A water content hydraulic fluid is one which contains water as one of the major constituents. There are several major classes of water content fluids, which contain varying amounts of water.

**INVERT EMULSIONS**

Invert emulsions usually contain about 40 percent water. In an invert emulsion, the water is dispersed as tiny droplets in a continuous oil phase. Emulsifiers are used to keep the water droplets suspended in the oil medium. The viscosity is dependent on the viscosity of the oil phase and, typically, is 350-450 SUS @ 100°F. Of the water content fluids, invert emulsions are closest in performance to petroleum base oils. They are also the least fire-resistant of the group, due to the high oil content. Invert emulsions are purchased premixed and are used principally in the mining industry.

**WATER GLYCOLS**

A water glycol fluid usually contains 35-45 percent water, with either ethylene glycol or propylene glycol making up the bulk of the fluid. The fluid may also contain water soluble, long chain polymers to improve viscosity. Water glycols are available in a range of viscosities similar to mineral oils. Water glycols are usually purchased premixed and are used where fire-resistance is desired, without sacrificing too much viscosity. They are also a frequent choice when fire-resistance and low temperature operation are required, since they generally have an operating range which extends as low as 0°F.

**HIGH WATER CONTENT FLUIDS (H.W.C.F.)**

H.W.C.F. is a term usually reserved for emulsions (soluble oils) and synthetic chemical solutions which contain from 90-98 percent water (usually 95 percent). This type of fluid will be the main focus of this report. H.W.C.F. are usually sold as concentrates, which are mixed on location, one part concentrate to 19 parts water. Because they are mostly water, all H.W.C.F., whether of the emulsion type or solution type, will have certain bulk properties in common.

The specific gravity of any 95/5 H.W.C.F. is slightly more than 1.00, versus only .86 for oil, which will affect suction characteristics. The vapor pressure of H.W.C.F. is much higher than that of oil, which makes H.W.C.F. systems much more prone to cavitation problems. The specific heat of water is 1.00, as compared to only .45 for oil, which means water has more than twice the ability to absorb heat than does oil. The thermal conductivity of water is .36 Btu/hr.ft.°(F/ft.), which is four times that of oil. In addition, in a more viscous fluid like oil, the slower boundary layer flow near the cool metal surfaces tends to retard heat transfer. The net result of these effects is that less cooling capacity is required for water-to-water heat exchanging. Field experience on systems converted from oil to H.W.C.F. has shown that if petroleum oil was replaced by H.W.C.F., and no other modifications made, the systems have run anywhere from 10°-25°F cooler.

The viscosity of 95/5 H.W.C.F. is about the same as water, 32 SUS. This lower viscosity results in higher leakage rates than with oil. In our testing with Oilgear pumps, we found slip rates to be as much as eight times higher than they are with oil. Other sources have reported leakage 20-30 times more than with oil, especially in valves. The low viscosity of water will allow a much higher velocity in piping than does oil for the same pressure drop. However, this higher velocity also creates a more turbulent flow, which contributes to erosion and wiring drawing problems. Being mostly water, H.W.C.F. will freeze at or close to 32°F and, due to the high vapor pressure of water, it is generally recommended keeping the maximum reservoir temperature below 120°F. Although the bulk fluid properties of the two types of H.W.C.F. are very similar, the chemistry of the two are quite different.

**OIL IN WATER EMULSIONS (SOLUBLE OILS)**

Soluble oil is actually a misnomer, since oil is not soluble in water. A soluble oil fluid consists of oil droplets suspended in a continuous medium of water. An emulsifier keeps the oil droplets suspended in the water. Generally, the solution will also contain lubricity and anti-wear additives, defoaming agents, liquid and vapor phase rust inhibitors, and bactericides. Oil droplet size for most soluble oil fluids is on the order of .002 inch. These are fairly large particles, which reflect a lot of light and so, the solutions appear milky white in color. Cutting fluids and coolants typically fall into this class of fluids. High water based hydraulic fluids are generally micro-emulsions, or micro-dispersions. These fluids are basically the same as emulsions, except the particle size is smaller (typically .0008 inch), and the solutions tend to be a little more translucent. Micro-emulsions are more stable and have better lubricity characteristics than emulsions and so, tend to have better anti-wear properties.

**WATER SOLUBLE SYNTHETIC CHEMICAL H.W.C.F.**

Synthetic chemical solutions are true solutions; the chemical additives are actually dissolved in the water, not just suspended in it. Particle size varies between 4-400 x 10⁻⁸ inch. This is smaller than the visible wave lengths of light, so they do not reflect light and, hence, are transparent; however, a dye is usually added to make the fluid more visible. As with the micro-emulsions, the synthetic chemical concentrate packages typically contain lubricity and anti-wear additives, rust inhibitors, defoamers, and bactericides. The synthetic chemical fluids usually work in one of two ways. Some consist of highly polar compounds dissolved in the water, which adhere to the hydraulic system surfaces and act to reduce friction and corrosion. Others contain chemical reactants, which combine with metal ions in the water, forming a soap, which adheres to the hydraulic system surfaces and also acts to reduce friction and corrosion.
These fluids are very similar to the above mentioned H.W.C.F., except additional additives, typically long chain polymers, are blended in to increase the viscosity of the fluid. These thickening additives create a fluid with the viscosity of oil (25-350 SUS), which still has over a 90 percent water content. In theory, these fluids are superior to other 95/5 fluids, because they would not only have the advantages of the high water content, but also the viscosity characteristics close to oil. A problem with this type of fluid is that it may gradually shear down, decreasing the viscosity of the fluid. A bigger problem with this type of fluid, though, is that it may not decrease leakage. This type of fluid derives its viscosity from very large molecules (long chain polymers) which interlock, forming a matrix within the fluid with the water molecules held within the matrix. This matrix structure results in viscous behavior at low shear rates, such as in a viscometer. At higher shear rates, however, the matrix begins to break, which results in a lower apparent viscosity. These long chain polymers have the ability to re-close if broken. This property helps prevent a permanent shear down of the fluid: however, even a temporary shear down results in a lower apparent viscosity and poor volumetric efficiency. Testing at Oil gear on some fluids detected little, if any, increase in apparent viscosity at high shear rates (3000 PSI). Research among fluid manufacturers in the area of increasing H.W.C.F. viscosity and lubricity is likely to continue, since loss of performance and pump life due to low viscosity is probably the biggest drawback of H.W.C.F.

ADVANTAGES AND DISADVANTAGES OF H.W.C.F.

On the surface, using water base fluids sounds like a fairly simple proposition. Water was the original hydraulic fluid, so the idea is not new. Water is cheap, inert, and abundant. The H.W.C.F. are the most fire-resistant fluids available. Transportation and storage costs are minimal, since only 5 percent of the fluid is stored or transported. H.W.C.F. is safer from the stand- point of leakage, since unlike oil, most of the leakage will simply evaporate. The heat transfer properties of H.W.C.F. are better than oil, and the viscosity of H.W.C.F. is constant, regardless of temperature.

These advantages do not come without some significant disadvantages, however. Using water base fluid results in much more leakage, both external and internal, which requires more power to do the same amount of work. Pump life is reduced by using H.W.C.F., so equipment will have to be replaced more frequently. The operating temperature of H.W.C.F. is restricted to between 40°F and 120°F, due to the freezing point and the vapor pressure of water. Corrosion problems must be dealt with, erosion problems are more severe and material compatibility is more of a problem with H.W.C.F. Cavitation is much more severe than with oil, and maintenance problems with H.W.C.F. are more demanding than with oil.

WATER

Unlike other hydraulic fluids, water seems like one fluid which could be counted on as being consistent and uniform everywhere. Strictly speaking, water is the same all over, but tap water is never just water; it always contains impurities and there is a large variation in the type and amount of impurities in different locations. The most common impurities are dissolved minerals and salts. The impurities of most concern are the salts of calcium and magnesium. The hardness of water is a measure of the amount of calcium and magnesium ions it contains. Most H.W.C.F. manufacturers recommend using water with a hardness of less than 250 PPM. With soluble oil type fluids, hard water can destabilize the emulsion, causing it to separate into oil and plain water.

With a soluble chemical type fluid, excessive hardness will cause the calcium and magnesium ions to combine with components of the fluid additive package; forming insoluble precipitates or scum, which can clog filter elements, and which effectively remove the additives from the fluid. Softening water is a process which removes calcium and magnesium ions from a solution, by replacing them with sodium ions. This may be satisfactory for some fluids, but not others. Deionized water is water from which nearly all impurities have been removed. Deionized water will work fine with some fluids, but others require a certain minimum amount of hardness in order to work properly. Distilled water contains no mineral impurities. Mixing fluids with water then is not as simple as it first sounds, and manufacturer's instruction should always be followed in regards to water quality.

PREPARING H.W.C.F.

This first step in preparing a H.W.C.F. is to obtain suitable water, as mentioned above. Some manufacturers recommend blending the fluid before introducing it to the reservoir. Water is never added to the concentrate. Usually, about half the water is put into the blending vessel, then the correct amount of concentrate is added with vigorous stirring. The remainder of the water is then added with stirring to form a final solution of 19 parts water to 1 part concentrate. This procedure is especially important when blending soluble oils since, if they are improperly mixed, the concentrate may tend to remain in globs, which can result in the hydraulic equipment running mostly on water.

MAINTAINING FLUID CONCENTRATION

For axial piston pumps, most fluid manufacturers recommend between 95/5 and 90/10 ratio of water to using concentrate. Using less than the recommended concentration may result in accelerated pump wear. Maintaining the correct concentration will insure the proper lubricity and maximum pump life. Concentration higher than what is recommended does not yield any increased benefit, but will result in increased fluid cost and, possibly other side effects, depending on the fluid. In an H.W.C.F. system, the fluid concentration should be monitored closely. The greater the fluid turnover from leaks or evaporation, the more frequently the concentration should be checked. Most fluid manufacturers recommend not adding either concentrate or plain water to a reservoir but, instead, a mixed solution of either higher or lower concentration to adjust the overall concentration, as needed. Fluid manufacturers’ recommendations should be followed when adding make-up fluid.

Every fluid manufacturer will provide literature, detailing just how the fluid concentration is to be checked. These procedures usually involve a chemical titration analysis, which compares the concentration of a known sample with a sample from the reservoir.

HARDNESS

A general rule, water hardness of the fluid should be held under 250 PPM. In a system with a lot of evaporation, adding tap water as make-up water will gradually increase the hardness of the fluid. This is because only the water evaporates; the minerals remain in the reservoir. So, adding tap water increases the mineral content of the reservoir and, eventually, the problems arising from excessive hardness will set in. There are chemical analysis techniques which can be used to monitor water hardness of the fluid in the reservoir but, the procedures available to us are difficult to use, and the results are often inexact. The best advice from the fluid manufacturers is to use a reasonably soft water to make up the original fluid, and then use only distilled water any time more water is added to the reservoir. This way, the mineral content of the reservoir remains constant at a known, low level.
The pH of a liquid is a measure of how acidic or how alkaline the liquid is. The pH scale is a logarithmic scale, which ranges from 0-14, with a pH of 7 being neutral. Plain water has pH of 7 (0 is acid; 14 is alkaline).

Most H.W.C.F. are alkaline in nature. This is because water base fluids are subject to microbiological infestation, and this type of activity is less likely to occur in an alkaline environment than in an acid environment. The pH of H.W.C.F. is generally between 8.5 and 9.9 in the mixed form. The pH of the concentrate is usually between 10 and 11. The pH of a H.W.C.F. should be monitored closely. The pH of a H.W.C.F. is an indication of the condition of the fluid. The pH should remain at a constant value between the limits prescribed by the manufacturer.

A change in the pH of a fluid indicates a change taking place in the fluid. It can be an indication of instability within the fluid, which could cause a separation of the fluid. A fluid can separate due to contamination such as from copper wear particles, which can destroy some emulsifiers. Excessive water hardness can also cause a separation of the fluid. A change in pH may also be an indication of microbiological activity within the fluid. Sudden changes in pH are an indication of something happening within the fluid. If a pH change is detected, then other tests can be run to determine what the problem is.

The two most common ways of measuring pH are with indicator sticks, or a pH meter. The pH indicator sticks are color coded indicator paper, whose color varies according to the pH of the fluid. The color is compared to color chart to obtain pH. pH sticks can only give an indication to nearest whole pH number, so they are fairly coarse indicators. They may also be affected by dyes in the fluid. Figure 1 shows a pH indicator stick and the corresponding color chart. A significant change in pH must occur before it can be detected with a pH stick. It is possible that damage to the fluid could occur before the pH changes enough to be detected with a pH stick. A pH meter gives a more precise measure of pH and can detect much smaller changes in pH.

A H.W.C.F. reservoir in contact with the outside environment which is maintained between room temperature and 120°F provides a perfect breeding ground for all sorts of microorganisms. Unless precautions are taken, such organisms will appear in H.W.C.F. systems and, eventually, will lead to premature filter plugging, foul smelling reservoirs, or even a breakdown of the fluid. The two main classes of organisms of concern to water base fluid users are bacteria and fungus, including yeasts and molds. H.W.C.F. do have protection from microbiological infestation. Being alkaline in nature helps retard bacterial and fungal growth. In addition, however, most H.W.C.F. also contain biocides to counter microbiological growth. In spite of efforts to counter-biological activity, the fact remains that a H.W.C.F. reservoir is an ideal incubator for such growth, and the reservoir should be monitored regularly to spot any such activity. As mentioned before, pH change in the fluid is a possible indication of biologically activity. Some micro-organisms feed on emulsifiers and produce acid waste. Plugged filters may be an indication of fungal growth, while a foul smelling reservoir is usually an indication of bacteria problems. Fungal growth can be plainly visible on the reservoir surface (see Figure 2), especially in stagnant reservoirs. If biological activity is suspected, the fluid should be checked with a Bacteria-Fungus indicator kit. These indicators consist of small plastic slides, coated with a substance which promotes bacterial and fungal growth, and additives which make the growth easy to see. The indicator is dipped in the suspect fluid and allowed to incubate for a certain time (usually 48 hours), after which the amount of growth in the reservoir can be gauged from the indicator. Figure 3 is an example of an indicator slide showing excessive bacteria growth. Indicators may be recommended by the fluid manufacturer and should be used in accordance to the instructions.
Any water base reservoir is going to contain a certain amount of bacteria and fungus. This is normal and, in fact, desirable, since the two tend to keep each other in check. Complete eradication of one may allow the other to grow unchecked. It is only when the growth gets out of hand that problems can result. A bacteria count of 10,000 organisms per cubic centimeter, for example, is considered slight contamination; while counts over one million organisms/cm³ will usually require treatment. If a reservoir is found to be contaminated with bacteria or fungus, corrective action must be taken, or reduced pump life can be expected. Corrective action can consist of either replacing the fluid or adding a biocide to the reservoir to eliminate excessive biological growth. If the fluid is to be replaced, the reservoir must be very thoroughly cleaned and flushed, using either soap or a cleaning fluid recommended by the fluid manufacturer. If a biocide is to be used, it should be recommended by the fluid manufacturer and used according to instructions. Improperly used biocides can result in worse problems than the ones they were supposed to eliminate.

Preventative maintenance is probably the best way to avoid microbiological problems. Closed reservoirs are always best for H.W.C.F. systems for a number of reasons, including preventing bacteria carrying foreign material from entering the reservoir. Periodically, check pH and microbiological growth, so potential problems can be spotted before drastic action becomes necessary.

SAFETY PRECAUTIONS

ALKALINITY

As previously mentioned, most H.W.C.F. in the mixed form have pHs between 8.5 and 9.9. Occasional contact with these fluids in the mixed form should not be harmful. Some manufacturers recommended wearing gloves if extended contact with the diluted fluid is anticipated. All manufacturers recommended wearing gloves when handling the fluid concentrate, which has a pH of between 10 and 11, which is strong enough to cause skin irritation after a short time. Care should be exercised when cleaning up H.W.C.F. leakage because, the longer the fluid sits exposed to air, the more water will evaporate, and the more concentrated and alkaline the fluid will become. Fluid manufacturers usually recommend wearing goggles when handling the concentrates, because they are strong eye irritants. If fluid blending must be done in confined areas, respirators are also recommended, because the concentrate vapors may be irritating.

LEAKAGE

Regardless of the type of H.W.C.F. used, leakage will be much more than with petroleum base fluids. If leakage from a soluble chemical type fluid is left to evaporate, the residue will be either a dry power or a thick waxy material. This residue usually cleans off fairly well with soap and water. When all the water has evaporated from a soluble oil fluid, the result is an oily residue which will have to be cleaned up like any other oil. In either case, it should be remembered that the solution becomes more concentrated as the water evaporates, so care should be taken when cleaning up leakage.

FLUID DISPOSAL

The fluid manufacturer should be consulted for the proper method of disposal. Product disposal information is normally contained in the OSHA product safety data sheet for the particular fluid, which should be obtained from the manufacturer when the fluid is obtained. The trend now is toward biodegradable fluids, which can simply be flushed down the sewer; however, this is not always true, and manufacturers’ instructions should be followed.

FILTERABILITY

Most fluid manufacturers recommend using 10 micron, return line filters. Most manufacturers recommend not using clay or diatomaceous earth filters for H.W.C.F., because they tend to remove additives from the fluid. We do not recommend using suction filters on our equipment, and this is even more important with H.W.C.F. because of the greater tendency of H.W.C.F. to cavitate. Filter elements must be compatible with water. Most filter media in use today are water compatible, resin impregnated papers; however, some of the glues used to bond the filters together are not suitable for long term use in water. If in doubt, the filter manufacturer should be consulted.

There are conflicting theories on the dirt holding capacity of H.W.C.F. Most literature on this matter indicates wear particles will stay in suspension longer in water than oil, due to the higher specific gravity of water. Other sources indicate that the settling rate of wear debris is more dependent on viscosity than specific gravity, and wear particles will settle out of water faster than out of oil. There may be some truth to both of these theories. A 1/4 inch ball bearing, for example, will obviously settle faster in water than in oil. However, as the surface area to weight ratio of particles increases, specific gravity may become the determining factor. It is not clear for what particle size or shape the change over might be, though.

Regardless of the settling rates, however, there will be more wear particles to catch when using a H.W.C.F., because wear rates are higher. Lubricity is much lower with water than with oil so, whatever contamination is present in the fluid will be more likely to cause damage in water than in oil, because of the weaker film strength of water.

Generally, the same rules apply to sizing filters for H.W.C.F. as for oil. It may be advisable to use more filter capacity with H.W.C.F., from the standpoint of frequency of element changes. It is probably even more important, though, to properly maintain H.W.C.F. If a reservoir is contaminated with fungus or fungus, some of the glues used to bond the filters together are not suitable for long term use in water. If in doubt, the filter manufacturer should be consulted.

SEAL COMPATIBILITY

Materials that absorb water should not be used in H.W.C.F. These include cork, leather, asbestos, and untreated cellulose. Certain elastomers, such as most urethane, low nitrile Buna-N, and butyl, are not compatible with H.W.C.F. As a general rule, most fluorinated elastomers, such as Viton, are compatible with water, as are high nitrile Buna-N's and neoprene. It should be noted that often, there are different grades of elastomer within the same class. The composition of Buna-N, for instance, can vary significantly but, usually, the material is referred to simply as Buna-N. The same is true of the urethane; some are compatible with water, but most are not. Seal manufacturers' literature will usually specify whether a given material is compatible with water. Fluid manufacturers also usually supply a compatibility list of common seal materials they have tested in their fluid. If an elastomer is not compatible with water; it does not necessarily mean it will deteriorate in water; although, occasionally, this is true. Usually, it means the material will either swell in water, or will experience a significant change in hardness. For static seals at least, even an incompatible material has a fair chance of functioning satisfactorily, if undisturbed; but, probably, will be trouble if the component is disassembled and reassembled. Figure 4 shows a Buna-N gasket, which was exposed to various H.W.C.F. for over three years.
Figure 4. Buna-N gasket exposed to H.W.C.F. for over three years.

**METAL COMPATIBILITY**

Due to the alkaline nature of the fluid, certain metals should not be used in H.W.C.F. systems. These include magnesium, cadmium, zinc, lead, and aluminum. Anodized aluminum is compatible with H.W.C.F. Some of the above mentioned materials are used in tube and pipe fittings and in castings. Fluid manufacturers usually supply a list of metals which are incompatible with their fluid. Most H.W.C.F. will not attack bronzes; however, copper wear particles in solution can destroy some emulsifiers. The use of copper in H.W.C.F. may also set up a galvanic cell situation. The copper and steel, both in contact with the H.W.C.F. (which is a fairly good electrolyte) may result in an electrolytic cell, where the copper is ionized into the fluid and then plated out on the steel parts. Galvanic action is accelerated by turbulence in the fluid. Some H.W.C.F. contain copper deactivators, which help retard galvanic activity. Copper, as an alloying element of bronzes, is not as susceptible to galvanic attack as pure copper but, copper plating has been documented in systems, where the only copper present was as a constituent of bronze. Some fluid manufacturers warn against running with too high a fluid concentration (above 10 percent), because this also could result in copper being leached out of copper bearing alloys and plated out on steel components.

**CORROSION**

Generally speaking, the corrosion inhibiting properties of most H.W.C.F. are excellent, as long as the fluid is properly maintained, and the components are completely immersed in the fluid.

Most corrosion occurring in a properly maintained fluid is the result of water vapor which evaporated from the fluid, and then recondensed on the top or sides of the reservoir. The majority of fluids contain a vapor phase rust inhibitor, which is supposed to remain in the water as it evaporates and recondenses, prohibiting the condensate form causing rust. However, vapor phase rust inhibitors are not as effective as liquid phase inhibitors and, unless the reservoir is tightly closed, they eventually evaporate away. As a result, most of the corrosion problems in water base fluid systems originate wherever water vapor can condense in the reservoir. The traditional method of protecting steel from rusting is to paint it. Water base fluids will act as a solvent for most paints. Generally, epoxy paints with special primers are recommended for components to be exposed to H.W.C.F. Oilgear, has had success using acid-resin primer, followed by a layer of our standard epoxy paint.

For a system originally built for oil, most manufacturers usually recommend removing the paint from the inside of the reservoir.

It should also be noted that paint coverage is much more important when dealing with H.W.C.F. Especially in areas above the fluid surface level, where water vapor will be condensing, the paint layer must be perfect. Any missed spots along weld beads or joints between plates, for instance, will initiate rust. Once a surface has been painted, it must not be damaged. A scratch in the paint which exposes bare metal will start rusting. Once rust gets a starting point, it can slowly work its way under the paint layer, eventually causing large areas to blister and flake off. While the liquid phase corrosion inhibitors in most H.W.C.F. offer excel lent protection, changes in the fluid as it ages or becomes contaminated may decrease the effectiveness of the corrosion inhibitors. Corrosion of untreated metal may then become a problem, especially since the fluid is alkaline by nature. Figures 5 and 6 show the results of a breakdown in liquid phase rust inhibitors.

**CAVITATION**

Figure 7 shows the opening of a case drain reservoir which was exposed to water vapor condensation for about three years.

In an oil system, cavitation is caused by small air bubbles formed in low pressure areas, such as suction ports which are collapsed violently by high pressure, such as in the high pressure port of a pump.

The bubbles collapse follows the gas laws of compression and, for hydraulic pressures of several thousand PSI, the bubble temperature may reach several thousand degrees and generate local pressures as high as 100,000 PSI.
If this collapse occurs near a metal surface, damage may occur to the surface. With a H.W.C.F., dissolved air is still a problem and, in fact, even more of a problem than in oil, because the higher specific gravity of water requires drawing a higher vacuum over it to draw the same head of fluid. However, water vapor presents an even bigger problem. Water is a very volatile fluid compared to oil, and any water vapor bubbles generated within the fluid will behave exactly like gas bubbles. The graph shown in Figure 9 indicates how the boiling point of water varies with pressure. If a 24 inch vacuum is drawn over water, it will boil at 140°F. If we measure the vacuum level at a pump inlet, it will normally be no more than a few inches mercury for a well designed suction line. The bulk of the losses occur after the fluid enters the pump. It must pass thru the narrow kidney openings, must accelerate to the rotational speed of the cylinder, and then accelerate to the maximum linear velocity of the piston. These losses can result in the loss of most of the atmospheric head available to move the oil. This is especially true at 1800 RPM. Also, the fluid temperatures are usually hottest just where the vacuum levels are highest. Even with a 120°F reservoir temperature, localized temperatures in the pump can easily be in the 140 to 150°F range. So vaporization of the H.W.C.F. as it passes thru the pump is possible. To help lessen this problem, a flooded suction should always be used with H.W.C.F. A flooded suction will not eliminate cavitation, however; in fact, testing at Oilgear has shown cavitation damage even with as much as 10 PSI supercharge pressure. This fact leads us to believe that the mechanism of cavitation in water is not fully understood. As a general rule, the inlet pressure to a pump should be kept as high as possible, either thru flooded suction or supercharge. H.W.C.F. temperatures should also be kept as low as practical (above 40°F).

Another factor which contributes to cavitation damage is corrosion. A weakening of the corrosion inhibitors in H.W.C.F. can result in a significant acceleration of the rate of cavitation damage. A freshly cavitated surface is especially susceptible to corrosion, and a freshly oxidized surface is more easily removed by cavitation action. So, the rate of damage done by cavitation when assisted by corrosion is greater than the combined damage, which would result from either effect alone.

### EROSION

Erosion damage is more severe with water base fluids than with mineral base fluids. This is because of the low viscosity and higher specific gravity of H.W.C.F. These two factors are reflected in the Reynolds number, which for H.W.C.F. is about 12 times that for mineral base fluid under similar conditions. This high velocity turbulent flow is much more likely to erode metal surfaces than oil flow, which is usually much closer to a laminar flow situation.

Wire drawing is a good example of erosion. Wire drawing usually begins with a small scratch, which becomes a flow patch for high velocity fluid. The high velocity turbulent flow erodes metal from surfaces in contact with it. Once the surface begins to erode, the surface roughness increases, which leads to even more turbulent flow and more erosion. Eroded particles in the high velocity stream will add to the erosive effect of the fluid.

Corrosive effects can also increase the destructive effects of erosion. Figure 8 is of a piece of pipe on the down-stream side of an Oilgear 3/8 inch, reverse flow relief valve run in H.W.C.F. The damage shown is probably the result of combined cavitation and erosion effects.

![Figure 8. Corrosive Effects of H.W.C.F. On Pipes.](image-url)
Figure 9. Pressure vs. boiling point temperature for water.