

HYDRAULIC SYSTEM DESIGN CONSIDERATIONS

It is rare that a fluid supplier would make suggestions concerning the design of a hydraulic system. However, we pride ourselves as not being a typical fluid supplier. Our staff also includes fluid power professionals adding a certain expertise when compared to our competitors. In the case where synthetic hydraulic fluids are being considered for a system; the user must be aware of certain design characteristics that may prove less than satisfactory. The choice of hydraulic fluid is important to system operation, equipment and personnel safety and environmental impacts. It is our hope that we can assist in the choice of the right fluid for your system and avoid the problems commonly associated with the use of water glycols. Please note; anhydrous synthetic fluids (those without water) usually do not have the same design problems as do the water glycols. Therefore, the focus of this article will be on water glycol fluids.

The fluid power industry is standardized on mineral oil based hydraulic fluids. There is not a single major component manufacturer that manufactures equipment for use with water glycol hydraulic lubricants. If the equipment OEM wants to design their systems to run on something other than mineral oil fluids, then the OEM must design to compensate for the accommodation of water glycols. Please note that many OEMs will limit speeds and pressures of components when run on water glycol lubricants. The OEM must do a comprehensive risk/benefit analysis comparing the benefits of the water glycol against equipment operation. If you are an equipment OEM you know this all too well. If you are an end-user and the equipment OEM has designed to a mineral oil spec., then it is incumbent on you to perform the risk/benefit analysis. To begin with let's discuss the strengths of water glycol fluids.

Water glycol has a number of beneficial properties that either mineral oil or vegetable oil fluids do not possess. With water content from between 35% to 60%, water glycol fluids are inherently fire-resistant. In order for them to support combustion, all of the water must be boiled off. Water glycol is, in most blends, "readily biodegradable" whereas mineral oil is not. This is one characteristic that vegetable based oil and water glycol both share. Water glycols do not oxidize like mineral oil and vegetable oil based fluids resulting in system varnishes and sludge. Water glycols do not emulsify like mineral and vegetable oils. Water glycols operate much better at low to extremely low temperatures. Water glycol cleans up much easier when spilled. It can be cleaned up with soap and water. Small releases will not harm water reclaim systems and wastewater treatment operations. Certain blends of water glycol can be used in food processing applications where incidental food contact is possible. Although vegetable based oils can be used in similar applications, mineral oil based fluids cannot because of their toxicity. Water glycols are usually much safer to handle and store than mineral oils. Finally, properly maintained water glycol systems will extend the equipment lifetimes. Now that we have looked at the beneficial properties; let's examine the challenges to water glycols.

Mineral oil and vegetable based hydraulic fluids are less sensitive to high system operating temperatures. As water glycol temperatures increase the viscosity does not thin as much as oils and it can become more difficult to maintain lubrication boundary layers. Whereas oils do sufficiently thin to maintain the lubricity needed. Water glycol systems require maintenance monitoring to assure

continuing chemical balance Critical to satisfactory performance, water glycols must maintain a base pH > 8.0 and water content levels sufficient to control viscosities. Systems subject to poor maintenance practices are not good candidates for water glycol fluids and lubricants. Glycol fluid water content is susceptible to evaporation when system temperatures are in excess of 50° C (122° F). This is a property that is limiting to the types of applications where water glycols can be used without making design accommodations. This may include pressurizing the reservoir, utilizing a heat exchanger, or both. Often over sizing the reservoir will allow more fluid dwell time to allow cooling through the process of thermal radiation. In any case it is important that the space that the reservoir is placed in has adequate ventilation to utilize the thermal radiation to the greatest effect. The greater the ΔT between the fluid temperature and the ambient air the greater the thermal effect. Something shared between oils and water glycols is the intolerance of water ingress into the systems. Oils are intolerant because water ingress causes emulsification and loss of lubricity. With water glycols the ingress of potable or raw water changes the chemical integrity by introducing calcium carbonates and magnesium resulting in white clumping of the fluid. This "spoils" the water glycol resulting in the need to change out the fluid. The clumps will not pass through close tolerance fits and will cause blockage. Water glycol fluids will react with certain elastomers causing them to possibly harden, crack, swell or dissolve. This is particularly troubling with shaft seals, o-rings, and piston seals. Paper media filters are not usually compatible with water glycol fluids. The water causes the paper to dissolve.

Design Considerations

The most susceptible components in any hydraulic system are the pump, rotary actuators (motors), and linear actuators (cylinders). In addition, some systems that have proportional or servo valves may also be highly sensitive, especially to fluid contaminants. In reviewing design considerations we will review each component and the possible impact of running water glycol fluids may have.

Pumps:

Currently there are three types of hydraulic pumps in general use; gear pumps, axial piston pumps, and vane pumps. All are positive displacement pumps and each has its own limitations and advantages. The pump is a mechanical device that converts energy from the prime mover (electric motor or engine) to fluid power energy. Pumps are rated by pressure and flow. Pressure is typically measured in psi or bar. Flow is measured in gpm (gallons per minute) or l/m (liters per minute) and is a result of volumetric displacement x rpm. When new; most gear pumps have a practical efficiency of 85% to 90% and will decrease over time. New piston and vane pumps' efficiencies are somewhere around 90% to 95% and too will lose efficiency as the pump wears. Industrial standards for pump lifetimes are between 8000 to 10000 hours of operation. All pumps work by mechanically squeezing the fluid between mating surfaces. In gear pumps it is the meshing of the gears pushing against the pump housing wall, in piston pumps it is the piston pushing in the piston silo against a valve plate, and in vane pumps it is the vanes pushing against the pump housing wall. In all cases the pumps are dependent on maintaining lubricity between mating surfaces to prevent material on material wear. All three types of pumps are sensitive to fluid contamination, some more than others. Gear pumps are the least sensitive while piston and vane pumps are the most sensitive. All pumps are also sensitive to fluid cavitations or air bubbles that form in the fluid. These bubbles when compressed will explode creating pitting and pockets in the pump material.

Pumps are designed to have a controlled rate of internal leakage to provide lubrication to the rotating parts and to provide pump cooling. As pumps wear over their lifetimes, the ability to produce pressure and flow diminishes along with ever increasing internal leakage. From a practical standpoint, when pump efficiencies start dropping below 80% to 85%, depending on the type, it is time to replace the pump or rebuild it. The challenge is to be able to run the pump for the longest period of time before reaching the replacement efficiency. The type of fluid chosen is critical to this achievement. Fluid manufacturers are always in the development of blending a better fluid that will provide the lubricity needed, good thermal transfer, anti-cavitating, good bulk modulus, and other characteristics beneficial to the application. For well over a century, petroleum based mineral oils have provided the best general answer. This is precisely why most hydraulic pumps have been designed around using mineral oil based fluids.

Gear pumps are the most commonly used hydraulic pumps. They are less mechanically complicated and are cheaper to manufacture. Gear pump housings come in a variety of materials from cast aluminum to 316L stainless steel. The manufacturer decides on the best combination of materials for the target market. Even though gear pumps are less efficient than piston or vane pumps, the advantage of low cost and contamination robustness make them a good choice for the majority of applications, from mobile to portable to fixed sites. Gear pumps are used in applications that are \leq 3000 psi (210 bar). Some gear pumps will achieve pressures in excess of 3000 psi but this is the exception rather than the rule. Because of the operating characteristics of gear pumps, pressures \leq 3000 psi and general robustness; water glycols are an excellent choice. However, there are two possible limiting factors; pump case materials and pump elastomers. Since gear pumps are literally manufactured globally, and they come in a variety of case materials; there is the possibility of a pump case manufactured from non-anodized aluminum. Water glycols react with non-anodized aluminum and will produce a white soapy substance, thus spoiling the fluid and attacking the pump case. Also there is a higher probability that incompatible elastomers may be used. It is extremely important that before putting a water glycol in the system, contact the pump OEM to determine the pump materials and the compatibility with water glycols. Also the pump OEM or equipment OEM can advise as to whether they require derating of the maximum pump pressure or speed in order to maintain pump warranties.

Vane pumps are not used as much in applications as they once were and many of their traditional applications have been replaced by piston pumps. However, one great advantage that a vane pump provides is that it runs quieter than either gear pumps or piston pumps. Also, vane pumps exceed gear pumps in pressures up to \leq 4000 psi. Of the three pump types vane pumps tend to be the most dirt sensitive. Water glycol works well in vane pumps as long as fluid temperatures are controlled and the lubrication boundary layers are maintained. For some mobile applications where noise is an application consideration vane pumps are making a resurgence in use. A common wear test, ASTM D7043, is performed with a Vickers Vane Pump.

Axial piston pumps present specific challenges to water glycol fluids. Most major manufacturers derate their pumps if water glycol is used. Piston pumps are capable of routinely achieving continuous running pressures $>$ 5000 psi (345 bar). Some units are now approaching 7500 psi (520 bar). This upward movement in pressure is primarily due to the demands created in the mobile equipment industry. Generally water glycols are not used in high pressure high speed piston pumps. They really test the fluid's ability to maintain adequate lubrication boundaries and to remain cool. A good share of piston pumps are used as hydrostatic units where the system return flow is fed back into the inlet side of the pump without the use of large hydraulic reservoirs. The higher pressures,

speeds and absence of large reservoirs are a weight saving strategy. These units are used a great deal in mobile equipment drive systems and water glycols are not suitable for these high pressure applications. However, some blends of water glycols are used in lower pressure drive systems such as landscaping equipment. These systems run at slower speeds and pressures from 1500 to 2000 psi.

Piston pumps come in two basic types; fixed displacement and variable displacement. A fixed displacement piston pump is just that. Output flow can only be varied by pump speed whereas in a variable displacement piston pump, the pump volume can be adjusted; thus varying the flow without varying the speed. Variable displacement pumps have a greater number of moving parts making lubrication critical. The ability to adjust pump volume is clearly an energy saving feature and positively affects the pump lifetime. To date there is only one major pump manufacturer, Bosch/Rexroth, which has allowed water glycol to be used without derating the piston pump (A4VSO 125 thru 355). This particular pump is not to be used in hydrostatic applications and is to be used in open system applications.

Pump design considerations in reference to water glycol applications are focused on pump type, pump pressures, pump speeds, whether mobile or fixed site, and operating temperatures. The pump manufacturer's recommendations, as to the pump's ability to handle water glycol fluids, are critical to fluid selection. Included below is a guide to assist in the evaluation process:

WATER GLYCOL SUITABILITY FOR PUMPS BASED ON OPERATING CONDITIONS

| OPERATING CONDITION | AL GEAR PUMP | GEAR PUMP | VANE PUMP | FIXED DISP. PISTON PUMP | VAR. DISP. PISTON PUMP |
|------------------------------------|--------------|-----------|-----------|-------------------------|------------------------|
| ≤ 3000 psi | FR | R | R | R | FR |
| ≥ 3000 psi | N/A | FR | FR | FR | FR |
| PUMP SPEED < 1800 rpm | R | R | R | R | FR |
| PUMP SPEED < 3500 rpm | NR | FR | FR | FR | NR |
| FIXED LOCATION | R | R | R | R | FR |
| MOBILE | FR | FR | FR | FR | FR |
| OPER. TEMP. < 50° C w/o HEAT EXCH. | R | R | R | R | FR |
| OPER. TEMP. > 50° C w/o HEAT EXCH. | FR | FR | FR | FR | NR |
| OPER. TEMP. > 50° C w HEAT EXCH. | R | R | R | R | R |

N/A - NOT APPLICABLE, R – RECOMMENDED, FR – FURTHER RESEARCH REQUIRED, NR – NOT RECOMMENDED

Motors:

Motors are essentially pumps working in reverse. They convert the fluid energy back into mechanical energy. In the case of rotary actuators (motors) the energy is converted to rotational force (torque). Force is a function of pressure and speed is a function of flow. High pressure high torque, high flow high speed. Motors by and large are fixed displacement. Motors are classified into one of four types; Low Speed High Torque (LSHT), High Speed Low Torque (HSLT), Low Speed Low Torque (LSLT), and High Speed High Torque (HSHT). The two most common types are LSHT and HSLT. Just as in pumps there are four common materials; aluminum, cast iron, cast steel and stainless steel. Although pumps are designed as gear, vane, and axial piston; motors also have another type of design, orbital. The

orbital motors are exclusively LSHT and are the most popular design of hydraulic motor in use today. Just as in pumps the materials that the motors are constructed of is critical. A number of orbital motors that don't tolerate water glycol will begin leaking first around the motor shaft seal. As long as the pressures and speeds are within allowable manufacturer's limits, the only other concern is the motor materials including the elastomers.

Unlike pumps which can be, quite often, placed in more controlled environments, such as an equipment room, motors can and are subjected to whatever the environment offers. The robustness of the motor is critical to resisting the expected environmental conditions. For example: motors that are used in food processing applications must be able to withstand direct water wash down with harsh chemicals without deteriorating or allowing ingress of water and chemicals. Other than hoses and fittings, rotary and linear actuators are the chief sources of fluid leakage. Thus, not only must motors keep the prevailing environment out, but must keep the hydraulic fluid in. OEM equipment designers carefully select the type of motors to be used not only on the work to be done, but also on the expected operating environmental conditions. In the analysis of benefit and risk for utilizing water glycols, the motor OEM's input is critical to the final decision.

Cylinders:

Cylinders are actuators that convert fluid power force into linear mechanical motion; pushing, pulling, lifting, or lowering. Although the construction of a cylinder is fairly simple, having only one moving part, other considerations are critical to application suitability. Cylinders are made of a number of materials; plastics and composites, steel, aluminum and stainless steel. Cylinders are either double acting or single acting. Double acting means that fluid can be applied to either side of piston, rod end or tail end. Single acting cylinders are capable of applying fluid force to only one end, usually the tail end, and retract by means of some other force such as gravity or springs. To contain and direct the force sealing is critical at the piston and rod. Therefore, water glycol and seal capability are crucial to the application.

Cylinders are applied based on force and speed of actuation. Cylinders are sensitive to force media viscosities. Where extremely high speed is required with low to medium force; pneumatic cylinders are usually applied. Since air or gases have low viscosities (viscosity is a measure of resistance to flow) but high compressibility or low bulk modulus; they are limited to the high speed low force applications. High force and low to medium speeds is where hydraulic cylinders are applied. A basic rule is that the higher the speed the lower the fluid viscosity and/or the greater the flow. Although water glycols have excellent viscosity properties at low temperatures and viscosities equal to mineral based fluids at normal ambient temperatures, as ambient temperatures and fluid temperatures increase water glycols remain more viscous than similar weight mineral based oils. High fluid temperatures and extremely high actuation speeds may be a challenge to the capability of water glycols in certain applications. Although these applications may be rare they remain a consideration of the benefit/risk analysis. Contacting the equipment OEM to ascertain speed and force considerations is required.

Just as with motors, cylinders are exposed to a variety of environmental conditions. Cylinders are too challenged with maintaining both internal and external integrity. As a component, cylinders represent the single greatest threat to leakage. Systems with a large quantity of cylinders are a good application for fluids that are eco-friendly.

Other Condition Considerations:

In doing the benefit/risk analysis of water glycol for any given application other less critical components must be considered. The size and placement of the reservoir, the type of filtration and system cooling all represent points of analysis.

Reservoirs:

The reservoir performs a variety of functions in a hydraulic system. First and foremost it is the storage tank for the hydraulic fluid. It can be constructed of a variety of materials including aluminum, plastics and composites, mild steel, and stainless steel. As a fluid storage tank it must assure that the fluid is protected from the environmental elements, maintain the fluid integrity and provide a ready supply to the pump. Other functions of the reservoir include providing fluid cooling through the process of thermal radiation, maintain positive pump head pressure, and suppression of fluid turbulence.

The material that a reservoir is constructed from affects other system operational parameters. Reservoirs constructed of aluminum, mild steel, and stainless steel provide the benefit of fluid cooling through the process of thermal radiation to the external atmosphere. In open loop hydraulic systems and to assure that the reservoir is able to supply fluid to the pump and provide adequate cooling, it is a rule of thumb to size it a minimum of 3 times the system flow. For example: systems with flow requirements of 10 gpm would have a reservoir of 30 gallons minimum. In theory the fluid would have 40 seconds dwell time in the reservoir for every 20 seconds under load. The 40 seconds will provide sufficient dwell time to cool the fluid and suppress the turbulence under normal conditions. However, when reservoirs are constructed of plastic or composites and a heat exchanger is not used, reservoir sizing may be 4 to 5 times system capacity. This allows for longer dwell times. It is almost imperative that with plastic or composite constructed reservoirs that an external heat exchanger should be employed. As far as construction materials, aluminum tanks should be closely investigated. Aluminum is a fine material as long as it is anodized or painted with a coating that does not react with the water glycol. Non-anodized aluminum reacts with water glycols producing a change in the water glycol resembling a white soapy fluid. The fluid will only not perform adequately but will continue to degrade the aluminum if left unchecked. If the hydraulic system has a non-anodized aluminum reservoir, water glycol cannot be used without changing the reservoir.

Tank turbulence from return hydraulic fluid must be controlled. Uncontrolled tank fluid turbulence creates conditions that can result in pump cavitation when the pump is installed in the reservoir. Also fluid turbulence promotes water evaporation in water glycols. Therefore, tanks without baffling or insufficient baffling will present problems.

Reservoir breathers should be of a filter breather type. A filter breather not only helps slow water evaporation but also controls the ingress of air born contaminants. In a non-pressurized tank the breather performs an important function by allowing for the equalization of atmospheric pressures between the inside of the tank and the outside ambient pressure.

Filters:

The filtration system is an important characteristic of a well functioning hydraulic system. Water glycol fluids are compatible with most filter types. The only caveat is the compatibility of water glycol

with paper media spin-on filters. The paper media reacts with the water in water glycol causing the paper to dissolve. This property defeats the purpose of the filter and actually adds contaminants into the system. Substitution of the paper media spin-on with a fiberglass media spin-on is an easy fix for the problem. Water glycols are compatible with other media types such as polypropylene. Filter ratings do not change when using water glycol and remain the same μm rating as with the manufacturer's recommendation for use with mineral oils.

Heat Exchangers:

If the hydraulic system doesn't already have an external heat exchanger, it might be wise to consider adding one. Since water glycol is subject to water evaporation at fluid temperatures $> 50^{\circ}\text{C}$ (122°F) causing changes in viscosity, the use of a heat exchanger to keep the fluid temperature at the optimum setting will reduce maintenance and extend equipment lifetimes. Normally a heat exchanger can be added for a few hundred dollars.

Bypass Valves (Dump Valves):

Another feature that can be added to help control heat and to conserve energy, if the system didn't come with one, is to install a bypass valve (dump valve). The way that it functions is to return hydraulic fluid back to the tank when the system is unloaded without going over the pressure relief valve. If the fluid is allowed to return to the tank over the pressure relief it is under full system pressure and will generate high heat as it travels over the valve. Again this is a simple fix, but can add savings, reduce the water glycol fluid maintenance and ultimately extend the life of the hydraulic system components.

The Risk/Benefit Analysis:

Water glycols have a number of advantages but before deciding to convert the hydraulic system the responsibility is on the end-user to make the final decision based the best available information. Along with the fluid supplier it is advisable to contact a trusted fluid power professional. The fluid power professional can help to evaluate the hydraulic system and assist with contacting component OEMs to determine fluid compatibility. In addition, a fluid power professional has the skill and expertise to add to or change the system enhancing the suitability for use with water glycol fluids. Also they can be contracted to do the full system conversion.

An additional issue that must be considered in the risk/benefit analysis is the capability to perform the required fluid maintenance. Mineral oil based hydraulic fluids are fairly maintenance free except for changing filters when they become full of dirt and changing the fluid when it is worn. However the only way to determine mineral based oil's health is through fluid sampling, which if not done routinely can lead to operating with worn out hydraulic fluid accelerating system wear. On the other hand; depending on the water glycol blend, the maintenance requirements are fairly simple and straight forward. It will require a modest investment in testing equipment, including a means to test the fluid viscosity and fluid pH. Of all the water glycols, the food grade fluid wear the quickest and need to be replaced more often. Water glycol wear is determined by the pH. Water glycol fluids must be within a range of > 8.0 pH and < 10.0 pH. When the pH falls below 8.0 then it is an indication that the fluid is worn and needs to be replaced. Viscosity can easily be maintained by adding de-ionized or distilled water when the viscosity climbs too high. Normal viscosity is around 200 SUS @

20° C. Fluid sampling and analysis 2 to 4 times a year will, just as with mineral oil based systems, indicate overall system health.

Filter maintenance is no different than in any other hydraulic system except right after fluid conversion. After conversion the return filters will have to be closely monitored and changed more frequently since the water glycol will scrub the system clean of old oxidation byproducts, varnishes and sludge. Also, residual oils, which have a lower density, will accumulate on the top of the fluid in the reservoir requiring removal by skimming. Once the system has been thoroughly purged, routine filter maintenance is equal to or better than filter maintenance for mineral oil based fluids. If not already equipped many end-users take the opportunity to change the basic filtration system to a two stage system when converting the fluid. The first stage is usually 25 µm with a bypass feature. The second stage is a non-bypass type 10 µm filter. Both filters should be equipped with some type of dirt indicator, whether mechanical, electronic, or both. Consideration should also be given to increasing the dirt holding capacity of the filters. By increasing the holding capacity the frequency of filter changes will be decreased. Your fluid power professional can assist in sizing the filters both for micron rating and dirt holding capacity.

The incorporation of fluid monitoring and maintenance can easily be added to a PPMP (Planned Preventative Maintenance Program). Effective maintenance is one of the key features to extending the life of a any hydraulic system. A good maintenance program not only extends the life of the system but it cuts down the time lost to unplanned component failure.

Safety must be considered when doing the risk/benefit analysis. Water glycols provide not only fire-resistance but also good environmental safety. Hydraulic fluid water glycols provide excellent worker safety with a minimum risk to health from exposure. Also water glycols can be safely stored and handled without risk to facilities, equipment, the environment or workers.

Concluding Considerations:

In final analysis the potential user must consider a number of issues from component compatibility to maintenance capability.

To assist in the risk/benefit analysis a convenient decision tree has been included on the following page.

