Proper fluid selection and maintenance for heat transfer applications

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Key Words
Fluid types, corrosion risk, temperature range, toxicity, evaporation, viscosity, expense, bio-fouling, inhibitors, disposal, thermal properties, compatibility, electrical conductivity, density, flammability, fumes, bath, bath circulators, chillers and heat exchangers

Goal

Whether your temperature control unit (TCU) is a water bath, refrigerated/heated bath circulator, cooling/heating recirculating chiller or recirculating chiller, a fluid will have to be selected. If you are operating between approximately 5 °C and 95 °C, then water seems the likely choice. You might find yourself close to a source of tap water, filtered water, distilled water, reverse osmosis (RO) water, or deionized (DI) water. However, just using the nearest convenient source may not be the right choice. While these water types all have their uses, not all are suitable for your TCU needs. Regardless of how it has been treated, all water starts out with the same basic properties, advantages and disadvantages. Before we look at the properties associated with water, let's define the various fluid properties important to use in a TCU:

Viscosity

Viscosity describes a fluid's resistance to flow due to the friction between its molecules. It is important when selecting a fluid for use in a TCU because the fluid must be pumped either around the bath or out to the application and back. Fluids with a higher viscosity are naturally harder to pump. Most fluids, other than water, also become more viscous as the temperature is decreased. Increased viscosity makes the fluid harder to pump, reducing flow, and may form an insulating boundary layer–both of which reduce its capability to move heat energy.

There are two ways viscosity is measured:

- Dynamic viscosity measures the force required to shear the fluid and is reported in centipoise (cP)
- Kinematic viscosity is dynamic viscosity divided by density and is reported in centistokes (cSt)

Thermo Scientific™ Polar Series Accel 250 LC Cooling/Heating Recirculating Chiller

For a TCU, kinematic viscosity is the preferred measurement, as highly dense fluids will be harder to pump and less dense fluids will be easier to pump. This consideration is not reflected in dynamic viscosity.

Density

Density is the mass per unit volume typically expressed in grams per cubic centimeter (g/cm^3) and pounds per gallon (lb/gal) or pounds per cubic foot (lb/ft^3).

Specific Gravity

Specific gravity is the ratio of the density of the liquid to the density of water at a specified temperature. When using the metric system, density = specific gravity. Because it is a ratio of densities, it does not have a scientific unit (SI) or physical dimensions but is commonly referred to as “SG”.

Temperature Range

A manufacturer’s specified temperature range for a given fluid is likely to extend to the pour point and the flash point or boiling point for non-flammable fluids. For use with a TCU, considerations such as viscosity and fire point almost always narrow the usable temperature range.

- Pour point: The lowest temperature at which an oil or other liquid will pour.
- Flash point: A substance will ignite briefly, but vapor might not be produced at a rate to sustain the fire.
- Fire point: The fire point of a fluid is the temperature at which it will continue to burn for at least 5 seconds after ignition by an open flame.

Most tables of material properties will only list material flash points, but in general the fire points can be assumed to be about 10 °C higher than the flash points. However, this is no substitute for testing when the fire point is safety critical!

The highest working temperature as defined by the EN 61010 (IEC 1010) must be limited to 25 °C below the fire point of the bath fluid.

Thermal Conductivity

Thermal conductivity is the heat energy transferred per unit thickness and is measured in watts per meter, per degree Kelvin (w / (m. °K)). When the thermal conductivity value for a material or fluid is used to calculate heat transfer, the answer will be in watts per square meter (w/m^2).

Figure 1: Thermal Conductivity

Figure 1 shows how heat applied to one side is transmitted to the other side. How well it does this depends on the thermal conductivity of the material being heated.

Specific Heat

Specific heat capacity is the quantity of heat required to raise the temperature of a substance’s unit of mass by a unit change in temperature. It is specified as:

- Calories per gram, per degree Celsius or Cal/g. °C
    - One calorie of energy will change the temperature of one gram of water one degree centigrade
- British thermal units per pound, per degree Fahrenheit or BTU/lb °F
    - One BTU will change the temperature of one pound of water one degree Fahrenheit 1 BTU/lb °F = 1 Cal/g. °C
- Kilojoules per kilogram, per degree Kelvin or kJ/kg. °K
    - One kilojoule of energy equals 1000 watts for one second
- 1 kJ/kg. °K = 0.24 Cal/g. °C or BTU/lb °F

Lower specific heats (metals, plastics, oils, alcohol) take less energy (Kcal/hr) per kilogram to increase or decrease temperature. Higher specific heats (water) take more energy per kilogram to increase or decrease the temperature. For use in a TCU, this means that fluids with higher specific heats have a higher capacity to carry heat either into or away from the application.

Figure 2: Specific Heat Comparison Between Oil and Water

1 kg. oil = 1.08 liter	1 kg. water = 1.0 liter
S.H. = 0.361 Cal/g ºC	S.H. = 1.0 Cal/g ºC
Apply 900 watts for 5 minutes and the new temperature is 199.1 ºC	Apply 900 watts for 5 minutes and the new temperature is 87.4 ºC

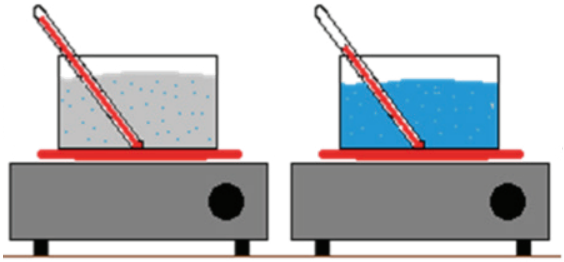


Figure 2 shows what happens when you heat two fluids with different specific heat numbers.

pH

The pH scale goes from 0 to 14 and describes the level of acidity or basicity of a fluid. Water is pH neutral at 7. Any value lower than 7 is acidic, while any value larger than 7 is basic (alkaline). It is worth noting that the pH scale is logarithmic, where pH 4 is ten times more acidic than pH 5 and one hundred times more acidic than pH 6. This is a crucial consideration when checking and maintaining pH in your fluid. See Fig. 3.

Thermal Expansion

Thermal expansion is the amount a given fluid expands when heated, or contracts when cooled. It is very low for water–a liter of water at 20 °C expands to 1.04 liters at 95 °C (4%) and it is much higher for silicon oil–a liter of a typical silicone oil at 20 °C expands to 1.10 liters at 120 °C (10%). Thermal expansion must be considered when using a wide temperature range and not using water or the TCU can overflow.

Wetted Material Compatibility

Most any fluid will have some effect on the materials with which it comes in contact. It could cause any of the following:

- Swelling: Will the fluid cause a wetted elastomer to swell?
- Corrosion: Does the fluid cause a wetted metal to corrode through chemical or galvanic corrosion?
- Disintegration: Will the fluid cause a wetted elastomer to disintegrate?

To determine whether a particular fluid is compatible with the wetted materials of a particular TCU is not as straightforward as it may seem. That is because compatibility is not always a “yes” or “no” answer; it often has some sort of grading such as:

- A = Excellent
- B = Good
- C = Fair
- D = Severe Effect

If a material has an A or B rating, it may be simple to say that it is compatible. But if it is rated as a C or D, what does that really mean? Is it going to last a month, a year or ten years? Without actual testing, it is not always reasonable to venture a guess. Since long-term testing is not often practical, short term testing may prove that a material is not usable, but may still fall short in proving (definitively) that it is usable.

Fluid Resistivity or Conductivity

Resistivity measures how strongly the fluid opposes the flow of electric current and is measured in Ohms (Ω).

- 1 million Ohms = 1 Megohm cm (Meg Ω)

Conductivity measures the fluids ability to pass electric current and is measured in microsiemens (µs).

- Conductivity is the inverse of resistivity or 1/Meg Ω = µs (Figure 4)

Ultrapure water does not do a good job of conducting electricity. It is the dissolved ions (salts) that make it the conductive fluid with which we are all familiar. The more salts present in the water, the greater its capacity for conducting electricity. That is why sea water is more conductive than drinking water.

Figure 3: pH Scale

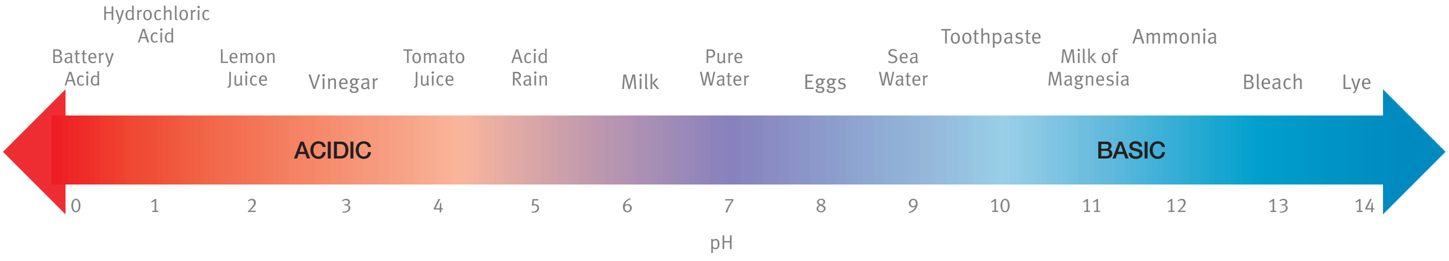


Figure 3 illustrates the pH of some common fluids.

Figure 4: Conductivity/Resistivity Scale

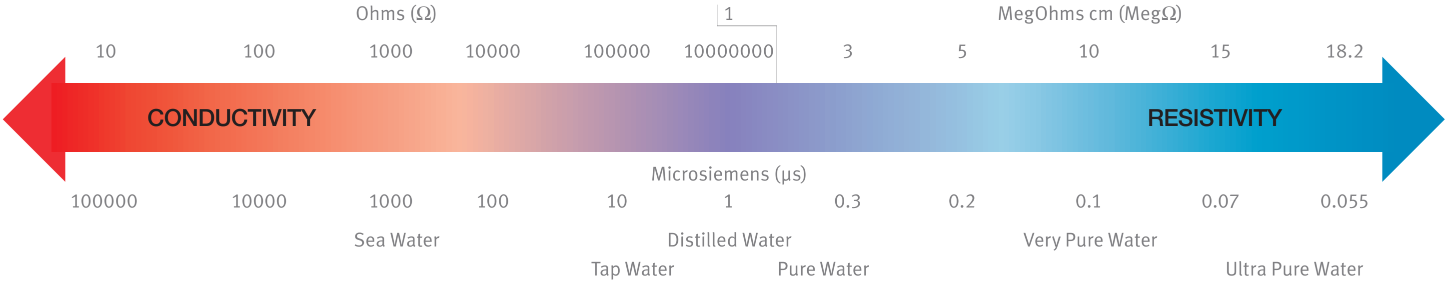


Figure 4 illustrates the relationship between resistivity and conductivity for a variety of common water types.

- Typical tap water has many ionized substances that conduct electricity
- Ultrapure deionized water is a poor conductor of electricity and has a resistivity of 18.2 Megohm cm or a conductivity of 0.055 microsiemens
- Ultrapure water exists in an unbalanced state and it will leach ions from almost everything with which it comes in contact; this can weaken wetted materials leading to pitting corrosion and polymer failure
- Resistivity increases with temperature; in some instances it can approach 10% per degree centigrade

Some applications, particularly in the manufacturing of semiconductor chips, have a specific requirement to be electrically isolated. Having a conductive supply of water in contact with the tool can give an undesirable electrical path, similar to having an extra ground wire. In these cases, ultrapure water may be a necessity. But for all other applications that do not call out a specified level of resistivity or conductivity, it is possible to have water that is too clean. Remember that water is already a powerful dissolver. And when combined with oxygen, it is a powerful oxidizer. Removing ions readies the water to accept more ions from your TCU, pipes and application. So do not use DI water unless the application requires it in writing. Otherwise, distilled water is a much better choice.

Corrosion

The two most common types of corrosion associated with using a TCU are pitting corrosion and galvanic corrosion. Pitting corrosion in a TCU is most often caused by a pH imbalance and aggressive deionized water. The pH imbalance can be caused by:

- Low quality, untested tap or municipal water
- Tap or municipal water that has had dissolved solids concentrated due to evaporation and refilling
- Water that has not been changed at recommended intervals
- Additives that have broken down over time

Galvanic corrosion refers to corrosion that is caused by having at least two different (dissimilar) metals in a corrosive, conductive fluid (electrolyte). For galvanic corrosion to occur, the following conditions must be present:

- Two or more different metals (copper and aluminum for example)
- The metals are in electrical contact with each other via an electrolyte (water is an electrolyte)

The further away from each other that the two metals are in the galvanic series (Figure 5), the stronger the electrical current (think battery). The stronger the electrical current, the more likely it is that the anode metal is going to corrode and deposit on the cathode metal (ions are going to leave the aluminum and attach themselves to the copper).

Unchecked galvanic corrosion can destroy both the TCU and the application in short order. To slow or prevent galvanic corrosion in recirculating systems:

- Avoid dissimilar metals that are far apart (high potential) on the galvanic series of metals slows the process.
- Maintain the system at the correct pH level because high pH is more corrosive and aids the migration of ions
- Use an approved inhibitor that coat the metals with a layer of sacrificial ions protecting the underlying metal

Fluid Properties

All Water
Usable Temperature Range: 5 °C to 95 °C
Freeze point: 0 °C
Boiling point: 100 °C (sea level)
Flashpoint: none
Viscosity: 1 cSt @ 20 °C
Thermal Conductivity: 0.58 w/(m. °K) or 0.3445 Btu/(ft.hr. °F)
Density: 1 g/cm3
Specific Gravity: 1
Specific Heat: 1 Cal/g. °C or 1 Btu/lb. °F
Advantages:
Great capacity to carry heat
Low viscosity
Compatible with many materials
Disadvantages:
Can support bio-growth
Evaporates readily at top of temperature range
Corrosive to ferrous metals
pH needs to be maintained

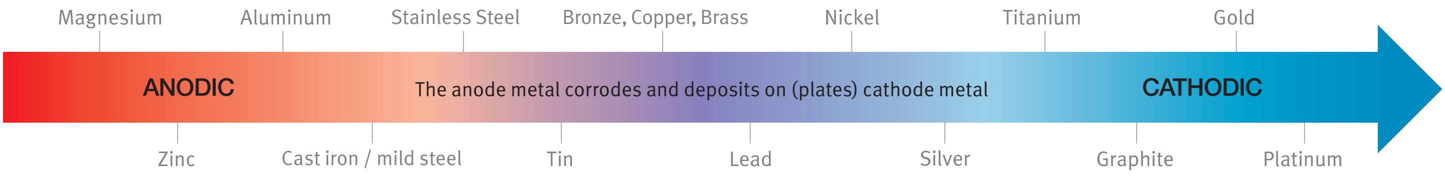
From this, each water type has additional advantages and disadvantages:

Tap Water

Well or municipal water should not be used unless it has been tested by a lab to meet the minimum requirements spelled out in the operator's manual, or recommended by the manufacturer. The primary risks of using untested and untreated tap water are corrosion caused by an out of range pH value and/or the concentration of dissolved solids, and those dissolved solids precipitating out of solution and forming scale. Table 1 shows an example of a TCU water quality table.

Additional Advantages:
Low cost and readily available
Additional Disadvantages:
Not sterile
Dissolved solids can be concentrated and collected

Figure 5: Galvanic Series



In Figure 5, the further two elements are apart in the table, the more likely galvanic corrosion is to take place.

Table 1: Example of TCU Water Quality Table

Process Fluid	Permissible (PPM)	Desirable (PPM)
Microbiologicals (algae, bacteria, fungi)	0	0
Inorganic Chemicals		
Calcium	<25	<0.06
Chloride	<25	<10
Copper	<1.3	<1.0
0.020 ppm if fluid in contact with aluminum		
Iron	<.3	<0.1
Lead	<0.015	0
Magnesium	<12	<0.1
Manganese	<0.05	<0.03
Nitrates/Nitrites	<10 as N	0
Potassium	<20	<0.3
Silicate	<25	<1.0
Sodium	<20	<0.03
Sulfate	<25	<1
Hardness	<17	<0.05
Total Dissolved Solids	<50	<10
Other Parameters		
pH	6.5-8.5	7-8
Resistivity	0.01*	0.05-.01*

* MΩ-cm (compensated to 25 °C).

Filtered Water

Water that meets or exceeds the above requirements by filtering is also acceptable.

Distilled Water

Distilled water is created by evaporating and then condensing tap water. This process removes most minerals that could cause corrosion and mineral precipitation or concentration. Distilled water is highly preferred for most TCU applications.

Additional Advantages:

Low cost and readily available

Sterile

Does not need to be tested for water quality

Additional Disadvantages:

Must be purchased or requires specialized equipment to produce onsite

Reverse Osmosis (RO) Water

RO water is created by using pressure to force water through a membrane. It has all of the advantages of distilled water, but depending on the level of processing can also leach ions like the deionized water described below.

Additional Advantages:

Typically Sterile

Does not need to be tested for water quality

Additional Disadvantages:

Should be tested to insure that the resistivity is 3 MegOhm cm or less

Must be purchased or required specialized equipment to product onsite

Deionized (DI) Water

Deionized water is created by flowing water through a resin bed cartridge that removes ions (dissolved metallic salts).

Additional Advantages:

Does need to be tested for water quality

Additional Disadvantages:

Should be tested to insure that the resistivity is 3 MegOhm cm or less

Must be purchased or required specialized equipment to product onsite

Aggressively leaches ions from everything it touches

Process does not guarantee sterility

Water Additives

There are many useful additives to water that can:

- Lower the freeze point (freeze point suppressant)
- Reduce corrosion (inhibitor)
- Prevent bio-growth (biocide)

But additives also include their share of myths, such as:

- Increasing thermal conductivity
- Lubricating the pump
- Reducing corrosion without an inhibitor
- Preventing bio-growth without a biocide

Additives not recommended by the TCU manufacturer, and/or are not specifically formulated for TCU use, should not be used.

Freeze Point Suppressants

Glycols are the most common freeze point suppressant and come in two types, ethylene glycol (EG) and propylene glycol (PG), which are most often mixed in a 50:50 ratio with water. Regardless of which myth you have heard, glycols are only really useful as a freeze point suppressant.

Ethylene Glycol

EG mixed 50:50 by volume with water (EGW) has a freeze point of -36.8 °C and can be used at temperatures down to about -30 °C. Keep in mind that the evaporator surface where the cooling takes place is much colder the fluid temperature (setpoint temperature) and may be at or below the freezing temperature of the fluid. Lowering the temperature of glycol/water also raises the viscosity, lowering the flow rate from the pump and/or the mixing within a bath. This higher viscosity can also form a boundary layer that clings to the much colder evaporator and insulates it from the rest of the fluid, limiting how low of a temperature can be achieved and reducing cooling capacity.

Propylene Glycol

PG mixed 50:50 by volume with water (PGW) has a freeze point of -34.0 °C and can be used at temperatures down to about -20 °C. The viscosity of PGW goes up much sooner than EGW further limiting the pumping and cooling capacity at low temperatures. The only real advantage of PGW is that it is less toxic (some would call it non-toxic) than EGW making it more suitable for the food and medical industries.

What you should know about either ethylene glycol or propylene glycol and water:

- They are effective as a freeze point suppressant only when mixed with water
- While EGW is poisonous, some microorganisms can still thrive in it
- Without an inhibitor, they do not prevent corrosion
- The inhibitors used in automotive anti-freeze (EG or PG) are often silicates that may gel and cause a loss of cooling capacity or clog small passages
- The inhibitors used in automotive anti-freeze (EG or PG) may not be compatible with TCU wetted materials
- The pH of EGW and PGW, particularly in applications above room temperature, needs to be monitored as the pH will decrease as the glycol breaks down and the mixture will become corrosive
- EGW and PGW have lower thermal conductivity than water alone – they do not improve cooling

Fluid Properties of EGW and PG

Fluid Properties of EGW and PGW		50% / 50% Uninhibited Ethylene Glycol/ Distilled Water (by volume)	50% / 50% Uninhibited Propylene Glycol/ Distilled Water (by volume)
Temperature Range	Freeze Point	-37 °C	-34 °C
	Boiling Point	107.2 °C	105.6 °C
	Flashpoint	None, but if all the water is boiled away, EG is flammable	None, but if all the water is boiled away, PG is flammable
Viscosity	Dynamic	27.5 cP at -20 °C	74.3 cP at -20 °C
		4.9 cP at 20 °C	6.3 cP at 20 °C
	Kinematic	25 cSt at -20 °C (27.5 cP / 1.1 g/cm3)	70 cSt at -20 °C
		4.5 cSt at 20 °C	6 cSt at 20 °C
Density		1.12 g/cm^3 at -20 °C	1.06 g/cm^3 at -20 °C
		1.08 g/cm^3 at 20 °C	1.03 g/cm^3 at 20 °C
Thermal Conductivity		0.4 w/(m. °K)	0.4 w/(m. °K)
Specific Gravity		same as density	same as density
Specific Heat		0.83 Cal/g. °C at -20 °C	0.81 Cal/g. °C at -20 °C
		0.87 Cal/g. °C at 20 °C	0.92 Cal/g. °C at 20 °C
Advantages		Wider temperature range than water alone	Wider temperature range than water alone
		Low cost and readily available	Low cost and readily available
		Good capacity to carry heat	Good capacity to carry heat
		Low viscosity	Low viscosity
		Compatible with many materials	Compatible with many materials
		Sterile	Sterile
			Less toxic – safer to use, easier to dispose of than EG
Disadvantages		Does not remove heat as well as water alone	Does not remove heat as well as water alone
		The viscosity goes up as the temperature goes down	The viscosity goes up as the temperature goes down
		Can support bio-growth	Can support bio-growth
		Evaporates readily at top of temperature range	Evaporates readily at top of temperature range
		Can become corrosive without inhibitor – automotive inhibitors are not compatible with our units	Can become corrosive without inhibitor – automotive inhibitors are not compatible with our units
		pH needs to be maintained to prevent corrosion	pH needs to be maintained to prevent corrosion
		Toxic - needs to be handled and disposed of with care	More viscous at lower temperatures

Inhibitors

Corrosion inhibitors can reduce the rate of corrosion of the wetted metals in a TCU/application loop. It is especially critical to use an inhibitor when you have mixed metals including aluminum and copper and/or when you are using a glycol.

They work by a providing a layer upon the metal to be protected. This layer acts either as a sacrificial anode that is removed from the protected metal by the cathode or as a layer on the cathode that interrupts the galvanic process.

The layer of inhibitor is removed through erosion and the galvanic process and is constantly replenished by the flow of the water containing it. Over time, the inhibitor will be depleted and need to be replenished.

Because flow is required to maintain the inhibitor layer, inhibitors will not protect metals when the fluid is stagnant. In fact, some inhibitors contain elements that are nutrients to microorganisms causing them to thrive and potentially excrete an acid that causes corrosion.

Recommendations for selecting/using an inhibitor:

- Do not use an inhibitor intended for use in a boiler or furnace
- Do not use an inhibitor intended for automotive use
- Only use an inhibitor that is approved by the manufacturer of the TCU
- Use an inhibitor any time there is aluminum as a wetted material in your application
- Do not let water, with or without an inhibitor, stagnate

Biocides

There are many types and purposes for biocides, but for use in a TCU/application loop we will concentrate on the ones that can be added to water to protect against or remove a biological infestation or growth.

The most common biocide is chlorine and it is available in many forms:

- Liquid household bleach (sodium hypochlorite)
- Granular chlorine (calcium hypochlorite)
- Tablet chlorine (sodium dichloroisocyanurate or Aquatabs™)

Most TCU manufacturers warn against, or prohibit, its use in any form, but do not offer a viable alternative. The issue is the potential for severe corrosion caused by intentional or accidental overdosing. No TCU manufacturer is going to warranty corrosion or damage caused by the misuse of chlorine or any other biocide or inhibitor.

The secret to successfully using chlorine is to measure and maintain the level of free chlorine and the pH. The simplest and most cost effective way is to buy pool or spa test strips and use them regularly — at least once a month or anytime the water is topped off or replaced. Chlorine needs to be maintained at 5 parts per million (ppm) and the pH needs to be maintained above 7.

It is worth noting that municipal water systems are allowed up to 4 ppm chlorine so the dose of 5 ppm is quite low — low enough to not cause undue corrosion within the life of the TCU. See the appendix for guidelines on how to correctly use the above forms of chlorine, and avoid unwarranted damage.

Nalco Premix/Nalco Kit Mixed with Distilled Water

Nalco has specially formulated an inhibitor and biocide package for use in TCUs. It is available as a concentrate kit that gets mixed with distilled water or premixed with DI water that is ready to use. Nalco has all of the advantages/disadvantages of water, as well as the following:

Advantages:
Compatible with many materials
Inhibitor protects against corrosion
Sterile
Can be used 50:50 with glycol
Biocide prevents bio-growth
Proven affective with a wide range of wetted material compatibility
Disadvantages:
More expensive than water alone
Concentrate kit cannot currently be shipped internationally

Silicone Oil

Silicone oil (polydimethylsiloxane) comes in a variety of viscosities and temperature ranges. The higher-viscosity silicone oils typically also have a higher fire point and work well at temperatures that cannot be achieved with water (> 95 °C). The lower viscosity silicone oils are intended for use below 0 °C, where their lower viscosity allows them to still be effectively pumped or circulated. Silicone oil can also be used between 5 °C and 95 °C for applications that cannot use water.

Independent of the temperature range or viscosity, silicone oils have the following advantages/disadvantages:

Advantages:
Wide temperature range
Low rate of evaporation
No bio-growth
Non-corrosive
Widely compatible
Disadvantages:
Expensive
Messy – fumes can create oil film
Disposal
Not compatible with silicone hose or ABS plastic
Immiscible in water (does not mix)

Silicone Oil Comparison		SIL 100	SIL 180	SIL 300	Dow Corning™ 200 Fluid, 50 cs
Temperature Range	Heating Up Range	N/A	N/A	15 °C to 85 °C	15 °C to 30 °C
	Operating Range	-75 °C to -5 °C	-40 °C to 95 °C	85 °C to 160 °C	N/A
	Working Range	-5 °C to 75 °C	95 °C to 200 °C	160 °C to 300 °C	30 °C to 150 °C
	Fire Point	>100 °C	>225 °C	>325 °C	>250 °C
Viscosity	Dynamic	3 cP at 20 °C	11 cP at 20 °C	200 cP at 20 °C	48 cP at 20 °C
	Kinematic	3.37 cSt at 20 °C	11.8 cSt at 20 °C	185 cSt at 20 °C	50 cSt at 20 °C
Density		0.89 g/cm3 at 20 °C	0.93 g/cm3 at 20 °C	0.93 g/cm3 at 20 °C	0.96 g/cm3 at 20 °C
Thermal Conductivity		0.1w/(m °K)	0.1w/(m °K)	0.1w/(m °K)	0.1w/(m °K)
Specific Gravity		0.89 g/cm3 at 20 °C	0.93 g/cm3 at 20 °C	1.08 g/cm3 at 20 °C	0.96 g/cm3 at 20 °C
Specific Heat		0.4 Cal/g °C at 20 °C	0.36 Cal/g °C at 20 °C	0.37 Cal/g °C at 20 °C	0.35 Cal/g °C at 20 °C
Additional Disadvantages		–	Outgasses at high temperatures – should be used in a fume hood	Outgasses at high temperatures – should be used in a fume hood	Outgasses at high temperatures – should be used in a fume hood

Synthetic Fluids

Synthetic fluids share the following advantages/disadvantages:

Advantages:

- Low temperature range
- Low viscosity
- Lower price than some silicone oils
- Compatibility issues with some polymers
- Low odor compared to mineral oil

Disadvantage:

- It can coke up on high watt density heating elements

Synthetic Fluid Comparison		Synth 60	Synth 200	Synth 260
Temperature Range	Heating Up Range	N/A	N/A	N/A
	Operating Range	-50 °C to -35 °C	20 °C to 60 °C	40 °C to 150 °C
	Working Range	-35 °C to 45 °C	60°C to 210 °C	150 °C to 250 °C
	Fire Point	70 °C	>235 °C	>235 °C
Viscosity	Dynamic	2 cP at 20 °C	100 cP at 20 °C	140 cP at 20 °C
	Kinematic	2.6 cSt at 20 °C	116.3 cSt at 20 °C	135.9 cSt at 20 °C
Density		0.76 g/cm3 at 20 °C	0.86 g/cm3 at 20 °C	1.03 g/cm3 at 20 °C
Thermal Conductivity		N/A	N/A	N/A
Specific Gravity		0.76 g/cm3 at 20 °C	0.86 g/cm3 at 20 °C	1.03 g/cm3 at 20 °C
Specific Heat		0.5 Cal/g °C at 20 °C	0.47 Cal/g °C at 20 °C	0.48 Cal/g °C at 20 °C
Additional Disadvantages		–	Strong odor at high temperatures – should be used in a fume hood Changes color (oxidizes) faster than silicone oil and does not last as long	Strong odor at high temperatures – should be used in a fume hood Changes color (oxidizes) faster than silicone oil and does not last as long

HFE and PFPE (Hydrofluoroether and Perfluoropolyether)

These types of fluids, more commonly known by their brand names, Fluorinert™ and Galden™, are solvents originally intended for industrial cleaning such as vapor degreasing. They have also found a use as a coolant in some TCU applications that require a non-conductive fluid or one that does not leave a residue in case of a leak.

Advantages:

- Dielectric (non-conductive)
- If there is a leak, it evaporates without residue (no cleaning)
- Low viscosity
- Can be used at ultra-low temperatures

Disadvantages:

- Expensive
- It evaporates readily requiring a sealed or semi-sealed TCU reservoir
- High density requires more pump power
- Not compatible with some polymers and may require “special” pump seals

3M™ Novec™ HFE 7200

Temperature Range:

Freeze point: -138 °C
Boiling point: 76 °C
Operating range: -110 °C to 60 °C
Fire point: N/A

Viscosity:

Dynamic: 0.61 cP at 25 °C
Kinematic: 0.43 cSt at 25 °C

Density: 1.43 g/cm3 at 25 °C

Thermal Conductivity: 0.068 w/(m °K)

Specific Gravity: 1.43 g/cm3 at 25 °C

Specific Heat: 0.29Cal/g °C at 25 °C

Conclusion:

When selecting a fluid for your temperature controlled bath, circulator or chiller, there are a number of things to consider before purchasing, using or disposing, including but not limited to: pH level, corrosion risk, temperature range, toxicity, evaporation, viscosity, expense, evaporation, bio-fouling, inhibitors, disposal, thermal properties, compatibility, electrical conductivity, density, flammability and fumes.

Appendix

Instructions for Chlorine Usage in Thermo Scientific Temperature Control Systems

Introduction

For water-based cooling, there are a variety of water types that might be chosen: tap, filtered, distilled, reverse osmosis and deionized are the most common. All of these can support microbial life that can foul the application, fluid lines and the temperature control unit (TCU), whether it is a recirculating chiller, heated/refrigerated bath circulator or water-to-water heat exchanger.

Liquid or tablet chlorine can be used to help prevent or stop microbial growth in your TCU.

First let’s look at the various types of water:

Tap water is an obvious choice for filling a TCU. Short term usage of tap water may not cause any adverse affects on the components in the TCU or your application, but in the long term problems may arise such as deposition/concentration of dissolved solids, corrosion and bio-growth. Tap water is not necessarily sterile and even if it is, algae, bacteria and other forms of microbial life can enter the system.

Filtered water is generally preferred to tap water as it will have fewer dissolved solids and may have filtered out any microbial life. However, again airborne microbes may enter the system.

Distilled water is considered the “cleanest” form of water because in a sealed container it is sterile by definition and has very low quantities of dissolved solids. Because of these properties, it is the preferred option for most any TCU.

Reverse osmosis (RO) water can be similar to distilled or can be as pure as the deionized water described below. While RO water is less likely to cause algae or other bio-fouling than deionized water, it may not be sterile. In addition, if the level of purity is unknown, it may be best to avoid RO water as it can cause some of the same corrosion issues stated below for deionized water.

Deionized (DI) water and demineralized water are essentially the same. As ionized salts and minerals are removed, the purity and the electrical resistivity of the water increases. The purity of the water is typically rated by its electrical resistance in MegOhm cm (million Ohms per centimeter) with 18.2 MegOhm cm water being considered “ultrapure”. The processes that produce this type of water may filter out some microbial life, but does not kill it and is therefore not sterile. Having ions (metal salts) removed from water causes an imbalance where the water will leach ions from whatever material with which it comes into contact. This leaching can cause metal (even stainless steel) to pit, corrode and weaken. This is why we do not recommend using water with a resistivity more than 3 Megohm cm.

Chlorine

It is commonly known that chlorine can cause corrosion of many metals, even stainless steel, so why would we recommend its use? Because the concentrations necessary to cause corrosion are many times greater than the desired 5 parts-per-million (ppm) used to prevent bio-growth and it only takes 5 milligrams (mg) of chlorine per Liter of water to reach 5 ppm.

It is also necessary that pool test strips or other methods be used to measure and maintain the desired chlorine content (5 ppm) and pH (6.5 to 7.5). Without measuring and maintaining the fluid, an imbalance will occur that could cause damage to the TCU or application.

Monitoring + Treatment = Prevention

Using distilled or RO water (less than 3 MegOhm cm resistivity) as a starting point is highly recommended. When chlorine is added to distilled or RO water, the free chlorine concentration effectively will be equal to the concentration of chlorine added. Many municipalities put up to 4 ppm chlorine in their tap water, which can vary batch to batch, requiring testing before adding chlorine. Tap water would also have to be tested to see if it conforms to the water quality table in our operations manuals.

We do not recommend adding chlorine to DI or RO water with a resistivity higher than 3 megOhm cm.

The quantities listed below for chlorine use are for clean water devoid of any existing chlorine. For tap water, the existing chlorine level must be determined prior to adding additional chlorine.

Liquid Chlorine

Sodium hypochlorite (also known as liquid household bleach at 6% concentration) can be used. Two drops of liquid bleach per liter of water using standard Thermo Scientific droppers are required to attain 5 ppm chlorine. Liquid chlorine loses its strength readily, but is easy to monitor and maintain.

Granular Chlorine

Calcium hypochlorite (also known as pool chlorine) is most commonly available in granules and large tablet form. Various concentrations are available, so the dosage to reach 5 ppm chlorine must be administered carefully. Online calcium hypochlorite calculators can be helpful.

Tablet Chlorine

Sodium dichloroisocyanurate can be found in water purification tablets, such as Aquatabs. These come in 3.5, 8.5, 17, 33, 67 and 167 mg tablets. Depending on how much water is being mixed, any size could be used as long as it is mixed at 8.5 mg sodium dichloroisocyanurate per liter of water. Mixing in this ratio will (approximately) result in the desired 5 ppm chlorine.

Fluid Preparation & Maintenance for All Types of Chlorine

- Determine the total amount of fluid required for your system before proceeding and have enough water, chlorine and pool test strips on hand. The TCU operations manual will have the reservoir or bath volume. To this, you need to add the volume of the fluid lines and application (as applicable).
- The ppm of chlorine in tap water should be measured before mixing and the amount of chlorine added adjusted to achieve the desired 5 ppm chlorine. The ppm of chlorine in distilled, RO and DI water should be measured after mixing and before being put into your TCU.
- Any liquid chlorine or chlorine dissolved in water will degrade in a matter of days so do not store it before using it. Granules or tablets are much more stable and can be stored for long periods of time. This is another reason to check the ppm concentration even if you have added the correct amount of liquid chlorine.
- When water evaporates from your system, the level of chlorine may change. Adding new water with chlorine in it will change the ratio from what is desired. Additional chlorine should not be added without first topping off your system with just water and then determining the need for additional chlorine by measuring the pH.
- The duration of time that chlorine will remain in solution is dependent on factors such as water temperature, pH and exposure to direct sunlight. It is recommended to follow regular procedures that maintain chlorine levels at recommended levels.
- When the pH of the water in use falls outside of the desired range of 6.5 to 7.5, the unit should be drained and refilled with a fresh water/chlorine mix.
- The chlorine quantities in the fluid preparation guide below are approximate and do not replace determining the actual concentration of chlorine and pH using pool test strips or other means.
- The best preventative measure is to fill the unit as prescribed below every time the unit is put in service. The unit should be drained when it is not being used for extended periods of time. Applying a wet vacuum to the drain line will assist in removing excess water that may be trapped in crevices of the TCU’s plumbing.
- Regularly inspect the fluid to determine if it is running clean.
- If the TCU, fluid lines or application is already showing signs of bio-growth, or develops bio-growth, it should be shocked with 10 ppm chlorine circulated for 30 minutes but not exceeding 60 minutes.

- It is not recommended to increase the dosage beyond 10 ppm chlorine as higher concentrations of chlorine will become aggressive to the materials of construction within the TCU and possibly the application as well.
- If the TCU has been out of service for a period of three months or more, the entire system should be shocked, as described above, followed by draining and refilling with treated water at 5 ppm chlorine levels.

Fluid Preparation: Sodium Hypochlorite (Liquid Household Chlorine Bleach)

Although chlorine bleach is a well known household chemical, it does present hazards, and it is strongly recommended that you read the MSDS and adhere to the handling instructions before proceeding to treat your fluid.

2 drops of 6% bleach will be required for each liter of fluid in your reservoir and application.

Example:

TCU reservoir or bath = 7 Liters
Fluid in application and hoses = 3 Liters
Total fluid in application, hoses and TCU = 10 Liters
Total number of drops required = 20 Drops

Add 2 drops of chlorine per liter of water in a separate container. Stir the fluid to mix completely. Once the level of chlorine has been confirmed, pour the fluid mixture into the reservoir or bath of your TCU. Fill the reservoir or bath and follow the normal start up procedure as indicated in the TCU manual. Check the ppm level of chlorine again and adjust by adding chlorine or draining and diluting with additional water, if necessary.

Fluid Preparation: Calcium Hypochlorite (Pool Chlorine Granules)

It is strongly recommended that you read the manufacturers MSDS, and adhere to the handling instructions before treating your fluid. Because of the highly concentrated nature of this product, do not guess at the amount to use - more is not better! If you cannot properly weigh the granules, do not use it!

77 milligrams at 65% available chlorine concentration will be required for every 10 liters of fluid in your reservoir and application.

Example:

TCU reservoir or bath = 12 Liters
Fluid in application and hoses = 8 Liters
Total fluid in application, hoses and TCU = 20 Liters
Total number of drops required = 154 mg

Using the specified available chlorine percent, determine the amount of calcium hypochlorite required (use an online calcium hypochlorite calculator as required). Dissolve the granules in one liter of water and let sit ½ hour before using. All of the inert ingredients may not dissolve, so carefully pour the mixture into the rest of the water to avoid including any solid bits or filter them out. Fill the reservoir or bath and follow the normal start up procedure as indicated in the TCU manual. Check the ppm level of chlorine again and adjust by adding tablet(s) or draining and diluting with additional water if necessary.

Fluid Preparation: Sodium Dichloroisocyanurate (such as Aquatabs Tablets)

It is strongly recommended that you read the MSDS and adhere to the handling instructions before proceeding to treat your fluid.

1 tablet (8.5 mg) will be required for each liter of fluid in your reservoir and application.

Example:

TCU reservoir or bath = 7 Liters
Fluid in application and hoses = 3 Liters
Total fluid in application, hoses and TCU = 10 Liters
Total number of tablets required = 10 Tablets

Add one 8.5 mg chlorine tablet per liter of water and allow 1 ½ minutes for the tablet to dissolve. The tablets are carbonated and the carbonation will need to be removed prior to adding the fluid mixture to the TCU. Stir and/or shake the fluid and let stand for 15 minutes. Once the level of chlorine has been confirmed, pour the fluid into the reservoir or bath of your TCU. Fill the reservoir or bath and follow the normal start-up procedure as indicated in the TCU manual. Check the ppm level of chlorine again and adjust by adding tablet(s) or draining and diluting with additional water, if necessary.

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