# Secondary Loop Systems

## *Natural refrigerants – the natural choice for secondary systems*

Information paper No. 2

## Different Heat Transfer Fluids

The expression “heat transfer fluid”, later referred to as HTF, is used for liquids used to capture and transport the energy of an indirect cooling system on the cold side (evaporator side) or on the warm side (condenser side). Older types of indirect refrigeration systems mainly used calcium chloride (salt solutions), which were denoted by the English word "brine" = salt water. As other chemicals began to be used in systems engineering e.g., glycols, alcohols and new organic salts, a name change was necessary.

In this paper, only water-based single-phase HTFs are taken into consideration and no synthetic oils (usually low temperature use) or phase-changing media (two-phase media) for instance ice slurries and carbon dioxide ($CO_2$).

All HTFs have their advantages and disadvantages, perhaps with the only exception of water, which has “no” disadvantages other than its freezing point. Requirements for an HTF can be summarized as:

- Energy efficient – Good thermophysical properties such as specific heat and heat conductivity
- Sufficient freeze protection
- Low viscosity
- Compatible with materials used
- Safe to handle
- Environment-friendly
- Low cost and/or low life-cycle cost
- Long-term solution
- Low corrosivity
- Low environmental $CO_2$ footprint
- Easy and cheap disposal

The most common water based HTF’s can be divided into five families:

- Alcohols: Ethyl alcohol (Ethanol) and Methyl alcohol (Methanol)
- Glycols: Ethylene glycol, Propylene glycol (dihydric alcohol)
- Polyols: Glycerine (also Glycerol) trihydric alcohol

- Salts or brines
  - Inorganic salts: Calcium chloride, Potassium carbonate
    Organic salts: Potassium acetate, Potassium formate
- Others: ammonia/water

Below is a simple overview for highlighting different types of HTF's and their general characteristics:

Aqueous based HTF

**Alcohols**: Highly flammable, low boiling point, toxic or cause intoxication if consumed. Ethanol has a very low surface tension that may cause foaming and leakages in sealing devices. Due to safety and risk limitations, usable up to approx. 30 % meaning a freezing point of -20°C. Alcohols have very good thermal properties down to -5/-10°C. Methanol is toxic if swallowed, in contact with skin or if inhaled. Alcohols are commonly used in heat pumps.

**Glycols:** Moderately flammable, high toxicity for monoethyleneglycol (MEG) with lethal dose for grown up ca. 10 cl. MEG have reasonable viscosity down to -35°C. In case of monopropyleneglycol (MPG) the viscosity increases sharply below -20/-25°C. Glycols have a tendency to become weakly acidic through oxidation to glycolic acids after long time use and may need to be exchanged. MEG and MPG are suitable for cooling and heat pump applications.

**Glycerine:** Low toxicity (food additive E 422) for human and aquatic environment. Although glycerine has an even higher viscosity than MPG it is usable down to -20°C with reasonable viscosity.

**Salts – inorganic**: Potassium carbonate has a high pH value (about 12) involving risk for eyes when contact. Freezing point down to -35°C. Calcium chloride is highly corrosive when oxygen is present also towards stainless steel. Often titanium heat exchangers are required. Corrosion inhibitors are needed and are often made of chromates, which are toxic and sensitizing. Good properties with low viscosity at low temperature applications. Sodium chloride (table salt) has a higher freezing point and is corrosive like other chloride salts.

**Salt – organic**: Potassium acetate and potassium formate and mixtures thereof. Both salts are low toxic (Potassium acetate is also a preservative E 261 used in food). Compatible with most materials but cannot be used together with galvanized steel as it is not compatible with zinc. Very good thermal properties even at low temperatures. Potassium formate solutions have almost the double electrical conductivity compared with potassium acetate.

**Ammonia/water:** Very good thermal properties also at low temperatures. Tough odour even at very low concentration. Very high pH 13-14, already at very low concentrations. High grade quality materials are therefore needed. Ammonia is not compatible with copper. Follow local regulations when using ammonia.

Non-aqueous based HTF:

- Non-aqueous : Hydrocarbons, silicon oils etc.
- Non-aqueous : Carbon dioxide ($CO_2$) 2-phase

**Hydrocarbons:** hydrocarbons often have a very low freezing point, down to -60 to -80°C. They feature a very low viscosity but are poor in specific heat and thermal conductivity. Compatible with most construction materials. The products are often combustible, fatal if swallowed, respiratory irritation, toxic to aquatic substances which needs to be considered.

**Silicone oils (polydimethylsiloxane):** Very low freezing point down to -100°C or sometimes even lower. Very poor thermal properties but low viscosity. Very expensive compared with water-based HTFs.

**$CO_2$:** Carbon dioxide is a natural media, has very low pressure drops – small pump works, non-corrosive but the installation may be more expensive due to the need for higher pressure. Another drawback is that $CO_2$ is very sensitive to water – forming carbonic acid.

For more detailed information about different products, please refer to the supplier.

**Within this information paper only 1-phase water based HTFs are discussed.**

The HTF should be chosen with concern to how it will be used (temperature range), environmental aspects and how the system is built including material selection. It is also needed to consider which type of demands each HTF will imply for the system design and material choices. Generally, there is no ideal HTF for all types of application.

When using concentrates intended to be mixed with water, it is important to use the right water quality. Contact the supplier of the HTF for exact information as to the water quality required for the product. If using organic salts or propylene glycol with inhibitors for applications within the food sector, it is advisable either to use ready-mixed solutions from the supplier, or to mix with deionized water. Motor radiator glycol must not be used in this type of system, as the corrosion inhibitor composition is different and would cause pump damages. Do not mix different types of HTF in the same system. Corrosion inhibitors, for instance, may counteract each other and impair the corrosion protection. The freezing point may also be difficult to predict.

When choosing an HTF, environmental considerations may be of crucial importance. From this point of view, consideration should be given to the overall environmental impact of the product. This refers to the effect of the product's impact on the local environment, work environment, exterior environment, and health risks as well. This information is normally available in the safety data sheet or other information of the product.

One should select an HTF that provides environmental and energy benefits that are tailored to the specific system. If a "green" product that does not fit the system is chosen, the environmental gain may be mitigated or disappear completely.

An intersection between the highest possible efficiency of an HTF-filled system on the one hand and maximum operation safety on the other can only be achieved by cutbacks on the one or the other side.

The following fluid properties should be valued when choosing an HTF:

a. Thermophysical properties

Density, viscosity, heat transfer properties and temperature range are normally to be found in the product data sheet. Viscosity and density are important parameters of an HTF in system-dimensioning, e.g., pressure drop and pump size. The lower the viscosity of the HTF the easier it is to pump and the lower the pressure drop. Of course, the flow profile (laminar/turbulent) also influences pressure drop. The heat transfer properties such as specific heat and thermal conductivity are important for heat transfer area/size in evaporators, condensers, or any heat exchanger. Of course, the flow profile (laminar/turbulent) also influence the heat transfer and consequently the heat transfer area.

All aqueous based HTF's are using the good properties of water. To lower the freezing point different types of depressing substance are added as for instance different types of salts. The need for a certain freezing point is crucial. However, the less freezing point depressing substance is added to water the better properties are achieved. Therefore, never use an HTF with a certain freezing point for all applications. Allow a safety margin (THTF - TRefrigerant) towards freezing or as close as possible to the operational temperature of the HTF.

When choosing HTF different properties may be compared such as ν (kinematic viscosity), ρ (density), k (thermal conductivity) and cp (specific heat capacity) (table 1, 2) or differences in pressure drop and heat transfer coefficient (Diagrams 1, 2, 4, 5, 6)

Reynolds number (Re) = w*d/ν

Laminar flow (Re < 2300) Turbulent flow (Re > 2300)

Pressure drop calculation

ΔPlam = 32 * ρ * ν * w * L / d2 ΔPturb = 0.092 * ρ * ν0.2 * w1.8 * L / d1.2

Heat transfer coefficient

klam = 1.86 * λ2/3 * (ρ cp)1/3 * (w/d L)1/3 kturb = 0.023 * λ2/3 * (ρ cp)1/3 * ν (1/3-0.8) * w0.8/d0.2

Pumping energy demand (Diagrams 3, 7, 8)

$$PPR_{12} = (\nu_1/\nu_2)^{1.95} * (\rho_1/\rho_2)^{-0.05} * (\lambda_1/\lambda_2)^{-2.3} * (c_{p_1}/c_{p_2})^{-1.05}$$

where:

w = Fluid flow velocity (m/s)
d = Diameter (m)
L = Tube length (m)
$\rho$ = Density (kg/m3)
⊠ = Kinematic viscosity (mm2/s), (cSt)
$\mu$ = Dynamic viscosity (Pa.s), (cP)
cp = Specific heat (J/kg K)
$\lambda$ = Thermal heat capacity (W/m.K)
$\Delta P$ = pressure drop, (Pa)
k = heat transfer coefficient, (W/m2K)
PPR12 = Pumping energy demand, (-)

The above equation is taken from [Sherwood95].

Using the thermophysical properties from the different products, PPR12 describes the amount of energy needed to pump a fluid 1 relative to fluid 2 to yield the same heat transfer performance.

The main contribution to pressure drop is caused by the fluid itself, obviously dependent on its flow rate, dimensions, and flow profile (Reynolds number). The above equations are calculated for smooth pipes, meaning the pipe material or roughness are not taken into account. For a detailed system design, pipe bends, valves, flanges, dimensional changes (reduction and enlargement), etc. need to be considered in pressure drop calculations as well.

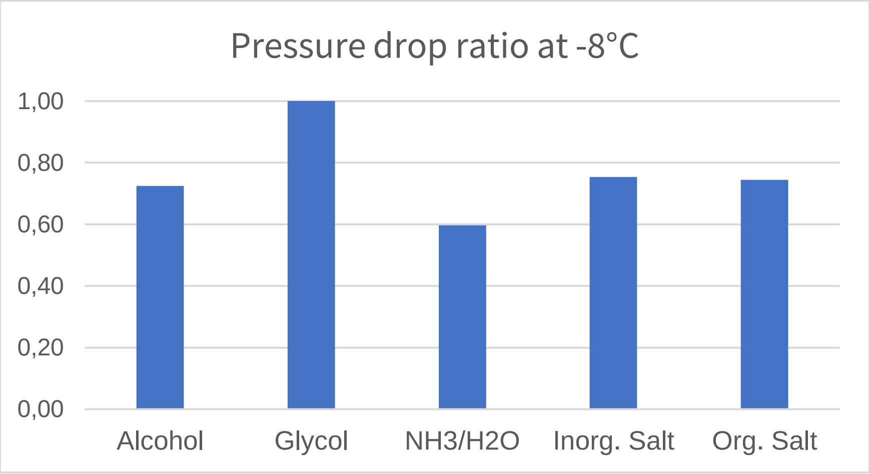
## Comparison between different HTFs

Common products from the mentioned five aqueous HTF are compared: alcohol (Ethanol), glycol (MPG), others (NH3/water), inorganic salts (calcium chloride) and organic salts (CRANE Temper). In addition to thermophysical properties, pressure drops, heat transfer coefficient and pumping energy demand are also compared.

HTF – medium temperature application. Typical inlet temperature to cabinets or rooms is approximately -8°C for fridges. Suitable freezing point for HTF is then -15°C.

Table 1: Thermophysical properties of typical secondary fluids at -8°C

| HTF -15°C at -8°C | Ethanol | MPG | $NH_3$/Water | $CaCl_2$ | Organic salt[1] |
|---|---|---|---|---|---|
| Concentration, % | 24.4 | 32.9 | 10.8 | 18 | - |
| Density, $kg/m^3$ | 974 | 1037 | 961 | 1168 | 1121 |
| Dynamic Viscosity, cP | 9.38 | 12.95 | 2.51 | 3.70 | 4.09 |
| Kinematic Viscosity, cSt | 9.63 | 12.49 | 2.61 | 3.17 | 3.765 |
| Specific Heat Capacity, J/kg K | 4284 | 3855 | 4235 | 3122 | 3381 |
| Thermal Conductivity, W/m K | 0.419 | 0.411 | 0.477 | 0.535 | 0.486 |



| **Re number** | |
|---|---|
| Alcohol | 1661 Lam |
| Glycol | 1282 Lam |
| $NH_3/H_2O$ | 6134 Turb |
| Inorg. salt | 5044 Turb |
| Org. salt | 4306 Turb |

Figure 1: Relative pressure drop calculated for circular tube of 16 mm in diameter and a length of 10 m at a flow rate of 1 m/s in comparison to MPG.

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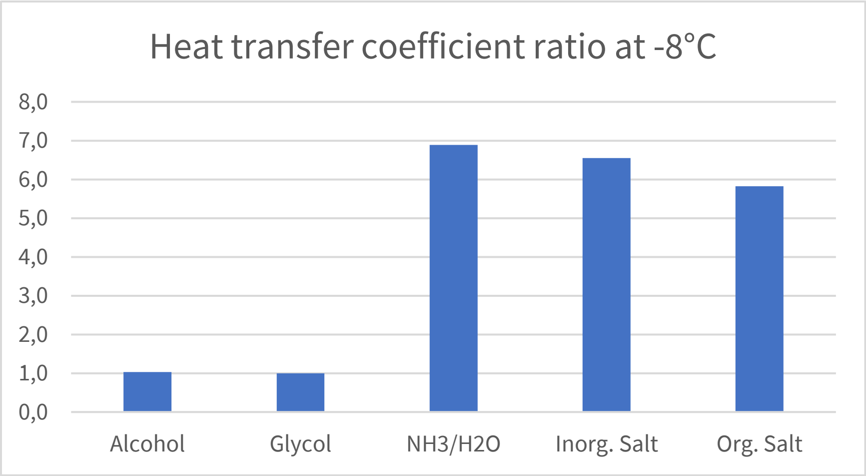
[1] The numbers presented here are specific for a commercially available heat transfer fluid and have been determined empirically by the producer.



| **Re number** | |
|---|---|
| Alcohol | 1661 Lam |
| Glycol | 1282 Lam |
| $NH_3/H_2O$ | 6134 Turb |
| Inorg. salt | 5044 Turb |
| Org. salt | 4306 Turb |

Figure 2: Heat transfer coefficient calculated for circular tube of 16 mm in diameter and a length of 10 m at a flow rate of 1 m/s in comparison to MPG.

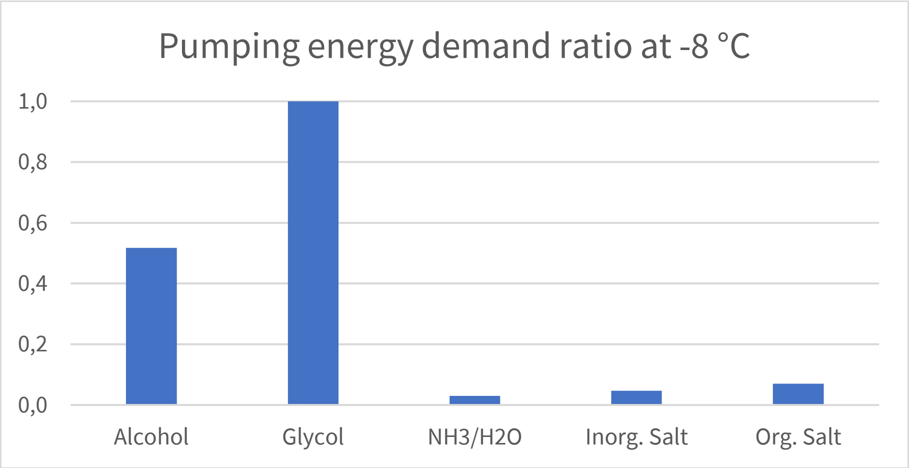
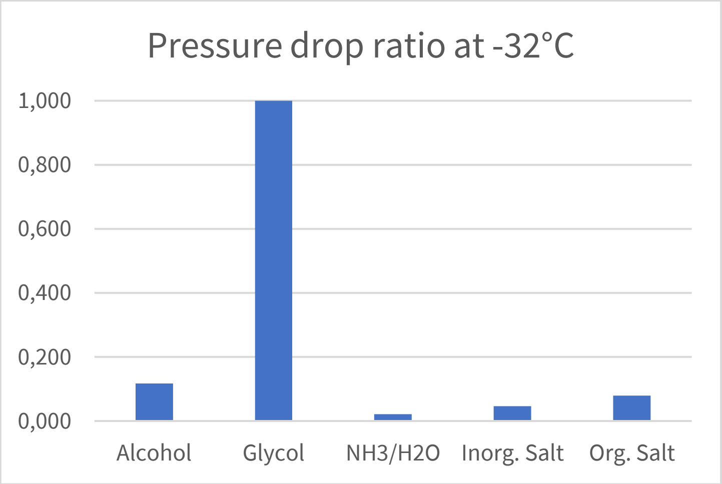


Figure 3: Pumping energy demand ratio in comparison to MPG calculated according to the formula presented above.

HTF – Low temperature application. Typical inlet temperature to cabinets or rooms is approximately -32°C for fridges. Suitable freezing point for HTF, is then -40°C.

Table 2: Thermophysical properties of typical secondary fluids at -32°C

| HTF -40°C at -32°C | Ethanol | MPG | $NH_3$/Water | $CaCl_2$ | Organic salt[2] |
|---|---|---|---|---|---|
| Concentration, % | 53.1 | 54.0 | 21.0 | 28.3 | - |
| Density, kg/m$^3$ | 949 | 1068 | 939 | 1285 | 1225 |
| Dynamic Viscosity, cP | 42.90 | 364.75 | 7.85 | 17.02 | 28.91 |
| Kinematic Viscosity, cSt | 45.22 | 341.53 | 8.33 | 13.24 | 23.60 |
| Specific Heat Capacity, J/kg K | 3367 | 3359 | 4296 | 2682 | 2865 |
| Thermal Conductivity, W/m K | 0.294 | 0.321 | 0.385 | 0.490 | 0.408 |



| **Re number** | |
|---|---|
| Alcohol | 354 |
| Glycol | 47 |
| $NH_3/H_2O$ | 1921 |
| Inorg. salt | 1208 |
| Org. salt | 678 |

Figure 4: Relative pressure drop calculated for circular tube of 16 mm in diameter and a length of 10 m at a flow rate of 1 m/s in comparison to MPG. All fluids have Re < 2300, i.e., laminar flow.

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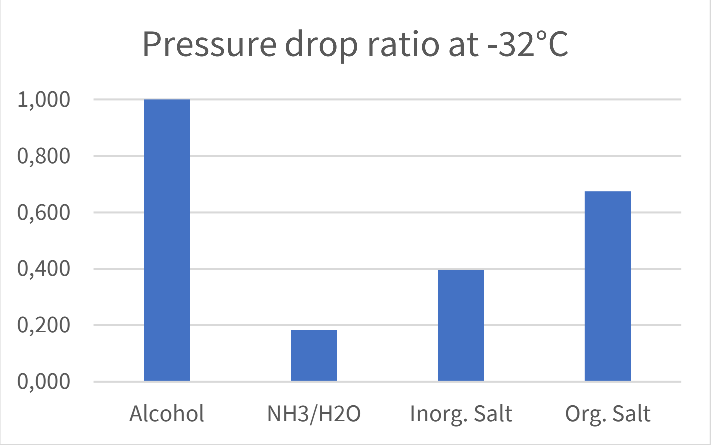
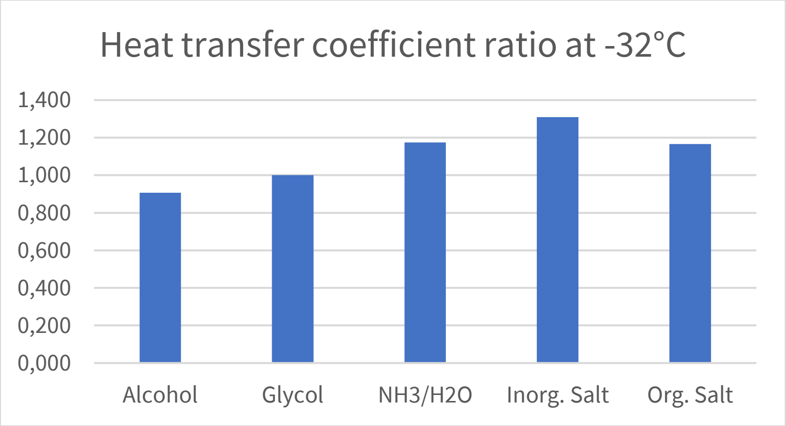
[2] The numbers presented here are specific for a commercially available heat transfer fluid and have been determined empirically by the producer.



| Re number | |
|---|---|
| Alcohol | 354 |
| Glycol | 47 |
| $NH_3/H_2O$ | 1921 |
| Inorg. salt | 1208 |
| Org. salt | 678 |

Figure 5: Relative pressure drop calculated for circular tube of 16 mm in diameter and a length of 10 m at a flow rate of 1 m/s in comparison to ethanol. All fluids have Re < 2300, i.e., laminar flow.



| Re number | |
|---|---|
| Alcohol | 354 |
| Glycol | 47 |
| $NH_3/H_2O$ | 1921 |
| Inorg. salt | 1208 |
| Org. salt | 678 |

Figure 6: Heat transfer coefficient calculated for circular tube of 16 mm in diameter and a length of 10 m at a flow rate of 1 m/s in comparison to MPG. All fluids have Re < 2300, i.e., laminar flow.

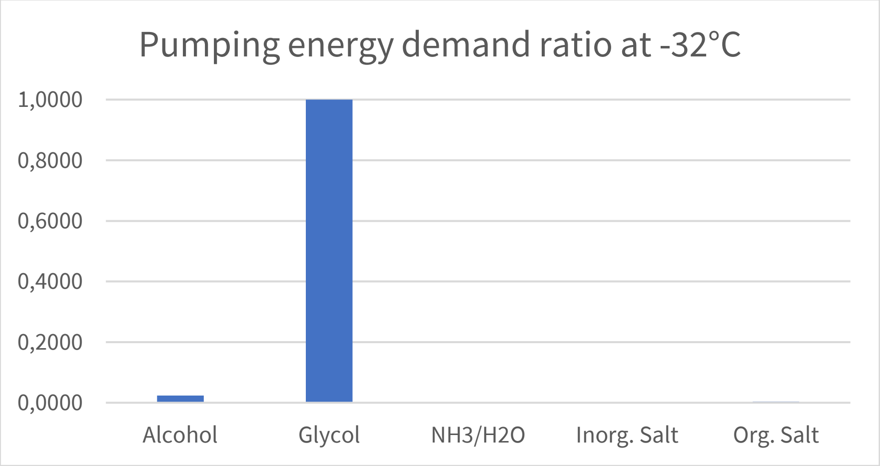


Figure 7: Pumping energy demand ratio in comparison to MPG calculated for laminar flow according to the formula presented above.

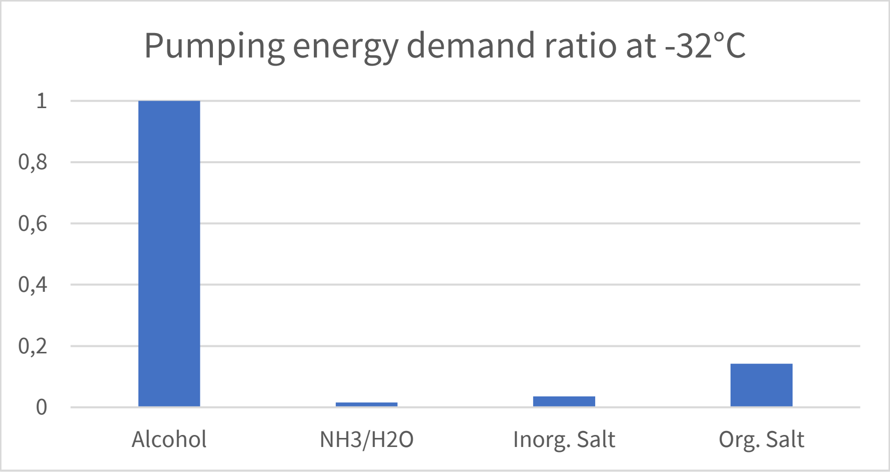


Figure 8: Pumping energy demand ratio in comparison to Ethanol calculated for laminar flow according to the formula presented above.

All HTFs have advantages as well as disadvantages and therefore it is vital to choose an HTF for the actual application. The flow profile is important for both pressure drop and heat transfer. The Reynolds number describes the relationship between flow rate, dimension, and viscosity. By experimenting with these quantities, the flow profile can be optimized. For low pressure drop laminar flow is preferrable but for an effective heat transfer turbulent flow is desired. The flow rate 1 m/s can be assumed as a good orientation value for the dimensions of HTF piping systems. Note that a high flow rate may cause erosion and noise, especially in copper tubes.

### b. Freezing point

Water based HTF benefit from the good properties of water. The smaller the amount of freezing depression substances added, the better the properties. At the same time, an adequate amount must be added to ensure the appropriate freezing point. A rule of thumb is that the freezing point is 5°C lower than the minimum operating temperature as a safety margin.

It is recommended to check the freezing point continuously during operation or whenever operational disturbances has occurred.

### c. Toxicity

Different kind of applications may demand different types of requirements regarding the HTFs toxicity. A wide range of HTF can be found on the market which can serve all needs, from food approved HTFs to HTF where the grade of toxicity is not an issue. For a save working environment avoid if possible toxic, flammable products or other hazards. Different HTF may have different inherent hazards also when they are all water-based products. The type of hazard exposure may also differ a great deal from one HTF to another. In some cases, corrosion inhibitors may be hazardous. Information regarding toxicity is found in the HTFs Safety Data

Sheet (SDS). Normally there are four ways of exposure; inhalation, skin contact, eye contact and ingestion which all are included in the SDS.

### d. Health and environmental aspects

The chemicals commonly used as HTF do not pose a serious threat to our environment. The main content consists either of inorganic salts or of organic substances that are readily degraded mainly to carbon dioxide and water. On the other hand, different products may have effects that can affect the environment in the short term. For example, if an HTF is accidentally released into a watercourse, it may cause local oxygen deficiency. The products can also contain low levels of additives, such as corrosion inhibitors, which are not always easily biodegradable. Always check the SDS for further information. Corrosion element such as for instance copper or other contaminants may harm the biological part of sewage plants. Therefore, one should minimize the risk of leakage especially for groundwater as the conditions for degradation are worse there.

All types of HTFs should be treated as chemicals and should not be released into sewage disposal systems deliberately. Restrictions valid for the solution used may be obtained from the supplier. Before emptying a system of a HTF and handling used products it is advisable to contact the local environmental and public health authorities. Used HTFs are to be classified as industrial waste. Even very small amount of heavy metals such as for instance copper, chrome and nickel are very hazardous to bacteria in the biological treatment in sewage treatment plants already at concentrations even below 1 ppm.

### e. Material compatibility

Many types of corrosion and other problems are avoided by considering the following:

- Select and install components whose metal compositions are as homogeneous as possible
- To avoid galvanic corrosion, it is advisable to choose high-quality steel or metals, as they are less sensitive to corrosion and may therefore last longer. The cheapest is not always the cheapest in the long run.
- Be sure to follow the material recommendations given both by the heat transfer fluid supplier and by the other suppliers of components. Don’t forget that some types of material might not be suitable from the point of view of temperature.
- When designing and assembling the system, keep in mind that it must be easy to charge.
- Air purge and service. Oxygen in the system always promotes corrosion processes. High and local pressure drops might induce air, and thereby oxygen, to penetrate the system. This is avoided by selecting the right pipe dimensions.
- Erosion in the system (internal wear of pipe walls) is avoided with the right flow velocity. Especially copper is sensitive to erosion at high flow rates.
- Contaminants in the liquid – metallic ions and corrosion deposits – might damage shaft seals in pumps. This can be avoided by using in-line or by-pass filters.
- The air in the system is removed with the help of efficient air purgers placed where the static pressure of the system is low. Vacuum air purging is an excellent method.

Automatic top air purgers must be provided with a valve, so that they can be shut off from the system when necessary (see passage headed Air purging).

### f. Corrosion

There is always a risk for corrosion in systems with water-based HTF’s. Corrosion can in worst-case lead to holes in pipe walls, but corrosion residues can also cause impact on, for example, impellers and seals. However, by designing the systems to match the selected HTF the corrosion risk can be minimized.

The corrosion process is of electrochemical nature, which means that the reactions occur during delivery (oxidation) or absorbed (reduction) electrons. For corrosion to occur, electrons must be able to easily migrate between the places where these reactions take place. Metals are known as good electrical conductors, which is also the reason why metals tend to corrode. In addition, the corrosive material is in contact with a conductive liquid. Liquids containing ions in solution are conductive, as all water-based HTFs do, to a greater or lesser extent. HTF consisting of water mixtures of methanol or ethanol are least conductive, followed by water mixtures of glycols, glycerine and urea. Most conducting are the brines consisting of water solutions of inorganic (e.g., calcium chloride) or organic salts (such as potassium formate or potassium acetate). Inorganic brines have normally higher conductivity than organic brines. When comparing organic brines potassium formate (250 mS/cm at 25°C) has approximately twice the conductivity compared to potassium acetates (135 mS/cm at 25°C)

For corrosion to take place it is requires that an “oxidizing agent” is present. In the secondary cooling system, it is almost exclusively dissolved oxygen in the liquid that is oxidizing agent. Copper, for example, cannot corrode at all unless oxygen is present and even in the case of steel, the corrosion rate can be greatly reduced by removing oxygen from the system. **Therefore, it is very important to minimize the oxygen content in the HTF.** First and primary, this is done to remove free oxygen contained in any air bubbles in the liquid.

This is done after filling, through high-point air-purgers or microbubble separators. In addition, it is important that the bound oxygen, that is, the dissolved oxygen in the liquid, is removed. The higher the temperature and the lower the pressure, the less (gases) oxygen can be dissolved. The bonded oxygen can therefore be removed via vacuum degasser and by raising the temperature of the liquid after filling so that the bound oxygen is removed from the liquid. It is also important that the system has a certain overpressure so that no new air is entered through gaskets or the like.

Common types of corrosion that may occur in the system of HTF’s are general corrosion, galvanic corrosion, local corrosion, such as crevice corrosion and erosion corrosion.

#### i. General corrosion

General corrosion occurs evenly across the surface exposed to the conductive liquid. In some cases, corrosion stops after a while as a protective layer of corrosion products on the surface is formed, which protects the metal from further corrosion - the metal is passivated. Various metals are passivated in different environments (type of liquid, pH, etc.) and sometimes the ability of the metal to passivate can be improved by adding an alloying element to the metal, as in stainless steel. Examples of other materials that are often passivated are titanium, aluminium and copper. Since the pH of the HTF (acidity) can be critical in the event of a material being passivated or not, it is important to ensure that the HTF has the correct pH for the different materials present in the system or vice versa.

General corrosion can also be prevented or decelerated by adjusting the fluid environment. This can be done by adding substances so that the pH is corrected to an appropriate level or by adding so-called passivators or inhibitors. Passivators operate in such a way that they react with the metal surface to passivate it. Heat transfer fluids normally contain corrosion inhibitors to prevent corrosion, the inhibitors inhibit the corrosion process by slowing down either the reduction or oxidation reaction. There are many different types of corrosion inhibitors on the market and they are developed according to the type of heat transfer fluid, as different type of inhibitor may be needed to different types of heat transfer fluids.

### ii. Galvanic corrosion

Galvanic corrosion occurs when two metals of different redox potentials are connected to one another in a conductive liquid. Therefore, materials that have a large difference in "self-corrosion potential" or normal potential (see galvanic series below) should not be connected directly. This depends, however, to some extent on the liquid. Therefore, in systems with copper that is a noble metal, less noble metals such as zinc, magnesium and aluminium should be avoided. This is especially valid for liquids with extra high electrical conductivity.

Galvanic corrosion can also occur in an alloy consisting of two metals with different redox potentials. A common example is dezincification of brass, which means selective release of zinc from the alloy. Brass become a residue of porous brass with poor strength. However, dezincification can be avoided if the zinc content is not too high (<34%) and the alloy also contains small amounts of other substances (arsenic, antimony, lead aluminium and silicon). I secondary refrigeration systems only dezincification resistant brass components (DZR brass) must be used. Brass is commonly used in valves and pump impellers.

When soldering copper in secondary systems, so-called copper or silver brazing solder should be used instead tin-containing soft solder. This aspect should be considered when using microbubble separators and manometers (pressure sensors), as they may contain soft solder.

**The Galvanic Series**

Table 3: A selection of common construction metals

| **High redox potential** |
|---|
| Graphite |
| Stainless steel |
| Silver |
| Nickel, passivated |
| Silver brazing solder |
| Copper-Nickel |
| Bronze |
| Copper |
| Brass |
| Tin |
| Cast iron |
| Mild steel |
| Galvanized steel |
| Zinc |
| **Low redoy potential** |

When selecting materials, it is a good idea to select metals that are as close as possible to each other in the galvanic series to minimize the risk for galvanic corrosion. It is preferable to use the same material throughout the installation. If necessary, isolate different metals.

### iii. Localized corrosion

Examples of localized corrosion that may occur in the brine system are so-called crevice corrosion and erosion corrosion. Both corrosion types arise where the concentration of the oxidant (oxygen) differs from place to place. In slits, the liquid is often stagnant and when the oxygen is consumed there, its concentration becomes lower compared to the other locations in the fluid system, gradient corrosion may occur. The reason is that the potential difference between the two sites increases and the metal in contact with the low-oxygen liquid corrodes. The passivable metals, which have a protective layer of corrosion products on the surface, are particularly sensitive. The layer, which consists of different metal oxides, dissolves and corrosion occurs. The same phenomena arise under deposits of dirt particles that may occur in poorly cleaned systems. At the metal surface under the deposits, oxygen concentration is low, which leads to a potential difference and corrosion occurs. It is therefore important that after installation of the system, clean it properly before filling it up.

### iv. Flow- and erosion corrosion

Some materials are sensitive to flowrates of the fluids. This is especially true for copper, which is a common material in HTF systems. The reason is that the corrosion products formed on the surface of the metal/copper protect the metal from corrosion, are water-soluble. Increased flow rate will remove this layer, leaving the metal surface exposed and corrosion rate will increase. If the fluid has high conductivity, which many HTF have, the protective oxide layer (corrosion products) becomes more porous and causes poor adhesion to the surface, which causes the risk of flow corrosion to increase. Carbon steel and cast iron are also sensitive to flow corrosion while titanium and stainless steel are completely insensitive.

Flow corrosion and erosion corrosion are often used synonymously, but in strict terms, erosion corrosion requires the presence of solid particles in the liquid. These particles mechanically grind the metal or its protective layer of corrosion products so that the corrosion rate increases. Also, free air bubbles can lead to erosion and the risk of erosion corrosion increases as fluid flow rate increases. Flow and erosion corrosion often occur simultaneously because the first corrosion type results in solid particles in the liquid.

To avoid flow and erosion corrosion, it is important that the HTF system is well cleaned and vented and that the flow rate is not too high. Especially this applies to heat exchangers that have copper pipes of small dimensions and 180° pipe bends. Particles in the liquid are also a cause of erosion. To keep the particles in the liquid in low amounts, a partial or by-pass flow of liquid can be passed through a filter where these are filtered off.

### g. Chemical stability

Chemical stability refers to if the product is subject to chemical change or if it may react in its intended use. Glycols have a tendency to become a little acidic after long time use (oxidation to glycolic acids) and may be subject to exchange. $CO_2$ is very sensitive to water – forming carbonic acid. Salt based HTF are normally very chemically stable. Different types of corrosion inhibitors may differ in chemical stability. Monitoring the fluid’s quality is crucial for a long-life and well-functioning system, this is done differently depending on type of HTF. Normally to check the pH and density regularly will give good guidance on the fluid’s quality. Also, more advanced analysis may be needed, please consult the supplier for more information. In the products safety data sheet chapter “Stability and reactivity” more information will be found.

### h. Oxygen diffusion

Essential parts of chilled water applications are often made of copper and ferrous materials, which are not resistant to oxygen corrosion. The presence of oxygen in the cooling water causes copper and ferrous materials to form oxides or rust on the contacting surfaces. A sustained ingress of oxygen will result in continuous metal corrosion resulting in metal deposits that can lead to clogging of system components. This is why it is highly recommended to use an HTF with corrosion inhibitor.

The ingress of oxygen into the water is largely a result of improper ventilation during the filling procedure and operation, malfunctioning air purgers, as well as oxygen intake at pumps and at mechanical connections. Oxygen ingress through most plastics and sealing materials is due to the molecular structure and low density, making them permeable to gas. However, the oxygen diffusion through plastics occurs only above 14°C fluid temperature and is therefore relevant for heating applications.

Oxidation of metal leads to a reduction of the oxygen level in the water, thereby creating an imbalance of the oxygen partial pressures, causing new oxygen from the ambient air to penetrate the plastic and sealing walls.

Oxygen diffusion may be evaluated for specific materials. An external, independently recognised laboratory “tgm Staatliche Versuchsanstalt” evaluated oxygen diffusion through the pipe wall according to the procedure outlined in ISO17455. There are currently no standards available, which define limiting values for cooling systems.

Results for pre-insulated plastic pipe (PE pipe/PUR insulation/PE jacket; di40/D90mm) show low oxygen diffusion at low temperatures.

Table 4: Comparison of oxygen diffusion rates by fluid temperatures above 0°C for pre-insulated plastic pipes.

| Water temperature | 5°C | 14.5°C | 14.5°C | 40°C |
|---|---|---|---|---|
| Oxygen diffusion related to jacket surface area in mg/($m^2$*day) | 0.083 | 0.32 | 0.96 | 1.77 |

Mechanical-type connections (non-welded) with elastomer seals are usually used in any pipe system, independent of the pipe material. The same test procedure evaluated the oxygen ingress into a stainless-steel pipe system with flanged connections, specifically evaluating the oxygen ingress through the sealing material, which in this case were EPDM gaskets (di40/D83mm).

The following graph represents the above results with water at 40°C.

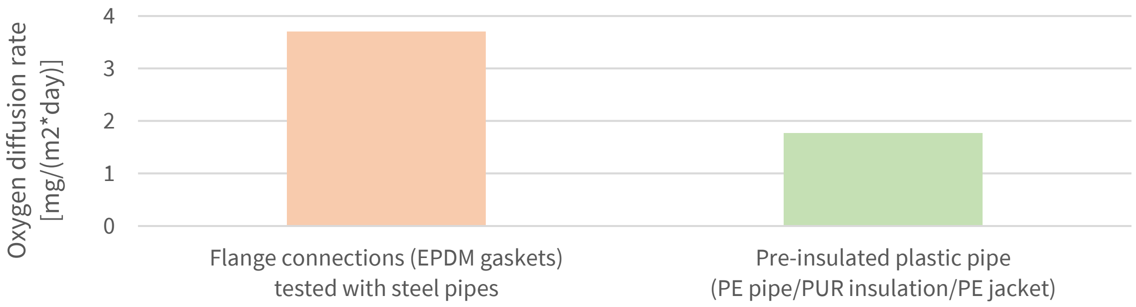


Figure 1: Comparison of oxygen diffusion rate for flange connections and pre-insulated plastic pipes.

In practice, it is impossible to achieve 0% oxygen ingress into the pipe system over its complete lifespan. Therefore, it is standard industry practice to use the below measures to reduce the corrosion caused by oxygen within the pipe system:

- selection of materials that are suitable regarding the HTF
- installation of horizontal pipes with a gradient

- use of appropriate corrosion inhibitors
- filling of the system from bottom to top
- use of vacuum or negative pressure during filling where feasible
- use of dynamic air venting valves at all high points in a system
- continuous removal of excess oxygen during operation

## Literature:

[Sheerwood95] Greg Sherwood "Secondary Heat Transfer Systems and the Application of a New Hydroflouroether", 1995 International CFC and Halon Conference

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