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Hydraulic fluid analysis: avoiding the potential pitfalls

Part 1: careful sampling and correct procedures
are essential to exploit this valuable maintenance tool

Part 2: interpretation of test results, plus do-it-yourself on-site tests

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Hydraulic fluid analysis: avoiding the potential pitfalls

Analysis of hydraulic fluids, if done properly, can suggest maintenance procedures to improve hydraulic equipment reliability and extend system life. Significant cost savings can result.

Where to take a sample

There are two types of fluid sampling: static and dynamic. *Static sampling* involves extracting a fluid sample from a reservoir or a dead zone, where there is slight fluid movement. Little useful information is gained from static sampling because:

- contaminant concentration gradients exist within static fluids. Water and particles tend to segregate and settle due to gravity. Therefore, samples taken from different sections within the static container yield completely different results, and
- particles from reservoirs may describe system histories, but provide little information on what is happening *now*. Large reservoir volumes dampen out dynamic changes and conditions within the system.

Dynamic sampling (where there is extensive fluid movement) is the best way to obtain a

representative sample from a hydraulic system. However, sampling valves must be installed at several points in the system and therefore more effort and expense is involved. Still, this expense and effort is a modest price to pay for accurate results.

There is no rule-of-thumb for locating sampling valves optimally in a system. Obviously, the more locations available, the more comprehensive information can be extracted. Here are some valve location options:

Pump effluent monitoring. Locating a sampling valve in the pressure line can be an effective way to monitor the component most prone to contaminant failure — the pump. Fluid from this sampling point will contain a combination of contaminants: those entering from the reservoir, sloughing off the suction strainer, desorbed (captured then released) from the intake filter, and generated by the pump itself (wear/cavitation debris and corrosion products). Samples here can effectively identify incipient and impending pump failures. Further, directional valves, actuators, etc. are immediately subjected to the pump effluent fluid and contaminants therein.

Component monitoring. Samples taken downstream of actuators such as cylinders and motors (after subtracting pump effluent levels) monitor in-

gression from wiper seals, hose fibers, corrosion, filter desorption, and wear debris. These samples are effective at identifying ailing components and unusually high ingestion points.

Return line monitoring. If only *one* sample location can be selected, the return line (upstream of the return-line filter) is the choice of the authors. Simply put, the return fluid contains all the contaminants that the system just experienced, including those contaminants ingested and generated by the system. When samples are taken and analyzed frequently, overall system health can be effectively monitored. The only exception is when a high-efficiency pressure-line filter is employed that may cover up the signs of an ailing pump.

Sampling do's and don'ts

Getting a *representative* fluid sample into a *clean* bottle is the single most difficult step of the oil analysis process for hydraulic fluids. Sampling hydraulic fluids literally must be done with the care of a surgeon. Small procedural errors produce large test result errors.

The amount of particulate matter we are concerned with in hydraulic fluids is extraordinarily small. If all the particles from a typical 125-cc bottle of hydraulic oil having an ISO 13/10 contaminant level were concen-

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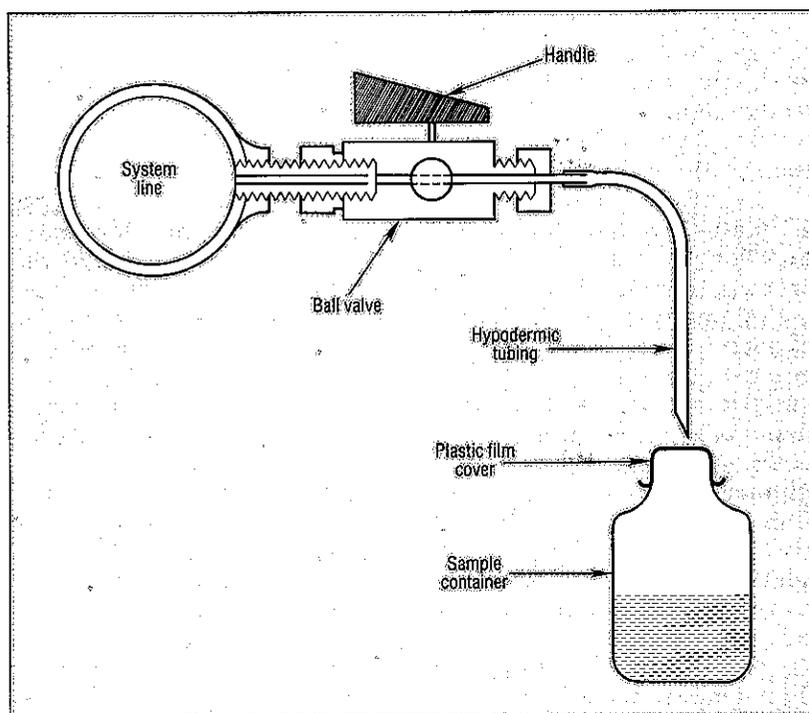


Fig. 1. Sampling system consists of a ball valve whose handle is rotated to release hydraulic fluid into a sampling bottle. The bottle, covered with a plastic sheet or film, should be kept upright on its way to a laboratory.

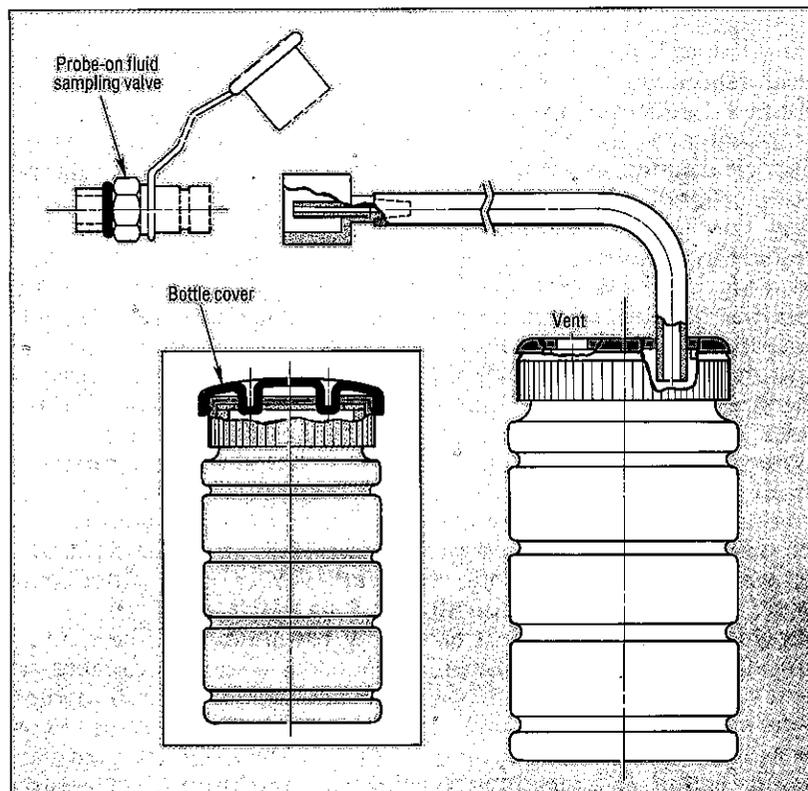


Fig. 2. Probe-on-style, hydraulic-fluid sampling valve system consists of a sampling valve, plastic tubing with a probe on one end, and a sampling bottle with a lid having two finger-like extensions, which stop-up two ports in the bottle cover.

trated in one spot, virtually nothing could be seen with the naked eye. Yet, on occasion we still see fluid samples taken in soft drink bottles, coffee cans, and the like. Frequently, more dirt enters the hydraulic fluid during the sampling process than was in the fluid originally.

There are two accepted ways to obtain a dynamic sample from a hydraulic line. The first procedure, Figure 1, uses a ball valve to obtain the fluid sample. It is very effective if two precautions are observed:

- a plastic film cover must be used to prevent the entry of environmental contaminants during the sampling process. Further, the sample bottle must remain upright en route to the laboratory so that particles are not caught behind the plastic cover, and
- before taking the sample, a volume of fluid equal to at least five times the valve assembly volume must be expelled. This flushes out the in situ contaminants from the valve assembly.

The second accepted dynamic sampling procedure, the probe-on-style, Figure 2, has gained prominence recently among mobile equipment manufacturers. Here are some benefits:

- these sampling valves, Figure 3, are inexpensive and easy to install. Several can be located in a single system. Valves also can be

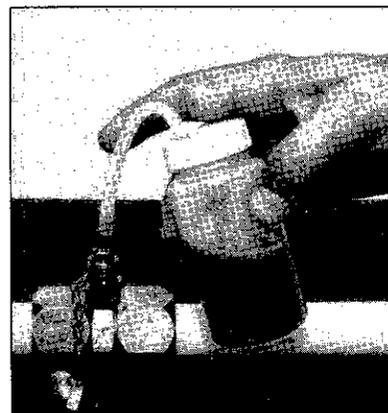


Fig. 3. Sample of hydraulic fluid is withdrawn using a probe-on sampling system. The sample fluid is withdrawn via the probe-on-style fluid sampling valve.

used for pressure diagnostics and portable fluid analysis described later

- although these sample valves must also be flushed, much less fluid volume is involved
- certified *ultraclean* sample bottles are available, eliminating concerns regarding original cleanliness
- accidental entry of environmental contaminants is unlikely with this design because the bottle cap does not need to be removed during sampling. Before shipment to the laboratory, the flexible tube is discarded and the vent/fill holes are sealed. (Note: bottles should have removable caps, for removal by the laboratory only. Bottles with flexible necks and tubes that remain on the bottle during shipment to the laboratory should be avoided. During shipment, these necks and tubes trap particles which cannot be resuspended for analysis), and
- sample bottles of this configuration can be shipped to the laboratory in any orientation, even upside down.

The final consideration when taking a fluid sample is how high to fill the sample bottle. The recommended procedure is to never fill more than two-thirds of the bottle. Particles and water settle rapidly in fluid and the only way these contaminants can be resuspended is through agitation. It is impossible to properly agitate bottles that are completely full. Some laboratories deal with this by pouring off fluid from full bottles. However, pouring off the fluid changes the contaminant concentration of the remaining fluid.

Laboratory procedures

Many commercial laboratories offer fluid analysis service, but they may not have the experience, staff, equipment or procedures to deal with the particular requirements of hydraulic fluid analysis. We suggest you ask the following questions before

committing your analysis project to a specific laboratory:

- are sample bottles (if provided by the laboratory) certified *clean* or *ultraclean*? What cleanliness specification is used? Ultraclean bottles should have no more than 1.5 particles greater than 10 μ m/ml. How frequently are bottles sampled for cleanliness? Does the laboratory use certified bottle cleaners?
- are bottles agitated before analysis for wear metals, additives, water, and particles by a paint shaker no less than five minutes? This is critical! Particles frequently bind tightly to bottle sides and bottoms. Certain additives such as rust inhibitors make it especially difficult to resuspend settled particles. Fluid samples that have sat on the shelf for several days should be agitated for at least 15 minutes. (Note, failure to agitate the fluid before any analysis step during which an amount of the fluid is removed changes the contaminant concentration for subsequent analysis of the remaining fluid.)
- are laboratory instruments calibrated frequently, using fluid standards and calibration fluids? Particle counters especially need to be calibrated. Ask the laboratory how this is done and how frequently. Get specific answers.
- verify that the laboratory is removing background effects before analysis. Particle-counter dilution fluid must be filtered rigorously to less than 0.01 particles greater than 10 μ m/ml. All water and air should be removed from the fluid before particle counting. Additive effects should be subtracted out of tests for water using Karl Fisher titration.
- are technicians certified on all the equipment they will use? Certification should include consistency and accuracy tests. When were technicians last retested?
- will the laboratory provide test results within 72 hours after receipt of the sample? While waiting for test results, components can degrade further.

Interpreting test results

There is clearly much confusion among hydraulic-equipment users regarding the meaning of oil analysis results. Generally, no interpretation should be made without application and system information. What is normal or proper for one system or application may approach catastrophe for another. Avoid taking action based only on computer interpretations or other highly structured criteria. Here are a few interpretation guidelines:

Viscosity. Viscosity is generally reported in Saybolt Universal Seconds (SUS or SSU) or ISO viscosity grades. As hydraulic fluid ages, viscosity increases slowly. These increases in viscosity are caused by fluid base and additive oxidation. Unusually high operating temperatures accelerate the process. Therefore, rapid swings in fluid viscosity may signal the presence of system hot spots. Generally, any swing in viscosity of 10% or more is an indication that the fluid is nearing the end of its useful life.

Acids. As hydraulic fluids oxidize due to the presence of air, water, and elevated temperatures, acidic by-products are formed. The acid value of a fluid is measured using the Total Acid Number (TAN) in mg of KOH/gm, or rather the number of milligrams of potassium hydroxide (an alkaline agent) required to neutralize one gram of fluid. Some fluids are formulated with a low neutralization number (0.2 mg KOH/gm), while those containing the antiwear additive zinc dialkyldithiophosphate (ZDDP) start off with values from 0.6 to 1.5 mg KOH/gm.

When fluids begin to oxidize, the neutralization number increases rapidly, generally accompanied by an increase in viscosity. However, for zinc antiwear fluids, the number decreases about 0.5 mg before finally increasing steadily as oxidation progresses. As a rule, a change in

the TAN of more than 1.0 mg is an indication that the fluids need to be changed.

Water contamination. Water has been the hidden source of many hydraulic fluid and system failures. Do not underestimate its devastating effect. Often, water causes the damage for which other factors get blamed. Some examples of damage caused by water:

- oxidation and corrosion
- rapid degradation of crucial antioxidant and rust inhibitors, forming acids and precipitants
- destruction of ZDDP antiwear additives, forming hydrogen sulfide and sulfuric acid. Increased wear due to particles results
- particles stick together like wet sand, increasing the rate of silting of valves and orifices
- air stays entrained in fluids much longer when water is present. Oxidation and corrosion accelerate
- filters loose efficiency and life. Some filters may swell and lose their strength
- fluid viscosity is affected, forming non-Newtonian fluids, resulting in a loss of hydrodynamic lubrication
- valves lock with ice-crystals when temperatures fall below freezing, and
- bacteria grow on reservoir bottoms at fluid/water interfaces.

Hydraulic equipment users should stop hydraulic system operation if water contamination exceeds 500 ppm (0.05%) in critical systems. Generally, continuous use of water-removing filters will keep water contamination within acceptable limits.

Wear metals. The presence of excessive amounts of wear and cavitation debris in hydraulic fluids are the tell-tale signs of an impending component failure. Maintenance should be scheduled before harm to other components and catastrophic failure results. The types and relative amounts of wear metal can be measured using spectrometry. (Absolute amounts cannot be de-

termined because spectrometry is generally limited to particle sizes below 15 micrometres).

Commercial laboratories tend to use either atomic emission or inductive coupled plasma spectrometry because 20 or more elements can be measured at one time. For instance, the presence of iron may indicate wear of pump pistons, vanes, or gears, as well as wear of bearings and cylinder bores. Copper debris may signal pump thrust plate wear, cylinder gland guide degradation, and bushing wear. Aluminum particles may be generated from pump/motor housings and some cylinder glands. The presence of chrome may indicate debris from cylinder rods, valve spools, or bearings.

In addition, ferrography can detect and measure wear debris during the early stages of equipment failure (since the full spectrum of particle sizes are quantitatively assessed) and should be used to compliment spectrographic analysis. A typical ferrography report would indicate presence and quantity of:

- normal rubbing wear
- fatigue chunks (typical gear surface wear)
- spheres (fatigue cracks in roller bearings)
- laminar particles (gears or roller bearings)
- severe wear particles
- cutting wear particles (high unit pressure)
- oxide particles (including rust)
- dark metallo-oxide particles (typical hard steels), and
- non-ferrous metal particles.

However, only a few laboratories do analytical ferrography routinely.

Particle counts. Solid contaminants affect the operation of hydraulic systems more than any other single factor. While there are several types of laboratory equipment that can count contaminant particles accurately, there is much confusion over interpretation of the results. How much contaminant can a specific

machine tolerate? At what contaminant level should the fluid be changed? The *Contaminant Life Index* (CLI), see box, was designed by Diagnostics to answer these questions.

Because each machine is often unique in design and application, the CLI will adjust accordingly. Once a CLI value is determined for each piece of equipment, it can be used as a reliable basis for comparison against particle count data from fluid analysis and can be directly translated into the widely used ISO Solid Contaminant Code.

Additives. Spectrographic analysis, oxidation tests, infrared analysis, and lubricity tests can indicate the condition of key additives. Test results are usually compared to those of new fluid to assess degradation of antiwear, antioxidant, viscosity improver, rust inhibitor, and extreme-pressure additives.

Lubricity. The most reliable method for assessing a fluid's lubricity (or antiwear properties) is the Fluid Contact Gamma Test developed by the Fluid Power Research Center at Oklahoma State University. The test is performed under boundary-layer lubrication conditions with a test journal/pin bearing combination. The reading produced is a measure of total journal/bearing wear, indicating the fluid's lubricity.

Field analysis of fluid

Hydraulic fluid condition is of preeminent concern and should be monitored regularly. So important is it for some systems that daily monitoring is not frequent enough. To accomplish such routine monitoring, the analysis must often be done quickly in the field by maintenance personnel. Among other things, field analysis can qualify the need and timing for more comprehensive analysis in the laboratory.

Water test. Some forms of field analysis can be done without in-

struments or test kits. For instance, the presence of water in hydraulic fluids can usually be observed by its color, or turbidity. Simply pour a sample of the fluid into a transparent container. If it shows up milky or hazy, water is probably present. If there is still doubt, drip a little of the fluid onto an open hot plate. If water is in the fluid, you will hear a crackle or pop. Be sure to wear eye protection. In the field this can be done by placing a few drops of fluid in a shallow depression in a piece of aluminum foil and then heating the foil with a match.

Additive oxidation. The oxidation of additives often can be observed by sediment on the bottom of sample bottles after settling for 12 or more hours. Discoloration and foul fluid odor is a sign of fluid and additive breakdown. Field fluid that has been oxidized will appear thicker and more viscous than new fluid. Check the fluid's viscosity by putting a drop of new fluid beside an equal size drop of used fluid on a slick surface, and then slowly tilt the surface. The less viscous fluid will run first.

Patch test kit. Field contaminant analysis kits are available from several sources. One type, referred to as the patch test, has been used widely for more than 20 years. After training, tests conducted using the patch test kit can be done either in the laboratory or in the field. An average of 30 minutes is needed for each test sample.

For the patch test, a measure of fluid is drawn through a fine membrane. Particles deposit on the membrane surface. The membrane is then removed and the contaminant aggregate is observed with a microscope. Using photograph comparisons, the contaminant level is approximated based on color and contaminant density on the membrane.

The major benefit of the patch test is that the actual contaminants are viewed by the tech-

How clean should hydraulic fluid be?

The questions of the Contaminant Life Index at right relate actual applications to cleanliness requirements.

A. Pump contaminant sensitivity. The contaminant sensitivity of the hydraulic pump is a critical factor in estimating the contaminant sensitivity of the overall system. For those pumps that have Omega Ratings (NFPA RS T3.918-1976) specified by their manufacturer, the score for this category is simple. For unrated pumps, the sensitivity must be estimated by the equipment user. Generally, vane pumps are more sensitive than piston pumps which are more sensitive than gear pumps. However, the experience of the user with the particular pump is probably the best guide. When no information is available, score this category as *average*.

B. Operating pressure. Because the contaminant sensitivity of hydraulic components varies with operating pressure, this category is heavily weighted. Operating pressure is the pressure *under load* during normal work cycles. Score this category by multiplying the appropriate score factor by the score of part A.

C. Duty cycle severity. This category penalizes systems that operate for extended periods at 130% of normal operating pressure. This information must be observed from pressure gages during peak work cycles. Equipment subject to rigorous performance requirements in the field generally has higher duty-cycle severity. When no other information is available, score this category as *medium*.

D. Fluid type. A fluid's performance affects the system's contaminant sensitivity. Both viscosity and fluid type are involved. To score this category, note the score factor under the

corresponding fluid type and multiply this factor times the value (100 minus the ISO viscosity grade). If the viscosity grade is over 100, just use 100. For *water only* fluids, use 150 as the score (don't multiply by viscosity).

E. Number of servovalves. Count the number of servo, solenoid, or proportional control valves in the system. Assign the corresponding value.

F. Presence of water. Water contamination accelerates solid contaminant wear. Estimate the amount of water as a percentage (by volume) and multiply the corresponding score factor times the score of part A. Generally, oil that is hazy in color will have between 0.05 to 0.15% water. Note: 1% equals 10,000 ppm.

G. Contaminant abrasivity. Score abrasivity (hardness and angularity) of airborne particles in the immediate area of the machine as high, medium, or low.

H. Maximum system flow rate. The score for flow rate should correspond to system or pump specification. This assigns relative replacement costs of the hydraulic components.

I. Cost of downtime. If downtime costs are known, assign the score using the first table. Otherwise, the score should correspond to estimated cost of the equipment (the second table).

J. Safety risk upon failure. The risk associated with hydraulic failure is strictly judgmental, but is a critical part of the fluid cleanliness decision. Assign the score according to the risk level.

Total the individual scores to obtain the CLI value. The CLI Translation Table, then converts the CLI value into terms of standard particle counts, including the ISO Code and NAS 1638 cleanliness classes. Particle counts produced from oil analysis then can be compared easily with the contaminant tolerance established by the Contaminant Life Index.

CONTAMINANT LIFE INDEX (CLI)	MACHINE I.D.:	DATE:	CLI SCORE:
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For Determining Required Cleanliness Levels of Hydraulic Systems

A. Pump Contaminant Sensitivity:

Sensitivity	Unity	Insensitive	Mild	Average	High	Highest
Omega Rating	1-1.02	1.02-1.04	1.04-1.16	1.16-6	6-60	> 60
Score	3	10	35	175	350	450

Score Totals

A. _____

B. Operating Pressure (under load): Score = Score Factor x Part A Score

Pressure (PSI)	0-500	501-1000	1001-2000	2001-3000	3001-4000	4001-5000	5001-6000	> 6000
Score Factor	0.12	0.16	0.35	1	3	10	50	100

B. _____

C. Duty Cycle Severity:

Severity (% time above 130% operating pressure)	MILD (0)	MEDIUM (1-4%)	ROUGH (5-10%)	SEVERE (above 10%)
Score	0	30	65	100

C. _____

D. Fluid Type: Score = Score factor x [100 - ISO Viscosity Grade (100 max)]

Type	Phosphate Esters	Mineral (Petroleum)	Other Synthetics	Water Glycols	High Water Based Fluids	Water Only
Score Factor	0.1	0.25	0.50	0.75	1.00	Score 150

D. _____

E. Number Of Servo Valves In Use (Including Proportional Control & Solenoid):

Number	0	1-2	3-4	4-6	7-8	9 +
Score	0	40	80	120	160	200

E. _____

F. Presence Of Water: Score = Score Factor x Part A Score

Amount (%)	0-0.01%	0.01%-0.05%	0.05%-0.15%	0.15%-1%	> 1%
Score Factor	0.05	0.15	0.4	0.75	1

F. _____

G. Contaminant Abrasivity:

Description	HIGH abrasive & metallic particles	MEDIUM road dust	LOW industrial
Score	100	50	0

G. _____

H. Maximum System Flow Rate:

Flow(GPM)	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	>90
Score	0	20	30	40	50	60	70	80	90	100

H. _____

I. Cost Of Downtime:

Cost (\$ Per Hour Downtime)	< 100	101-500	501-2000	2001-5000	5001-10,000	10,001-50,000	50,001-100,000	> 100,000
Score	0	25	50	75	100	125	150	200

I. _____

OR

Cost of Equipment (\$)	< 5,000	5001-10,000	10,001-25,000	25,001-50,000	50,001-100,000	100,001-200,000	200,001-500,000	500,001-1,000,000	> 1,000,000
Score	0	25	50	75	100	125	150	175	200

J. Safety Risk Upon Failure:

Amount	None	Low	Medium	High
Score	0	150	300	400

J. _____

Total Add Scores A-J To Obtain "Contaminant Life Index" (1000 Maximum Value)

CLI Translations:

CLI Value	Gravimetrics MG/LT (AC Fine Test Dust)	Particles Per Millilitre < 10 Microns	ISO Code	NAS 1638	Disavowed "SAE" Level
0-100	30	4350	21/18	12	9
101-200	15	2175	20/17	11	8
201-300	7.5	1088	19/16	10	7
301-400	3.75	544	18/15	9	6
401-500	1.88	272	17/14	8	5
501-600	0.94	136	16/13	7	4
601-700	0.47	68	15/12	6	3
701-800	0.23	34	14/11	5	2
801-900	0.12	17	13/10	4	1
901-1000	0.06	8	12/9	2	0

nician. The presence of wear debris or other abrasive solids can be clearly observed. The user can see what is doing the damage as well as the damage (wear debris) that has already been done. Although not a quantitative technique, the patch kit can provide a good indication of the contaminant severity existing in the system, at very little cost and in a brief time.

Probe-on contaminant monitor. A screen-type contaminant monitor uses a probe-on technique that eliminates the need to draw an initial sample into a bottle, Figure 4. The device employs the mechanical filtration of particles to measure solid contaminant levels. This is achieved with a precision screen having an exact pore size and pore density.

During a test, fluid enters the device from the sampling valve under pressure. The fluid passes through the calibrated screen and begins to actuate a small piston, coupled to a linear displacement dial indicator.

As fluid passes through the screen, particles begin covering the screen's pores. The particles gradually close off available pores until flow through the screen is reduced to near zero. At this point the filtrate volume is measured from the dial indicator reading. The greater the volume

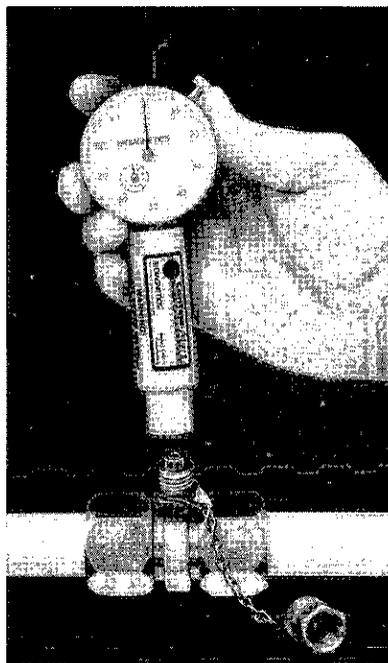


Fig. 4. Probe-on, screen-type contaminant monitor/analyser avoids the need to draw a sample of hydraulic fluid into a bottle. Note that a probe-on-style fluid sampling valve is used with the monitor/analyser.

of fluid that passed through the screen before the screen was blocked by the particles in the fluid, the cleaner the fluid.

Either electronically or with a nomograph, this reading is quickly translated into approximate particle counts and cleanliness level classes. Immediately after the reading, the handle is depressed to expel the fluid in the

reverse direction through the screen (backflushing). This cleans the unit for immediate re-use.

The contaminant monitor produces a direct quantitative reading; no interpretation is required. Relatively little time is required — only about two minutes on the average with no cleaning or lengthy preparation needed between readings. Also, laboratory evaluations indicate that this test produces accurate and repeatable readings. It appears most useful in providing *contaminant trend analysis*.

Frequency pays off

Conducting routine field fluid analysis is most important. Equipment problems can occur so quickly and with such little warning that relying strictly on periodic *laboratory* analysis may not be enough. Applying good *field* oil analysis techniques every other week is far superior to *sophisticated* laboratory analysis *semiannually*.

Finally, fluid analysis is to no avail if required servicing is not ordered and promptly carried out. Problems must be identified, corrected, and prevented from reoccurring. Always focus on the root cause of problems; you must direct corrective action at the source. HP

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