Hydraulic Fluid Contamination and Assessment

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About 95% of all hydraulic problems are cause by heat, assembly, and contamination.

Heat problems are generally a design problem.

Assembly could be improper hose installation.

Contamination is everyone’s concern.
You are a Fluid Power Machine

- Pump - Heart
- Arteries - Pressure Lines
- Veins - Return Lines
- Kidneys - Filter
- Kidney Loop - Off-line Filtration
- Muscles - Cylinders & Flow Controls
- Brain - PLC (Programmable Logic Controller)
- Our Sensors (Sight, Smell, Touch, & Hearing, - Instrumentation
- Nervous System - Servos & Proportional Control Systems
- Lungs - Pneumatic System
How careful do you want a hospital and doctor to be when working on you?

- That is how you should treat a hydraulic system, with the same cleanliness as human surgery.
Sizes of Particles in Micro-meters

- Grain of Table Salt 100
- Human Hair 70
- Lower Limit of Visibility 40
- White Blood Cells 25
- Red Blood Cells 8
- Average Bacteria 2
- 100 mesh screen = 149
- 325 mesh screen = 44
- 1 micro-meter = .000039 in or 39/1,000,000 of an inch
Sources of Contamination

1. New Oil

2. From manufacturing and handling of components during shipping and fabrication

3. Ingressed contamination

4. Wearing of components
Particles found in new fluids range from rust, dirt, sand, & water from either condensation or leakage into a container from sitting in the elements.

**Examples of Water**
Take a five gallon pail that has been empty and screw the cover back on and leave it outside in the rain. After a couple of good rains, you may have $\frac{1}{4}$” of water in the bottom of the pail and yet the cap was screw on tightly.
When stored properly, one can still find various particles.

New oil has a rating of approximately 33 micron or 17/16/14 on the ISO 4406 chart from a reputable supplier.

The Hydraulic Specialist study guide suggests that new oil is in the range of 20/18/14. That means there are between 81 and 160 particles 14 micron in size per ml.
**FLUID CLEANLINESS STANDARDS**

**ISO CODE**

Particles
≥ 4 microns

Particles
≥ 6 microns

Particles
≥ 14 microns

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**ISO 4406 CHART**

<table>
<thead>
<tr>
<th>RANGE NUMBER</th>
<th>NUMBER OF PARTICLES PER ml</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MORE THAN</td>
</tr>
<tr>
<td>24</td>
<td>80,000</td>
</tr>
<tr>
<td>23</td>
<td>40,000</td>
</tr>
<tr>
<td>22</td>
<td>20,000</td>
</tr>
<tr>
<td>21</td>
<td>10,000</td>
</tr>
<tr>
<td>20</td>
<td>5,000</td>
</tr>
<tr>
<td>19</td>
<td>2,500</td>
</tr>
<tr>
<td>18</td>
<td>1,300</td>
</tr>
<tr>
<td>17</td>
<td>640</td>
</tr>
<tr>
<td>16</td>
<td>320</td>
</tr>
<tr>
<td>15</td>
<td>160</td>
</tr>
<tr>
<td>14</td>
<td>80</td>
</tr>
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<td>13</td>
<td>40</td>
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<td>12</td>
<td>20</td>
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<td>11</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>2.50</td>
</tr>
<tr>
<td>8</td>
<td>1.30</td>
</tr>
<tr>
<td>7</td>
<td>.64</td>
</tr>
<tr>
<td>6</td>
<td>.32</td>
</tr>
</tbody>
</table>
Technical Data

Filter Efficiency Standards – ANSI-ISO Beta Ratio Information

1. BETA-Means counting particles less than 40 microns in size and using AC fine test dust (ACFTD) as test containment.

2. RATIO-I is:
   \[
   \text{Particle Count} \times \text{In Upstream Oil (one pass thru filter)} \over \text{Particle Count} \times \text{In Downstream Oil (one pass thru filter)}
   \]
   * The number of particles of a given size or greater per unit of volume.

3. Example:
   \[
   \frac{1,000 \text{ particles} \mu \text{ or greater in upstream oil sample}}{500 \text{ particles} \mu \text{ or greater in downstream oil sample}} = 2 \quad (\mu = \text{micron})
   \]

4. Terminology- \( B_{10} = 2 \) (Beta ten ratio equals two)

5. Other ratio numbers and equivalent efficiencies
   
   \[
   \begin{align*}
   \text{Beta}(x) = 1 & \quad \text{represents} \quad 0.00\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 1.14 & \quad \text{represents} \quad 12.28\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 1.5 & \quad \text{represents} \quad 33.33\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 2 & \quad \text{represents} \quad 50.00\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 3 & \quad \text{represents} \quad 66.67\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 4 & \quad \text{represents} \quad 75.00\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 10 & \quad \text{represents} \quad 90.00\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 16 & \quad \text{represents} \quad 93.75\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 20 & \quad \text{represents} \quad 95.00\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 50 & \quad \text{represents} \quad 98.00\% \text{ efficiency in one pass} \\
   \text{Beta}(x) = 75 & \quad \text{represents} \quad 98.67\% \text{ efficiency in one pass}
   \end{align*}
   \]

   **DON'T LET BETA RATINGS MISLEAD YOU**

   There is only one Industry Standard: ISO 4572.

   The ISO (International Standards Organization) 4572 standard was developed to create a common testing format for filter manufacturers to rate filter media efficiencies. This standardization gives the end user the ability to reliably compare published filter ratings between manufacturers. Part of that standard says the maximum reliable filtration ratio is \( \text{Beta}(x) = 75 \) (commonly known as the absolute rating). That's it. Anything above \( \text{Beta}(x) = 75 \) cannot be statistically verified. So, filters with ratings higher \( \text{Beta}(x) = 75 \) are immediately suspect in terms of reliable, consistent performance data.

6. A "2/20/75" rating for a filter media is the most common way of describing media efficiency on three particle sizes.

   A "2/20/75" rating of 5/10/15 means 50% efficiency on 5\( \mu \) or greater, 95% efficiency on 10\( \mu \) or greater, and 98.67% efficiency on 15\( \mu \) or greater particles in one pass.
Contamination Basics

Filtration Fact
Properly sized, installed, and maintained hydraulic filtration plays a key role in machine preventative maintenance planning.

Filtration Fact
The function of a filter is to clean oil, but the purpose is to reduce operating costs.

Contamination Causes Most Hydraulic Failures
The experience of designers and users of hydraulic and lube oil systems has verified the following fact: over 75% of all system failures are a direct result of contamination!

The cost due to contamination is staggering, resulting from:
- Loss of production (downtime)
- Component replacement costs
- Frequent fluid replacement
- Costly disposal
- Increased overall maintenance costs
- Increased scrap rate

Functions of Hydraulic Fluid
Contamination interferes with the four functions of hydraulic fluids:
1. To act as an energy transmission medium.
2. To lubricate internal moving parts of components.
3. To act as a heat transfer medium.
4. To seal clearances between moving parts.

If any one of these functions is impaired, the hydraulic system will not perform as designed. The resulting downtime can easily cost a large manufacturing plant thousands of dollars per hour. Hydraulic fluid maintenance helps prevent or reduce unplanned downtime. This is accomplished through a continuous improvement program that minimizes and removes contaminants.

Contaminant Damage
- Orifice blockage
- Component wear
- Formation of rust or other oxidation
- Chemical compound formation
- Depletion of additives
- Biological growth

Hydraulic fluid is expected to create a lubricating film to keep precision parts separated. Ideally, the film is thick enough to completely fill the clearance between moving parts. This condition results in low wear rates. When the wear rate is kept low enough, a component is likely to reach its intended life expectancy, which may be millions of pressurization cycles.

Actual photomicrograph of particulate contamination (Magnified 100x Scale: 1 division = 20 microns)
Where does manufacturing contamination come from?

- Components ports not plugged
- Components stored in bad environment
- Pumps/motors prefilled with dirty or unfiltered oil
- Use of floor dry or similar oil absorbents in shop areas
- Dirty hands, shop rags & lint used during assembly
- Dirty work benches
- Dirty oil in test bench use to performance check components
- Welding and fabrication contaminate
- Broken tools during manufacturing
- Fittings laying around and not cleaned
- Dirty hoses from assembly that were not cleaned and capped
- Assembly in a fabrication environment
- Dirty manufacturing procedures
- Dirty cutting fluid
- Improper flushing techniques
- Is a high enough velocity used to create flow turbulence when flushing parts?
- Dirty ports plugs
- Shop rags used to plug ports
- Not cleaning around ports before removing plugs for assembly
- Reservoirs not clean properly before assembly
- Filters on the shelf but not in sealed container
Contamination Types and Sources

Filtration Fact
New fluid is not necessarily clean fluid. Typically, new fluid right out of the drum is not fit for use in hydraulic or lubrication systems.

Filtration Fact
Additives in hydraulic fluid are generally less than 1 micron and are unaffected by standard filtration methods.

Types of Contamination
1. Particulate Silt (0-5μm) Chips (5μm+)
2. Water (Free & Dissolved)
3. Air

Particulate Contamination
Types
Particulate contamination is generally classified as “silt” or “chips.” Silt can be defined as the accumulation of particles less than 5μm over time. This type of contamination also causes system component failure over time. Chips on the other hand, are particles 5μm+ and can cause immediate catastrophic failure. Both silt and chips can be further classified as:

Hard Particles
– Silica
– Carbon
– Metal

Soft Particles
– Rubber
– Fibers
– Micro organism
Contamination Types and Sources

**Damage**

A. Three-body mechanical interactions can result in interference.
B. Two-body wear is common in hydraulic components.
C. Hard particles can create three-body wear to generate more particles.
D. Particle effects can begin surface wear.

**Sources**
- Built-in during manufacturing and assembly processes.
- Added with new fluid.
- Ingested from outside the system during operation.
- Internally generated during operation (see chart below).

**Generated Contamination**

**Abrasive Wear**—Hard particles bridging two moving surfaces, scraping one or both.

**Cavitation Wear**—Restricted inlet flow to pump causes fluid voids that implode causing shocks that break away critical surface material.

**Fatigue Wear**—Particles bridging a clearance cause a surface stress riser that expands into a spall due to repeated stressing of the damaged area.

**Erosive Wear**—Fine particles in a high speed stream of fluid eat away a metering edge or critical surface.

**Adhesive Wear**—Loss of oil film allows metal to metal contact between moving surfaces.

**Corrosive Wear**—Water or chemical contamination in the fluid causes rust or a chemical reaction that degrades a surface.

If not properly flushed, contaminants from manufacturing and assembly will be left in the system.

These contaminants include dust, welding slag, rubber particles from hoses and seals, sand from castings, and metal debris from machined components. Also, when fluid is initially added to the system, contamination is introduced.

During system operation, contamination enters through breather caps, worn seals, and other system openings. System operation also generates internal contamination. This occurs as component wear debris and chemical byproducts react with component surfaces to generate more contamination.
Contamination Types and Sources

**Water Contamination**

**Types**
There is more to proper fluid maintenance than just removing particulate matter. Water is virtually a universal contaminant, and just like solid particle contaminants, must be removed from operating fluids. Water can be either in a dissolved state or in a “free” state. Free, or emulsified, water is defined as the water above the saturation point of a specific fluid. At this point, the fluid cannot dissolve or hold any more water. Free water is generally noticeable as a “milky” discoloration of the fluid.

**Typical Saturation Points**

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>PPM</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic Fluid</td>
<td>300</td>
<td>.03%</td>
</tr>
<tr>
<td>Lubrication Fluid</td>
<td>400</td>
<td>.04%</td>
</tr>
<tr>
<td>Transformer Fluid</td>
<td>50</td>
<td>.005%</td>
</tr>
</tbody>
</table>

**Visual Effects Of Water In Oil**

- 1000 ppm (.10%)
- 300 ppm (.03%)
Contamination Types and Sources

**Effect Of Water In Oil On Bearing Life**

<table>
<thead>
<tr>
<th>% Water In Oil</th>
<th>% Bearing Life Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0025%</td>
<td>25 ppm</td>
</tr>
<tr>
<td>0.01%</td>
<td>100 ppm</td>
</tr>
<tr>
<td>0.05%</td>
<td>500 ppm</td>
</tr>
<tr>
<td>0.10%</td>
<td>1000 ppm</td>
</tr>
<tr>
<td>0.15%</td>
<td>1500 ppm</td>
</tr>
<tr>
<td>0.25%</td>
<td>2500 ppm</td>
</tr>
<tr>
<td>0.50%</td>
<td>5000 ppm</td>
</tr>
</tbody>
</table>

Effect of water in oil on bearing life (based on 100% life at .01% water in oil.)

**Sources**
- Worn actuator seals
- Reservoir opening leakage
- Condensation
- Heat exchanger leakage

Fluids are constantly exposed to water and water vapor while being handled and stored. For instance, outdoor storage of tanks and drums is common. Water may settle on top of fluid containers and be drawn into the container during temperature changes. Water may also be introduced when opening or filling these containers.

Water can enter a system through worn cylinder or actuator seals or through reservoir openings. Condensation is also a prime water source. As the fluids cool in a reservoir or tank, water vapor will condense on the inside surfaces, causing rust or other corrosion problems.
Contamination Types and Sources

Filtration Fact
A simple ‘crackle test’ will tell you if there is free water in your fluid. Apply a flame under the container. If bubbles rise and ‘crackle’ from the point of applied heat, free water is present in the fluid.

Filtration Fact
Hydraulic fluids have the ability to ‘hold’ more water as temperature increases. A cloudy fluid may become clearer as a system heats up.

Damage
- Corrosion of metal surfaces
- Accelerated abrasive wear
- Bearing fatigue
- Fluid additive breakdown
- Viscosity variance
- Increase in electrical conductivity

Anti-wear additives break down in the presence of water and form acids. The combination of water, heat and dissimilar metals encourages galvanic action. Pitted and corroded metal surfaces and finishes result. Further complications occur as temperature drops and the fluid has less ability to hold water. As the freezing point is reached, ice crystals form, adversely affecting total system function. Operating functions may also become slowed or erratic.

Electrical conductivity becomes a problem when water contamination weakens the insulating properties of a fluid, thus decreasing its dielectric kV strength.

Typical results of pump wear due to particulate and water contamination
Clearance between the spool and the housing is .000100

Distance per side is .000050

1 micron or 1 micrometer is .000039 inch

Filtration to stop wear should be 1 micron in size
In an electrically operated valve, the forces acting on the solenoid are: flow forces, spring forces, friction forces and inertia forces.

Flow, spring and inertia forces are inherent factors, but friction forces are to a great extent dependent on system cleanliness. If the system is heavily contaminated with particles similar in size to the radial and diametrical clearances, higher forces will be needed to move the spool.

An even worse situation results from siting, where contaminant is forced into the clearances under pressure, eventually leading to breakdown of the oil film and spool binding.

This situation occurs when valves subjected to continuous pressure are operated infrequently. Such valves should preferably have local filtration of a high efficiency in the pressure line, but due account should be taken of possible pressure surges generated during component operation. The use of filters as a special protection for single units or groups of units can result in the need for a large filter element of high capacity, if the general cleanliness level in the system is poor.

Some idea of the forces needed to break this spool binding, compared with the force available from the solenoid, can be gained from the example of a CETOP 3 valve operating at 3000 psi (210 bar). If a valve of this type remains in the spring offset or energized position for a lengthy period of time, siting takes place between spool and core and can cause total immobility. The force needed to overcome this state has been found through experiments to be approximately 30 pounds, but both spring and solenoid are designed to exert only 10 pounds. The effect of the excessive siting can be total system failure.
Contamination Basics

The actual thickness of a lubricating film depends on fluid viscosity, applied load, and the relative speed of the two surfaces. In many components, mechanical loads are to such an extreme that they squeeze the lubricant into a very thin film, less than 1 micrometer thick. If loads become high enough, the film will be punctured by the surface roughness of the two moving parts. The result contributes to harmful friction.

### Typical Hydraulic Component Clearances

<table>
<thead>
<tr>
<th>Component</th>
<th>Microns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-friction bearings</td>
<td>0.5</td>
</tr>
<tr>
<td>Vane pump (vane tip to outer ring)</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Gear pump (gear to side plate)</td>
<td>0.5-5</td>
</tr>
<tr>
<td>Servo valves (spool to sleeve)</td>
<td>1-4</td>
</tr>
<tr>
<td>Hydrostatic bearings</td>
<td>1-25</td>
</tr>
<tr>
<td>Piston pump (piston to bore)</td>
<td>5-40</td>
</tr>
<tr>
<td>Servo valves flapper wall</td>
<td>18-63</td>
</tr>
<tr>
<td>Actuators</td>
<td>50-250</td>
</tr>
<tr>
<td>Servo valves orifice</td>
<td>130-450</td>
</tr>
</tbody>
</table>

### Relative Sizes of Particles

<table>
<thead>
<tr>
<th>Substance</th>
<th>Microns</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain of table salt</td>
<td>100</td>
<td>.0039</td>
</tr>
<tr>
<td>Human hair</td>
<td>70</td>
<td>.0027</td>
</tr>
<tr>
<td>Lower limit of visibility</td>
<td>40</td>
<td>.0016</td>
</tr>
<tr>
<td>Milled flour</td>
<td>25</td>
<td>.0010</td>
</tr>
<tr>
<td>Red blood cells</td>
<td>8</td>
<td>.0003</td>
</tr>
<tr>
<td>Bacteria</td>
<td>2</td>
<td>.0001</td>
</tr>
</tbody>
</table>

### Micrometer Scale

Particle sizes are generally measured on the micrometer scale. One micrometer (or “micron”) is one-millionth of one meter, or 39 millionths of an inch. The limit of human visibility is approximately 40 micrometers. Keep in mind that most damage-causing particles in hydraulic or lubrication systems are smaller than 40 micrometers. Therefore, they are microscopic and cannot be seen by the unaided eye.
Ingressed Contamination

- Reservoir vent port
- Access covers not sealed
- Components ports left open
- Cylinder wiper seals damage by outside sources such as rust or nicks in rods
- Cavitation
- Wear of components cause by dirty oil or too low of viscosity of oil
- Wrong or poor additives
- Too course of filtration
Wearing of Components

Motors
What has been written about pumps applies generally to motors because of their similar design. It must be remembered that a majority of the contaminant passing through the pump will also reach the motor where it will cause a similar performance degradation. If, for example, due to wear, the volumetric efficiency of the pump falls to 85% of its original value and the volumetric efficiency of the motor falls to 90% of original, then the overall volumetric efficiency of the pump and motor will drop to $0.85 \times 0.9 = 76.5\%$ of the original value.

Hydrostatic Transmission
Hydrostatic transmissions most often consist of a servo controlled pump and a fixed volume motor. Wear to a critical surface in any component will degrade the overall performance of the transmission. Failure of a component can spread debris throughout the system causing extensive and expensive secondary damage. High efficiency filtration is a key factor in achieving long, reliable service from a closed loop hydrostatic transmission.

Directional Valves
In most directional valves, the radial clearance specified between bore and spool is between 4 to 13 micrometers. As is well known, the production of perfectly round and straight bores is exceptionally difficult, so it is unlikely that any spool will lie exactly central in the clearance band. In a CETOP 3 valve, a spool is likely to have less than 2.5 micrometers clearance.
Piston head contamination damage — Shoes can also become loose on the piston head as a result of severe scoring and pitting from contamination.

Ruined Pistons

Telltale effects of contamination and seizing on the piston diameter can be seen in these photos. Pistons in this condition cannot be reworked.
Examples of Wear on Components

Examples of Wear on Actual Vickers Components

Vickers guide to Pump Failure Analysis contains many examples of failures caused by contamination. Typical contamination damage to a piston/shoe, piston and cylinder block is shown here.

Summary

As explained above, an individual large particle arriving at the wrong place at the wrong time can cause catastrophic failure. A small quantity of silt-sized particles can also cause problems by eroding a surface or by building up in a critical area.

Surfaces within components are designed to be separated by an oil film, the thickness of which may be continually changing. When this gap is bridged by contaminants, wear will occur, thereby generating further particles which may be ground into many more smaller particles. Fine particles, individually or in small quantities, may not cause damage. But if present in slightly higher concentrations, they can lead to failure through sifting.

Piston Pump Failures—Cylinder Block

The individual cylinder bores within a cylinder block are prone to excessive wear and tear. This can be due to dry run, lack of lubricity in the fluid or contaminants. Cylinder blocks with worn or scored bores should never be reused.

The top surface of a cylinder block that contacts the valve plate can also become scored or pitted due to improper operating conditions such as aeration, cavitation, contamination and high system temperature.
Special Thanks

Thanks to our industry partners for their contribution with this presentation:

Eaton/Vickers Corporation & Parker Hannifin Corporation

Please continue your education by checking out the following:

*The Systemic Approach to Contamination Control* By Vickers

*The Handbook of Hydraulic Filtration* By Parker