INTRODUCTION TO FLUID CONTAMINATION

I. FLUID CONTAMINATION

It is estimated the 75 to 85 percent of system failures are a direct result of fluid **contamination.** Contamination can be defined as any detrimental matter in the fluid. Contamination can be detrimental to the system or to the fluid itself. Each dirt particle acts like an "abrasive seed" that produces additional dirt particles as it passes through the clearances in pumps, valves, conductors, and actuators. Contamination affects the system in many ways:

1. Increased internal leakage which lowers the efficiency of pumps, motors, and cylinders and decreases the ability of valves to control flow and pressure accurately. It also wastes horsepower and generates excess heat.

2. Corrosion of the system from acids that form due to fluid breakdown and mixing of incompatible fluids in the system.

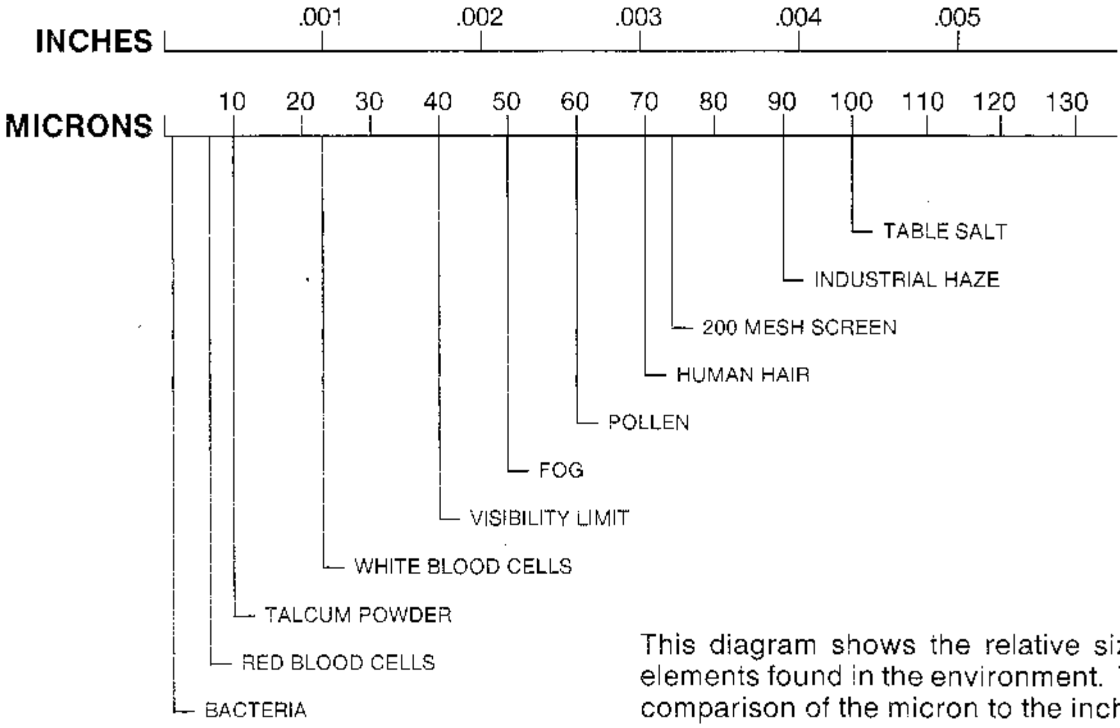
3. Sticking of parts due to sludge or silting. Silting is a collection of fine particles in critical areas of control valves which will impair the shifting of the spool.

4. Seizure of parts or components caused by large amounts of contaminants getting stuck in the clearances.

Dirt particles are usually sized using a metric unit of measure called a micrometre, otherwise known as the micron. A micron is a very small unit of measure equal to 39 millionths of an inch. Twenty-five microns is equal to one-thousandth of an inch. Particles are sized by measuring the longest dimension. The clearances in components can be as small as one-half micron. When abrasive particles enter the clearance between moving parts they score and hone the surfaces to greater clearances.

The key to Roilgard systems is versatility. While there are many transfer, filter and treatment units on the market, Roilgard offers creative solutions. Because of its design, manufacturing and testing capabilities, custom designed units can be developed for specific applications. Each function added to a system has been designed to improve operation by reducing material and labor costs. Where possible, automatic systems with programmable controls are utilized to eliminate guesswork and oversights in operations.

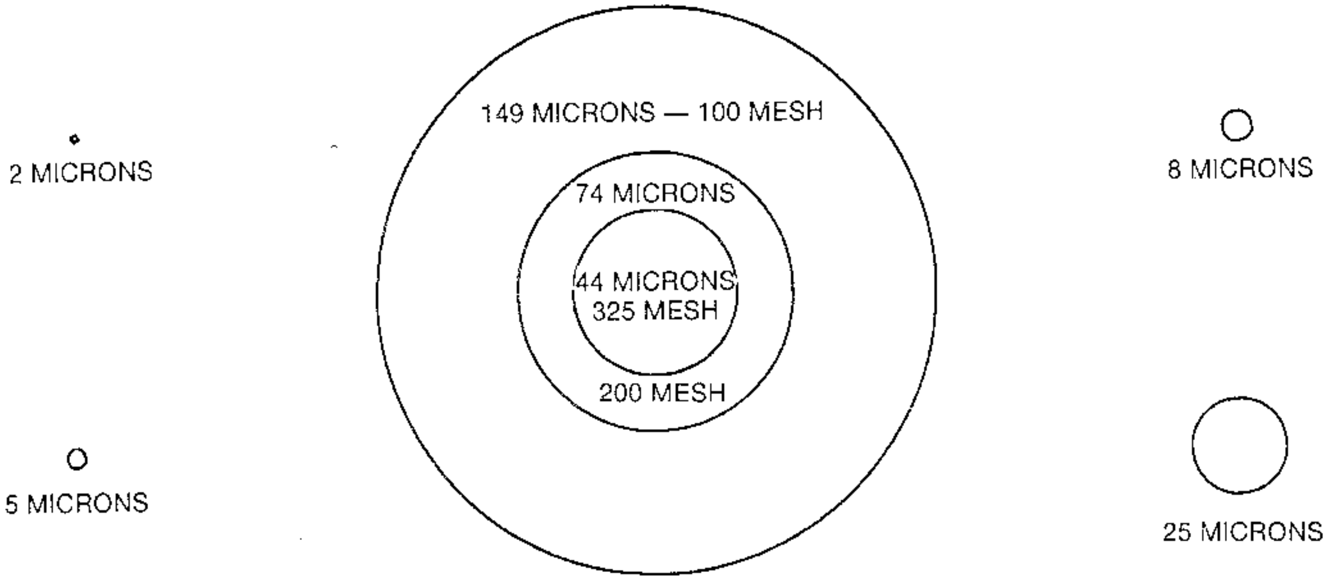
Generally, the small particles pass through the clearance without doing damage and the large particles cannot get into the clearance. The particles that are approximately the same size as the clearance will get lodged in the clearance and cause the machining effect. Unfortunately, the smallest particle that can be seen with the naked human eye is forty microns. Particles that do damage to most systems are in the range of three to thirty microns.



This diagram shows the relative sizes of various elements found in the environment. There is also a comparison of the micron to the inch.

RELATIVE SIZE OF MICRONIC PARTICLES

MAGNIFICATION 500 TIMES



RELATIVE SIZES

Lower limit of visibility (naked eye)	40 MICRONS
White blood cells	25 MICRONS
Red blood cells	8 MICRONS
Bacteria (cocci)	2 MICRONS

LINEAR EQUIVALENTS

1 Inch	25.4 Millimeters	25,400 MICRONS
1 Millimeter	.0394 Inches	1,000 MICRONS
1 Micron	25,400 of an Inch	.01 MILLIMETERS
1 Micron	3.94×10^{5}	.000039 INCH

SCREEN SIZES

MESHES PER LINEAR INCH	U.S. SIEVE NUMBER	OPENING IN INCHES	OPENING IN MICRONS
52.36	50	.0117	297
72.45	70	.0083	210
101.01	100	.0059	149
142.86	140	.0041	105
200.00	200	.0029	74
270.26	270	.0021	53
323.00	325	.0017	44
		.00039	10
		.000019	.5

A Micron is 39 Millionths of an Inch

This diagram shows some of the typical clearances that can be found in various fluid power components. Therefore, it becomes very critical to remove the dirt particles that are approximately the same size as the clearances. In most cases, those are very small particles and they cannot be seen with the naked eye.

TYPICAL CRITICAL CLEARANCES — FLUID SYSTEM COMPONENTS

ITEM	MICRONS	TYPICAL CLEARANCE INCHES
Gear Pump (Pressure Loaded)		
Gear to Side Plate	1/2 - 5	0.000,02 - 0.000,2
Gear Tip to Case	1/2 - 5	0.000,02 - 0.000,2
Vane Pump		
Tip of Vane	1/2 - 1*	0.000,02 - 0.000,04
Sides of Vane	5 - 13	0.000,2 - 0.000,5
Piston Pump		
Piston to Bore	5 - 40	0.000,2 - 0.001,6
Valve Plate to Cylinder	1/2 - 5	0.000,02 - 0.000,2
Servo-Valve		
Orifice	130 - 450	0.005 - 0.018
Flapper Wall	18 - 63	0.000,7 - 0.002,5
Spool-Sleeve	1 - 4	0.000,04 - 0.000,16
Control Valve		
Spool-Sleeve	1 - 23	0.000,04 - 0.000,90
Disc Type	1/2 - 1*	0.000,02 - 0.000,04
Poppet Type	13 - 40	0.000,5 - 0.001,5
Actuators	50 - 250	0.002 - 0.010

*Estimate for thin lubricant film

II. SOURCES OF CONTAMINANTS

There are three general sources of contaminants.

1. **Built-in Contaminants.** These are particles remaining in the system following assembly of the system. They include, but are not limited to, core sand, weld spatter, grinding dust, metal chips from manufacturing and assembly, lint, and airborne contaminants. It is the responsibility of the machine builder to remove these contaminants before shipment. One approach is to connect up a portable filtration device and circulate oil through the complete system until a predetermined cleanliness level is achieved. Another approach is to pre-clean all system components prior to assembly and utilize "good housekeeping techniques" in the assembly area. The first method is preferred because it can remove contaminants that still may get into the system during assembly, even "with good housekeeping."

2. **Introduced Contaminants.** These are foreign particles which enter the system after the machine is completed and working in its particular application. Introduced contaminants are from the surrounding environment and enter the system through fluid filler tubes, reservoir breather caps, air leaks past seals, and added new oil.

3. **Generated Contaminants.** These contaminants are produced by the system during normal operation. They include wear contaminants such as small pieces of metal, sealing materials, etc., which result from wear on the moving parts of components within the system. Chemical reaction contaminants are the result of chemical reactions that can take place in the system.

III. TYPES OF CONTAMINANTS

There are two major types of contaminants — **FLUIDS** and **SOLIDS.** Probably the most destructive fluid contaminant is "Air." It causes severe cavitation and can destroy a pump in a matter of minutes. The air, which is usually dissolved in the fluid, is pulled out of solution at the inlet side of the pump due to the pressure at the pump suction port being a vacuum. Small bubbles form when the air is pulled out of solution. At the pump pressure port, these bubbles collapse with explosive force which can actually rip small pieces of metal from the pump's housing and wear plates causing increased leakage. The higher the vacuum at the pump suction port, the greater chance that cavitation will occur. Therefore, the inlet vacuum should be reduced as much as possible by removing any restrictions in the suction line.

Mixing incompatible oils can result in a fluid contaminant. For instance, if a mineral base oil is mixed with phosphate ester, seals will swell and sludge may form, plugging critical openings and filters. Water when mixed with certain automatic transmission fluids can cause sludge and small hard crystalline particles to form. Brake fluids when added to a conventional hydraulic system can destroy seals. If volitiles such as diesel fuel, gasoline, solvents, etc., are mixed with hydraulic oil the viscosity will be reduced and damage to the system may occur due to lack of lubrication. With the exception of air, most fluid contaminants do their damage over an extended period of time.

Damage from solid contaminants is immediate and depends on the size and number of dirt particles. Resilients such as teflon sealant, pipe dopes, pieces of O-rings and seals, etc., do their damage by plugging critical orifices in control and servo valves and by robbing close fitting parts of lubrication. Other solids such as rust, system wear particles, weld spatter, sand, dirt, etc., do their damage by machining away metal in close fitting areas.

AIR

SOURCE:
Obviously air is nearly everywhere. Fish can live and breathe underwater because oxygen from the air around us is dissolved in water. In the same way air is dissolved in water, there is air and oxygen dissolved in oils. Water based hydraulic oils, such as water-glycol fluids, contain an exceptionally high level of dissolved gasses.

Oils also contain varying degrees of entrained air. Entrained air can either be on the surface of the oil in the form of foam, or it can be in the bulk fluid in the form of tiny bubbles. For oil to foam or become aerated, there must be some mechanical force to pump the air into the fluid. Solid and liquid contaminants cannot cause foam; however, they can change the surface tension of oils in such a way that foam is stabilized and foam inhibitors are no longer effective. We have very little control of the amount of dissolved air in oils. However, some of the factors that cause entrained air are maintenance related:

- Low fluid levels
- Suction leaks
- Turbulence
- Contamination

EFFECTS:
Dissolved air plays an important role in oil oxidation. It can also be a factor in cavitation with water containing hydraulic fluids. Entrained air can cause a variety of problems, including:

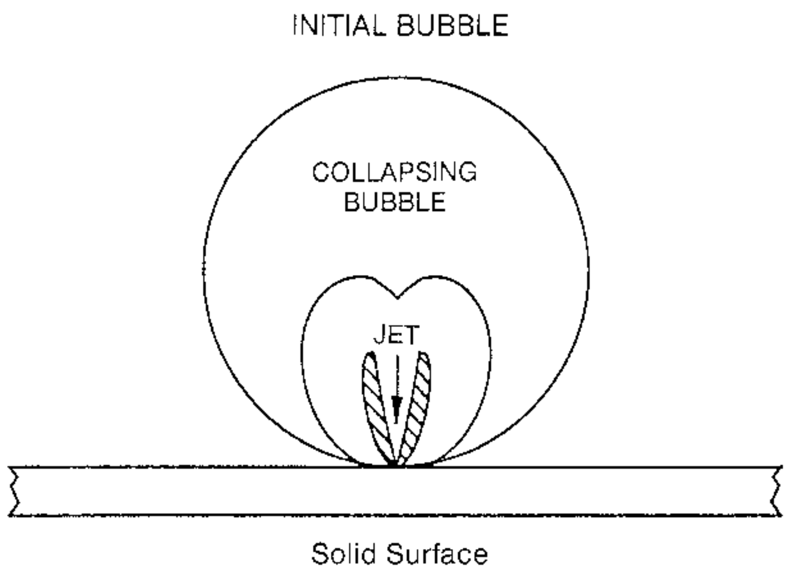
- Fluid losses due to overflow
- "Soft" cylinder operation
- Lubricant starvation
- Accelerate oxidation
- Cavitation

CAVITATION

Cavitation wear is caused by high impact pressures created when vapor gas bubbles in a liquid violently collapse due to gross changes in fluid pressures. Cavitation itself is a two step process. First, at low pressures a bubble or void is formed. After the void is formed, it implodes when it is subjected to high pressures. The bubble may be created by **turbulence,** by **dissolved gasses** drawn out of solution by a vacuum, or by formation of lubricant vapor when the pressure in the fluid falls below the **vapor pressure of the lubricant.** The best way to eliminate cavitation is to prevent the formation of bubbles in the fluid. Some of the causes of cavity formation include:

- Inlet restrictions or leaks
- Low temperature start-up
- Foaming and aeration
- Water contamination
- Low vapor pressure fluids
- Improper pump mounting.

A surface damaged by cavitation may have a frosted appearance or deep rough pits and grooves, depending upon the extent of damage. It is nearly impossible to eliminate sudden changes in liquid pressure (basic cause of cavitation) in some applications, such as ship propellers. The cavitation damage resistance of a machine component can be improved by increasing the fatigue strength of the material it is fabricated with.



HEAT

SOURCE: Most systems are designed to operate at a bulk fluid temperature of 60° C (140° F) or less. Many industrial systems are optimized to 50° C (120° F). A component that is too hot to hold your hand on is probably hotter than 50° C (120° F). Below are some factors that contribute to high system operating temperatures:

- Fluid shear
- Internal leakage of pumps and valves
- Sludge and dirt deposits
- High ambient temperatures
- Cooler malfunction

EFFECTS: The oxidation rate of an oil doubles for every 10° C (18° F) increase in temperature above 60° C (140° F). An oil's viscosity is cut in half every 10° C (18° F) too. From a practical standpoint then, an oil at 70° C (160° F) has half the life expectancy and provides half as thick an oil film as it would at 60° C (140° F). Other effects of high temperatures include:

- Seal hardening and oil leaks
- Adhesive and corrosive wear
- Additive degradation
- Copper corrosion
- Loss of de-emulsibility products
- Oxidation and sludge formation

Although high temperatures lower oil viscosity, ultimately they can raise an oil's viscosity. This is because thick grease-like sludge is produced in high temperature lubricating oil oxidation.

OXIDATION AND SLUDGE FORMATION

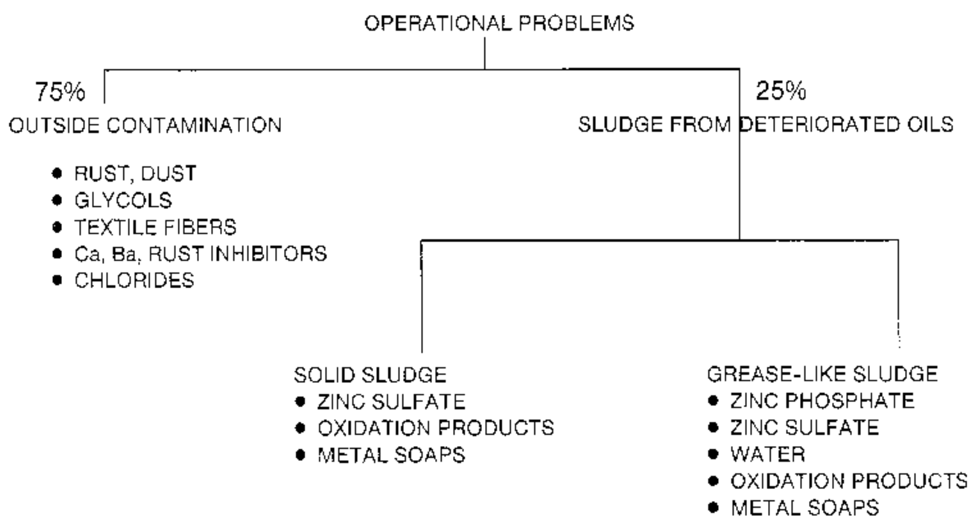
Lubricating oil oxidation is a complex autocatalytic free radical chain reaction. Once oxidation starts, it proceeds at a very rapid rate. Copper, steel, lead and water accelerate the oxidation process. Below is the most widely recognized mechanism for oil oxidation:

Initiation:	$RH + O_2$ — $R^* + O_2$
Propagation:	$R^* + O_2$ — $R\,O_2$
Propagation:	$R\,O_2^* + RH$ — $ROOH + R^*$
Branching:	$ROOH$ — $R\,O^* + OH^*$
Termination:	$R^* + R^*$ — RR
Termination:	$R\,O_2^* + R^*$ — $ROOR$
Termination:	$R\,O_2^* + R\,O_2$ — $ROH + ROR + O_2$

Because of the various routes that oil oxidation can follow, oxidation products are complex and varied. Acids that are especially aggressive to copper are formed in oxidation. Esters, aldehydes, alcohols and ketones are also formed. A recent study of injection molding machines linked oil oxidation to the following valve problems:

- Malfunction or sticking of valve spools
- Failure of solenoids
- Oil leakage from solenoid valves due to deterioration of O-rings

5 YEAR STUDY OF SLUDGE IN HYDRAULIC UNITS 20 UNITS/YEAR



DIRT

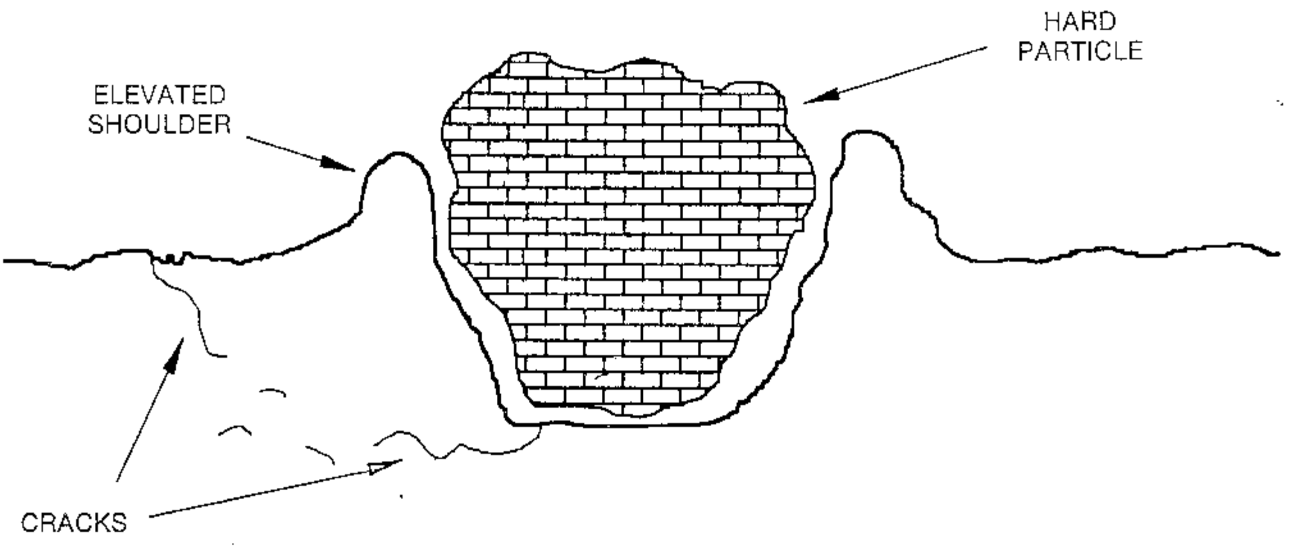
Every day we breath in dirt particles that can choke servo-valves and cause pump wear. That is why reservoirs have breathers on them and we, for the most part, breath unfiltered air. Some of the most common sources of dirt in fluids include:

- Built-in dirt
- Installed dirt from repairs
- New and make-up hydraulic fluid
- Cylinder rod seals
- Leaky breathers
- Wear debris

Particulate contamination is the #1 source of fluid related failures. Below are just some of the problems associated with contaminated oils:

- Fatigue and abrasive wear
- Stuck valves and burnt out solenoids
- Accelerated oxidation and sludge buildup
- Plugged suction strainers and filters

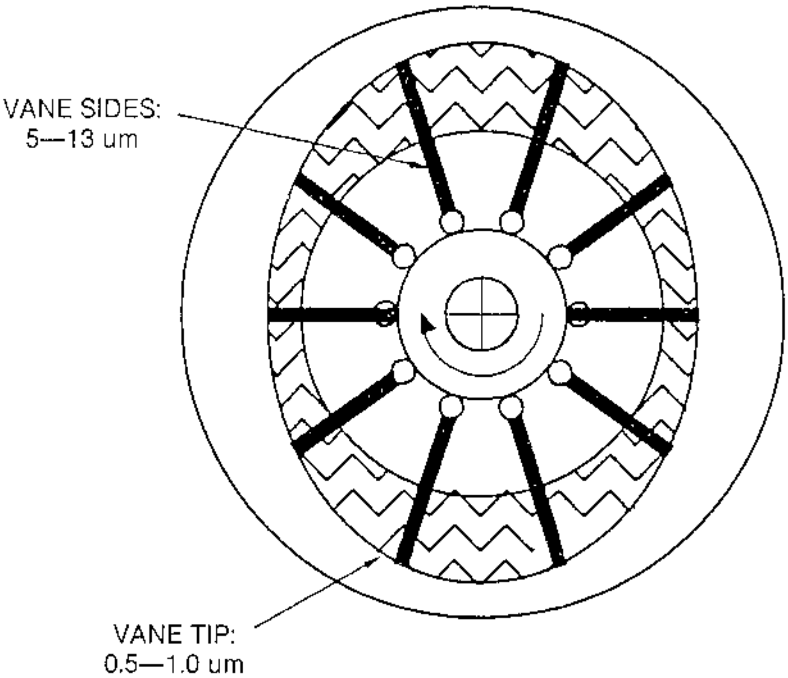
PARTICLE INITIATED FATIGUE



ABRASIVE CONTAMINANTS

Fluid systems cannot tolerate dirt. Tight clearances within a pump are necessary to transport fluid without leakage. Particles become trapped between the sealing surfaces of a pump and increase the pump's dynamic clearances through abrasive wear. This results in greater pump leakage, heat generation, and reduced efficiency.

VANE PUMP DYNAMIC CLEARANCES

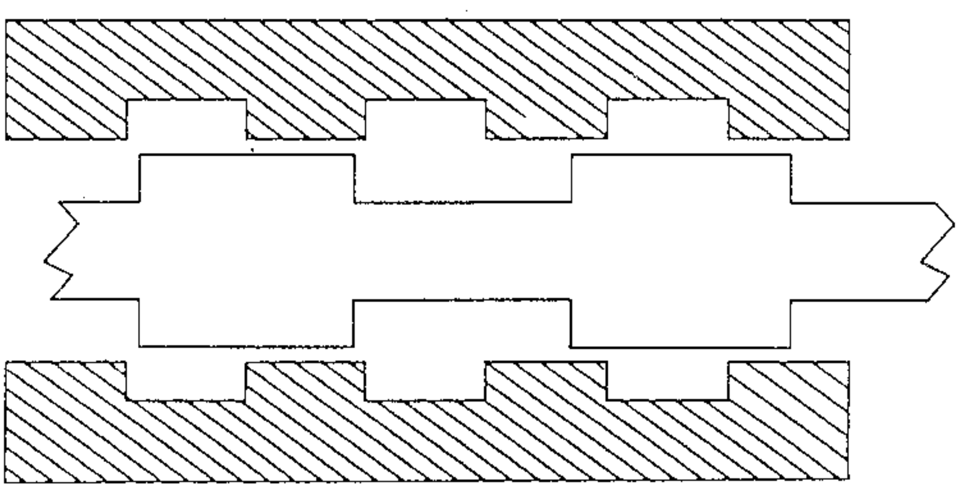


Dynamic Clearances	
Gear Pump	
Tooth to Side Plate	0.5 - 5 um
Tooth Tip to Case	0.5 - 5 um
Piston Pump	
Piston to Bore	5 - 40 um
Cylinder to Plate	0.5 - 5 um

Clearances in valves are extremely small to prevent leakage. Dirt can jam spools and cause solenoids to burn out. Contamination also can create quality control problems because it causes valves to perform erratically.

TYPICAL VALVE DYNAMIC CLEARANCES

Servo Valves	1 - 4 um
Directional Valves	2 - 8 um



WATER

Water is present in air at levels as high as 3.5% weight. Water is also naturally present in oil at some equilibrium level. The water content of an oil varies with fluid temperature, composition, and atmospheric conditions. Generally, inherent water concentrations in oil are 500 ppm (0.05% weight) or less. The sources of water contamination include:

- Condensation
- Metalworking coolants
- Improper oil storage
- Leaky coolers

Water contamination in oil based lubricants and hydraulic fluids dramatically decreases lubricant life. Additives used in oils are polar compounds that generally are active on metal surfaces. Water is a polar compound too. Therefore, water-additive interactions tend to be significant. Water hydrolytically degrades oil additives. It can also cause them to be stripped out by filters and separators. Other effects of water contamination include:

- Cavitation
- Decreased oil film thickness
- Accelerated oxidation rates
- Corrosion and sludge formation
- Bearing fatigue

BEARING FATIGUE TEST RESULTS

Lubricant	Water Concentration	Life Ratio
SAE 20	25 PPM	4.98
SAE 20	100 PPM	1.92
SAE 20	400 PPM	1.00

IV. DETECTION OF CONTAMINANTS

In order to determine if there are any contaminants in a system, it is necessary to obtain a sample of fluid from the system that is representative of the fluid in the system. In order to do this, two things are required.

1. A container to put the sample in and
2. A method of taking the sample fluid.

Probably the most important of the two items is the container. A container that has been specifically cleaned for this purpose must be used. Any old container lying around the shop simply will not suffice. Chances are that it is dirtier than the fluid in the system. If a dirty container is used, the contaminants in the container will mix with the fluid sample and cause erroneous results. A good sample container exhibits the following:

1. About 12 ounces in size
2. Glass construction
3. Wide-mouth
4. Have a screw-on cap
5. Have a plastic film between the cap and bottle
6. Have a label to write on
7. Be cleaned and qualified in accordance with ANSI B93. 20M-1972(R1980) American National Standard Procedure for Qualifying and Controlling Cleaning Methods for Fluid Sample Containers.

Currently two methods are used to draw a sample of fluid from the system. One method utilizes a sample tap installed in an area of turbulent flow in a low pressure line, usually a return line. The sample is taken while the system is running after it has been warmed-up and all circuits and actuators have been energized several times to insure complete mixing of the fluid in the system.

The other method involves taking the sample out of the reservoir using a small syringe type pump, to extract the sample and pump it into the container. As in the previous method, the system should be warmed-up and running when the sample is taken. More detailed information on obtaining a sample can be found in ANSI B93.19-1972 (R1980) Method for Extracting Fluid Samples from the Lines of an Operating Fluid Power System (for particulate analysis), ANSI B93. 44M-1978 Methods for Extracting Fluid Samples from a Reservoir of an Operating Fluid Power System, or contact us for a video on the proper procedures.

V. FLUID SAMPLE TESTING

After obtaining a sample, a visual inspection can be made. Holding the sample up to the light will reveal any particles larger than 40 microns. Water in the sample will make it look cloudy or milky. An extremely large number of small particles, 20,000 per ml greater than 10 microns may also give the sample a cloudy appearance. All fluids are different and they will not appear the same when a given amount of water or dirt particles are present. In order to obtain quantitative and qualitative results, the sample must be analyzed by a trained individual using very specialized equipment.

Listed below are various tests and their descriptions that can be performed on a fluid sample. Not all tests are performed on all samples. Testing depends on the type of fluid and the type of system that the sample came from and the requirements of the individual responsible for maintaining the system.

1. **Air Content.** The **entrained** (not dissolved air) can be measured by removing it using a vacuum and measuring its volume. In order to obtain accurate results, this test must be conducted immediately after obtaining the sample. Therefore, it is always done in "house" which requires the equipment and trained personnel. This test is usually not performed unless severe aeration of the system is occurring.

2. **Water Content:** Water content can be measured in two ways. The first method utilizes a centrifuge which measures the water mixed with the oil. (Held in suspension with the oil due to the additive package.) The water is collected at the bottom of the centrifuge tube and its volume is compared to the total volume of the sample originally placed in the centrifuge tube. The results are usually expressed as percent water by volume. This method is used where large amounts of water are present, usually 0.5 percent by volume and greater. The second method utilizes the Karl Fischer Titrometer which measures the total water present by determining the electrical conductivity of the sample when compared to a known reference. This method can measure the dissolved water and the water that is held in suspension. It is good for very small amounts of water, usually down to 0.01 percent by volume. Water can be very destructive to a system, therefore it is a test that is run quite frequently if water is a suspected contaminant.

3. **Clarity Test:** A turbidity meter can be used to measure the relative amount of suspended particles, either fluid or solid, in a sample by comparing it to the virgin fluid using light blockage to a photocell. The color or clarity of the used sample is compared to the new oil. If there was a significant difference between the two colors, the fluid was generally replaced. This test does not confirm the type, size and quantity of contaminant, just that the used fluid has changed its color for one of various reasons. However, this test is an indicator that the fluid may have undergone irreversible damage. This test is not performed very much because in today's economy fluid cost is high, therefore, testing has to determine what the contaminant is so that the proper action can be taken to solve the problem and save the fluid by recycling or refining it.

4. **Filter Patch Test:** The patch test can measure the relative amount above a given size of solid particles by filtering a measured amount of sample through a known pore size filter patch and comparing the patch color to a reference chart or weighing the patch before and after the sample is run through it. If the patch is weighed before and after, the results are usually given as mg of dirt per litre of fluid which is known as the gravimetric level. This is an industry accepted standard method. Further information can be obtained by examining the filter patch under a microscope. For instance, the size distribution of particles can be estimated and the type of contaminants can be also determined; i.e., aluminum, rust, pieces of O-ring, etc., using a trained eye.

5. **Particle Count Test:** The particle count is determined by passing the fluid sample through the sensor of a particle counter which is a sophisticated machine that can count and size particles in predetermined micron sizes which are selectable by the operator. Most particle counters can count and size particles in five or six different micron sizes simultaneously. Results are usually given as number of particles per ml greater than a given micron size. This is also an industry accepted standard for determining system cleanliness. Particle counting is probably the most common test that is run on fluid samples. For more information refer to ANSI B93.28M-1973 (R1980) Method for Calibration of Liquid Automatic Particle Counters Using "AC" Fine Test Dust.

6. **Infra-Red Spectrograph:** The infra-red spectrograph can determine the type and relative amount of liquid contaminants or additives in the sample by passing light whose wavelengths is varied across the infra-red spectrum through the sample. The amount of light absorbed by the sample is measured at each wavelength and since each chemical compound has its own characteristic wavelength it can be identified. This test is performed when liquid or other chemical contaminants are suspected. The results of the infra-red scan indicate whether or not the fluid sample has changed chemically. Usually the virgin fluid is run first in order that a comparison can be made between the used and new fluids.

7. **Atomic Absorption Spectrograph:** The atomic absorption spectrograph measures the amount of each metallic chemical such as iron, copper, lead, zinc, silicone, aluminum, tin, nickel, chromium, etc. A light of fixed characteristic wavelength for the chemical element being tested is passed through the sample which has been essentially vaporized by an extremely hot flame. The amount of light absorbed indicates the quantity of that chemical element. The results are usually presented as parts per million (ppm) by weight. Atomic absorption spectrograph is performed on a wide variety of samples to determine wear metal content in order to predict which component may be undergoing irreversible degradation and possible catastrophic failure.

VI. REDUCTION OF CONTAMINANTS IN HYDRAULIC SYSTEMS

There are three ways to reduce contaminants in hydraulic systems — Design, Prevention, Filtration. The level of contamination can be reduced by proper system design. For instance, the system can be sealed to keep dirt out, the reservoir can be slightly pressurized to prevent dirt from entering, filtering type breather caps can be used, better shaft and rod seals could be used, etc.

Preventing contaminants from being added to the system is a little more difficult because the "human factor" is usually involved. However, requiring the use of pipe plugs, tube caps, etc., during disassembly, assembly operations for repair or routine maintenance operations and requiring the use of a portable filter buggy when adding or replacing fluid are two methods of preventing contaminants from entering the system. Banning shop rags and replacing them with throw-away lint-free paper cloths is another method. A pump has a better chance of surviving a bout with a paper cloth than a cotton one.

After the contaminant is already in the hydraulic system, the only way to remove it is by filtration.

THE BENEFITS OF COST EFFECTIVE FILTRATION

A. A MAJOR TRACTOR MANUFACTURER

Two hundred and eighty machine tools under one roof. Hydraulic problems had reached epidemic proportions. They decided to apply oil testing and improved filtration as a solution.

Oil samples were taken from each hydraulic system every ninety days. System filters were improved on many machines. Bypass filter carts were used on all machines. Air filters were installed where necessary. Operator training seminars gave the plant personnel an understanding of the program's goals. Many machines were flushed to remove deposits and sludge.

After only nine months they concluded that the results were outstanding. Their rate of repair calls to machine tools was steadily declining. They did a complete cost study of their most important sixty machines. They concluded, that on a twelve month basis, they would save **$1,000,000** on hydraulic and electrical maintenance.

The cost of the program was under $100,000. In addition, they only bought half as much oil as they did the year before.

B) A PLASTIC INJECTION MOLDING PLANT
A round of oil samples determined that their Cincinnati-Milacron injection molding machines were badly contaminated with sludge. They began a program of flushing and bypass filtration. Routine oil analysis was carried out every three months.

During a sales call, after a year of the program, the maintenance director was asked how the program was going. He called in his hydraulic maintenance mechanic and asked him how many pumps he had replaced in the last year. The mechanic replied, "None." The director then told me that in the previous year they had replaced one pump per month. He said the savings in hardware alone was over **$20,000**. The cost was negligible. They had four buggy filter assemblies before the program began, but they never used them. They were happy with the arrangement.

C) A MAJOR MANUFACTURER OF CONSUMER ELECTRONIC APPLIANCES
A call was placed by a hydraulic equipment distributor. The radial piston pump on a hydraulic stamping machine had failed. The pump was replaced, and the new one failed immediately. In one week, six pumps failed on this machine. The manufacturer was convinced that the pumps were no good. No one knew where to turn.

An oil sample was taken and analyzed. The patch test showed that the oil was full of metal chips, residue of the original pump failure. The machine had no system filter. The distributor supplied a filter, and the manufacturer installed it quickly. The machine has not had another pump failure in four years. Savings: six piston pumps per week at $1,600 each, **$9,600/week!** Not to mention that through that entire week the machine tied up a dozen maintenance people, and did not make a single part.

D) A MAJOR PAPER MILL
The wet end pressure roll bearings are served by a separate hydraulic/lube system containing 300 SSU hydraulic oil. A bearing failed and shredded itself.

Upon analysis of an oil sample, it was pronounced full of metal particles. It was recommended that they get a bypass filter on the system immediately. They didn't have one, but they thought that a sister mill did. That filter was shipped to the mill, but it was returned because no one knew what to do with it. In all, it took two weeks to get a bypass filter on the unit. In that time seven more bearings failed. The cost of the bearing was only about **$200**, but the cost of removing and re-installing the rolls was very high. Downtime on this machine costs the mill **$6000** per hour. The total cost of these failures was **$200,000** to **$300,000.** After the bypass filter was installed, there were no more failures.

E) A MAJOR PLASTICS MANUFACTURER
A late model Cincinnati-Milacron injection molder was scheduled to be sold. The oil cooler had broken, and the system was full of water, sludge and rust.

It was suggested that they flush the system with a lubricating and cleaning solvent. The flushing had to be accompanied by by-pass filtration with several filter buggies. The system was to be warmed and circulated thoroughly. The customer carried out this procedure, filled the system with oil, and went back into production.

The cost of replacing the injection molder was over **$250,000.** The flushing and filtration cost about **$3,000.**

F) A LARGE EARTH MOVING CONTRACTOR
This company operates the largest Caterpillar and Komatsu earth moving machines. These machines have a powershift transmission; gears can be selected without using a clutch. A powershift transmission is essentially a self-contained hydraulic system. It has a hydraulic pump, a multiple spool valve body for directing shift changes, and operating cyclinders.

A late model Komatsu bulldozer began to shift erratically. A portable filter patch test kit was used. The patch from the transmission was covered with large particles of dirt, sand and metal. The customer immediately changed the oil and filter, but the patch did not improve. A double filter buggy and extra filters were delivered on an emergency basis.