Understanding Hydrostatics:
An Essay of Details, Idiosyncrasies
and Easily Misunderstood Concepts

Fluid Conditioning

QSINE

Understanding Hydrostatics: An Essay of Details, Idiosyncrasies and Easily Misunderstood Concepts - Fluid Conditioning
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Preface

Often when we at Qsine are implementing hydraulic systems we are faced with questions like: “Why do you do that?”; “What does this one do that That one won’t?”

In many circumstances the questions arise with the focus on cost differences but in far more circumstances we see that the questions should arise when there are no cost differences. Like many things, high quality hydraulic systems often go unnoticed but poor quality ones get a lot of attention.

People familiar with hydraulics know from experience that components span very broad ranges of quality, performance and price. However, creating a high quality system requires more than simply piecing high quality components together. A system’s overall quality results from the mix between understanding basic, fundamental concepts and focusing on intricate details.

Strong knowledge of fundamentals will get to effective solutions but it is only after proper attention has been paid to details that high quality systems emerge. We have seen many very good (and often expensive) systems crippled by either the lack of attention or misunderstanding of fine details. Performance, reliability and life fell short of expectations even though the system was schematically correct and efficient.

We have helped many of our customers make decisions about hydraulic equipment by sharing our experiences with them over the years. However, we have noticed that our verbal tips and coaching are quickly forgotten. This seems only natural since the client’s primary concerns are what the hydraulic systems are doing and not how they are doing it. Our intention is to write a series of papers, or tips, on both the basic concepts and the details of hydraulic systems that we have found important.

The series “Understanding Hydrostatics: An Essay of Details, Idiosyncrasies and Easily Misunderstood Concepts”, is a reference that focuses on refinements. The techniques are geared towards performance enhancements through craftsmanship more than system functionality and design skills. Hence, information presented in the Series will not generally be recordable in schematic or logic diagrams.

SUMMARY

Here is a tip sheet and check list for reservoirs and filters pertaining to fluid conditioning. Detailed discussion for these tips follow.

Reservoirs

- Use a round reservoir that will allow the fluid to swirl or circulate to improve heat, air and particle removal.
- To make the fluid swirl and maximize the reservoir performance ensure that the reservoir is ported such that:
  - Return oil enters well below oil level to prevent aerating the oil and direct it along the tangent of the tank to force the swirl.
  - The pump inlet faces into the swirl and is offset from the edge of the reservoir. This will improve cavitation resistance by feeding the pump with a positive pressure and prevent particles from entering the pump.
  - The case drain ports are well below oil level to prevent aerating.
  - There is a drain at the lowest point of the tank to drain off condensation and other contamination.
- Ensure that the fluid is deep enough to prevent vortexing.
- Acid dip (pickle) steel tanks to remove mill scale and oil the inside to prevent rusting.
- Paint the reservoir with a light color to radiate and reflect heat.
- Ensure there is a large, sealed, access cover for cleaning.
- Clean the reservoir’s inside thoroughly, removing all metal chips, dust and welding slag and cap or plug all openings before installation.
- Ensure there is a fluid level sight indicator or dipstick.
- Use a 10 micron or finer breather and avoid pressurized breathers if possible.
- Always use a filter cart to transfer fluid into a reservoir.

Filters

- Use a 10 micron, return filter for most low-mid performance systems.
- Consult your fluid manufacturer for approval if you use a filter finer than 10 micron.
- Avoid inlet or suction strainers and remove them if they come with a piece of equipment. An inlet strainer that is catching contamination is an indication of a procedural problem surrounding the system.
- Use pressure filters when downstream component are safety or up time critical and/or expensive relative to the filter.
- When using pressure filters, avoid bypasses and adhere to strict service intervals.
- In general, replace the first filter element after 10-25 hours of operation and subsequent filters at 250-500 hour intervals.
- Fluid changes can generally be made at 1500-2000 hour intervals.
- Filter and fluid analysis tests are the best way to determine service intervals.
- Ensure you filters are located for convenient service.
- Set up a service log and ensure filter replacements occur on schedule.

INTRODUCTION

75-85% of all hydraulic failures are due to
poor hydraulic fluid conditioning.

The above fact is widely known in the fluid power industry. It implies that hydraulic machinery fails only 15-25% of the time due to old age, manufacturer's defects, misapplication etc. It also implies that improving fluid conditioning can greatly reduce maintenance costs, downtime and aggravation.

What exactly is "hydraulic fluid condition"? And what makes it poor or good?

Fluid condition is a statement of a fluid's purity, or conversely, a measurement of its contamination. Contamination is anything that hinders or inhibits a fluid from performing any of it's main duties: to transmit power, to lubricate components and to cool the system. Elements such as solid particles, air, water and heat are all considered fluid contamination. Air increases the compressibility of the fluid making it an inefficient power transmitter. Particles, air and water cause scoring and scuffing inside the hydraulic components. Air, water and heat all breakdown anti-foaming, lubrication and viscosity additives in the fluid, resulting in excessive component wear.   This wear degrades the component's performance and adds further contamination (particles and heat) to the fluid.

A system must be able to prevent contamination ingestion and promote contamination removal to maintain good fluid condition.

UNDERSTANDING PARTICLE CONTAMINATION

Contamination seems like a simple concept but it's details are often misunderstood. First of all, how does contamination get into a system? Contamination comes from component wear or failure during operation, ingestion from the environment during operation and it gets in during manufacturing, assembly and in field servicing.

It has been our experience that contamination entry during manufacturing and assembly is the least understood and the most misunderstood form of particle contamination.

Clean Reservoirs

Most reservoirs are manufactured from steel which has a hard, black, very abrasive mill scale on the surface. Hydraulic oil detergents and additives attack the mill scale releasing it from the inside of the reservoir where it will circulate through the hydraulic system. This is apparent in many old reservoirs where the mill scale is still present above the oil line and the steel is completely bare below it. We recommend that all hydraulic reservoirs, after fabrication is completed, be acid dipped to remove the mill scale and then oiled to prevent corrosion.

The reservoirs must also be thoroughly cleaned before being put into service. Welding and machining are required to install porting and access covers etc. Weld slag and machining chips, including any metallic dust, must be removed and all openings must be plugged before the reservoir is installed. Often people will not take the time to properly clean a tank because they believe that the filter will catch it all anyway. This is incorrect. A filter will not catch everything and often there is enough contamination to clog a filter and force the dirty fluid through the bypass or even collapse a filter element in the absence of a bypass.

To be cleaned easily, a reservoir must have a large, sealed access cover. The access cover will also be necessary for field service in the event of a component failure. Systems using reservoirs which cannot be cleaned are often unsalvageable after one component failure because the contamination cannot be removed satisfactorily.

Dirty New Oil

Contamination can also enter system from the fluid itself; even new oil. We have found that oil containers, from 45 gallon drums to 1 liter bottles, are contaminated right from the source. The slag that causes problems in reservoirs is also causing problems in the refining and packaging processes. During field servicing the fluids are often topped up via open topped buckets. A small, portable filter cart can be used in the shop or in the field. We recommend that systems always be filled or topped up using filter carts. Generally, a filter cart is inexpensive especially compared to the price of the equipment that it is filling.

Breathing

Contamination will also enter a hydraulic system from the environment during normal operation. The fluid level will change in any system as the fluid expands and contracts with temperature. Systems driving cylinders will experience significant level changes as fluid moves to and from the cylinder. The varying fluid level requires the reservoir to “breathe”. A good filler/breather will always be a benefit. We recommend a breather with a 10 micron element or finer. Ensure that the breather you select will permit air to flow freely (ie. not create vacuum or back pressure).

Pressurized breathers are also available. As the system warms up, the breather will maintain pressure in the reservoir. The positive pressure will keep contamination out and improve cavitation resistance. Use pressurized breathers with caution though; reservoirs that have large flat walls will tend to balloon. Back pressure in the tank is harder on pump and motor shaft seals and will increase leakage across worn seals. Pressurized breathers are ineffective for most cylinder applications because of the large fluid volume changes that occur in the reservoir. We recommend avoiding the use of pressurized breathers except for high altitude applications.

HYDRAULIC RESERVOIRS

Why discuss fluid conditioning, particularly contamination prevention and removal, by starting with hydraulic reservoirs? Many books and people start by stating the benefits of filters, strainers and coolers at this point and, generally, never even talk about reservoirs for fluid conditioning. However, the reservoir is the main fluid conditioning component in a system. A reservoir that is designed and built to condition the fluid, as opposed to just hold it, will supplement a filter, often out perform a cooler, outperform a strainer and not have the drawbacks of a strainer.

Generally, the reservoir holds the greatest proportion of oil in the system. So let's pose the question: Why not have just enough fluid to fill the pump and cylinder or motor and other components?

First of all, the capacity of a reservoir is not meant to compensate for any external leaks. Every component in a system has some inefficiencies, and when a system is working, these inefficiencies create heat and cause the system to warm. Contamination from wearing components gets into the fluid as does condensation from temperature cycles. Agitation, which is present particularly in mobile equipment, will cause the fluid to aerate. The reservoir's main function is to rejuvenate the fluid by dissipating all of the different types of contamination.

- *As a side note, a system that runs very hot does not necessarily have too small of a reservoir, it may be a poor or very inefficient concept for providing the required function.*

Reservoir Features

In general, a reservoir should be constructed high and relatively narrow as opposed to shallow and broad. This keeps the oil level well above the pump inlet to prevent vortexing and subsequent air entry into the pump. The return port should be submerged well below the oil level to prevent frothing or aerating of the oil.

For maintenance purposes, a reservoir needs to be equipped with a sight level gauge or a dip stick, an accessible filler/breather at the top of the tank, an accessible drain located at the lowermost point of the tank and an access cover to allow easy cleaning.

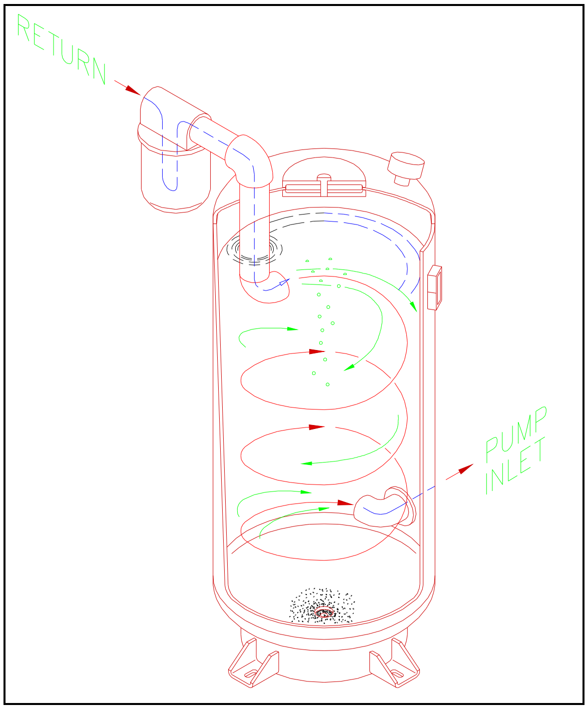

Figure 1. Round Reservoir

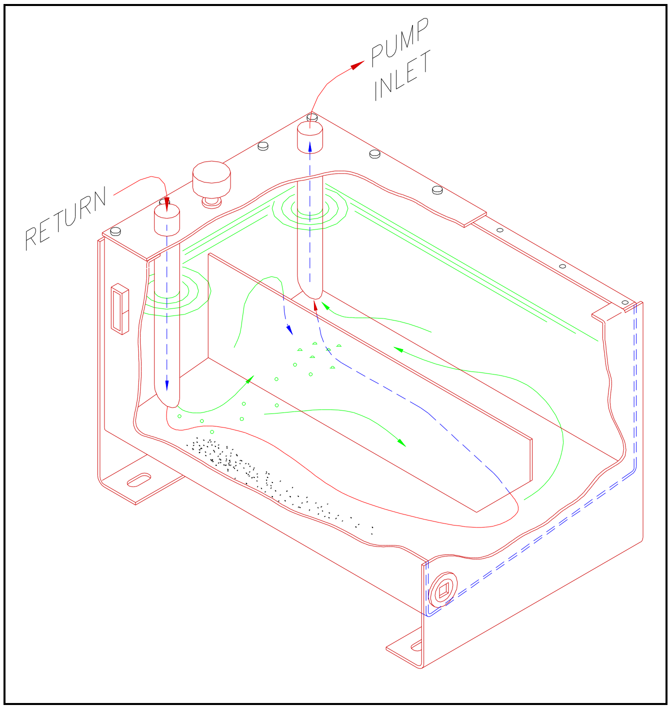

Figure 2. Rectangular Reservoir

For most applications, we recommend using round reservoirs (Figure 1) as opposed to rectangular reservoirs (Figure 2). The main advantage round tanks have over rectangular ones is that the oil can be swirled as illustrated. In a rectangular tank, fluid travels either around the baffle or over the baffle as shown. Even in the best case, as shown, the fluid flows along three of the four sides using the maximum distance in the tank. However, the flow path is point to point and circulation cannot be established. In many cases the situation is worse. If the return and pump inlet lines are placed closer together, it creates a dead volume in the tank where fluid does not flow at all.

For a given flow rate and considering the large cross section of the reservoir the average velocity of the fluid is very slow. Further, the moving fluid will tend to “tunnel” through the stationary fluid. Along the surface of the tank, particularly in the corners, the fluid is stagnant and thus cooling is inhibited.

In a round tank, a circulating path is inherent. Thus, fluid does not necessarily have to be on a direct path to the pump inlet to be in motion. A given volume of fluid may circulate around the circumference many times before it enters the pump. The swirling motion in a round tank utilizes the entire circumference of the tank for cooling. As a result, there very little stagnant fluid along the surface of the tank. The excess heat dissipation is generally greater than 25% compared to a rectangular tank of equivalent volume capacity.

We recommend painting the reservoir a light color. This will help cooling by radiating more heat and absorbing less.

The swirling also acts as a centrifuge, liberating trapped air and solid contamination. Air, being lighter than oil, is forced towards the center where the oil velocity is low and then floats to the surface. Solid contaminants, which are heavier than oil, either settle through the center or get forced out to the surface of the tank where they are harmless and eventually settle out. It is important to keep the velocity of the swirl slow enough to prevent holding particles in suspension and to avoid vortexes.

We recommend that the pump inlet face into the swirl. The energy of swirling fluid tends to place a positive pressure on the pump inlet which inhibits cavitation. The inlet should also be offset inwards from the tank's surface to prevent drawing in particles that are centrifuged to the outside.

Round tanks normally have spherical ends which, on vertical tanks, creates an ideal location for a tank drain. Being the low point, it is simple to drain off any accumulated condensation or settled particles.

FILTERS

First an opening remark:

> Many times we have seen people expect too much from their filters. For a filter to be effective, it must be in conjunction with, not instead of, good practices. Good practices are any procedures that prevent contamination from getting into the system and many are described above in *UNDERSTANDING PARTICLE CONTAMINATION*. The filter should only be depended upon to remove the contamination that cannot be prevented.

There are many types of filters, each meant for certain conditions caused by either the environment surrounding a system or the components within a system. We have found that giving general advice on selecting filters is dangerous but even more dangerous is taking under qualified advice. With this in mind, we felt it more appropriate to bring forward what filters should and should not be expected to do instead of giving a procedure on how to select one. The ability to properly select filters will require you to perform dedicated studies in order to interpret often non-standardized data and to discern accurate data by technically innovative companies from copied data by “me-too” companies. This however, is not a reason to throw up your hands and quit.

In many cases, filter selection is neither a difficult nor a critical procedure. High performance, high duty cycle and high cost systems are the most likely candidates for a comprehensive filter study. Keep in mind that a filter is a protective device and a suitable filter's cost should be compared to the value of the system it is protecting and not to the cost of other types of filters.

Generally, we classify systems that consist of components rated for 3,000 psi or less as low to mid performance systems. All gear pumps and motors and most open loop piston pumps are in this class. Most mobile control valves, cartridge valves, solenoid valves and many proportional electro-hydraulic controls are also in this classification. Pumps, motors and controls rate for 5,000 psi or higher and high accuracy proportional and servo electro-hydraulic controls are all considered high performance equipment.

For low to mid performance systems, we have had good success with 10 micron, paper element, return line, hydraulic filters. However, filter technology is improving and we are now moving towards synthetic elements with finer particle ratings. As of September 1998 we lack sufficient experience to make recommendations on these filters. Most of our fluids seem compatible with the filters and we foresee positive results in the long term. This paper will be updated when conclusive results are available.

Selecting a filter for high performance and/or critical applications is a meticulous task. We recommend that you get assistance from someone knowledgeable and trustworthy if you are at all uncomfortable with performing the task yourself.

The following discussion has been included to explain some filter terminology and will help to get you started in understanding filter performance:

Service Intervals and Testing

For most systems, filters should be replaced after the first 10-25 hours of operation and at 250-500 hour intervals thereafter. In extreme applications such as dirty environments or high duty cycles, intervals may need to be shortened and in competitive situations, it may be desirable to get longer intervals.

Sending old filters to testing laboratories for analysis is inexpensive and will help you determine if the chosen filter and interval times are correct. We also recommend having a fluid analysis performed on 500 hour intervals to monitor contamination levels and fluid breakdown. This again is an inexpensive procedure and will indicate if the filter and the service interval selected are correct or if additional filtering such as water removal is required. Normally fluid should be changed on 1500-2000 hour intervals.

Micron Ratings

A micron is a length measurement and is defined as one millionth of a meter or 39 millionths of an inch (0.000,039"). The micron rating of a filter indicates the fineness of the filter media and is specified either absolutely or nominally. However, not all filter ratings are the same.

Where possible we recommend selecting a filter that is rated based on the ISO 4572 standard Beta rating. The Beta standard permits a fair comparison of filter performances. Under ISO 4572, the particle size that the filter will trap 50% of is considered the nominal rating and the particle size that it will trap 98.7% of is considered the absolute rating.

Many filters are still rated based on non-standard tests. Without a standard test, an absolute micron rating is usually defined as the actual size of the largest pores in the filter media and the nominal micron rating specifies the size of the smallest particles that the filter can normally trap. Non-standard ratings leave much to interpretation and hence, we recommend filters that have a Beta rating and data to support the rating.

One note about micron ratings is the misconception that finer is better. Filters can over clean hydraulic oils. Meshes that screen out particles finer than 10 microns can strip out essential additives in some oils. Most modern hydraulic oils can be filtered finer than 10 micron but it is wise to get the fluid manufacturer’s approval if you plan to use a filter finer than 10 micron.

FILTER LOCATION

There are three locations where filters are usually installed: the return line to tank, the pump inlet or a pressure line.

Return Line Filters

Return line filters are generally the most effective method of fluid filtration. Return fluid pressures are light enough to keep filter construction light and inexpensive but great enough to overcome flow restrictions caused by very fine filters.

The most common return filters are spin-on canisters and tank immersion filters. We recommend the canister type filters over the tank immersion ones because element replacement is generally easier. More importantly, contamination accumulates on the outside surface of most in-tank filters. The disturbance of removing the element causes the contamination to fall off of the filter and into the tank. Great care should be exercised when removing these types of filter elements and we recommend avoiding them if possible.

One aspect to watch for with spin-on canisters is the height at which the filter is installed relative to the fluid level in the reservoir. If the canister is below the fluid level, removing it will cause the fluid to siphon out of the tank unless a valve is installed.

Inlet Strainers

Inlet strainers are typically installed on the pump inlet line, inside the reservoir. In general, they are ineffective because they must have very coarse mesh to prevent cavitating the pump. If they do catch contamination they will restrict flow as they load up, causing an eventual pump failure due to cavitation. Inlet strainers also tend to ice up in cold conditions which again will result in pump cavitation.

Our recommendation is to always avoid inlet strainers and to remove them from systems that have them. An inlet strainer that is trapping particles is an indication of a procedural problem (see *UNDERSTANDING PARTICLE CONTAMINATION)*.

Pressure Line Filters

Pressure line filters are used when downstream components are very intolerant of contamination. They ensure that any contamination which may have entered through the reservoir is trapped before the fluid arrives at the component.

Pressure line filters tend to be expensive because they must have enough strength to withstand the operating pressure. Hence, they should be used only when the components they protect are safety or up-time critical or expensive themselves relative to the filter. When a pressure filter is justified, avoid filters that have bypasses and ensure that the elements are replaced on time and at proper service intervals.

Servicing

The most important aspect of filter servicing is making sure it gets done. Regardless of the type of filter you choose or receive with your equipment, make sure that the filter is in an accessible location for servicing. Many times we have seen filters that have never been replaced because they are too difficult or inconvenient to service. It also helps to set up a service log and ensure that filters are replaced on correct intervals. Often filters go neglected because of everyday activities that push the once a month tasks off of the daily list. Usually all it takes is a reminder.

In fact, all of the tips and techniques described in this essay just need a reminder to be implemented. They are simple but plentiful. Use the summary at the beginning of this paper as a check list when you are either creating a system or comparing and evaluating competing systems.