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Kilfrost Specialty Fluids

Selecting a Thermal Fluid for Ground Source Heat Pumps

1. Summary

1. Despite the fact that all MEG containing thermal fluids have the highest acute oral toxicity, all three of the major glycol based thermal fluids; MEG, MPG and BIO-PDO™ have very similar overall environmental profiles.[1] Under the German Water Hazard Classification system all three of the major glycol bases are ranked WGK1 – Slightly hazardous to water.

2. When all the thermo-physical properties are considered, MEG based thermal fluids offer the highest efficiency in terms of heat transfer in ground source heat pumps. The bio-derived PDO and petroleum derived MPG based products coming second and third in terms of efficiency respectively. As the temperature of the circulating fluid is driven down below 0 ^{o}C, the differences in efficiency of these glycol based thermal fluids becomes even more significant.

3. Thermal fluids based on MEG are the most efficient in terms of hydraulic performance. Lower pressure drops are obtained and lower flow rates are required in systems containing MEG based thermal fluids operating at turbulent flow than systems containing BIO-PDO™ or MPG based fluids. The second most efficient in terms of hydraulic performance is BIO-PDO™ based thermal fluids with MPG based products being the third most efficient option. The differences in hydraulic efficiency become even more significant as the temperature of the circulating fluid is driven down below 0^{o} C.

2. Facts About Glycol Based Thermal Fluids

The thermal fluid used within a ground source heat pump is an integral part of the system. A well formulated thermal fluid will provide freeze, corrosion, scale and biological fouling protection for a ground 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 suitable fluid for a ground source heat pump, it is also important to consider the toxicity and environmental profile of the products on offer. 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.

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This document has been put together by Kilfrost in an attempt to define and explain the key differences between the major glycol based thermal fluid available on the market. The thermal fluids discussed are:

- Mono propylene glycol (MPG) – 1,2-propanediol based
- Mono ethylene glycol (MEG) – ethanediol based
- BIO-PDO™ - bio-derived-1,3-propanediol based

The toxicity and environmental impact of these fluids (information typically available on REACH compliant safety data sheets) and the different thermo-physical properties (provided by fluid manufacturers) that are associated with them are described. In addition, the overall impact on system efficiency on choosing one thermal fluid over another is discussed.

3. Toxicity and Environmental Impact

The toxicity and environmental impact of the three major glycol bases used in thermal fluids for ground source heat pumps are summarised in Table 1.

Table 1: Base Fluid Summary			
	MEG	MPG	BIO-PDO™
Source	Crude Oil	Crude Oil	Corn Starch
Mammalian Toxicity	High	Low	Low
Aquatic Toxicity	Low	Moderate	Moderate
Biodegradability	High	High	High
German Water Hazard Classification	WGK1 (Slightly Hazardous to Water)	WGK1 (Slightly Hazardous to Water)	WGK1 (Slightly Hazardous to Water)

As the data in Table 1 shows, both MEG and MPG are derived from non-renewable crude oil sources. BIO-PDO™, is derived from corn starch and provides a truly sustainable alternative for the ground source heat pump industry. Bio-derived MPG, which has physical properties identical to the crude oil derived MPG, is also available, however, the vast majority of MPG based thermal fluids available in the UK market utilise crude oil derived MPG in their formulations.

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 a medical professional.[2] The only low toxicity glycol based thermal fluids available on the UK market are MPG and BIO-PDO™ based products.

Although MEG based thermal fluids are undoubtedly toxic when ingested and pose a risk to mammalian life, they show a lower aquatic toxicity than both MPG and BIO-PDO™ based thermal fluids. Claims that MEG based thermal fluids are more environmentally harmful than both MPG and BIO-PDO™ based products are therefore misleading. All three of the major glycol bases are fully biodegradable and do not persist in the environment.[3] Under the German Water Hazard Classification system, all three are ranked the same, WGK1 (slightly hazardous to water).[4]

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4. Thermo-Physical Properties and 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 and 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 and turbulent flow rather than laminar flow. At transient turbulent and turbulent flow, higher heat transfer co-coefficients are obtained leading to improved heat transfer.[5]

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 thermal fluid temperature is driven down to 0 ^{o}C and below.[6]

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 and 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 <u>all of these properties combined</u>.

A useful and widely used way to summarise the overall heat transfer efficiency of a thermal fluid is to use the dimensionless Prandtl number. The lower this number the more efficient the thermal fluid is in terms of heat transfer. The most efficient fluid that could be used in a ground source heat pump is water, and in consequence, it shows lower Prandtl numbers compared to glycol based thermal fluids over its applicable temperature range (above 0 ^{o} C). The obvious limitation with water is the fact that it can't be used in systems in which the thermal fluid is driven down to near freezing conditions.

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

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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 between 0-20 ^{o}C, for a range of thermal fluids at 30 % v/v dilutions, is presented in Table 3. For comparison, this data is taken from both Kilfrost and competitor's literature.[7] The data in Table 3 shows that, in general, MPG based thermal fluids do have a higher specific heat capacity than MEG and BIO-PDO™ based thermal fluids. However, when viscosity and thermal conductivity are also considered the overall heat transfer efficiency of MPG based thermal fluids is lower. This is easily summarised using the dimensionless Prandtl number. The lower this number the more efficient the thermal fluid is at heat transfer. The data in Table 3 shows that between 0-20 ^{o}C, the overall heat transfer efficiency of MPG based thermal fluids is lower than that of MEG and BIO-PDO™ based thermal fluids. The difference is even more significant at lower temperatures. For heat pump systems in which the thermal fluid is driven down to even lower temperatures the difference in efficiency will be even more significant.

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Table 3: Physical Properties of 30 % v/v Inhibited Thermal Fluids at 0-20 ° C					
Property	Competitor's Inhibited MEG	Thermatrans TT (MEG)	Competitor's Inhibited MPG	Thermatrans Plus TTP (MPG)	Thermatrans Sustain TTS (BIO-PDO™)
Freeze Point (°C)	**-15**	**-15**	**-13**	**-12**	**-12**
Specific Heat Capacity ($Jg^{-1}K^{-1}$)					
20 ° C	3.645	3.828	3.848	3.837	3.649
10 ° C	3.617	3.796	3.820	3.790	3.610
0 ° C	3.589	3.742	3.793	3.700	3.550
Thermal Conductivity ($Wm^{-1}K^{-1}$)					
20 ° C	0.445	0.488	0.431	0.477	0.453
10 ° C	0.435	0.483	0.421	0.469	0.435
0 ° C	0.423	0.476	0.409	0.460	0.418
Viscosity (Cps)					
20° C	2.20	2.28	3.06	2.95	2.66
10 ° C	2.95	2.86	4.52	4.38	3.76
0 ° C	4.15	4.56	7.07	7.01	5.65
Density (kg/m^3)					
20 ° C	1045.25	1042.22	1028.35	1026.33	1023.31
10 ° C	1048.76	1046.30	1032.55	1030.50	1026.73
0 ° C	1051.78	1049.80	1036.20	1034.10	1029.42
Prandtl Number					
20 ° C	18.02	17.86	27.32	23.73	21.20
10 ° C	24.53	22.47	41.01	35.40	31.20
0 ° C	35.21	35.85	65.56	56.38	47.94

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5. Hydraulic Efficiency

Although the data in Table 3 shows that MPG based thermal fluids are inferior to both MEG and BIO-PDO™ based fluids in terms of heat transfer efficiency, in ground source heating, the limiting factor in heat transfer is between the ground and the collector. In consequence, it could be argued that the advantages offered by both MEG and BIO-PDO™ based thermal fluids in terms of heat transfer efficiency over MPG based thermal fluids are negligible. However, differing thermal fluids overall contribution to system efficiency is also determined by the hydraulic characteristics of the fluids. The viscosity and 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 on the Kilfrost inhibited thermal fluids presented in Table 3. *In each case the calculations are based on fluid flow through a 35mm diameter pipe with a Reynolds number of 5000. The results are shown in Tables 4-6.*[7]

Table 4:Hydraulic Characteristics at 30 % v/v at 20 °C			
Property	Thermatrans TT (MEG)	Thermatrans Plus TTP (MPG)	Thermatrans Sustain TTS (BIO-PDO™)
Flow Rate m/s	0.31	0.41	0.37
Pressure Drop (kPa/100m)	5.39	9.27	7.53

Table 5: Hydraulic Characteristics at 30 % v/v at 10 °C			
Property	Thermatrans TT (MEG)	Thermatrans Plus TTP (MPG)	Thermatrans Sustain TTS (BIO-PDO ™)
Flow Rate m/s	0.40	0.60	0.52
Pressure Drop (kPa/100m)	9.01	20.0	15.0

Table 6: Hydraulic Characteristics at 30 % v/v at 0 °C			
Property	Thermatrans TT (MEG)	Thermatrans Plus TTP (MPG)	Thermatrans Sustain TTS (BIO-PDO™)
Flow Rate m/s	0.62	0.97	0.78
Pressure Drop (kPa/100m)	21.7	52.0	33.81

As the data shows, to obtain a Reynolds number of 5000 in a pipe of diameter 35 mm using an MPG based thermal fluid will require higher flow rates and lead to larger pressure drops.[8] In systems where the temperature of the circulating thermal fluid is driven down towards 0 °C significantly higher pressure drops and flow rates can be expected with an MPG based thermal fluid than with a MEG or BIO-PDO™ based product.

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6. Discussion

Based on the data presented here it is clear that MEG based thermal fluids are the most efficient choice of glycol based products in terms of both heat transfer and hydraulic considerations. This data demonstrates that although MPG based thermal fluids do, in general, have a higher specific heat capacity than MEG and BIO-PDO™ based fluids, when all of the contributing thermo-physical properties are considered, MPG based thermal fluids are not as efficient as MEG and BIO-PDO™ based fluids. The difference in efficiency becomes even more significant as the temperature of the circulating fluid is lowered.

MEG based thermal fluids are widely used across Europe in ground source heat pumps. However, MEG is toxic and does pose a risk to animals and young children if left on site unsecured. If you are to select an MEG based product as a thermal fluid to maximise the efficiency of your installation it is essential that the higher toxicity of MEG is acknowledged and risk assessed accordingly. All MEG based thermal fluids are toxic, regardless of what additives are included and what manufacturers may claim. Accidental ingestion of any product that contains MEG must be treated by a medical professional.

With a professional installation there is no technical reason, other than oral toxicity, why MEG based thermal fluids should not be used in ground source heat pumps. Where the risk to human health is deemed to be too high, both BIO-PDO™ and MPG based fluids are available and suitable for the job. However, simply switching over to a low toxicity MPG or BIO-PDO™ based fluid, without considering the resulting changes in hydraulic and heat transfer efficiency is not advisable. A system originally designed to operate with an MEG based thermal fluid will not operate with the expected efficiency if an MPG or BIO-PDO™ based thermal fluid is installed.

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[2] Health Protection Agency - HPA Compendium of Chemical Hazards – Ethylene Glycol - properties, incident management and toxicology https://www.gov.uk/government/publications/ethylene-glycol-properties-incident-management-and-toxicology

[3] DWI Drinking Water Inspectorate. 1988 DWI0448 Report "De-Icing Agents. Volume 2 - Final Report" http://dwi.defra.gov.uk/research/completed-research/reports/dwi0448.pdf

[4] http://www.gshp.org.uk/DeMontfort/ThermalFluids.pdf

[5] An Introduction to Thermogeology: Ground Source Heating & Cooling. 2nd Edition, D. Banks. Chapter 9, p248-277

[6] Ashrae Handbook, 2009. Chapter 31. Physical Properties of Secondary Coolants (Brines) pp 31.1-31.13

[7] For an independent comparison of MEG & MPG based thermal fluids hydraulic & heat transfer characteristics see: A. Melinder. Update on Secondary Refrigerants For Indirect Systems. P7.

[8] 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.

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