Kilfrost Specialty Fluids

Thermal Fluids for Closed Loop Ground & Water Source Heat Pumps

The thermal fluid used within a closed loop ground and water source heat pump is an integral part of the system. A well formulated thermal fluid will provide freeze, corrosion, scale & biological fouling protection for a closed loop ground/water source heat pump and when properly installed and monitored will ensure that the maximum longevity of the heat pump system is obtained.

In addition to system protection, when selecting a thermal fluid, it is also important to consider the toxicity & environmental profile of the thermal fluid. In addition, the thermo-physical properties of the available fluids and the nature of the system itself should also be considered as these will have a significant impact on the overall system efficiency obtained.

This document has been put together by Kilfrost in an attempt to define & explain the key differences between the major thermal fluids available on the market. The thermal fluids discussed are mono propylene glycol (MPG), mono ethylene glycol (MEG) and Ethanol based thermal fluids. In addition, the new high efficiency Kilfrost GEO product is also discussed. The toxicity and environmental impact of these fluids and the different thermo-physical properties that are associated with them are described. Furthermore, the overall impact on system efficiency on choosing one thermal fluid over another is described.

Summary

1.1 All of the thermo-physical properties at the average circulating temperature of the thermal fluid will combine to determine the overall contribution to heat pump efficiency due to both heat-transfer & hydraulic considerations. No single property can be used to determine the overall efficiency of a thermal fluid. The overall heat transfer efficiency will depend on all of these properties combined.

1.2 When all the thermo-physical properties are considered, Kilfrost GEO offers the highest efficiency in terms of heat transfer for closed loop ground and water source heat pumps when compared to MEG, Ethanol or MPG based fluids.

1.3 Kilfrost GEO is the most efficient in terms of hydraulic performance. Lower pressure drops are obtained and lower flow rates are required in systems containing Kilfrost GEO operating at turbulent flow than systems containing MEG, Ethanol or MPG based fluids.

1.4 Kilfrost GEO offers the best human health and environmental profile of the four major thermal fluid types discussed due to its low toxicity, high biodegradability and low oxygen depleting potential.

1 Toxicity & Environmental Impact

The toxicity & environmental impact of four types of thermal fluid for closed loop ground and water source heat pumps are summarised in table 1.

Table 1: Toxicity & Environmental Impact of Thermal Fluids				
	MEG Based	**Ethanol Based**	**MPG Based**	**Kilfrost GEO**
Classification (CLP regulation 1272/2008)	Acute Tox. 4; H302 H373; May cause damage to kidneys through prolonged or repeated exposure by ingestion H302; Harmful if swallowed	H225; Flammable liquid category 2 H319; Causes serious eye irritation	Not classified as hazardous	Not classified as hazardous
Toxicity Notes	For Ethylene glycol: Lethal Dose, (LD) Human, adult **100 ml**	Base fluid generally accepted as safe (GRAS) by the FDA	Base fluid generally accepted as safe (GRAS) by the FDA	Base fluid generally accepted as safe (GRAS) by the FDA
Flammability & Fire Risk	Low	High	Low	Low
Chemical Oxygen Demand (COD)	1,290,000mg/L	1,645,500mg/L	1,560,000mg/L	820,000mg/L

The mammalian toxicity of MEG is well documented. Any thermal fluid that contains MEG should be treated as toxic, regardless of what additives are included in the formulations and what manufactures may claim. Any accidental ingestion of an MEG containing thermal fluid must be treated by medical professionals. In addition, MEG should not be used as a thermal fluid in any installation of closed loop ground and water source heat pumps in which a leakage of thermal fluid into sanitary waters or environmentally sensitive areas is a possibility. The mammalian toxicity of Kilfrost GEO, Ethanol and MPG based thermal fluids is low and in consequence such fluids pose a significantly lower risk to the wider environment than MEG based products. [1]

Of the fluid types compared in Table 1, only Ethanol based products pose a fire risk during transport, installation, circulation and storage of the thermal fluid prior to installation. All four of the thermal fluids compared are fully biodegradable and do not persist in the environment. However, in the event of a leak into aquatic systems the degradation of such fluids will consume oxygen, and in consequence, pose a risk to aquatic life. The amount of oxygen consumed on degradation is given by the chemical oxygen demand of the product (COD). The lower this number the less oxygen consumed by the fluid on degradation. Based on the data in table 1, of all the fluids compared, Kilfrost GEO consumes the least oxygen on degradation

2 Thermo-Physical Properties & System Efficiency

The thermo-physical properties (specific heat capacity, thermal conductivity, density and viscosity) of a thermal fluid determine how efficient the fluid will be at transporting heat energy. These properties will all contribute to the overall efficiency of the operating system in which the fluid circulates.

The thermo-physical properties (viscosity & density) will also determine the hydraulic efficiency of the fluid. The hydraulic efficiency of a fluid can be viewed as the ease at which a fluid can achieve turbulent flow within a pipe. The hydraulic efficiency of a fluid will determine the flow rates required and resulting pressure drops that can be expected to obtain Reynolds numbers that lead to transient-turbulent & turbulent flow rather than laminar flow. At transient turbulent & turbulent flow, higher heat transfer co-coefficients are obtained leading to improved heat transfer.[2]

In addition, the temperature the thermal fluid is driven down to in operation should also be considered. The differences in fluid properties within a heat pump will be more significant as the temperature the thermal fluid is driven down to 0 ^{o}C and below.[2]

All of the thermo-physical properties at the average circulating temperature of the thermal fluid will combine to determine the overall contribution to heat pump efficiency due to both heat-transfer & hydraulic considerations. No single property can be used to determine the overall efficiency of a thermal fluid. The overall heat transfer efficiency will depend on all of these properties combined.

The key thermo-physical properties that should be considered on selecting a thermal fluid for ground source heat pumps are summarised in table 2.

Table 2: Thermo-Physical Properties Summary	
Property	**Explanation of Term**
Specific Heat Capacity	This determines how much heat energy a fluid can absorb (per unit mass) for every degree Celsius change in temperature. Typical units will be J g^{-1} $^{o}C^{-1}$, kJ kg^{-1} $^{o}C^{-1}$, J g^{-1} K^{-1}, kJ kg^{-1} K^{-1}. *A higher specific heat energy means that a higher heat energy load can be absorbed by the fluid per unit mass per unit temperature rise.* Specific heat capacity will contribute to the overall heat transfer capabilities of the thermal fluid.
Viscosity	The viscosity of a fluid is a measure of how readily it will move within a pipe. *A fluid with a higher viscosity will require more energy to move along a pipe of fixed diameter than a fluid with low viscosity*. Typical units of measurement will be mm^2/s (Kinematic viscosity) or mPa.S (Dynamic viscosity). Thermal fluid viscosity will contribute to the overall heat transfer capabilities of the thermal fluid and is also critical to the hydraulic performance of the fluid.
Thermal Conductivity	The thermal conductivity of a substance is measure of its ability to conduct heat. The higher this number the more capable a substance is at conducting heat energy. This is usually expressed in units of W/m.K Thermal conductivity will contribute to the overall heat transfer capabilities of the thermal fluid.
Prandtl Number	The Prandtl number is a dimensionless number. It combines the above thermo-physical properties into a single number than can be used to give an indication of the overall heat transfer efficiency. *The lower this number (closer to water) the more efficient the fluid.*

The important thermo-physical data at 0 ^{o} C for a range of thermal fluids providing freeze protection to -15 ^{o}C, is presented in Table 3.

The data in table 3 shows that when specific heat capacity, density, viscosity & thermal conductivity are all considered the overall heat transfer efficiency of Kilfrost GEO is higher than the MEG, MPG and Ethanol based products. This is easily summarised using the dimensionless Prandtl number. The lower this number the more efficient the thermal fluid is at heat transfer.

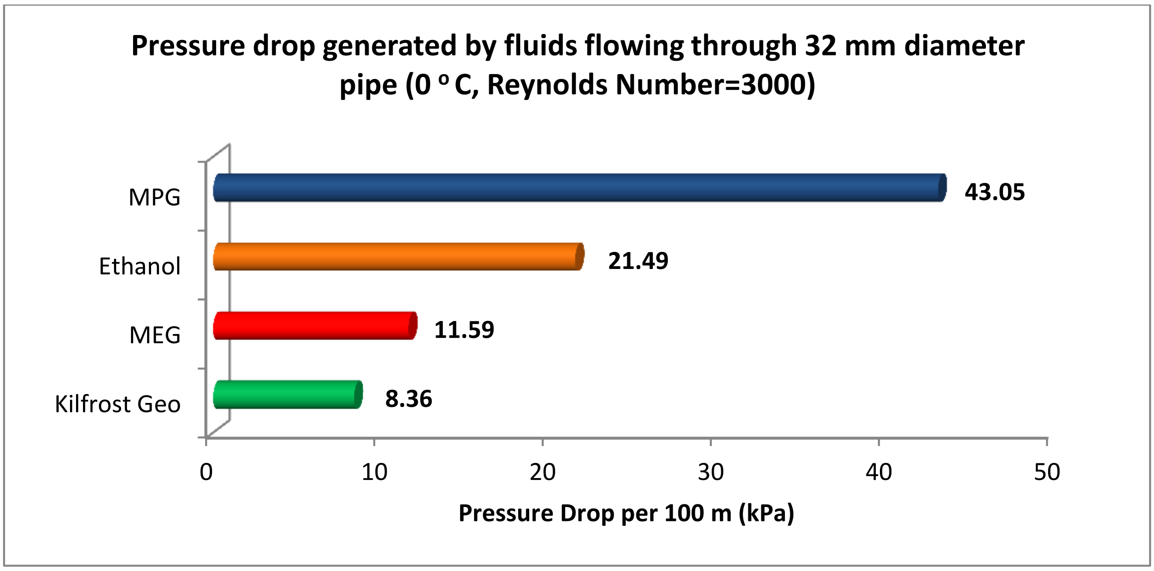
Table 3: Thermo-Physical Properties Comparison at 0 ^{o} C

	MEG Based	Ethanol Based	MPG Based	Kilfrost GEO
Freeze Point/ ^{o} C	-15	-15	-15	-15
Specific Heat Capacity $Jg^{-1}K^{-1}$	3.81	4.25	3.67	3.67
Thermal Conductivity $Wm^{-1}K^{-1}$	0.491	0.420	0.460	0.480
Viscosity (Cps)	4.57	6.00	8.73	4.00
Density kg/m^3	1049	960	1039	1123
Prandtl Number	35.45	60.71	69.6	30.61

3. Hydraulic Efficiency

In ground and water source heating, the limiting factor in heat transfer is between the ground or water and the collector. In consequence, it could be argued that the advantage offered by Kilfrost GEO in terms of heat transfer efficiency over the other fluids is negligible. However, differing thermal fluids overall contribution to system efficiency is also determined by the hydraulic characteristics of the fluids. The viscosity & density of the circulating fluid will determine the extent of pressure drops within the system and the flow rates that are necessary to achieve turbulent flow.

To demonstrate the differences that can be observed on selecting one thermal fluid over another a series of calculations have been conducted using the thermo-physical data presented in table 3. *In each case the calculations are based on fluid flow through a 32mm diameter pipe with a Reynolds number of 3000. The results are shown in chart 1.*[3]



As the data shows, fluid flow with a Reynolds number of 3000 in a pipe of diameter 32 mm at 0 °C leads to the development of a pressure drop with all thermal fluids. However, the type of thermal fluid used determines the extent of the pressure drop. The data shows that Kilfrost GEO leads to the lowest pressure drops in the system. In consequence, Kilfrost GEO is hydraulically superior to MEG, MPG and Ethanol based thermal fluids.

Conclusions

Based on the data presented here it is clear that Kilfrost GEO is the most efficient choice of thermal fluids in terms of both heat transfer & hydraulic considerations. This data demonstrates that when all of the contributing thermo-physical properties are considered, MEG, MPG and Ethanol based thermal fluids are not as efficient as Kilfrost GEO. The difference in efficiency will become even more significant as the temperature of the circulating fluid is lowered further.

In addition to its superior efficiency, Kilfrost GEO also offers the end user peace of mind with respect to its environmental and human health impact. The product is non-toxic, non-flammable and will consume less oxygen on degradation in aquatic systems compared to MEG, Ethanol and MPG based products.

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References

1. For a study on the ground-water polluting potential of MPG & MEG based fluids see: Kappler et al. *Biodegradability and groundwater pollutant potential of organic anti-freeze liquids used in borehole heat exchangers*. Geothermics, 36 (2007) 348-361.
2. An Introduction to Thermogeology: Ground Source Heating & Cooling. 2nd Edition, D. Banks. Chapter 9, p248-277.
3. For an independent comparison of MEG & MPG based thermal fluids hydraulic characteristics in ground source heating see: An Introduction to Thermogeology: Ground Source Heating & Cooling. 2nd Edition, D. Banks. Chapter 9, p268.