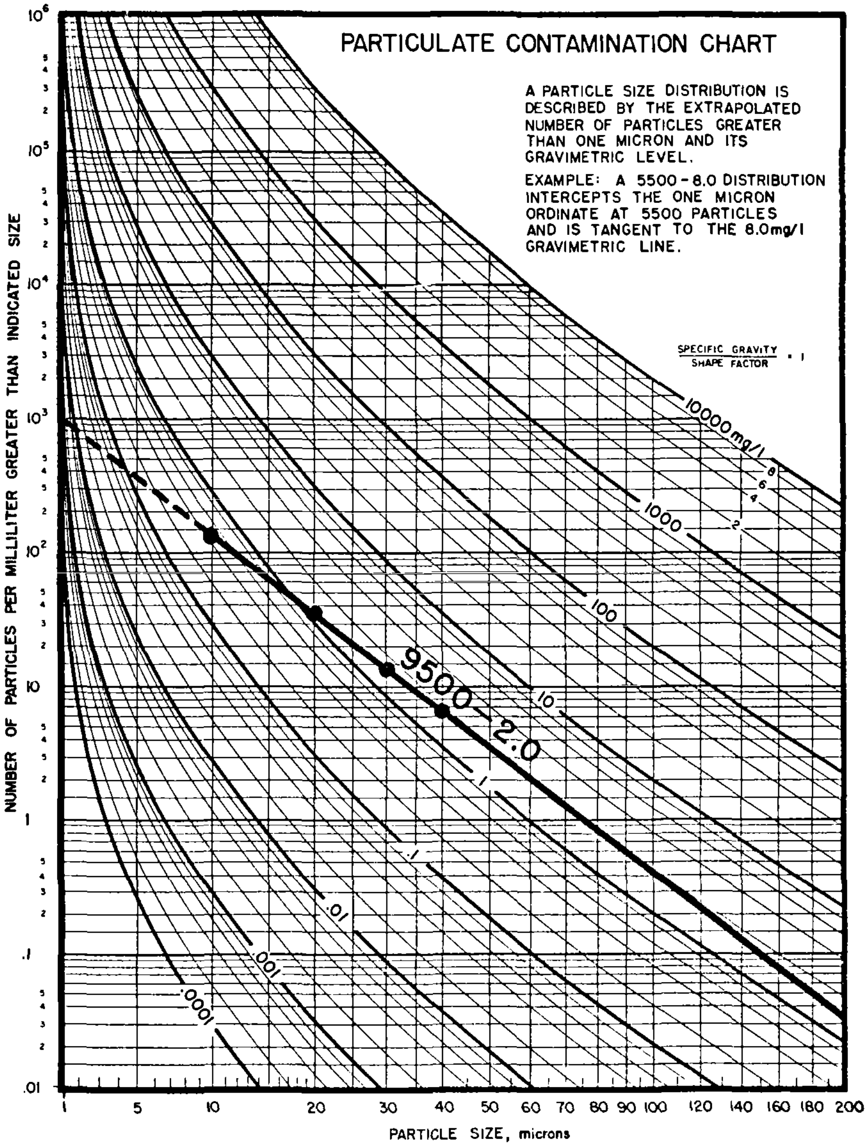

FIG. 2—*A 9500-2.0 distribution.*

distribution. For example, the gravimetric level of a fluid which is based upon the particle counts greater than 10 μm will not be accurate if the fluid contains a preponderance of particles (significantly more than indicated by a straight line extrapolation) below 10 μm. Such conditions can prevail in hydraulic systems containing old oil and where the system filter was not capable of controlling the build-up of fine particles. In such cases, a comparison of the actual gravimetric level with the gravimetric level from the chart is important in the detection and quantitative appraisement of fine particle build-up.

The use of automatic particle counters for obtaining distribution data has been found very acceptable in most contamination control work. Recent studies have shown remarkable agreement between particle counts obtained optically and with properly calibrated automatic particle counters. These same studies also have verified quantitatively the values associated with the gravimetric levels on the chart.

Contamination Level Requirements

The maximum contamination level which can be permitted to exist in a hydraulic system depends entirely upon the contaminant sensitivity of the individual components. Although control valves having small clearances and fluid passages can place severe limitations upon the size and number of particles in the fluid, in many industrial systems it is the pump that usually establishes the limits of the complete distribution. For example, in high pressure systems, the pump for volumetric efficiency reasons must exhibit very small clearances yet have elements moving at extremely high velocities. Such a combination of wear factors creates excruciating conditions which must be recognized and considered in order to achieve an acceptable pump performance, life, and reliability.

If a program of contamination control is to be pursued effectively, the contaminant limitations of the pump must be determined and expressed in a form which is interpreted and applied easily. The unique characteristics of the particulate contamination chart offer such a method because it can display acceptable particle size distribution regions for any operating conditions or component.

To establish acceptable regions for particle size distributions, the pump or other sensitive components needs to be subjected to special contaminant tolerance level tests. The purpose of these tests is to determine what exposure in terms of particle numbers and sizes will cause a specific performance deterioration in a given period of time. Such information can be extrapolated to reflect a maximum particle size distribution necessary to ensure a given service life for the component.

The tolerance level tests for pumps are conducted under full operating conditions of speed, pressure, and temperature. The oil to be used in the actual system also is used as the test fluid. Except for the duty cycle of the machine, an attempt should be made to simulate the various conditions associated with the application.

The contaminant tolerance level test for a pump is divided into two parts: (1) the size sensitivity test and (2) the gravimetric sensitivity test. The size sensitivity is defined as the particle size above which would promote fast, positive deterioration in the performance of the component. The quantity or gravimetric sensitivity of a component is defined as the maximum concentration of cut-off contaminant which does not cause degradation of performance. Cut-off contaminant is a particular test dust in which all particle sizes above the size sensitivity value have been removed. Such contaminant characterizes the influence of a specific filter in the system.

A fluid component's sensitivity to the size of contaminant can be established by subjecting the component to various 5-μm size ranges of contaminant under normal operating conditions of speed, pressure, flow, and temperature. A component such as a pump normally is subjected to a gravimetric level of each 5-μm size range contaminant to produce an accelerated effect upon the component. When the size sensitivity value is reached, flow degradation is pronounced and positive.

Once the micrometer cut-off size has been determined, various concentrations of contaminant below the cut-off size are added to the same component to establish the gravimetric level limitation of the component. The results of a typical contaminant tolerance level test on a hydraulic pump are presented in Fig. 3.

The data from a contaminant tolerance level test can be interpreted in terms of a contaminant tolerance profile which reflects operating time. The profile is derived by extrapolating the test degradation time to a specified operational time and adjusting the contamination level accordingly. An extrapolated 1000-h profile line has proved to be acceptable for defining an ideal contamination level and 333-h profile has been used to establish the minimum requirements for a filter to protect the component. The tolerance profile shown in Fig. 4 represents the operating restrictions for the pump presented in Fig. 3. Any contamination level having a particle size distribution which is below the 333-h profile would be considered acceptable but not ideal for maintaining the desired optimality of the pump.

Filter Performance

In order to implement a contamination control program, the capability of filter elements must be expressed in terms which can be directly related to the requirements of a system. In other words, the performance of a filter

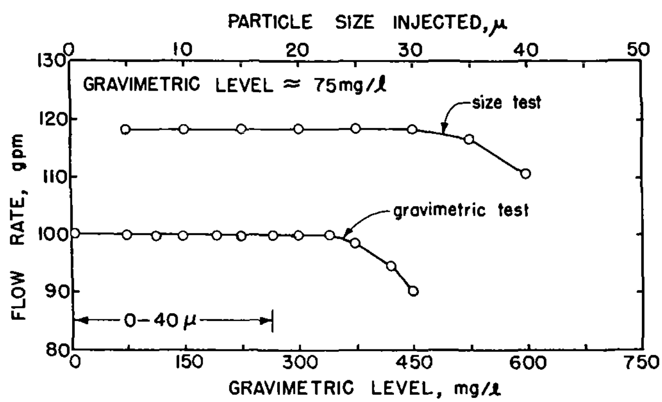

FIG. 3—*Typical results of contaminant level test.*

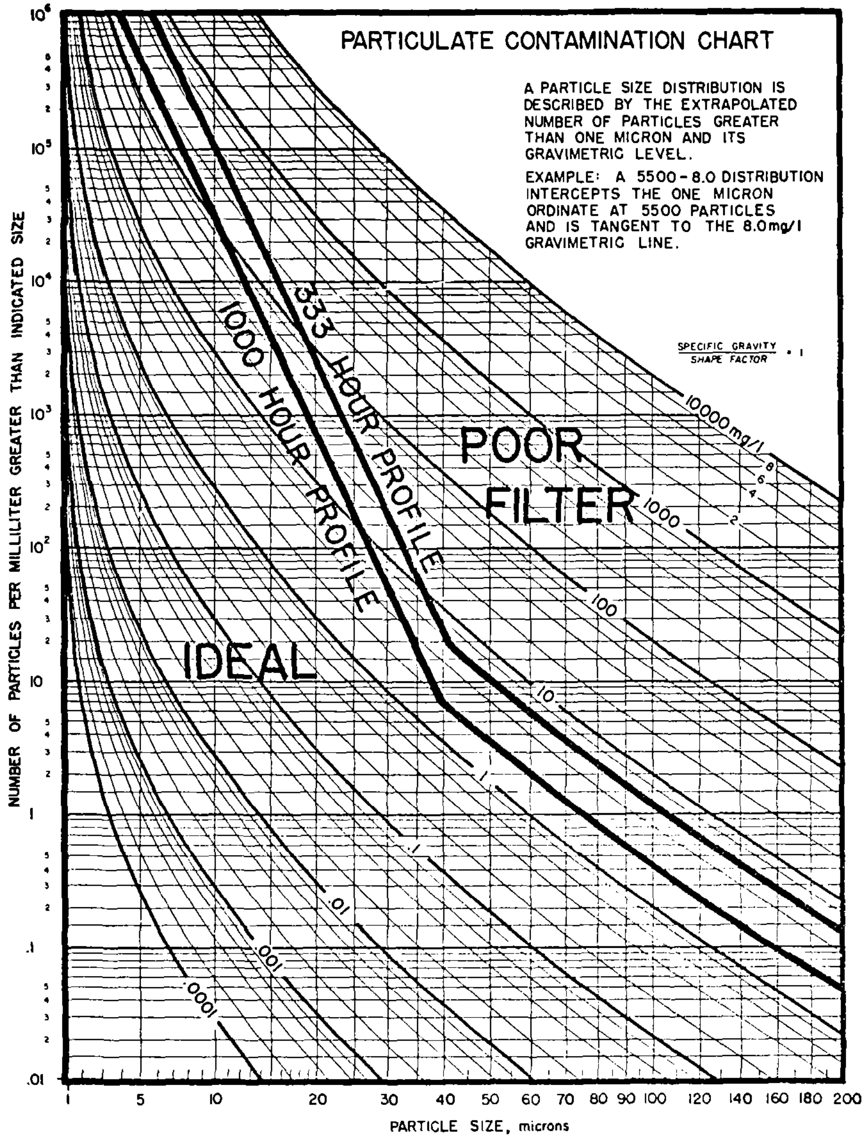

FIG. 4—*Pump contaminant tolerance profile.*

must be described in such a way that the user will know what contamination level will be maintained in his system. This means, of course, that the conventional micrometer ratings used for filters are not adequate for specifying the performance characteristics of elements. A proper rating should reveal the capability of an element to maintain a given particle size distribution in a fluid system.

Several methods have been proposed to establish and rate the performance of a filter on the basis of what it is capable of accomplishing in a system. The method which approaches the conditions of an actual system closest is called the multipass test. In this test, fluid is circulated through the test filter at rated flow while a contaminant slurry (a-c fine test dust) is continuously introduced into the test system. Fluid samples are extracted periodically to evaluate filter performance. The contaminant slurry is added until the desired differential pressure across the element is obtained.

The fluid samples are analyzed to determine their particle size distributions. The distributions provide a direct means of evaluating the capability of an element throughout its entire useful life. If the element's medium exhibits improvement in efficiency when contaminant is added, the distributions will be lower for each sampling period. If the element is initially stable (distributions are all the same) and eventually "dumps," the final samples will show a significant degradation in their particle size distributions.

A filter element is rated on the basis of its worst distribution during the entire test. There are many filter elements on the market today that are classified as "dumpers." They are constructed in such a way that a small differential pressure across the media will cause structural deformation and allow much of the contaminant collected to be released in the system. The multipass test exposes these elements, and the rating system will reflect their detrimental behavior.

The value of a filter element rating is based upon the worst particle size distribution found in the fluid samples. The distribution is identified by the extrapolated number of particles per milliliter in the distribution greater than 1 μm and the gravimetric level of the distribution. For example, consider the filter distributions shown in Fig. 5. The element is a "dumper" and received a rating of 30,000-30.

In addition to establishing the filtration performance rating of an element, the multipass test also provides the contaminant capacity of the test element. Thus, a method is available for appraising what particle size distribution an element can maintain in a system as well as the useful life of the element relative to another element.

Conclusions

The contaminant tolerance profile for the pump of a hydraulic system generally establishes the tolerance profile of the entire system. As shown in Fig. 6, filter distributions above the system tolerance profile are not satisfactory. A filter distribution below the profile provides adequate protection for the components and establishes a control mode.

The contamination control method presented in this paper has general application. By the use of the particulate contamination chart, a method is available to rate filters, describe the contamination conditions of an operating system, and represent the tolerance of system components with respect to contaminant size and quantity. The need for contamination control in

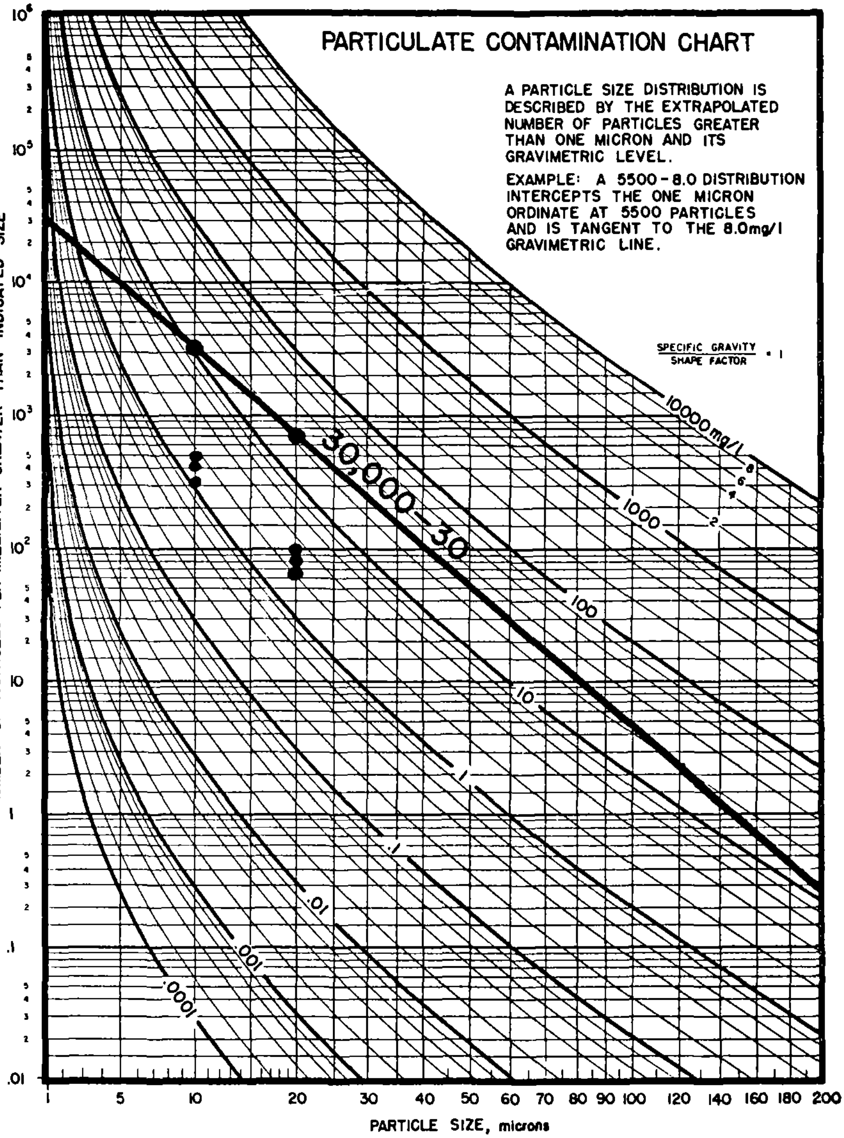

FIG. 5—*Filter performance rating.*

hydraulic systems is great, and the details of the method presented in this paper already are being incorporated in new component specifications.

The work highlighted in this paper represents the results of an intensive study at Oklahoma State University. Appreciation is extended to the sponsoring members of the Basic Fluid Power Research Program and the U.S. Army (MERDC) for providing the funds and establishing the goals for this work.

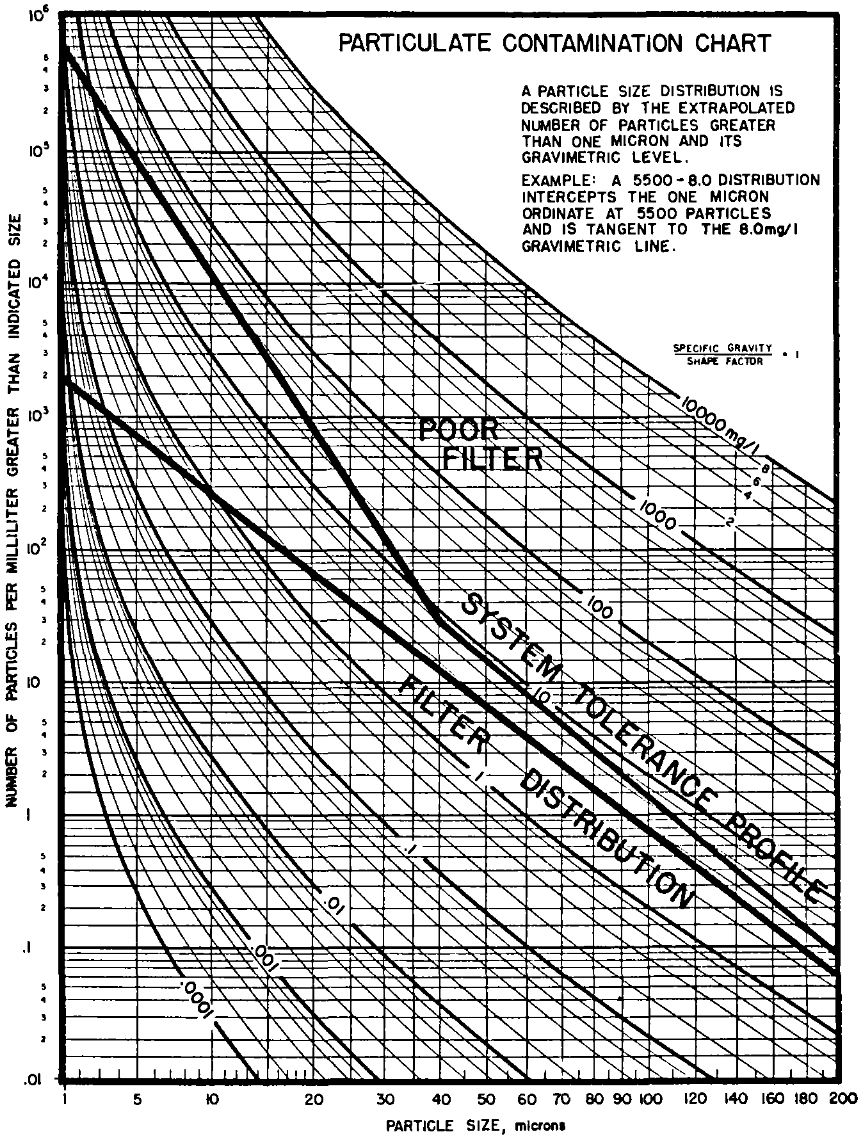

FIG. 6—*Contamination control conditions.*

References

[1] Cole, F. W., "Particle Count Rationalization," American Association on Contamination Control, 1966.

[2] Fitch, E. C., "A New and Fundamental Criterion for Specifying the Cleanliness Levels of Fluids for Industrial and Aerospace Utilization," *Liquid-Borne Particle Metrology,* Annals of the New York Academy of Sciences, Vol. 158, Art. 3, 1969, pp. 601–611.

[3] Fitch, E. C., "Correlation of Hydraulic Component Contaminant Tolerances with Filtration Capabilities," Paper 69-DE-44, American Society of Mechanical Engineers, May 1969.

[4] Contamination Control, Report 69-1, Basic Fluid Power Research Program, Oklahoma State University, Stillwater, Okla., July 1969.
[5] Fitch, E. C., "Hydraulic Filtration and Component Life Correlation," Paper 690604 Society of Automatic Engineers Farm, Construction and Industrial Machinery Meeting, Milwaukee, Wis., Sept. 1969.
[6] Fitch, E. C., "Measuring Contaminant Tolerances in Terms Compatible with Filtration Specifications," National Conference on Fluid Power, Chicago, Ill., Oct. 1969.

E. A. Kirnbauer[1]

Contribution of Hydraulic Fluids to System Contamination

REFERENCE: Kirnbauer, E. A., "**Contribution of Hydraulic Fluids to System Contamination,**" *Hydraulic System Cleanliness, ASTM STP 491*, American Society for Testing and Materials, 1971, pp. 50–68.

ABSTRACT: In the continuing investigation of causes of contamination in hydraulic systems, two types of contaminants attributable to hydraulic oils have been observed. The first is the reaction of some hydraulic fluids with water and the forming of precipitates. The second is the inability of some hydraulic oils as delivered to the customers to be filterable. Since this phenomenon is not consistent with all the oils meeting general categories of specifications, more needs to be learned about why some oils generate this type of contamination while others do not.

The test used to differentiate between the (2) types of fluid contaminants is described, and typical data is presented for petroleum based fluids, including single grade and multigrade motor oils, automatic transmission fluids, and hydraulic fluids. Photographs of some of the unusually shaped contaminants are included. The author suggests a test method which will allow the oil manufacturer and oil users to screen oils to eliminate those which may have undesirable characteristics. The author concludes with a request that the oil manufacturers and oil users work together to learn more about the cause of this phenomenon and its elimination.

KEY WORDS: hydraulic fluids, contamination, water, precipitates, filtration, lubricating oils, oil filters, additives, plugging, clearances, tests

With the increased sophistication of industrial and mobile equipment hydraulic systems, contamination control is becoming of considerable importance as a factor in the proper operation and frequency of maintenance of hydraulic systems.

As a result of this trend a substantial amount of work has been and presently is being done in hydraulic system contamination, including detection of its sources, techniques for analyzing and eliminating contamination, and methods for determining contamination tolerance levels of hydraulic system components.

[1] Corporate consultant, contamination, Pall Corporation, Glen Cove, L. I., N. Y. 11542.

The sources of contamination in hydraulic systems, in the past, have been generally classified as follows:

1. System generated.
2. Environmental.
3. Built-in contamination.

This paper covers observations we have made concerning petroleum base hydraulic fluids as a potential source for "built-in" contamination, and raises the possibility of a fourth class:

4. Reaction products where contamination is generated by reaction with the hydraulic fluid.

For the purpose of this discussion, the fluids used in industrial and mobile hydraulic systems are classified as follows:

1. Hydraulic petroleum base fluids, especially designed for use in hydraulic systems.
2. Automotive type lube oils used as hydraulic fluids.
3. Automotive type automatic transmission fluids used as hydraulic fluids.

It should be noted that automotive type lube oils and automatic transmission fluids are used frequently in the hydraulic systems of mobile equipment. Water-oil emulsion and synthetic hydraulic fluids were not considered in this study.

We have seen evidence of hydraulic system problems which appear to be caused by contaminants in or generated by the hydraulic fluid. These have occurred in both mobile and industrial systems which in one extreme case caused all of the filters of the hydraulic systems, including the coarse suction strainer, to become plugged. It is for this reason that we undertook this study.

Review of the data presented in this paper indicates that the contamination levels of the oils "as received" (as determined by clogging of a laboratory membrane when filtering the test sample and microscopic examination of the contaminant) vary substantially depending on the type of fluid and its source. Also, when adding small quantities of water, certain oils form emulsions or precipitates, which in some cases can be separated from the oil by filtering through a membrane.

The effect of water on the filterability and stability of hydraulic oils was considered important because water so often is found as a contaminant in both industrial and mobile hydraulic systems. Also water has been the suspected cause of certain field problems in hydraulic systems.

Except for some preliminary discussion with fluid suppliers and lubrication consultants, we have not performed any in-depth investigation regarding the nature and constituents of these contaminants. We have heard several opinions regarding the possible cause of this phenomenon including the following:

(*a*) Clogging of the filter membrane is caused by partial retention of portions of the additives not in solution such as viscosity improvers and detergent-dispersant additives.

(*b*) Interaction between additives resulting in filterable polymers.

(*c*) Membrane clogging is caused by random contaminants in those oils which are not manufactured and packaged under clean conditions.

The data presented in this paper are preliminary, relating to semiquantitative estimation of the total amount of contaminant. We feel that sharing our observations made to date will be beneficial to those who contemplate further investigation of this type of fluid contamination, and to those who wish to include fluid cleanliness requirements as part of fluid specifications when selecting a fluid for a more sophisticated hydraulic system with a known contamination tolerance (or contamination sensitivity).

Test Method Used for Assessing the Contamination Level of the Hydraulic Fluid Test Samples

Test Fixture

A test fixture per Fig. 1 was prepared. One liter of the fluid sample to be tested was placed into the container and pressurized by air to 15 psi at room temperature. The amount (cm^3) of fluid filtered prior to clogging a membrane with an area of 3.87 cm^2 was recorded. In addition to pressure testing, tests were performed using vacuum (per Fig. 1).

The membranes used for test were of two pore sizes and two types of materials:

(*a*) Epoxy impregnated inorganic fibers 3-μm absolute (also used as filter material).

(*b*) Cellulose acetate nitrate laboratory type filters, 5-μm grade.

The filterability data are reported in terms of milliliters of test fluid filtered per square centimeter membrane area at 15-psi differential pressure.

$$\text{filterability} = \frac{V}{A} = \frac{\text{cm}^3 \text{ oil to plug membrane}}{3.87 \text{ cm}^2}$$

for example: 985 cm^3 of oil passed through the membrane without plugging, the factor F = 254+.

Microscopic Examination

Part of the test sample was filtered through a laboratory membrane (0.45-μm pore size), and the particles retained on the membranes were examined microscopically.

Test Specimens

The hydraulic fluid specimens tested are summarized in Table 1. The hydraulic fluid samples were tested with and without the addition of 1 percent distilled water. Sources for the hydraulic fluid samples included a large storage vessel, 55-gal drums, and 1-qt containers which were procured from local gas stations.

TABLE 1—*Preliminary data obtained.*

Filterability Factor[a] of Oils from Various Manufacturers (pressure filtration tests)

Fluid Type	Sample No.	Filterability Factor	
		Without Water, %	With 1% Water
10W-30 motor oils	0	37.5	0
	I	32.4	58.2
	II	26.0	107.2
	III	22.0	31.0
	IV	18.0	47.8
	V	23.0	26.0
	VI	23.0	2.6
	VII	39.0	10.1
10W motor oils	X	254+	...
	Y	32.4	51.8
30 motor oils	A	6.45	6.45
	B	254+	254+
Automatic transmission fluids Suffix "A"—Type "A"	0	254+	...
	A	196.0	210.0
	B	89.0	120.3
	C	47.8	43.8
	D	18.0	37.8
	E	12.9	3.3
	F	10.3	10.3
	G	6.45	33.5
Hydraulic fluids	A	254+	254+
	B	254+	254+

[a] The filterability factor is the volume of oil in cm^3 which can be filtered through a 3-μm absolute filter disk with 1-cm^2 effective area before reaching 15-psi differential pressure.

Data Obtained on Various Hydraulic Fluid Test Specimens

Filterability Data

The data obtained are summarized in Tables 1, 2, and 3. Table 1 shows the filterability factors when using a 3-μm filter disk (inorganic fiber membrane) and 15-psi pressure.

Table 2 shows variations of test results due to change to cellulose acetate nitrate membranes and change to vacuum filtration.

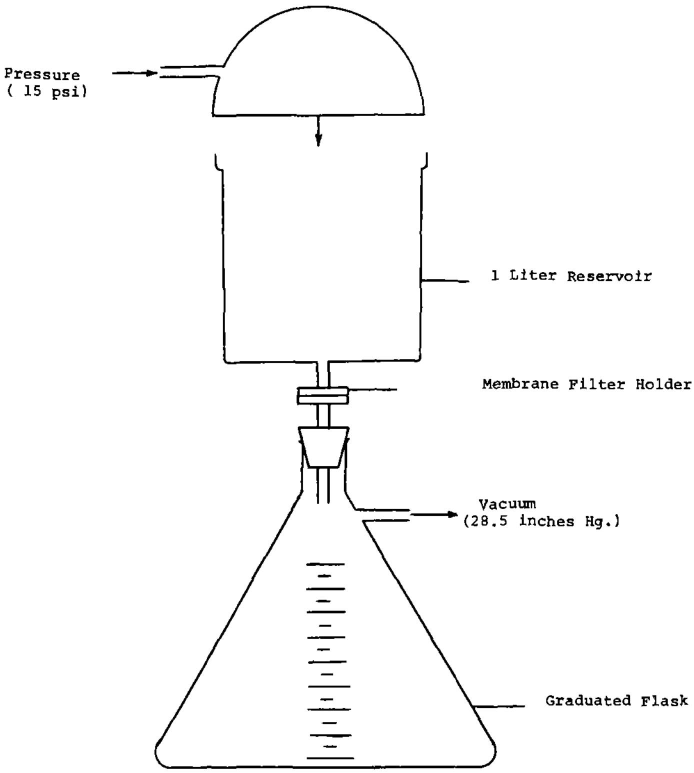

FIG. 1—*Test fixture.*

TABLE 2—*Comparison of the effect of pressure versus vacuum filtration using two types of membranes.*

Fluid Type	Pressure Test (15 psi) Membrane A	Vacuum Test (28.5-in. mercury) Membrane B
10W30 motor oil	22	7.7
	23	20.6
	18	15.5
	37	43
ATF	196	206
	47.8	35.9
	89	15.2
Hydraulic fluids	254+	254+

NOTE—Membrane A: 3-μm absolute pore size disk inorganic fiber membrane. Membrane B: 5-μm rated disk cellulose nitrate laboratory membrane.

Table 3 shows data from a particular fluid from one supplier. The samples were obtained from a large storage vessel, a 55-gal drum and from quart containers procured at local gas stations.

TABLE 3—*10W30 oil from one supplier (used as hydraulic fluid) pressure test with membrane A.*

Source	Filterability Factor, without water added
Storage vessel	23
55-gal drum	23
Quart containers	23

Reproducibility of Data

An insufficient amount of tests have been performed for establishing the reproducibility of the test method. However, most of the data of repeated runs showed less than ±10 percent variation.

Additional Filterability Data

Several filtration tests were performed with the following variations in testing:

1. Filtration at elevated temperature.
2. Exposure of the sample to ultrasonic energy prior to testing.
3. Agitation of the sample in a blender prior to testing.

There was no significant change in the filterability factor of the test samples.

Numerous tests were performed by passing the test samples which showed poor filterability factors through a 3-μm absolute system filter prior to performing the filterability test.

In all cases the filterability factor after filtration was 254+ (that is, no clogging of the test membrane occurred).

Visual and Microscopic Examination of the Test Samples

Figures 2–6 show photographs of some of the test samples prior to and after addition and 24-h exposure to 1 percent water. In addition, some of the contaminants were photographed and are also depicted in the photomicrographs in Figs. 2–6. As can be seen, the contaminant on those photomicrographs contains particle sizes up to 200 μm in size.

Discussion of Data Obtained

The data strongly indicated that certain of the fluids tested appear to be very clean while others appear to be a significant contributor to hydraulic system contamination. The latter ones could possibly cause improper operation of a hydraulic system for the following reasons:

1. Clogging of small orifices and clearances in hydraulic system components.
2. Premature clogging of system filters resulting in filter bypass and subsequent loss of effectiveness of the filter as a system protector.

These two potential problems can be best illustrated as follows:

Possible Effect on Small System Orifices and Clearances

Table 4 shows a summary of typical critical clearances of fluid system components.

TABLE 4—*Typical critical clearances fluid system components.*

Item	Typical Clearance μm	Typical Clearance In.
Gear pump (pressure loaded)		
Gear to side plate	½ to 5	0.000,02 to 0.000,2
Gear tip to case	½ to 5	0.000,02 to 0.000,2
Vane pump		
Tip of vane	½ to 5[a]	0.000,02 to 0.000,04
Sides of vane	5 to 13	0.000,2 to 0.000,5
Piston pump		
Piston to bore (R)[b]	5 to 40	0.000,2 to 0.001,5
Valve plate to cylinder	½ to 5	0.000,02 to 0.000,2
Servo valve		
Orifice	130 to 450	0.005 to 0.018
Flapper wall	18 to 63	0.000,7 to 0.002,5
Spool sleeve (R)[b]	1 to 4	0.000,05 to 0.000,15
Control valve		
Orifice	130 to 10,000	0.005 to 0.40
Spool sleeve (R)[b]	1 to 23	0.000,05 to 0.000,90
Disk type	½ to 1[a]	0.000,5 to 0.010
Poppet type	13 to 40	0.000,5 to 0.001,5
Actuators	50 to 250	0.002 to 0.010
Hydrostatic bearings	1 to 25	0.000,05 to 0.001
Antifriction bearings	½[a]	0.000,02
Side bearings	½[a]	0.000,02

[a] Estimate for thin lubricant film.
[b] Radial clearance.

Reference: *Machine Design*, May 1967.

Comparing the radial spool sleeve clearance of a servo valve (1 to 4 μm) or a control valve (1 to 23 μm) with the particle size obtained in some of the test samples shown in Figs. 2 and 5, it becomes obvious that these particles in larger quantities conceivably could effect performance of the valve, particularly with regards to valve silting and stiction.

In addition, if one examines the emulsions or precipitates generated in some automotive lube oils by the presence of water (most likely due to the dispersant and detergent additives), one can foresee problems of settling in low velocity areas which could result in partial clogging of the heat exchanger when using this type oil in a hydraulic system.

Possible Effect of Contaminant on Premature System Filter Clogging

1. We have seen cases of premature filter clogging because of an accumulation of substances on the filter element surface which can be best described as slimy materials. This, by the way, is not necessarily a function of the filter pore size although filter clogging may take longer as the filter pore size increases. However, we have seen cases where even 100-μm suction strainers clogged because of contaminant generated in the hydraulic fluid in the presence of water.

2. The data indicated that in general the 10W30 motor oils appeared to show higher contaminant levels (as indicated by the filterability factor) than the fluids specifically designed for use in hydraulic systems, while the automatic transmission fluids range from good to poor when using the filterability factor as a criterion. The limited testing on single viscosity material indicates similar results.

3. When comparing the data in Table 2, there appears to be a reasonably good correlation between data obtained by pressure testing with Membrane A (filter medium) and vacuum testing with Membrane B (laboratory membrane). This would indicate that the vacuum test using a standard membrane filter would be worthwhile to investigate for use in a proposed standard filterability test procedure (as will be discussed later).

4. The effect of water appears to be more substantial on some of the automotive lube oils tested, possibly due to precipitates formed by detergent-dispersant additives.

5. The data presented in Table 3 indicates that the mode of packaging did not seem to affect the filterability factor of the particular oil tested.

Conclusions and Recommendations

From the above the following can be concluded:

1. Water contamination will have a particle generating effect in some of the fluids tested.

2. Some of the fluids tested are poorly filterable in the "as-received" conditions even without adding water.

Therefore, it appears advisable to investigate what is causing clogging of the filter membranes when testing some of the as-received oils. Also, the forming of precipitates in the presence of water in oil, in many cases, may make this oil less desirable for use as a hydraulic system fluid.

In order to test this parameter, development of a standard test method seems advisable. The method I envision is a filterability test similar to that outlined in this paper which should be performed with and without 1 percent water contamination. Once developed and validated, the filterability test should be considered a parameter for the selection of hydraulic fluids. In addition, it is recommended that long-term storage of hydraulic fluid should be evaluated from a particle generation point of view.

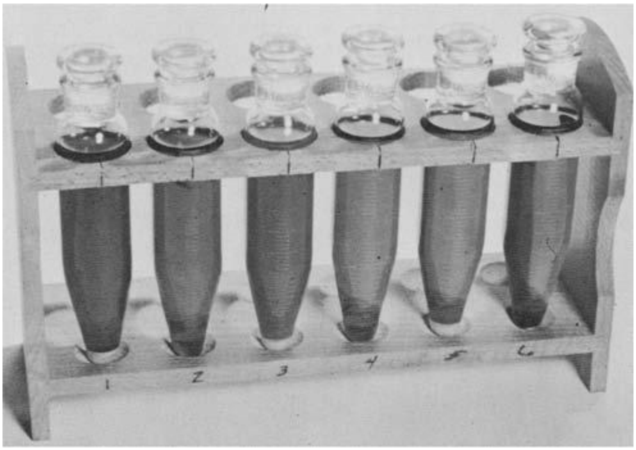

FIG. 2a—*ATF without water—2, 4, 6; ATF with 1 percent water—1, 3, 5.*

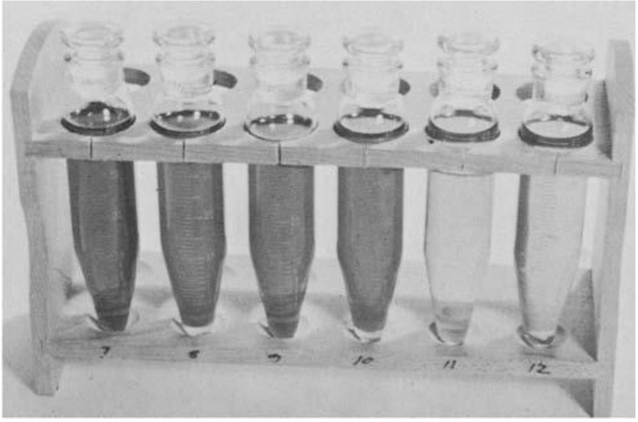

FIG. 2b—*ATF without water—7, 9; ARF with 1 percent water—8, 10; 10W-30 oil without water—11; 10W-30 with 1 percent water—12.*

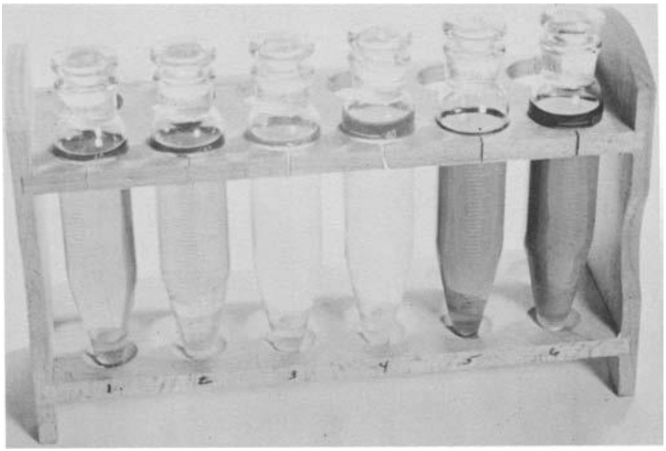

FIG. 2c—*10W-30 oil without water—1, 3, 5; 10W-30 oil with 1 percent water—2, 4, 6.*

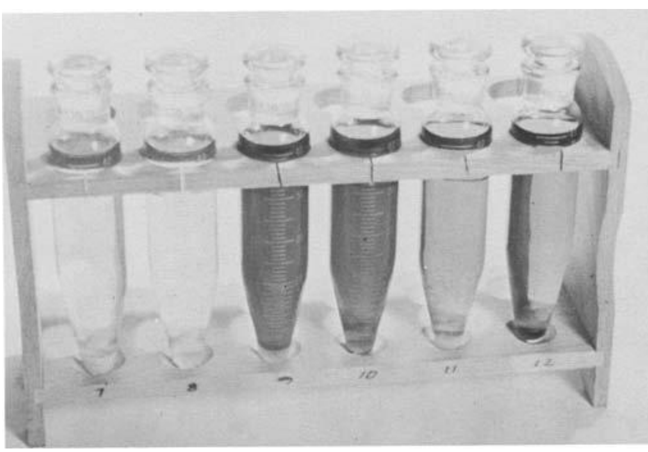

FIG. 2d—*10W-30 oil without water—8, 10, 12; 10W-30 oil with 1 percent water—7, 9, 11.*

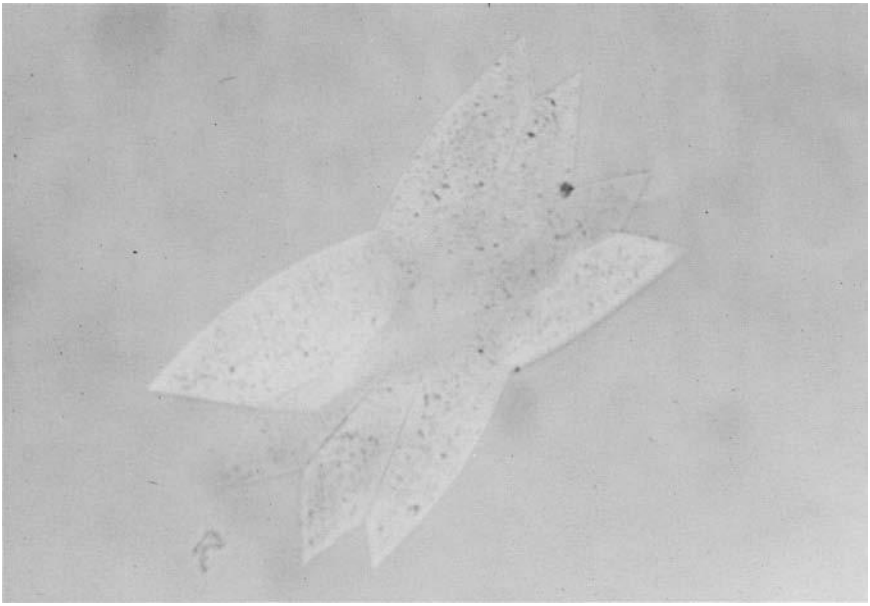

FIG. 3a—10W-30 oil. Photographed at ×200 magnification using polarized light, slightly uncrossed polars (85 deg). Particle longest dimension 100 μm.

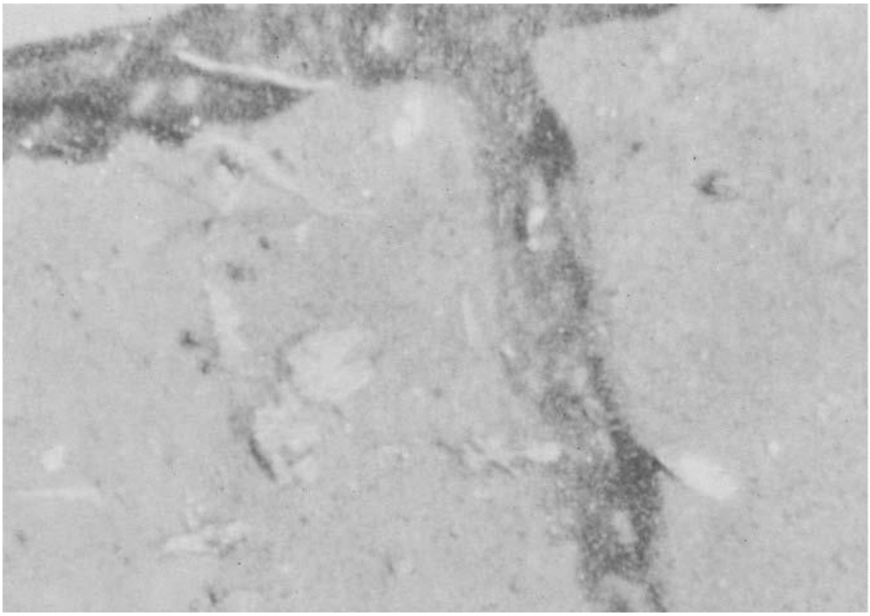

FIG. 3b—30 oil. Photographed at ×20 magnification using bright field light. Largest particles approximately 100 μm.

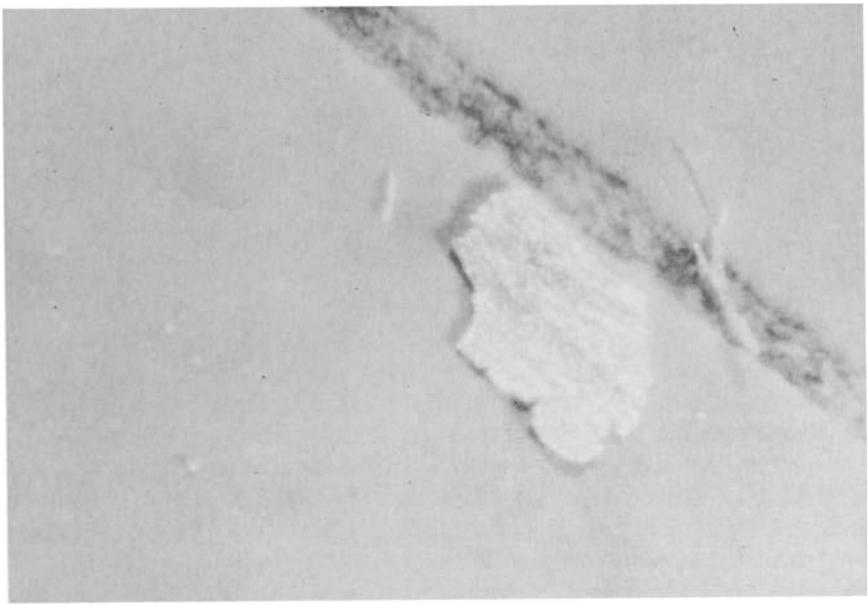

FIG. 3c—*10W-30 oil without water. Photographed at ×8 magnification using bright field light. Particles longest dimension approximately 350 μm.*

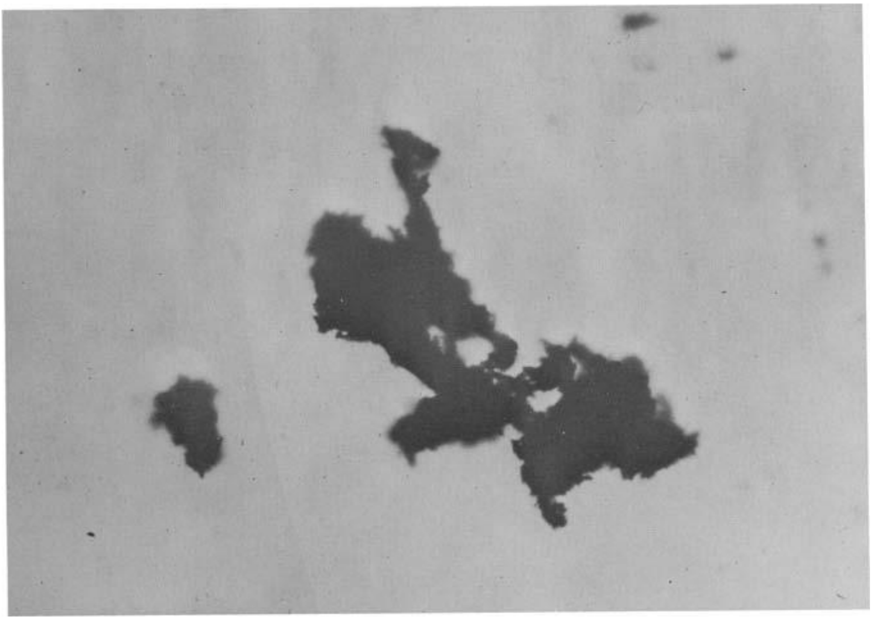

FIG. 3d—*10W-30 oil without water. Photographed at ×50 magnification using polarized light, slightly uncrossed polars (85 deg). Largest particle longest dimension approximately 30 μm.*

FIG. 4*a*—*10W-30 oil with 1 percent water. Photographed at* $\times 5$ *magnification using bright field light.*

FIG. 4*b*—*10W-30 oil with 1 percent water. Photographed at* $\times 8$ *magnification using bright field light. Analysis membrane shows a slimy deposit.*

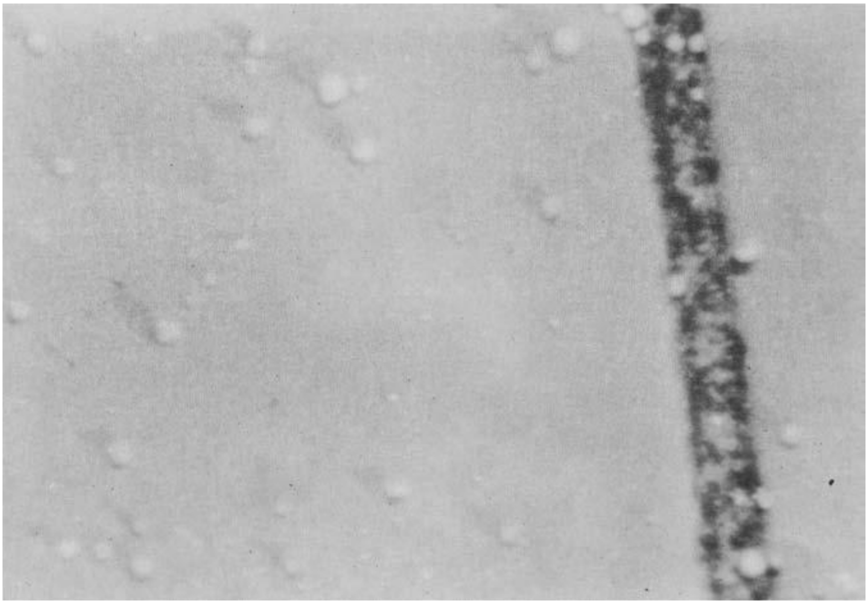

FIG. 4c—*10W-30 oil with 1 percent water. Photographed at* $\times$*20 magnification using bright field light. Average particle diameter approximately 50* μ*m.*

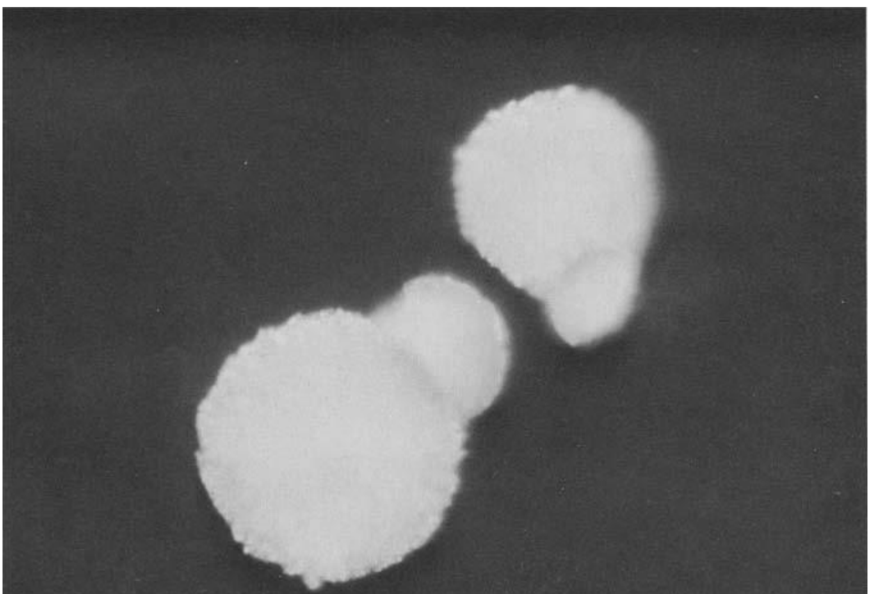

FIG. 4d—*10W-30 oil with 1 percent water. Photographed at* $\times$*200 magnification using polarized light, slightly uncrossed polars (85 deg). Largest particle longest dimension approximately 50* μ*m.*

FIG. *5a—10W-30 oil with 1 percent water. Photographed at ×200 magnification using polarized light, slightly uncrossed polars (85 deg). Needles approximately 30 to 40 µm long.*

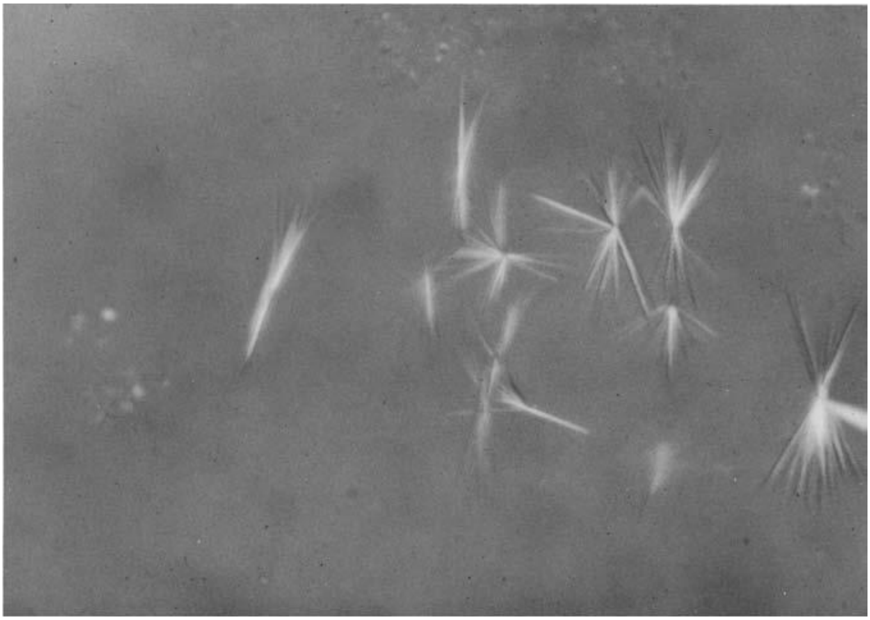

FIG. *5b—30 oil with 1 percent water. Photographed at ×200 magnification using polarized light, slightly uncrossed polars (85 deg). Crystals approximately 50 µm.*

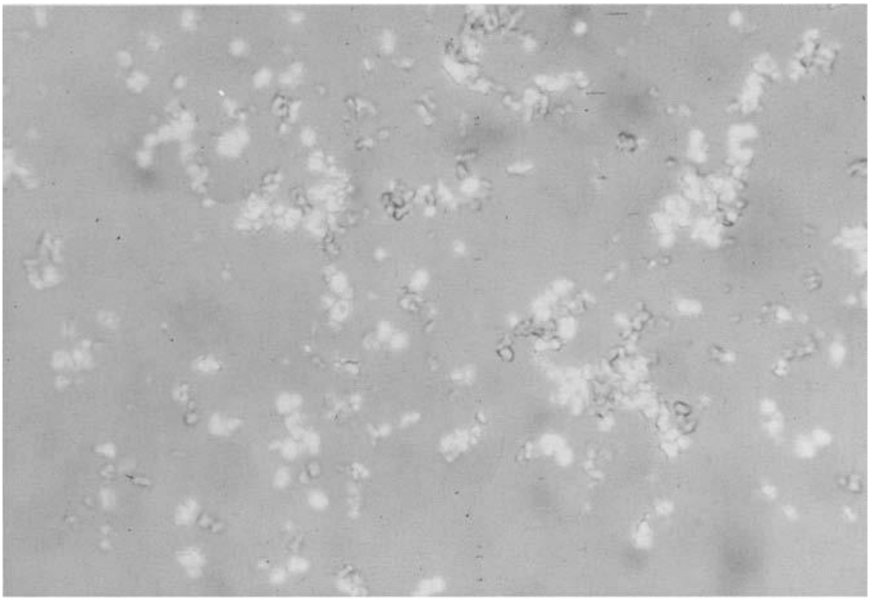

FIG. 5c—*30 oil with 1 percent water. Photographed at × 200 magnification using polarized light, slightly uncrossed polars (85 deg). Average particle dimension is smaller than 5 μm.*

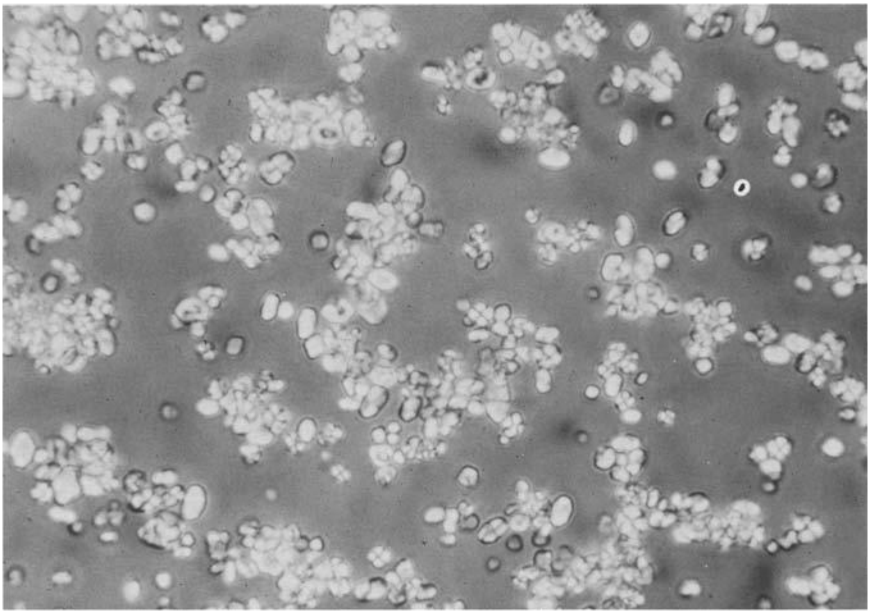

FIG. 5d—*30 oil with 1 percent water. Photographed at ×200 magnification using polarized light, slightly uncrossed polars (85 deg). Average particle dimension is larger than 5 μm.*

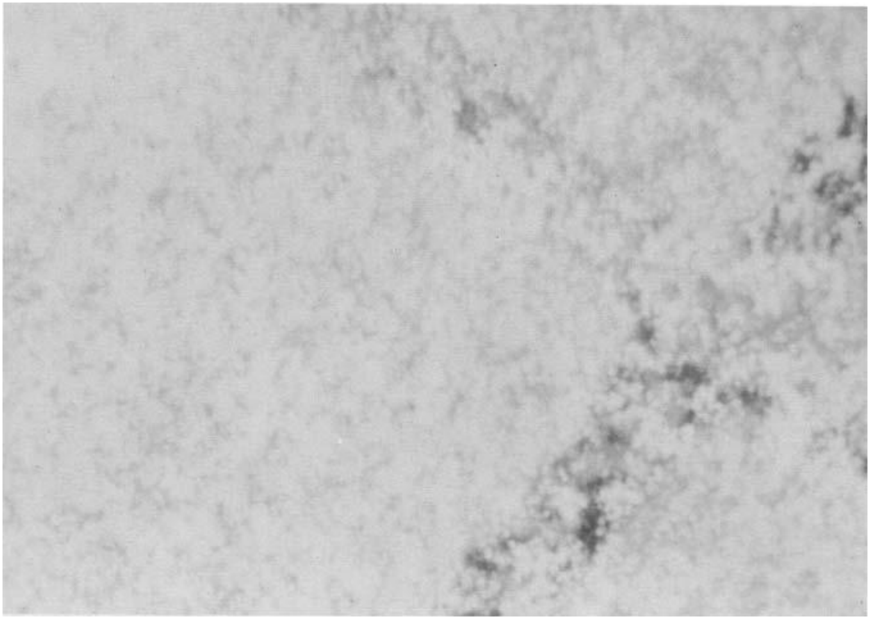

FIG. 6a—*ATF with 1 percent water. Photographed at* $\times 8$ *magnification using bright field light. Black membrane is covered with white deposit.*

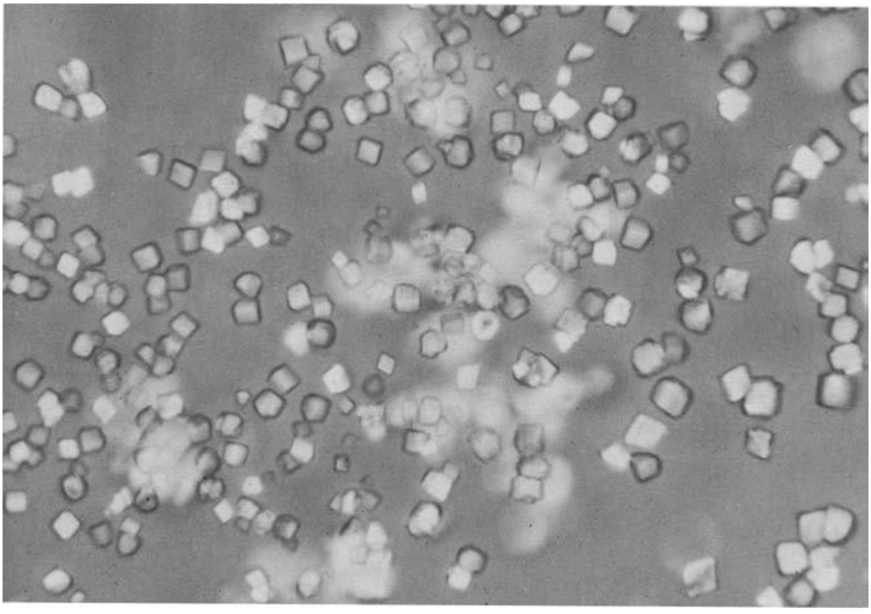

FIG. 6b—*ATF with 1 percent water. Photographed at* $\times 200$ *magnification using polarized light, slightly uncrossed polars (85 deg). Average particle size approximately 5* μm.

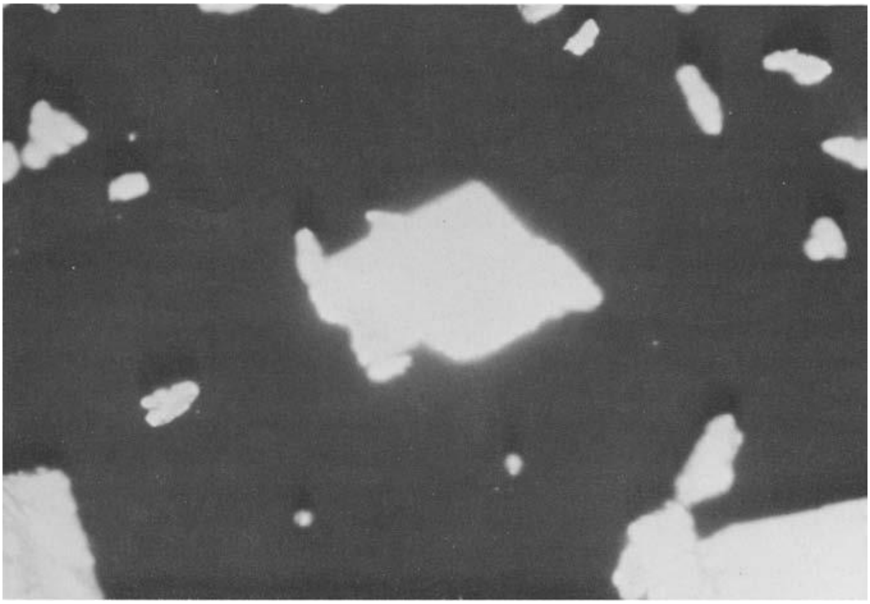

FIG. 6c—*ATF with 1 percent water. Photographed at* $\times 200$ *magnification using polarized light, slightly uncrossed polars (85 deg). Largest particle longest dimension 55 μm.*

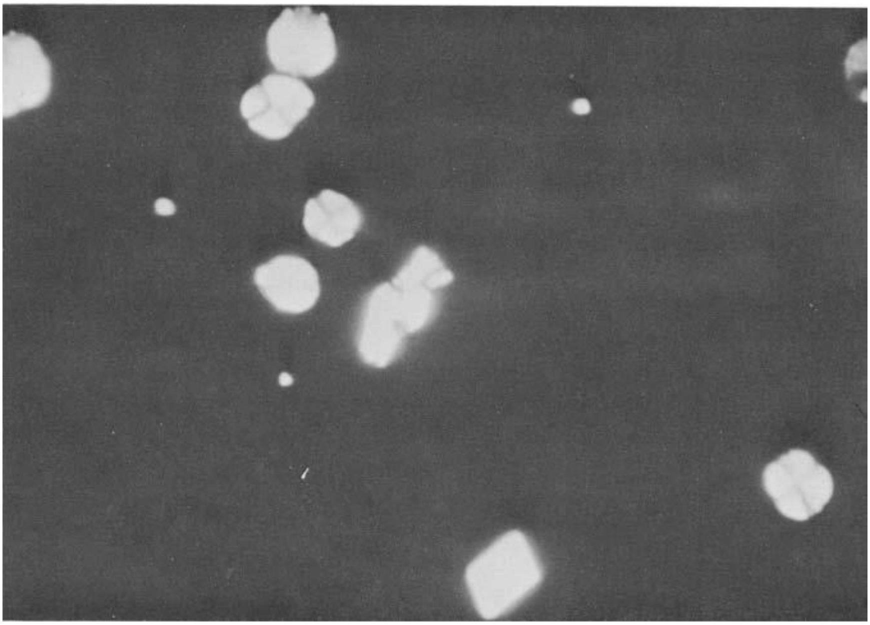

FIG. 6d—*ATF with 1 percent water. Photographed at* $\times 200$ *magnification using polarized light, slightly uncrossed polars (85 deg). Largest particle longest dimension 10 μm.*

Acknowledgment

I would like to thank Robert Pratt (Pall Corporation) for his assistance in developing the data presented and the representatives of several oil companies for technical review of the data pertaining to their particular oil.

In addition, I would like to thank Dick Leslie (Vickers) who has supplied me with confidential data on other oils.

I also want to thank Dr. H. Rylander (University of Texas, Austin, Texas) and Dr. E. Klaus (Pennsylvania State University, University Park, Pennsylvania) for their technical review of the data and helpful suggestions concerning possible causes of the problem.

I want to thank A. Siegelman (Glen Cove, New York) for preparation of the photomicrographs.

It should be noted that the conclusions presented herein are the author's, and this acknowledgment in no way implies the agreement of the listed individuals and companies with the author's conclusion.

D. A. Marlow[1] *and A. Beerbower*[2]

Status Report on the Tech O/F-7 Contamination Methods Program

REFERENCE: Marlow, D. A. and Beerbower, A., "**Status Report on the Tech O/F-7 Contamination Methods Program,**" *Hydraulic System Cleanliness, ASTM STP 491*, American Society for Testing and Materials, 1971, pp. 69–77.

ABSTRACT: Part I, written by D. A. Marlow, concerns the activities of ASTM Committee F-7-C on Contamination. Part II, written by A. Beerbower, concerns the methods that were developed by Technical Division O of Committee D-2 and recently turned over to Division C of Committee F-7. These include ten methods for sampling, three methods for processing samples, and four for analysis of particulates. Plans for further work to complete the coverage of sampling methods for additional situations, and some of the problems related to precision statistics, are described briefly. The new user is urged to avoid using methods more complicated than his situation actually demands.

KEY WORDS: particles, sampling, counting, size determination, precision, contamination, evaluation, tests

PART I *by D. A. Marlow*

Introduction

The subject of Part I is "The Activities of ASTM Committee F-7-01 on Contamination." There are three key points that in essence are applicable to ASTM Committee F-7 and thereby to Division C, F-7-01 on Contamination. These points are:

1. The "scope" of Committee F-7 through which Division C functions.
2. The operating policies and the purposes of Technical Committee F-7.
3. The background of Committee F-7 approach to aerospace industry methods for contamination.

I will begin with Point 1, the Scope of Technical Committee F-7 Aerospace Industry Methods (AIM). Point 1—The promotion of knowledge of aerospace, aircraft, and allied industry materials test methods and techniques and the provision of standards for use in industry through their adoption by,

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or development within, ASTM Committee F-7 and by recommendations to other ASTM technical committees or to other technical organizations.

Documentation, including methods of test, recommended practice, nomenclature, specifications and related technical information developed by this committee and by others with their consent, will be co-ordinated, letter balloted or otherwise promulgated.

Areas of standards developments applicable to this scope, but under the jurisdiction of other ASTM committees or other organizations are excluded from development by this committee unless those other technical bodies do not choose to act directly on the development of specific standards needed by the aerospace, aircraft, and allied industries. In such cases, Committee F-7 may elect to develop, letter ballot, co-ordinate, and promulgate the needed standards.

Before I proceed with Point 2, I would like to note that our committee as it exists today is the oldest sole ASTM aerospace activity. We feel it is also the hardest working, most productive, and efficient activity of its kind.

To date, test methods have been the primary documentation output of Committee F-7 with some work as to nomenclature and recommended practice, and no work on materials specifications. It is expected that this pattern of method promulgation will continue for the projected future. In Key Point 2 certain operating policies of ASTM Committee F-7 and thereby F-7-01, Division C are set forth to illustrate our service to the aerospace industry:

Item (*a*) *Letter Ballot*—To provide a valid aerospace letter ballot as the basis of the industry-wide participation and acceptance of material test method standards.

Item (*b*) *Coordinate*—To provide the coordination services required to find, develop, and process needful and applicable test methods regarding less of source, and prepare same for the letter ballot.

Item (*c*) *Plan*—To plan and schedule the documentation development work so that duplication is avoided, the broadest application possible from each document is realized, and that any interdependency of the documentation is recognized and resolved on a timely basis.

Item (*d*) *Develop*—To develop test methods, recommended practice, and nomenclature. Utilize the work of existing activities where possible and create new documents only where such are required by aerospace industry.

Item (*e*) *Disseminate*—To increase state-of-the-art knowledge through the conducting of Symposia and Panel discussions, by performing data research, and by publication.

Item (*f*) *Compile*—To compile and list the origin of the industry materials standards in existence or being developed regardless of source.

Item (*g*) *Report*—To periodically report to the aerospace industry the schedule and schedule compliance of Committee F-7 and of the other participating or cooperating activities. The report will list material test method documentation, its state of development, the responsible activity, and selected state-of-the-art knowledge.

At this point I would like to make clear, so that there is no misunderstanding, that Committee F-7 has no interest in doing or interfering in what is being done by others. The cooperation of other existing activities is sought wherever and whenever their output is usable. For the most part, Committee F-7 documents will be twofold; test methods that apply to more than one material, and test methods concerning a family of materials, within a given technology. *Contamination* is an example of the former, and *propellants* is an example of the latter. A single material will be of interest only if there is no present activity, and if it is predominantly an Aerospace application.

We note, of course, that an overlap of interest is obvious where the above twofold activities may interface. The only way to curtail duplication of effort in committee work and still provide a practical, economical service is to bring the interdependent activities together. This can be accomplished only when the work is performed in the same family and where master planning is possible. In this way, document output is maximized while conflicts in interest and jurisdiction are minimized.

Now let us examine the purpose of Committee F-7 aerospace industry methods. One purpose of Committee F-7 as previously stated is to create and adopt test methods, recommended practice, and nomenclature so as to provide the industry with a comprehensive family of related and interreferencible document standards. This family of standards are for use as design disclosure and definition documents, as procurement and receiving inspection documents, as research and development and manufacturing documents, as quality assurance documents, and as contract and buy-off documents.

A further purpose is to arrange and develop standards into a building block matrix whereby the required documents can be combined to establish complete control or definition with the absence or minimal need of taking exceptions to the standards. Mr. Beerbower will pointedly illustrate the building block matrix in his presentation. A working example is found in Committee F-7-C contamination methods where the sample procuring, the sample processing, and the sample analysis may be chosen to fit the application of a wide range of materials and end-use requirements by simply stating, for instance, "sample per F 303," "process the sample per F 311, and analyze per F 312." The standards matrix and recommended practice usage of same is a time saver and costly error eliminator.

A most needful purpose of this activity is to conserve time, funds, and manpower through flexibility. This approach brings together interfacing technologies and develops documents that in themselves are as flexible as possible in their application and requirements, and that will fit the matrices or building block concept.

For Key Point 3, the background of our approach to aerospace industry methods shows Committee F-7 functions to fulfill the needs of the aerospace industry. A number of these needs are listed here in the form we know best in F-7-01, Division C; that is, specific directions to produce an answer that will serve the need.

1. Application of a given document to as many materials as is practical.
2. A family of related documents that can be interreferenced and that work together.
3. Documents applicable to a given technology on a timely basis.
4. Documentation applicable to interacting materials.
5. Documentation applicable to interfacing technologies.
6. A documentation matrix system organized to allow quick and accurate choice of required documents.
7. A means of using documentation now in existence, but currently not known of or recognized by the aerospace industry.
8. Increasing the state-of-the-art knowledge.
9. Conserving manpower, calendar time, and funds.
10. Providing a valid aerospace industry letter ballot that ensures industry cognizance and that can be of benefit to other ASTM activities.

PART II *by A. Beerbower*

Early History

By the late 1950's it clearly was established that control of particulate contamination in the fuel was necessary to prevent rapid and disastrous failures of jet aircraft engines. This could be easily demonstrated on test stands, and a realistic level was soon agreed upon, using ASTM Method D 2276-60 T (published for information in 1959). The level was, and still is, defined in terms of milligrams per liter with 1 max as the normal shipping limit. Meanwhile, it became evident that related problems were arising on missiles, and that both the propellant and hydraulic fluid were involved. The propellant specifications tended to follow the jet fuel pattern with 1 to 10 mg/liter, but those on hydraulic fluid took a new turn.

It is evident that the problems of a fuel system have inherent differences from those of a hydraulic system, and that more is involved than the obvious fact that many thousands of gallons of fuel are used while the original few gallons of hydraulic fluid are still circulating. While both systems can fail by clogging control valves, fuel systems more usually fail by plugging nozzles. Hydraulic systems sometimes fail by jamming actuators, but it was the great number and delicacy of the valves in a hydraulic system that led to a new principle of particle size control as well as quantity control. Reasons for this change are shown in Fig. 1. Given a diametrical clearance of the valve piston of 15 μm, the 5-μm particle is essentially harmless. The 45-μm particle filters itself out, but the 15 μm is just right to silt up the clearance. A 200-μm particle can jam between spools or under a needle valve tip.

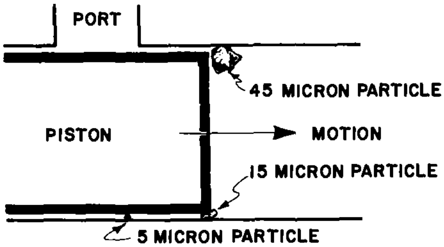

FIG. 1—*Particles in a servo valve.*

Unfortunately, due to the classified status of the missile programs, very little of the data justifying the decision has ever been published, but by 1960 it was customary to specify hydraulic fluids by the laborious particle count rather than the gravimetric method used for fuels. One "justification" was the apparently greater sensitivity, but this is an illusion; ovbiously, use of a larger sample and a better balance builds any degree of sensitivity desired into the gravimetric method.

As experience developed, it became evident that two other particle characteristics were of great importance. These were shape and chemical composition. Fibrous particles had to be counted separately as no "diameter" could be assigned, and they also represented a special problem in that they tend to mat, forming a larger "particle." On encountering a small clearance, this stalls and becomes a "filter" which accumulates ordinary particles until failure is inevitable. Even the 5-μm size participates in this reaction.

The composition of the particles becomes important when one hangs up as in Fig. 1. A metallic particle may deform and so escape, or even cut its way out. A siliceous one may crush due to brittleness, or again cut itself loose on repeated actuation. However, a plastic one will smear and become lodged permanently. The composition of the particles also serves a very important purpose in diagnosing the source of contamination.

The importance of the factors of size, shape, and composition reached back into the propellant technology, and the particle count method has become popular there also.

Tech O Program

Faced with this array of problems, the new Technical Division 0 (formed from Section I of Tech N) undertook a broad program designed to provide methods for all contingencies. This was set up by the chairman, J. L. Botkin, on a "building block" basis so that complicated options such as those in the jet fuel method D 2276 could be avoided. The basic plan consisted of only three steps:

1. Sampling.
2. Processing.
3. Analysis.

However, a great many possibilities had to be recognized in sampling, and the original plans (Figs. 2 and 3) are far from complete. At the time of changeover to Committee F-7, the ten methods shown in Table 1 had been accomplished. These cover a wide spectrum of conditions, and many are applicable to industrial systems. Very few difficulties were encountered in this part of the program, as these were generally formalizations of existing aerospace (National Aeronautics and Space Administration NASA) and U.S. Air Force (USAF) practices.

In the following discussion, it is important to note that all methods were renumbered when transferred from D-2 to F-7 in mid-1970. The new F number is cited first, with the old D number in parentheses.

TABLE 1—*Sampling methods.*

New Number	Old Number	Source of Sample
F 302	D 2388	Containers in field
F 318	D 2407	Air in clean rooms
F 303	D 2429	Components
F 301	D 2437	Noncryogenic system taps
F 304	D 2535	Components with convolutes
F 305	D 2536	Pressure-sensing instruments
F 306	D 2537	Storage vessels
F 309	D 2542	Noncryogenic propellants
F 310	D 2543	Cryogenic fluids
F 308	D 2545	Components or systems by blow down

Processing, strictly speaking, is covered entirely by F 311 (D 2391) for filtering liquid samples. However, as a matter of convenience two methods for characterizing analytical membrane filters were put in this group. The basic one is F 316 (D 2499), by which the pore size (maximum, average, and distribution) may be controlled. The second, F 317 (D 2767), also is related to porosity but measures the liquid flow rate.

The analysis of particulates includes the two basic methods, F 313 (D 2387) for gravimetric analysis and F 312 (D 2390) for sizing and counting particles. In addition, F 314 (D 2430) for identification of contaminants and F 315 (D 2546) for identification of solder and solder flux are used for diagnostic purposes. Each of the first three ran into problems, but all for different reasons.

F 313 hinges on the use of a microbalance for weighing the particulates from 100 cm^3 of fluid. The first description was protested by some balance manufacturers as being too restrictive, so an appeal was made to Committee E-1 for help. After some years of revisions, the description is acceptable, but Committee E-1 probably will continue to work on a better reference for us to use.

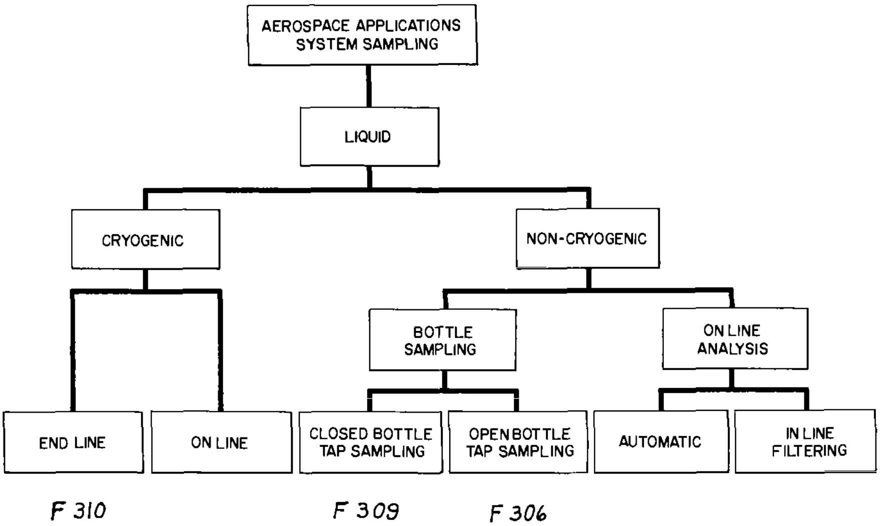

FIG. 2—*Proposed family of liquid sampling methods.*

F 312 was carefully set up to permit the use of either the globe and circle or linear reticule. This proved to be an emotionally charged matter, and is still not resolved completely.

F 314 provides good methods for the scope as stated. However, there is no provision for plastic chips (known to be of special importance), paint chips, or organic materials other than fibers.

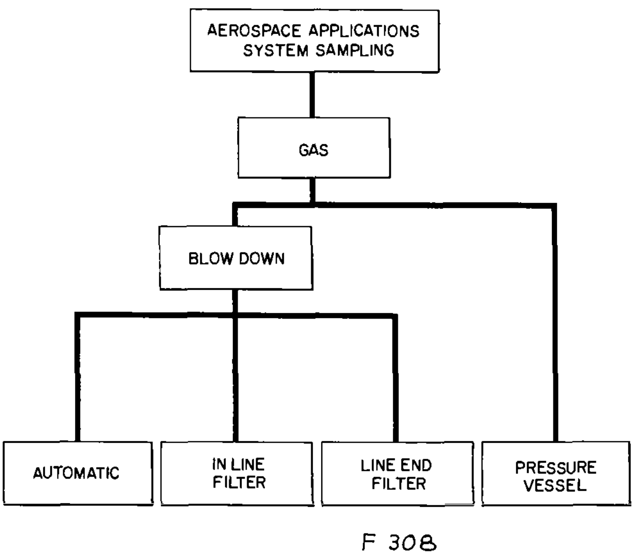

FIG. 3—*Proposed family of gas sampling methods.*

Interaction with Other Groups

Considerable friction arose in 1965 on the matter of interactions, and a Co-ordinating Committee on Contamination was formed by Headquarters to deal with it. Representatives from Committees D-2, F-1 on Electronic Parts, D-19 on Industrial Water, D-22 on Atmospheric Sampling and Analysis, the Society of Automotive Engineers (SAE) and the American Association on Contamination Control (A^2C^2) met three times. The first item on every agenda was an apparent overlap of ASTM's F 318 (D 2407), F 25, and D 2009 methods for air sampling with SAE's Aerospace Recommended Practice 743 (ARP-743). It was agreed eventually that Committee D-22 would attempt to prepare a unified modification of D 2009 and that the other groups would continue as they were until then. Another controversy on the similarity of F 312 (D 2390) and ARP-598 was never resolved, and SAE proceeded to issue ARP-598A the same year that F 312 became a standard method, though the differences are not very evident. The problems proved to be mainly due to poor communication, which the three meetings helped to correct, and no further meetings have been held.

The Federal Test Methods Standards (FTMS) Committee had indicated certain changes desired in D 2390 and D 2391 to permit using these in place of Method 3009.2. The changes were made in F 312 and F 311, but cancellation of the FTMS method is not yet complete. The Institute of Petroleum (IP) has expressed interest in these same methods, but negotiations are far from complete on an ASTM/IP standard.

Precision Statistics

The program is far from complete, as only single laboratory repeatabilities are available, but it is quite evident that the advantage lies with the "gravimetric" over the "sizing and counting particles" philosophy. Table 2 shows the comparison of F 313 (D 2387) and F 312 (D 2390). The former does not follow the building-block scheme as it includes its own processing instructions, so that the difference in precision is probably even greater than that shown. The results should serve to dispel forever the illusion that "seeing is believing." Over ten times the error results from the combined effects of misjudgment of size and failure to count every particle. It is believed that the former is the more important, as the error generated by counting all 14-μm particles as 15 to 25 would be obviously quite significant. The message should be clear: "If the situation does not demand examination of individual particles, gravimetric is best."

Only F 301 (D 2437) has been evaluated for repeatability, and the errors in sampling even by this sophisticated method were bad enough to mask almost completely even those due to F 312. The results had to be expressed in a rather complicated way to be technically correct, but are reduced to common terminology in Table 2 despite some loss of logic. They do *not* say

TABLE 2—*Repeatability statistics.*[a]

Method	F 313 (D 2387)	F 312 (D 2390)	F 301 (D 2437)
Procedure	Gravimetric, %	Sizing and Counting, %	Sampling, %
2500 particles	...	26	80
280 particles	...	34	100
33 particles	...	40	>100
6 particles	...	50	>100
Total (weight average)	3.6	39	~90

[a] All results are expressed in Committee D-2 format, that "duplicate results by the same operator should be considered suspect if they differ by more than this amount."

that such results are useless, but merely that "nit-picking" the difference between (say) 1000 and 2000 particles per 100 cm^3 is ridiculous. Counts of 1000 and 3000 *are* significantly different by F 301 [*1*][3]. However, it is probable that many of the thousands of man hours spent in recleaning systems, oils, etc., were wasted because of faith in statistically *insignificant* results.

Two articles on selecting an allowable contamination level should be cited. Hocutt [*2*] describes the procedure used for the YJ93-GE-3 turbojet hydraulic system, and Huggett [*3*] shows the effect of contamination control in improving the performance of a missile hydraulic system.

References

[*1*] Beerbower, A. and Hadel, J. J., "Evaluation of the Precision of Tap Sampling for Particulate Contamination," Tech O Symposium, June 1967.

[*2*] Hocutt, M. G., "Establishing Hydraulic System Operational Contamination Limits," SAE Preprint 650333, Aerospace Fluid Power Conference, 18–20 May 1965, pp. 227–233.

[*3*] Huggett, H. L., "Servo Valve Internal Leakage as Affected by Contamination," SAE Preprint 650334, Aerospace Fluid Power Conference, 18–20 May 1965, pp. 238–244.

[3] The italic numbers in brackets refer to the list of references appended to this paper.

W. J. Marsh[1]

Filtering—From the Moon to the Mines

REFERENCE: Marsh, W. J., "**Filtering—From the Moon to the Mines,**" *Hydraulic System Cleanliness, ASTM STP 491,* American Society for Testing and Materials, 1971, pp. 78–83.

ABSTRACT: The rapid advances in the level of hydraulic power utilized in underground mining equipment has not found necessary filtering and maintenance techniques keeping pace.

This paper describes methods employed to assure full flow filtration, incorporating a rather drastic departure from tradition in choice of filter opening to optimize life of component. Additionally, problems of adverse environment and fluid handling are described.

KEY WORDS: hydraulic equipment, cleaning, mobile equipment, underground mining, filtration, maintenance

I feel moved to comment on this title, "Filtering—From the Moon to the Mines." Obviously, hydraulic cleanliness is not as critical in mining as space programs. It is, however, at least as demanding in mining as most any other industry. Frankly, the title is for contrast and attention. We need to somewhat counteract the recent legislative "flurries," and the ever present tendency for the press to report the sensational, and the public tending to believe the worst. Sure, there are some bad mines, just as we have all seen bad foundries or bad machine shops. Perhaps this public uplift can be served by a little better description of conditions as they exist in the modern mining industry. They may be at least partially personified by our equipment sophistication.

As this is largely a nonmining group, I thought a very brief explanation of underground procedures would be in order.

If we refer to our general locality, the seams are essentially horizontally bedded. If the seam outcrops, it is entered by digging straight into the hillside establishing a "drift" mine. If the seam does not outcrop, it can be entered, in relatively shallow instances, by an angled entry, becoming a "slope" mine. Deeper seams must be approached, serviced, and extracted through vertical entries, thus, a "shaft" mine.

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Seam heights vary considerably, but generally in a range from 30 in. to about 6½ ft. Also varying considerably are the basic characteristics of the coals which determine its end use and oftentimes the method of mining.

A mining plan common to the Pittsburgh seam displays a series of tunnels or "entries," advancing on a predetermined survey course, a predetermined distance. At planned intervals they are connected by "crosscuts" which serve to assure a supply of fresh air to the advancing areas or "faces."

Vital and necessary support efforts include the above mentioned ventilation (fresh air normally is directed up the center entries and "returns" to the ventilating fan after sweeping the active working places), roof support (which is installing devices to keep the roof rock in place), electrical power distribution, basic haulage systems, water supply and discharge systems, and oftentimes compressed air lines.

People can be best categorized as willing and hard working. Many, however, served their apprenticeship in an equipment era demanding considerably less maintenance activity. I think we can best describe attitudes as not particularly mindful of design limitations.

Material handling is beset by long distances and relatively slow travel speeds. Compounding this is haulage priority of both loaded and empty mine cars. Fluids and lubricants, of course, are in this category. Let me now quickly tie an environmental condition with the mention of fluid movement. The condition to which I refer is just plain dirt. This is not to be confused with dust in finely divided form, which is controlled by a variety of methods. But remember, we are not on a paved floor, or under a fabricated ceiling, nor inside plastered walls. One main point of contaminant entry into hydraulic systems has been the actual transfer of fluid from a container to the mining machine. Other potential points in fluid handling might be from a bulk tank to oil car, bulk tank to drums, and drums to 5-gal containers. These latter points can be corrected by purchasing oil packaged in 5-gal containers—at a decided premium I might add. The chief offender, however, remains the actual entry of fluid into the machine.

Replacement of hoses and hydraulic components during repair functions further establishes prominent means of adding dirt in our systems.

The majority of prime producing equipment today are called "continuous miners." Several early versions [*1*][2] made their appearance, but these and subsequent models have never really earned (literally) the title "continuous." The term "conventional" equipment often is heard. This refers to separate pieces of equipment which respectively cut a relief area (or kerf) in the coal face, drill the coal for placement of explosives, and load the coal after shooting. Shuttle cars are accepted almost universally as the first step of the mine haulage system.

[2] The italic numbers in brackets refer to the list of references appended to this paper.

Today's continuous miner for coal may typically have 500 connected hp. Weight may vary between 35 and 50 tons. Prime energy source is direct electrical for the cutting, but electrohydraulics are vital. Moving from front to rear we find applications in the cutting head elevate and lower, gathering head elevate and lower, and at times the power for gathering arms and conveyor chain is hydraulic. Tramming, or machine movement, is motivated hydraulically and also all rear conveyor movements. It is this basic design of machine we will discuss in this paper.

Early last year a recap was made of hydraulic component changeout activity. It was frankly appalling. Investigation revealed the preponderance of failures due to fluid contamination (Table 1). These statistics are from certain steel mill studies, but I doubt seriously that continued analysis of hydraulic difficulties in the mines will vary a great deal. Also, conversion of circuitry into standard graphical diagrams revealed eleven areas in the system that were devoid of fluid filtering.

TABLE 1—*Trouble-shooting analysis (10 years).*

1. 50% fluid problems.
2. 25% mechanical failures.
3. 25% suction inlet problems.

The problem was referred to U.S. Steel's Applied Research Laboratory. The analysis and proposed corrections were presented and accepted. Explanation of a successful filtering revision in a mill application was dramatic evidence of need. This was the 43-in. hot strip mill at McDonald Mill in Youngstown, Ohio.

The circumstances were as follows, and I quote [*2*];

This 43-in. hot strip mill has a 6-stand finishing train following a 4-stand rougher. Stands of the finishing train are numbered 5 through 10. Stand 9 is equipped with a prediction-type automatic gage control. In this system, an X-ray gage located between Stands 8 and 9 measures actual strip thickness. A temperature sensor, similarly located, measures actual strip temperature. The hydraulic force required by Stand 9 to reduce the strip to the desired gage is computed in a simple analog computer. This calculation is constantly changed, as needed, to reflect the deviations monitored by the X-ray and temperature sensors. Controlled screwdown is accomplished in a closed-loop force system that utilizes a high-response wedge actuator and a force feed-back signal from the pressductors located in the stand. This signal, representing actual force in the stand, is compared to the calculated force required. Any difference between the two will result in a control error signal to the wedge electrohydraulic servo valve, which then orders wedge motion to reduce the error to zero. . . . .

Associated with each wedge actuator is a hydraulic-control enclosure that contains a hydraulic manifold, a servo valve, a filter, shutoff valves, an electrical junction box, and associated supply and return line piping.

The hydraulic power plant consists of three identical pump-motor combinations, an accumulator, a reservoir, filters, a heat exchanger, and an integral control panel. One pump-motor combination is not required for normal operation and is used for standby operation. The hydraulic power plant is designed to supply 70 gpm of clean phosphate-ester hydraulic fluid at 3100 psi at the proper operating temperature to the wedge.

This unit was initially installed with a recommended fire-resistant fluid of a phosphate-ester type having a viscosity of approximately 120 SUS at 100 F. After one month of operation, a series of servo valve failures occurred in which the valves became erratic in operation. Inspection disclosed signs of additive-plating on the high-pressure lobes of the "slave positions" and definite signs of impingement corrosion on both the slave pistons and the "pilot pistons." Very little is now known concerning fluid impingement corrosion or the corrective measures needed to eliminate the problem. In this case, it was decided to try several types of steel for the spools. When this failed to stop the problem, it was attacked from a fluid standpoint. The following measures were taken:

1. A change in fluid was made in order to use a phosphate-ester fluid known to be a non-additive or "pure" fluid. Also, the new fluid was of a viscosity more suitable to the pump limitations (namely a minimum of 150 SUS @ 100 F). The system was flushed and cleaned three times with the new fluid before a full charge was made.

2. New elements were installed in the original 5-μm and 3-μm filters.

3. A bypass "fullers earth" filtering system was installed near the power unit in order to thoroughly clean the fluid at any time it was deemed necessary.

4. A fluid monitoring program was initiated where daily samples would be taken during the first week of operation and weekly samples thereafter to guarantee a clean system. These samples were to be analyzed at the Research Laboratory for two important conditions; one, the amount of fluid contaminants in the various micron ranges, and two, the acidity of the fluid. The contamination count was to be made using the ARP-598 aerospace method of fluid contamination count with a maximum limit of 15,000 particles in the 5 to 15 μm range [*3*].

5. The acidity was to be held at a maximum of 0.08 using the ASTM Method D-974 [*4*].

6. If either criteria were not met during these scheduled analyses, the mill was to be notified and the system was to be shut down and the fluid was to be circulated through the "fullers earth" bypass system.

In the three years since this system has been operating under these controls, there has been no further problem with the servo valves.

Table 2 shows the results of typical samples taken recently from this system. Considering the fact that this is a hot-strip mill, the condition of this fluid in the aerospace cleanliness range is rather amazing. *But, it does demonstrate that the environmental conditions have nothing to do* with what happens inside the system—if proper filtering is adhered to.

TABLE 2—*Particulate count method.*

Sample Number	Date Taken	Neutron No.	ARP Count, 5 to 15 μm	Pressure, psi	Temperature, deg F
B-233........	4- 5-68	0.06	1 320	2 650	125
B-234........	4-11-68	0.08	4 200	2 650	138
B-235........	4-19-68	0.04	1 320	2 650	132
B-245........	7- 5-68	0.06	1 840	2 650	134
B-246........	7-12-68	0.06	9 000	2 650	138
B-247........	7-19-68	0.08	12 600	2 650	134
B-248........	7-23-68	0.04	3 620	2 650	132

Again, the reference to contaminant control is Aerospace Recommended Practice 598 (ARP-598). This specifically is a "Procedure for the Determination of Particulate Contamination of Hydraulic Fluids by the Particle Count Method." This is further defined as classes (Table 3) with respect to maximum contamination limits. Repeating: work done here is in the 5 to 15 μm size range. Later reference to particle counts on mining equipment refer to this standard procedure.

TABLE 3—*Aerospace Recommended Practice 598 (5 to 15 μm range).*

Class	Limit, max	Class	Limit, max
00	125	6	16 000
0	250	7	32 000
1	500	8	64 000
2	1 000	9	128 000
3	2 000	10	256 000
4	4 000	11	512 000
5	8 000	12	1 024 000

This background allowed us to proceed with corrective planning.

1. Fluid samples were drawn from several mining machines and contaminant counts were made (Table 4). This was a real "clincher" to formalize action.

TABLE 4—*Typical 5 to 15 μm count before full-flow fine-filtering.*

Miner No. 1	764 000
Miner No. 2	496 000
Miner No. 3	1 497 000
Miner No. 4	1 077 000

2. The original circuitry was studied, revised, and drawn to include all fluid passing through return filters. Actually, it developed most appropriate to use five separate filters. I might add that the total maximum flow of oil is 96 gal/min at 3000-psi relief setting. Another point of real importance is that all make-up oil must pass through a filter prior to entry into the reservoir. Filter opening size of 3 μm has been chosen. Although initially it was felt to be a rather optimistic approach, we have been able to obtain good results.

Results to date (Table 5) can not match what our associates have done in the mill application described (Table 2). Let me hasten to add, however, for an underground effort, it is not too bad. In fact, I am proud of the efforts of our field personnel. The first miner described was completed in March 1969. Subsequently, we have converted an additional eleven. Filter cartridge life has been surprisingly good.

TABLE 5—*Actual 5 to 15 μm count after full-flow fine filtering was installed.*

New fluid from bulk storage	133 920
15 minute operation: 10 μm element	258 960
30 minute operation: 10 μm element	100 000
15 minute operation: 3 μm element	49 200
3 days operation: 3 μm element	116 640
1 week operation: 3 μm element	52 320
4 weeks operation: 3 μm element	64 920
5 weeks operation: 3 μm element	39 000
6 weeks operation: 3 μm element	99 000
13 weeks operation: 3 μm element	133 920
15 weeks operation: 3 μm element	72 600

Technical feasibility of fine filtration has been proven in underground operations. Now the tough problem—changing people's established methods and building into their work a new awareness. In this instance cartridge change. Example! Let me add a couple more readings to this table. At four months the count was 177,000, getting pretty high. At eleven months, soaring to 381,000! Here it was decided that control could be best served by local particle counting. As a result, our own facilities were installed. The counts have now "come back down from the moon."

The object of all this is reduced component failure. This has happened. Over the past 14 months, changeouts have been made almost universally because of mechanical deficiencies. Cleanliness pays!

It is hoped that an easier means of field analysis may be found. A device currently is being tested. The instrument simply measures light intensity passing through a sample after first being "zeroed" on a filtered test quantity. We have not fully decided on its continued usage, but correlations to date with the ARP-598 method have been fairly good.

References

[1] *Lubrication Engineers Manual*, United States Steel Corporation, Pittsburgh, Pa.

[2] Schrey, W. M., "The Selection and Maintenance of Reservoirs, Strainers and Filters for Fluid Power Systems," Applied Research Laboratory, United States Steel Corporation, Monroeville, Pa., paper presented at the Industrial Hydraulics Seminar of the Upper Ohio Valley Chapter of ASLE, Wheeling, W. Va., 6–7 Nov. 1968.

[3] "Aerospace Recommended Practice 598; Procedure for the Determination of Particulate Contamination of Hydraulic Fluids by the Particle-Count Method," Society of Automotive Engineers, Inc., New York, 1960.

[4] "Neutralization Number by Color-Indicator Titration," American Society for Testing Materials, *1968 Book of ASTM Standards*, Part 17, p. 334.