Maintenance & Safety

Maintenance

We perform maintenance to:

- **Reduce wear**. Solid components wear when they come in physical contact; therefore, maintaining seals and lubrication systems will prevent metal-to-metal contact. Parts last longer, and machines run more efficiently (less energy is required).
- **Reduce corrosion.** Corrosion by-products are highly abrasive (oxides are minerals). By preventing corrosion, parts will last longer.
- **Repair leaks.** A leak-free system requires less working fluid, and less energy to compress the air or pump the hydraulic oil. In a hydraulic system, leaks require environmental cleanup.
- **Replace broken parts.**
- **Replace parts before they fail.** The airline industry uses this approach to prevent in-flight failure.

The common denominator in all of these cases is money...it's cheaper to perform maintenance now than to delay it.

Think of a manufacturing line with 20 people earning $15/hour in wages and benefits, producing 40 parts per minute, with $3 value added per part. What does an hour of downtime cost?

Assuming you can't assign the production workers to other tasks during the downtime, the cost of their labor is
$\dfrac{1\,\text{h}}{}\dfrac{20\,\text{people}}{}\dfrac{\$15}{\text{person hour}}=\$300$ lost labor . The parts we didn't make during the downtime have a value of
$\dfrac{40\,\text{parts}}{\text{min.}}\dfrac{60\,\text{min.}}{}\dfrac{\$3}{\text{part}}=\$7200$ lost parts . The cost of 1 hour of downtime is $7500 labor and parts not made, in addition to whatever repair costs are associated with the production machines. Of course, you can make the parts at the weekend, but then you'll have to pay overtime.

I worked for a company that manufactured oil filters in a large factory. The maintenance department did not have enough technicians to perform preventive maintenance on all machines, so some production line workers would come in on a Saturday to maintain their own machines. Management tried to save money by cutting out weekend overtime; the result was reduced productivity, because machines that used to be maintained on weekends were now neglected, and broke down during the workweek. In the end, management reinstated weekend overtime, and the machines ran well again.

The textbook states that half of all hydraulic system problems can be traced to the oil, in the form of:

- **Particulates.** Hard particles cause wear, which can lead to internal or external leakage, or part failure. Hard or soft particles can clog nozzles, orifices, and small passages.
- **Water.** In a warm fluid power system, water can cause corrosion; in a cold system it can freeze, splitting pipes.
- **Chemical breakdown.** When hydraulic oil gets too hot, it forms acidic compounds which attack the metal.
- **Leakage.** Internal leakage (past a seal in a cylinder piston) reduces efficiency, so energy costs rise and output power drops. External leakage (past a seal on a cylinder rod) also reduces efficiency, and in a hydraulic system can lead to fluid costs, cleanup, and air entrapment in the oil.

Where do particulates come from? There are three sources:

- **Built-in during assembly.** Metal chips from threading operations, pipe dope, sealant, weld beads, and solder beads are all sources of built-in contamination.
- **Generated internally.** Wear particles, rust scale, worn seal materials, and paint chips (if any internal parts are painted).
- **Introduced from outside.** Debris from dirty rags or funnels used in maintenance, or contaminated hydraulic fluid added to the system.

If the particulates are made of steel or iron, we can use magnets to trap them; otherwise, we need filters. We can characterize filters with five properties.

Filter Efficiency

The *efficiency* of a filter is the ratio of the number of particles trapped by the filter to the number of particles presented to the filter. So efficiency must be related in some way to the size of the particles. Consider this wire mesh screen filter. Its filtration efficiency for particles the size of the blue dot is close to 0% (not exactly 0%, because some particles may stick to the mesh). Filtration efficiency with for particles the size of the red dot is 100%...so clearly we need to specify efficiency *and* the particle size we're considering. The screen in your kitchen window is sized to keep out 100% of all mosquitoes, maybe 80% of gnats, and 5% of pollen particles (because they tend to clump).
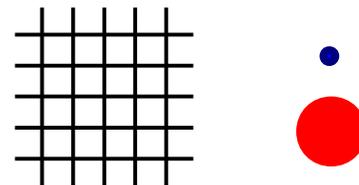
Beta Ratio

The *beta ratio* is the number of particles upstream of the filter that are bigger than a certain size, divided by the number of particles that get through the filter that are bigger than that size. We measure the size in microns (1 μm = 1 millionth of a meter, about 39 millionths of an inch). We write $\beta_N = \dfrac{\text{\# of upstream particles} > N \text{ μm}}{\text{\# of downstream particles} > N \text{ μm}}$. For example, if we had $\beta_{20} = 50$, that means that one in fifty particles measuring 20 microns will make it through the filter; 49 out of 50 are trapped by the filter.
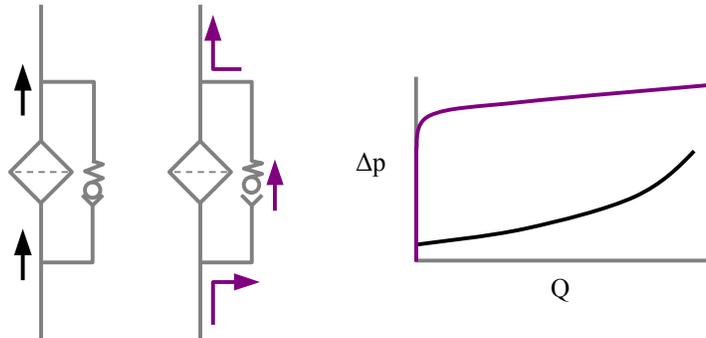
Capacity

The *capacity* of a filter is the amount of dirt the filter will hold before it becomes plugged. We send through a standardized test dust, specified by ISO 12103. Contaminated fluid goes in one side, and clean fluid comes out the other side. As dirt builds up on the filter, it gets harder for fluid to pass through, and the pressure drop across the filter increases. Once the pressure drop achieves some limit, we say the filter is clogged. The amount of dirt that caused it to clog is called the capacity of the filter.

It's impossible to make dust all in one size, so actual test dust contains a range of particle sizes. For example, fine grade test dust contains 2.5% to 3.5% of particles under 1 μm. About half of the particles are under 10 μm, and all particles are under 120 μm.

Size (μm)	Ultrafine (vol.% less than)	Fine (vol.% less than)	Medium (vol.% less than)	Coarse (vol.% less than)
1	1.0 – 3.0	2.5 – 3.5	1.0 – 3.0	0.6 – 1.0
2	9.0 – 13.0	10.5 – 12.5	4.0 – 5.5	2.2 – 3.7
3	21.0 – 27.0	18.5 – 22.0	7.5 – 9.5	4.2 – 6.0
4	36.0 – 44.0	25.5 – 29.5	10.5 – 13.0	6.2 – 8.2
5	56.0 – 64.0	31.0 – 36.0	15.0 – 19.0	8.0 – 10.5
7	83.0 – 88.0	41.0 – 46.0	28.0 – 33.0	12.0 – 14.5
10	97.0 – 100	50.0 – 54.0	40.0 – 45.0	17.0 – 22.0
20	100	70.0 – 74.0	65.0 – 69.0	32.0 – 36.0
40		88.0-91.0	84.0 – 88.0	57.0 – 61.0
80		99.5 – 100	99.0 – 100	87.5 – 89.5
120		100	100	97.0 – 98.0
180				99.5 – 100
200				100

Flow Rate & Pressure Drop

The fourth and fifth properties that characterize filters are *flow rate* and *pressure drop*. The two are interrelated. If we send fluid through a filter that has a spring-loaded bypass check valve, the pressure drop across the filter will rise as the flow rate rises (black line on the graph). If the filter is plugged, then fluid will go through the bypass valve (purple line on the graph). Even though you're sending contaminated oil past the filter, it's better than starving the downstream equipment of oil. Typically, this spring-loaded check valve is built into the filter, so it's replaced every time you change out the filter.

We have a couple of options for building a filter. If we use a wire mesh, we get:

- **Low pressure drop.** Energy consumption is low.
- **Coarse filtration.** Efficiency and capacity are low.
- **Cleanable.** Particles sit on the surface of the mesh, so if the filter is hard to reach, you can backflush it and drain the flushing fluid.

If we use cellulose and man-made fibers, we can build a *depth filter* out of paper, string, or pressed fiber. Now we get

- **Higher pressure drop.** Energy consumption is higher.
- **Finer filtration.** Efficiency and capacity are higher.
- **Disposable.** Particles are trapped *within* the media, so you can't clean the filter; instead, throw it away when it's full.
- **Lower purchase price.** Paper is much cheaper than screen wire.

If the pressure drop is high, then a paper filter may tear. To prevent this problem, paper media is sometimes backed with screen wire, or sandwiched between screen wire.

We filter to prevent failure of three types:

- **Catastrophic failure.** A particle gets stuck in a pump, cylinder, or motor, and it jams.
- **Intermittent failure.** A particle settles on a poppet valve, which doesn't reset. The particle is washed out next time the poppet opens fully. Intermittent failures are harder to diagnose because they're not easily repeatable.
- **Degradation failure.** Wear, corrosion, and cavitation.

In order to prevent these types of failure, we have to know something about the hardware we're trying to protect. The table at the right lists clearances between moving parts in various hydraulic components. Clearances determine the level of filtration we need. If the clearance is as small as ½ a micron, then we have to filter out particles that could get stuck in that size gap.

	Clearance (µm)
Gear pump	0.5 to 5
Vane pump	0.5 to 1
Piston pump	0.5 to 5
Control valve	1 to 23 (spool sleeve)

Once we know how clean the oil has to be, we need some way of characterizing how much dirt is in the oil.

There are several standards for oil cleanliness; the numbers for ISO 4406-1999 are listed in the table. This is nearly the same as the table in the textbook. Under an old ISO standard (described in the textbook) you use *two* numbers to define the cleanliness of a hydraulic oil. The first number is for particles bigger than 5µm. The second number is for particles bigger than 15µm. For example, to interpret ISO 15/12:

ISO number	Particles per ml
22	20 000 – 40 000
21	10 000 – 20 000
20	5 000 – 10 000
19	2 500 – 5 000
18	1 300 – 2 500
17	640 – 1 300
16	320 – 640
15	160 – 320
14	80 – 160
13	40 – 80
12	20 – 40
11	10 – 20
10	5 – 10
9	2.5 – 5
8	1.3 – 2.5
7	0.64 – 1.3

- The 15 means we have 320 particles bigger than 5µm in every ml of oil.
- The 12 means we have 40 particles bigger than 15µm in every ml of oil.

Under the current ISO 4406 standard, you use *three* numbers to define oil cleanliness; the first number is for particles bigger than 4µm, the second for particles bigger than 6µm, and the third for particles bigger than 14µm. For example, to interpret ISO 16/14/11:

- The 16 means we have between 320 and 640 particles bigger than 4µm in every ml of oil.
- The 14 means we have between 80 and 160 particles bigger than 6µm in every ml of oil.
- The 11 means we have between 10 and 20 particles bigger than 14µm in every ml of oil.

Fluid power component manufacturers publish cleanliness requirements for their parts, so you know what type of oil to buy.

Safety

The textbook has one page on safety, and this topic is not in the index. Engineering design is all about planning for failure. Every mechanical, electrical, or fluid device will fail someday under some circumstance, so we build in *fail-safe* design features. Fail-safe means that *when* a component or system fails, nothing bad happens. Fail-safe does *not* mean the component or system cannot fail. Some examples of fail-safe design include:

- **Hydraulic test stand fittings.** All hoses and fittings have bult-in check valves. If you don't make a good connection, oil doesn't spurt out.
- **PRV.** Both hydraulic test stands use pressure relief valves to prevent excess pressure from building up. PRVs are used on water heaters for the same reason.
- **Electrical fuses and circuit breakers.** Electrical systems are protected from melting or causing fires.

Fail-safe behavior is also important. It's important to develop safe work habits, because people are creatures of habit. Examples in the fluid power lab:

- **Safety glasses.** If you're in the habit of wearing eye protection in the lab, you don't have to think about whether a test stand is running or not.
- **Door locks.** If you are in the habit of leaving the lab door unlocked while in the lab, then rescue will be faster if there is an emergency. The first responder may not be a firefighter...it could be a technician or secretary without a key.

Finally, it' important to fully train operators so they understand what can go wrong and what to do, not just how to run the machine.