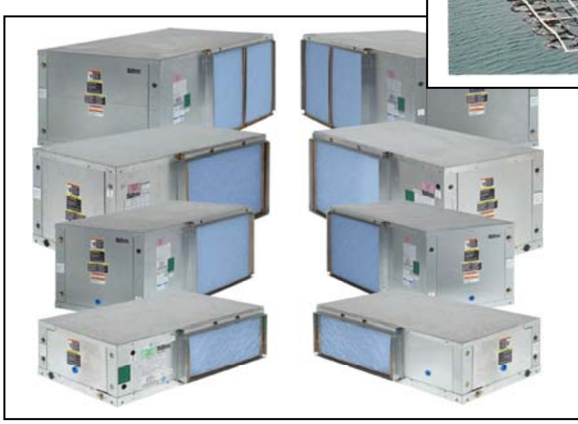
Application Guide AG 31-008

Geothermal Heat Pump

Design Manual



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Introduction

This application guide is written to assist the designer in Geothermal heat pump design. It is a companion guide to McQuay's Catalog 330-1, ***Water Source Heat Pump Design Manual,*** which discusses Boiler/Tower heat pump design. It can be downloaded from www.mcquay.com or contact your local McQuay representative.

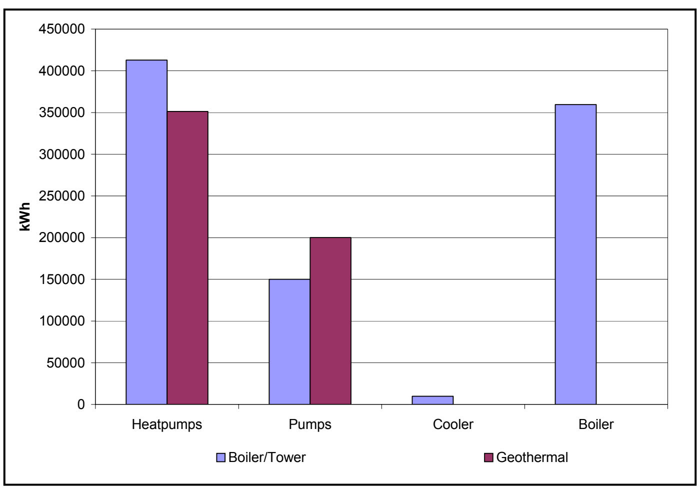
For the most comprehensive guide to Geothermal heat pump design, it is recommended that designers refer to *Ground-Source Heat Pump Systems: Design of Geothermal Systems for Commercial and Institutional Systems*, available from the American Society Of Heating, Air-conditioning and Refrigeration Engineers (ASHRAE) at www.ashrae.org.

Why are Geothermal Heat Pumps So Effective?

It is not unusual to hear how Geothermal water source heat pump systems are very energy efficient, but what is it that makes them so efficient? Both Boiler/Tower and Geothermal systems use basically the same heat pump equipment and the COPs (Coefficient of Performance) are similar when rated at the same conditions. A Geothermal system's summer design conditions are close to a Boiler/Tower system's (90°F loop design temperature is common), but the winter design temperature is often much lower. While it is true that Geothermal systems do not have a boiler or a cooling tower, there is a large water pressure drop in the ground loop that requires a large pump horsepower.

One advantage of the system is the closed loop water source heat pump design. The concept allows energy that is not required in some areas of the building (cooling load) to be moved and used in areas that do require energy (heating load). For many applications, water source heat pump systems match or exceed the performance of even the most sophisticated VAV air systems.

Figure 1 – Comparison of Boiler/Tower vs. Geothermal Heat Pumps



Loop Operating Temperatures

While it is not unusual for Geothermal and Boiler/Tower summer design loop temperatures to be around 90°F, Geothermal systems can have a winter design condition below freezing (25°F to 30°F) in cooler climates. Most Boiler/Tower systems are designed for 60°F to 70°F.

The real energy savings do not come from design conditions, but from part load operating performance. Even in colder climates, most heat pumps used in commercial applications operate in cooling most of the time. This is particularly true for units serving core areas of a building. The colder the loop is in cooling, the better the heat pump performance (usually measured as EER or Energy Efficiency Ratio). Because Boiler/Tower systems maintain the loop temperature above 60 to 70°F, the heat pumps have an EER around 22. Geothermal systems allow the loop temperature to be potentially much cooler and the EER for the heat pumps can be as high as 36.

In addition, the loop temperature over the course of the year is much cooler for Geothermal systems. Boiler/Tower systems will operate at design conditions as soon as there is a net heat gain in the building which causes the loop temperature to rise. The cooling tower controls will not start to reject heat until the loop temperature is near the cooling setpoint.

Evaluating the performance over the entire year requires annual energy analysis. Software tools such as McQuay's Energy Analyzer™ can be used to track the energy consumed by heat pumps in Boiler/Tower and Geothermal systems. Figure 1 shows annual energy usage for a 160,000 ft² high school in Minneapolis. The Geothermal system uses 60% of the energy used by the Boiler/Tower system. In this case, the savings are over $13,000/year.

Cooling Tower and Boiler Energy

Boiler/Tower systems require some form of cooling tower (Either a closed circuit evaporative cooler or an open cooling tower with a heat exchanger). These devices reject heat to the atmosphere based on the ambient wet bulb temperature. They consume power in two ways. First, their fans and pumps use electricity. Second, their water pressure drops must be accounted for when sizing the circulating pumps. Figure 1 shows the annual energy usage for a closed circuit cooling tower to be 958 kWh/yr.

Boilers are used in Boiler/Tower systems to maintain the loop temperature above the minimum setpoint. Most of the required heat in a heat pump system comes from other heat pumps on the loop operating in cooling. The actual number of hours a Boiler/Tower loop requires supplemental heat is very small. In the example in Figure 1, the boiler actually ran only 1506 hours, mostly on weekends.

When the boiler is required, it will consume either natural gas or electricity. Also, the boiler adds a pressure drop to either the main loop or to a tertiary pump. The latter has the advantage that it only uses power when the boilers are required. Figure 1 shows the energy use by the boiler to be 1,227,000 kBtu/yr (359,000 kWh/yr).

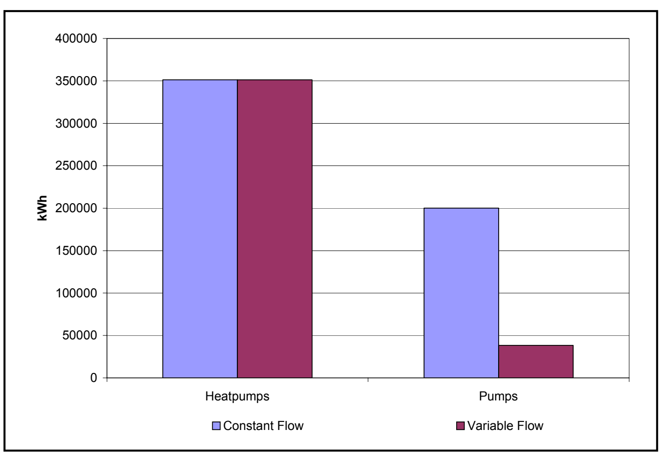
It is not uncommon to use boilers for other heating loads in addition to maintaining the minimum loop temperature (i.e. the ventilation load and entrance heaters). In evaluating Geothermal and Boiler/Tower systems, how these loads are accommodated should be carefully considered.

Pump Work

At first glance, Geothermal systems would appear to require significantly larger pumps to meet the pressure drop from the ground loop. However, geothermal systems do not have a cooling tower or a boiler pressure drop. In addition to the loops being carefully designed to minimize pressure drops, the use of reverse return piping, common headers and carefully sized piping can all help to reduce the pressure drop. It is not unusual for a Geothermal system to be under 100 ft. of head and not significantly greater than a Boiler/Tower system.

Geothermal systems tend to be designed with higher flow rates that result in higher pump work than Boiler/Tower systems.

Figure 2 – Constant vs. Variable Flow



ASHRAE Standard 90.1-2001, Energy Standard for Buildings Except Low Rise Residential Buildings, requires hydronic systems with a total pump power exceeding 10 hp to be variable flow (6.3.4), and that each water source heat pump have a two position isolating valve that closes when the compressor is not operating (6.3.4.4). Figure 2 shows the annual energy savings from switching to variable flow for the example shown in Figure 1. Variable flow offers an additional $6,000/year in savings.

The pump work is very high in constant flow heat pump systems because it is based on the sum of the flow rate requirements of all the connected heat pumps and the flow must be provided 24 hours a day. Switching to variable flow lowered the pump work by 80% in this example.

It is not recommended that the design flow rate or pipe size be reduced for variable flow systems as it is likely that most of the heat pumps may operate at the same time for a short period. This is long enough to cause nuisance trips because heat pumps cannot operate for any duration without flow.

Ventilation Load

Ventilation loads are often a significant load throughout the year. Water source heat pumps usually have a dedicated system for heating and cooling the ventilation air. How effective this system is will dictate the overall performance of the building. Geothermal systems will often have advanced ventilation systems that provide excellent energy savings and improve the overall building operating cost. Ventilation systems are discussed in detail in ***Ventilation System Design*** (see page 33).

Other Benefits

In addition to the energy and operating cost savings, Geothermal systems offer many other advantages. Because there are no cooling towers and boilers, there is no need for sump heaters, tower water chemicals and make-up water.

Decentralized Design

Each water source heat pump is in close proximity to the zone it serves, avoiding the large duct runs associated with central air systems. An equipment failure only affects the zone where the failed unit is located. Central system equipment failures can drastically affect large portions of the building.

Equipment can be changed to meet the specific needs of an occupant (i.e. in a retail environment, the unit can be sized to meet the load of a new tenant). Individual power metering is possible, allowing occupants to control and pay their own energy costs. As the building is constructed, only a minimum amount of equipment needs to be provided until an occupant is found and the tenant design complete.

Easy To Service

Water source heat pumps are easy to service and do not require specialized training. The owner has many more options regarding maintenance and service. The refrigerant charges are small, which helps minimize safety requirements within the building.

Small Mechanical Rooms

Water source heat pump systems generally require smaller mechanical rooms than other HVAC systems. Geothermal system mechanical rooms are even smaller, requiring space for only the circulating pumps, the main header and some chemical treatment equipment. This frees up more useable/leasable space for tenants or occupants.

Figure 3 Typical Heat Pump Arrangements

Flexible Equipment

Heat pumps come in all shapes and sizes to meet space requirements. Sizes range from ½ ton to 30 tons. They can be located above the ceiling, in a closet or in the occupied space.

Indoor Air Quality (IAQ)

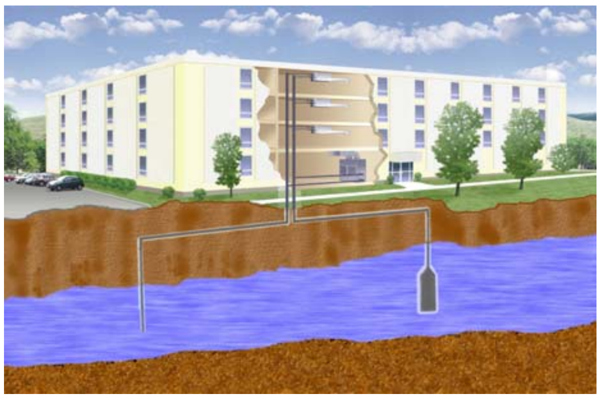
Heat pump systems with properly designed ventilation systems offer a good solution for indoor air quality (IAQ). The units can be supplied with double-sloped, cleanable drain pans and closed cell insulation. A proper ventilation system, along with the heat pumps, can help control moisture for good IAQ.

Loop Design Theory

Loop Types

A ground loop is a heat exchanger that either extracts or adds heat to the ground. The ground itself is not a perfect heat sink/source because the energy added to the ground by the loop can change its temperature over time. The principles of this interaction are common in all loop types and will be discussed here. Geothermal systems come in several different configurations, each with its own strengths and weaknesses. These are discussed below.

Figure 4 – Open Loop



Open vs. Closed Loop

Open loop systems draw ground water directly into the building and heat/cool the heat pumps with it. The system requires sufficient ground water to meet the needs of the building. Ground water often has minerals and other contaminants in it that detrimentally affect the equipment.

Open loop systems that use lake water are also available, but should use filtration equipment or secondary heat exchangers to deal with contaminates. Lake water, used in a open loop application, should be used in climates where the entering water temperature is above 40 degrees F. The ground must have the capacity to take open loop system discharge. These cannot be used below 40°F without the risk of freezing. In addition, open loop systems must allow for the increased pump head from the lake/ground water level to the heat pumps. Open loop systems are not common on commercial and institutional applications and will not be covered here.

Closed loop systems have a dedicated fluid loop that is circulated through the ground or pond in order to exchange energy. The ground/pond water and loop water do not mix. Closed loop systems are further broken down into loop types.

Figure 5 - Horizontal Loop

Horizontal Loop

A horizontal loop runs piping parallel and close to the surface. The undisturbed ground temperature often changes seasonally depending upon where the loops are installed. Horizontal loops are easier to install but require significantly more area (approximately 2500 ft²/ton) than other loop types.

Figure 6 – Vertical Loop

Vertical Loop

Vertical loops run perpendicular to the surface and the holes can be several hundred feet deep. At these depths, the undisturbed ground temperature does not change throughout the year. Vertical loops only require approximately 250 to 300 ft²/ton.

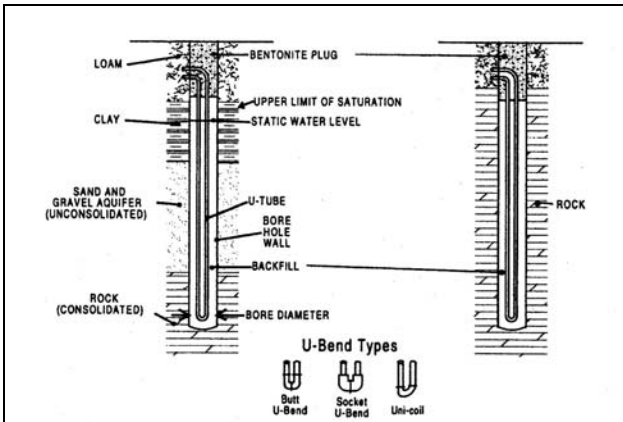
Figure 7 – Surface Water Loop

Surface Water Loop

Surface water or pond loops use a body of water as the heat sink. Heat escapes the water through surface evaporation, so the process is closely connected to pond temperature and ambient wet bulb. In winter, when the pond could be frozen, heat transfer is dominated by contact between the loops, the bottom water and the soil surface at the bottom of the pond.

Ground Loop Fundamentals

Figure 8 – Typical Vertical U Tube Installation[1]



The ground loop is a heat exchanger that is similar to a cooling coil or an evaporator in a chiller. The goal is to transfer energy from the heat pump loop fluid to/from the ground.

The purpose of loop design is to estimate the required loop length. This is best done with computer software, but a basic understanding of the process is helpful. The heating and cooling loads provide the designer with the energy transfer rates for sizing the loop. The design supply fluid temperatures must be estimated. The larger the loop for a known load, the cooler the supply fluid temperature will be. Lower fluid temperatures improve

[1] Copyright 1997, American Society Of Heating, Air-conditioning and Refrigeration Engineers Inc., www.ashrae.org. Reprinted by permission from Ground-Source Heat Pump Systems: Design of Geothermal Systems for Commercial and Institutional Buildings

the heat pump performance and capacity. The designer must find a balance between heat pump fluid supply temperature and the capital cost of the ground loop.

At steady-state conditions, there is heat transfer from the heat pump fluid to the ground. The temperature difference between the ground and the fluid in the loop provides the impetus for the energy to move. The resistance of the pipe, the grout and the ground restrict the energy movement as follows:

$$Q_c = L(t_g - t_w)/R$$

Where

Q_c is the heat load (Btu/hr)

L is the pipe length (feet)

t_g is the ground temperature

t_w is the fluid temperature

R is the thermal resistance to heat transfer.

The challenge in loop design is that the ground temperature does not stay constant. For horizontal loops, where the pipe is near the surface, the ground temperature can change seasonally with the weather. In all cases, the loop itself affects the ground temperature. For loop design, it is common to break the effects into three parts:

- **Long Term Effect**. This is the change in the ground temperature over many years. If the building has a net heat gain or a net heat loss, the ground temperature will change. The more densely placed the boreholes are, the larger the effect. Ground water moving through the bore hole field can help remove energy and limit the long-term temperature change. For commercial applications, the ground temperature generally climbs.

  An example of long term effect would be a 6°F average ground temperature rise over 10 years due to the heat added to the borehole field. The penalty will not be present during the first year, but the heat build up will change the system performance over time.

- **Annual Effect**. Over the course of a year, the heat load on a bore field will change and this will affect the ground temperature on a monthly basis. It is this “flywheel” effect that can actually cause the warmest ground loop temperature to occur after the peak load has occurred.

- **Short Term Effect**. The actual load on the loop will affect the fluid supply temperature. For example, if the building were shut down, the fluid temperature would quickly become the ground temperature. However, the loop temperature would be the ground temperature plus the design approach at design load. The actual hourly load also affects the borehole field’s ability to dissipate heat. Therefore, the ground temperature will change with the hourly load. Most loop sizing software group the design day loads into four-hour intervals rather than using all 24 hours.

These three effects must be estimated to find the required pipe length. The length may be established by the winter heating load requirement or the summer cooling load requirement. If a winter peaking load establishes the length, the designer should go back and evaluate the cooling performance with the longer length. This will improve the summer performance and may allow smaller heat pumps to be used for some spaces.

Borehole Thermal Resistance

Many factors affect the thermal resistance of the ground loop. These include the pipe properties, flow rate, backfill and grout properties, soil properties and fluid properties.

Pipe Properties

Table 1 – Equivalent Diameters and Thermal Resistances for Polyethylene U-Tubes[2]

U-Tube Dia.	SDR or Schedule	Pipe (Bore) Thermal Resistance (h•ft•F°/Btu)			
		For Water Flows Above 2.0 US gpm	**20% Prop. Glycol Flow 3.0 US gpm**	**20% Prop. Glycol Flow 5.0 US gpm**	**20% Prop. Glycol Flow 10.0 US gpm**
¾ in. (0.15 ft)	SDR 11	0.09	0.12	NR	NR
	SDR 9	0.11	0.15	NR	NR
	Sch 40	0.10	0.14	NR	NR
1.0 in. (0.18 ft)	SDR 11	0.09	0.14	0.10	NR
	SDR 9	0.11	0.16	0.12	NR
	Sch 40	0.10	0.15	0.11	NR
1 1/4 in. (0.22 ft)	SDR 11	0.09	0.15	0.12	0.09
	SDR 9	0.11	0.17	0.15	0.11
	Sch 40	0.09	0.15	0.12	0.09
1 1/2 in. (0.25 ft)	SDR 11	0.09[1]	0.16	0.15	0.09
	SDR 9	0.11[1]	0.18	0.17	0.11
	Sch 40	0.08[1]	0.14	0.14	0.08

Based on using borehole cuttings for backfilling around u-tube. Use **Table 2** corrections for other conditions.
[1] Water flow must be at least 3.0 US gpm to avoid laminar flow for these cases.

Table 1 shows thermal resistances for four common pipe sizes. Avoiding laminar flow at design conditions is important to provide good heat transfer. For water, the flow rate should be at least 2.0 US gpm for ¾" through 1 ¼ " pipe, and at least 3 US gpm for 1 ½"pipe to avoid laminar flow.

Backfill and Grouts

The backfill also plays a major part in performance. Air gaps or separation should be avoided as air is a natural insulator. Grouting is the most common material for backfill. It can seal the borehole off from surface water penetration. Standard grout actually has a poor conductivity, so the bore hole diameter should be minimized (Approximately 5" diameter) to limit the grout's affect. There may be local code requirements to grout the entire borehole, or the borehole may penetrate multiple aquifers that need to remain isolated.

Table 2 – Thermal Resistance Adjustments For Other Borehole Backfills or Grouts[3]

(Add value to Base Resistances in)

Natural Soil Cond.	**0.9 Btu/h•ft•F°**		**1.3 Btu/h•ft•F°**			**1.7 Btu/h•ft•F°**	
Backfill or Grout Conductivity	**0.5 Btu/h•ft•F°**	**2.0 Btu/h•ft•F°**	**0.5 Btu/h•ft•F°**	**1.0 Btu/h•ft•F°**	**2.0 Btu/h•ft•F°**	**0.5 Btu/h•ft•F°**	**1.0 Btu/h•ft•F°**
4 in. Bore							
¾ in. U-tube	0.11 (NR)	-0.05	0.14 (NR)	0.03	-0.02	0.17 (NR)	0.05
1 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.13 (NR)	0.04
5 in. Bore							
¾ in. U-tube	0.14 (NR)	-0.06	0.18 (NR)	0.04	-0.04	0.21 (NR)	0.06
1 in U-tube	0.11 (NR)	-0.04	0.14 (NR)	0.03	-0.02	0.16 (NR)	0.05
1 1/4 in U-tube	0.06	-0.03	0.09	0.02	-0.02	0.12 (NR)	0.04
6 in. Bore							
¾ in. U-tube	0.18 (NR)	-0.07	0.21 (NR)	0.04	-0.05	0.24 (NR)	0.07
1 in U-tube	0.14 (NR)	-0.06	0.17 (NR)	0.03	-0.04	0.21 (NR)	0.06
1 1/4 in U-tube	0.09	-0.04	0.12 (NR)	0.03	-0.02	0.15 (NR)	0.05
1 1/2 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.11 (NR)	0.04

(NR) Not Recommended
Air Gaps add 0.2 t o0.4 h•ft•F°/Btu to Bore Resistance
Note some adjustments are negative, which indicates a thermal enhancement and a lower net thermal resistance compared to natural backfills.

Table 3 shows the thermal conductivities for enhanced grouts. Enhanced grouts can significantly improve the borehole performance, which can lead to fewer or shallower boreholes. However, it is more costly. Each project is unique and a job-by-job analysis is required to evaluate whether enhanced grouts will actually reduce the construction cost.

Table 3 – Thermal Conductivities of Typical Grouts and Backfills[4]

Grouts and Additives	**k (Btu/h•ft•F°)**	**Thermal Enhanced Grouts**	**k (Btu/h•ft•F°)**
20% Bentonite	0.42	20% Bentonite – 40% Quartzite	0.85
30% Bentonite	0.43	30% Bentonite – 30% Quartzite	0.70-0.75
Cement Mortar	0.40-0.45	30% Bentonite – 30% Iron Ore	0.45
Concrete @ 130/150 lb/ft³	0.60-0.80	60% Quartzite – Flowable Fill (Cement + Fly Ash+ Sand)	1.07
Concrete (50% quartz sand)	1.1-1.7		

Soil Properties

The thermal conductivity of the soil at the site is required to estimate the ground loop performance. For large (over 50 tons) projects, the soil should be tested (refer to ***Ground Testing***, page 26). The advantage to testing is that more accurate soil data will allow the designer to minimize the safety factor and reduce the number of holes. The savings from the reduced number of holes should more than pay for the test.

Table 4 – Thermal Conductivity and Diffusivity of Sand and Clay Soils[5]

Soil Type	Dry Density (lb/ft³)	5% Moist		10% Moist		15% Moist		20% Moist	
		k	α	k	α	k	α	k	α
Coarse 100% Sand	120	1.2-1.9	0.96-1.5	1.4-2.0	0.93-1.3	1.6-1.2	0.91-1.2	-	
	100	0.8-1.4	0.77-1.3	1.2-1.5	0.96-1.2	1.3-1.6	0.89-1.1	1.4-1.7	0.84-1.0
	80	0.5-1.1	0.60-1.3	0.6-1.1	0.60-1.1	0.6-1.2	0.51-1.0	0.7-1.2	0.52-0.90
Fine Grain 100% Clay	120	0.6-0.8	0.48-0.64	0.6-0.8	0.4-0.53	0.8-1.1	0.46-0.63	-	-
	100	0.5-0.6	0.48-0.58	0.5-0.6	0.4-0.48	0.6-0.7	0.37-0.48	0.6-0.8	0.41-0.55
	80	0.3-0.5	0.36-0.6	0.35-0.5	0.35-0.5	0.4-0.55	0.34-0.47	0.4-0.6	0.30-0.45

Thermal Conductivity (k) - Btu/h•ft•F° and Thermal Diffusivity (α) - ft²/day
Coarse grain = 0.075 to 5 mm – Fine Grain less than 0.075 mm

Table 4 shows the thermal properties for sand and clay soils, which range from 0.3 to 1.9 Btu/h•ft•F°. Most soil is a combination of fine and coarse grain. A Sieve analysis can be used to determine the percentage of each so that a weighted average can be developed to find an overall conductivity. Moisture content is a major factor, but sand or clay do not need to be heavily saturated to provide good conductivity.

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Table 5 – Thermal Properties of Rocks At 77°F[6]

Rock Type	%[1] Occurrence in Earth's Crust	k - All[2] Ther. Con. Btu/h•ft°F	K - 80%[3] Ther. Con. Btu/h ft•°F	c_p Spec. Heat Btu/lb-°F	ρ Density lb/ft^3	α (k/ρ c_p) Ther. Diff. ft^2/day
Igneous Rocks						
Granite (10% Quartz)	10.4	1.1—3.0	1.3-4.9	0.21	165	0.9-4.3
Granite (25% Quartz)			1.5-2.1			1.0-1.4
Amphibolite	42.8	1.1-2.7	1.5-2.2		175-195	
Andesite		0.8-2.8	0.9-4.4	0.12	160	1.1-4.7
Basalt		1.2-1.4		0.17-0.21	180	0.7-0.9
Gabbro (Cen. Plains)		0.9-1.6		0.18	185	0.65-1.15
Gabbro (Rocky Mtns.)		1.2-2.1				0.85-1.5
Diorites	11.2	1.2-1.9	1.2-4.7	0.22	180	0.7-1.0
Grandiorites		1.2-2.0		0.21	170	0.8-4.3
Sedimentary Rocks						
Claystone		1.1-4.7				
Dolomite		0.9-3.6	1.6-3.6	0.21	170-475	1.1-2.3
Limestone		0.8-3.6	1.4-2.2	0.22	150-475	1.0-4.4
Rock Salt		3.7		0.20	130-435	
Sandstone	1.7	1.2-2.0		0.24	160-470	0.7-4.2
Siltstone		0.8-1.4				
Wet Shale (25% Qrtz.)	4.2	0.6-2.3	1.0-4.8	0.21	130-165	0.9-1.2
Wet Shale (No Qrtz.)			0.6-0.9			0.5-0.6
Dry Shale (25% Qrtz.)			0.8-4.4			0.7-1.0
Dry Shale (No Qrtz.)			0.5-0.8			0.45-0.55
Metamorphic Rocks						
Gneiss	21.4	1.0-3.3	1.3-2.0	0.22	160-175	0.9-1.2
Marble	0.9	1.2-3.2	1.2-1.9	0.22	170	0.8-1.2
Quarzite		3.0-4.0		0.20	160	2.2-3.0
Schist	5.1	1.2-2.6	1.4-2.2		170-200	
Slate	.	0.9-4.5		0.22	170-475	0.6-0.9

Table 5 lists the thermal properties for rock. Again, there is a wide variation in performance. Because of its high porosity, rock generally has lower performance. The 80% range is more conservative and is recommended unless the designer has detailed information.

Effects of Ground Water

Ground water movement through the bore hole field can have a large impact on its performance. Ground water recharge (vertical flow) and ground water movement (horizontal flow) can all carry away large amounts of energy. Evaporation can also cool the surface soil and improve horizontal loop performance.

Fluid Properties

In colder climates, where the supply loop temperature may be less than 40ºF, antifreeze will be required. Antifreeze will change the properties of the loop fluid. Refer to APPENDIX 1 for properties of various antifreezes. Adding antifreeze will generally lower the thermal capacity of the fluid and increase the viscosity. The latter will increase pump work. Also, the Reynolds number will decrease and raise the flow rate at which laminar flow begins. To offset these effects, the design flow

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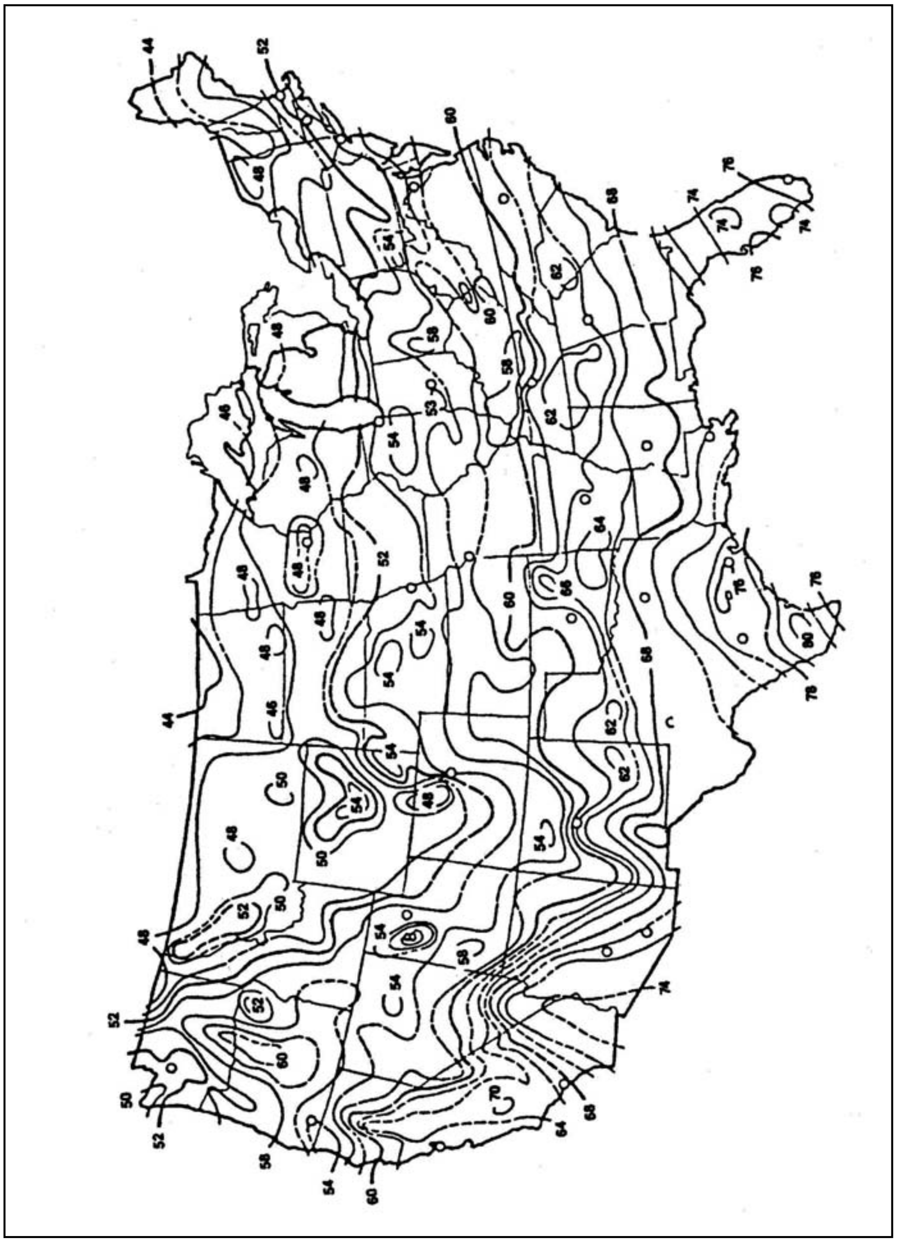
rate may need to be increased. Most loop design software programs include a range of antifreezes and take into account the change in properties.

Ground Temperature

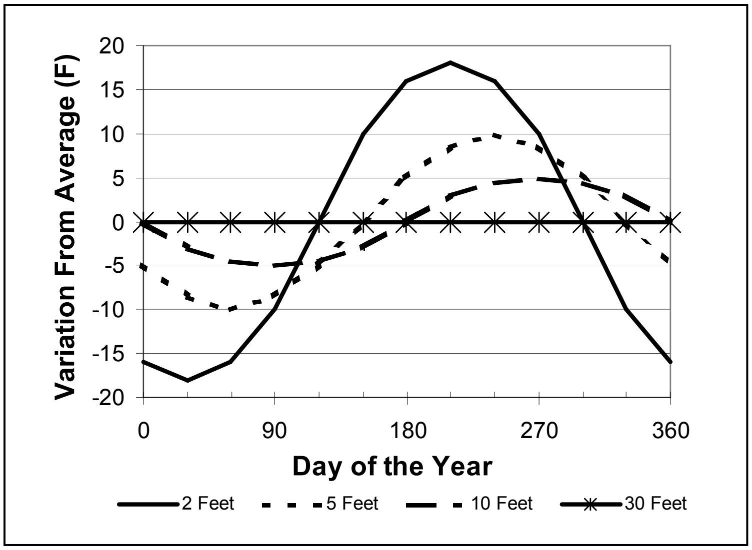
Undisturbed ground temperature is best obtained from local water well logs and geological surveys. Figure 9 shows the approximate ground water temperatures in the USA. The undisturbed ground temperature will remain constant throughout the year below 30 ft. Above 30 ft., the ground temperature will change with the season. ***Appendix 1 – Ground Temperatures***, page 36, has the ground temperatures for many locations around the world.

Figure 9 – Approximate Ground Water Temperatures in the USA[7]



[7] W.D. Collins, *Temperature Of Water Available For Industrial Une in the United States*, U.S. Geological Survey Paper 520-Fl, Washington, D.C. 1925

Figure 10 – Shallow Ground Temperature Variation with Season[8]



The graph shows the variation from undisturbed ground temperature for various depths. For instance, horizontal systems usually stay within 5 ft. of the surface, which can swing by as much as 20°F from summer to winter.

Annual Energy Load and Balance

Key issues with Geothermal systems are the annual energy load and balance. If the building rejects more heat into the ground than it removes, then the borehole field average temperature will climb over time. Even if the heating and cooling loads are balanced, the amount of the energy rejected will affect the monthly ground temperature.

How fast and how much the temperature changes will depend on building usage, borehole spacing and ground water movement. Close borehole spacing will restrict the ability of the borehole to dissipate heat. On the other hand, good ground water movement will help carry away heat. If the building uses more heat then it rejects, the reverse will be true.

Monthly Effects and Equivalent Full Load Hours

The amount of energy transferred to or from the field will affect the ground temperature and the future performance of the field. This effect is generally considered on a monthly basis. A key factor is building use. Consider a school and a hospital, both with a 200-ton design load. Even though they have the same number of heat pump tons, the hospital operates around-the-clock and moves much more energy to and from the field than the school.

Most loop sizing software uses Equivalent Full Load Hours (EFLH) for heating and cooling to estimate the energy transfer effect. Equivalent full load hours are the annual heating and cooling loads divided by the installed capacity. For the hospital and school example given above, even though the installed capacity would be the same, the annual loads for the hospital will be much higher and the equivalent full load hours will be higher.

Estimating the equivalent full load hours requires some judgment and understanding of how the building is used. ***Appendix 4 – Equivalent Full Load Hours***, page 39, provides Equivalent Full Load Hours for various cities and building types based on constant temperature setpoints. The following will provide the designer with some guidance on factors that affect Equivalent Full Load Hours.[9]

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[9] Carlson, Steven W., Jeff W. Thornton. *Development of Equivalent Full Load Heating and Cooling Hours For GCHPs.* RP-1120. ASHRAE. Atlanta, Ga. 2002.

- **Occupancy Hours.** The amount the building is used has the greatest effect on EFLH. EFLHs can increase 95 to 120% with a tripling in operating hours.
- **Internal Gains.** Increasing the internal gains will increase the EFLH, but not as drastically as usage. Doubling the internal gains can result in a 15% to 30% increase in EFLHs.
- **Ventilation Rates.** Changing the ventilation rate in a building proportionally changes both the installed equipment capacity and the annual loads. As a result, EFLHs do not change significantly with changes in ventilation rates.
- **Setback/Setup Control.** Where night setback is used, the EFLHs are reduced by about 20%. Where night setup is used, the EFLHs are reduced by about 5%.

The above information can be used to estimate the EFLHs for use with Loop sizing software. More accurate EFLHs can be calculated using annual energy analysis software that provides annual cooling and heating loads based on building location, use, internal gains, etc. McQuay's Energy Analyzer™ can provide the annual energy balance for most buildings to quickly assist designers.

Long Term Effects

An understanding of the annual energy balance is necessary to understand the long-term effect on the bore hole field. A quick rule of thumb is to assume a 1°F to 5°F temperature rise over a 10-year period. **Table 6** provides another method based on equivalent full load hours. For warm climates where the loop is expected to handle almost continual cooling, the ground temperature can rise over 10°F, even with the bore holes widely spaced. These values are worst case scenarios. Ground water will most likely reduce the impact.

Occupancy Use vs. EFLHs Example

Occupancy	Heating (EFLH)	Cooling (EFLH)	Heating Load (MMBtu/yr)	Cooling Load (MMBtu/yr)
Chicago				
8 am to 3 pm School year (9 mo.)	461	501	559	607
8 am to 3 pm year round	461	574	599	695
8 am to 10 pm	452	831	548	1,007
24/7	315	1,233	382	1,494
Atlanta				
8 am to 3 pm School year (9 mo.)	190	811	233	992
8 am to 3 pm year round	190	881	233	1,081
8 am to 10 pm	183	1,308	224	1,601
24/7	87	1.943	106	2,379

The table above shows a model school located in Chicago (Winter load dominant) and Atlanta (Summer load dominant). Increasing the occupancy to around-the-clock use more than doubles the EFLHs for cooling. The heating EFLH declined since the internal heat can be used. While the design capacity remained unchanged, changing to around-the-clock use increased the field pipe length by 33%.

Reviewing the changes in EFLHs demonstrates several concepts regarding geothermal design.

- Building design loads are not enough. How the building is used is also very important. This is not generally an issue with other HVAC designs.
- Even northern locations have a net energy imbalance that will alter the long term average ground temperature.
- Rules of thumb such as "180ft/ton" must be very carefully applied.

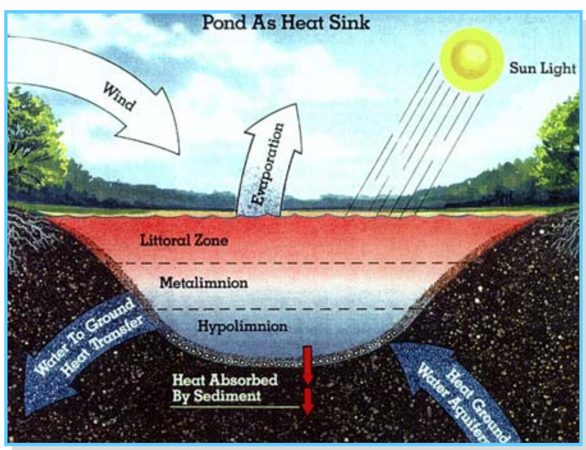
Table 6 – Long Term Temperature Change in Ground Field Temperature for a 10 By 10 Vertical Ground Loop with a 100 Ton Load[10]

Eqv. Full-Load Hrs. Heating Cooling	Bore Separation (ft)	Ground Temp. (t_g) & Entering Water Temps. (Htg. & Clg.)					
		t_g = 50°F (EWT = 35/80)		t_g = 60°F (EWT = 45/85)		t_g = 70°F (EWT = 60/95)	
		kg = 1.0	*kg* = 1.5	*kg* = 1.0	*kg* = 1.5	*kg* = 1.0	*kg* = 1.5
		Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)
1500 500	15 20 25	—4.4°F (318) —2.3°F (276) —1.2°F (258)	—4.4°F (248) —2.3°F (216) —1.2°F (202)	- - -	- - -	- - -	- - -
1000 1000	10 15 20	12.9°F(318) 5.4°F(237) 3.4°F(220)	11.8°F(245) 4.3°F(186) 1.9°F(172)	NR 4.7°F(245) 2.5°F(263)	11.8°F(313) *4.7°F (225)* 2.4°F(206)	- - -	- - -
500 1500	15 20 25	15.1°F(379) 7.8°F (277) 4.1°F(224)	15.1°F(294) 8.0°F (216) 4.3°F(190)	NR 6.7°F (326) 3.5°F(287)	12.8°F(345) 6.7°F (254) 3.5°F(224)	NR 6.7°F (336) 3.5°F(293)	NR 6.7°F (259) 3.5°F(229)
0 2000	15 20 25	- - -	- - -	NR 10.3°F (406) 5.4°F (325)	NR 10.4°F (316) 5.5°F (252)	NR 10.4°F (4L4) 5.4°F (332)	NR 10.5°F (322) 5.5°F (257)

Correction Factors for Other Grid Patterns			
1 x l0 Grid	2 x 10 Grid	5 x 5 Grid	20 x 20 Grid
C_f=0.36	C_f=0.45	C_f=0.75	C_f= 1.14

Surface Water Fundamentals

Figure 11 – Pond Loop Summer Mode[11]



Surface water or pond systems use different heat transfer mechanisms than vertical and horizontal loop systems. Ponds gain heat from solar radiation, convection from air (when the air is warmer than the water) and ground conduction. The ground conduction is dominant in winter, particularly with frozen lakes.

Cooling is mostly accomplished by evaporation at the surface with some radiant and convective heat transfer. Evaporation is dependent on the surface temperature of the water, the wind speed and the ambient wet bulb. At night, radiant heat transfer to a cool dark sky can provide significant cooling. For instance, up to 50 Btu/ft² of cooling will occur from a lake that is 25°F cooler than the sky on a clear night.

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[11] Courtesy of Loop Group, Fort Wayne, IN

The temperature gradient in ponds causes stratification both in summer and winter. Water becomes more dense as it cools until it reaches its highest density at 39.2°F.

Figure 12 - Pond Loop – Winter Mode[12]

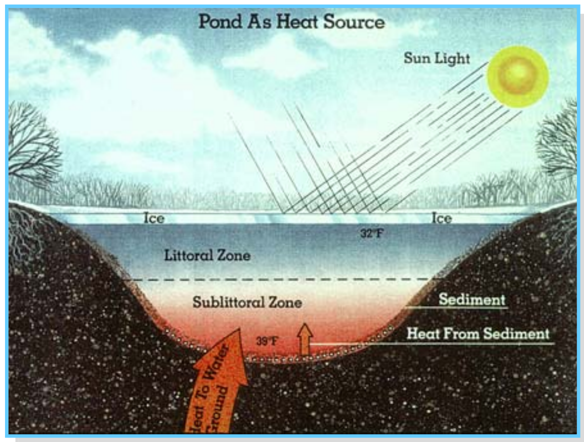
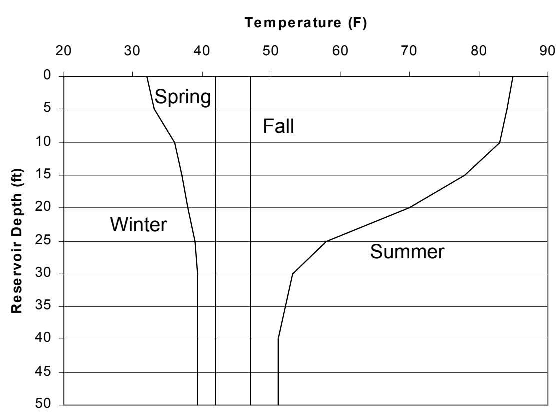


Figure 13 shows the ideal temperature vs. pond depth for four seasons. Reviewing the summer curve, the thermocline can be seen between 10 and 30 ft with colder water at the bottom. In winter, the surface water is coldest. The bottom of a deep pond is 5°F to 10°F warmer.

The ideal temperatures shown in Figure 13 do not always occur. This is due to high rates of inflow/outflow from the pond, insufficient depth for stratification, fluctuations in water level, wind, etc. The best data can be obtained by thermal survey of the pond, or a nearby pond.

Figure 13 – Pond Depth vs. Temperature[13]



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[12] Courtesy of Loop Group, Fort Wayne, IN.
[13] Copyright 1997, American Society Of Heating, Air-conditioning and Refrigeration Engineers Inc., www.ashrae.org. Reprinted by permission from Ground-Source Heat pump Heat pump Systems: Design of Geothermal Systems for Commercial and Institutional Buildings

Design Considerations

The designer must perform their normal tasks, such as zone-by-zone load analysis. In addition, the designer must also specify the geothermal type, total bore length, minimum separation distance, pipe diameter, U-bend type, operating parameters and antifreeze properties. This section will provide the designer with some detail on how to solve these issues.

Equipment and Equipment Rating

Figure 14 – McQuay Enfinity™ Geothermal Heat Pump With R-410a Refrigerant

Geothermal water source heat pumps are slightly different than Boiler/Tower heat pumps. The wider fluid operating range generally requires additional insulation of internal co-axial coil, thermal expansion (TX) valves and heat exchangers optimized for geothermal operating conditions. A geothermal heat pump can be safely operated in a Boiler/Tower system, but the reverse is not generally true.

It is important that the designer select equipment can operate at the required operating conditions for the specific geothermal project.

ARI and ISO

In the past there were three Standards provided by ARI (Air-conditioning and Refrigeration Institute) for heat pumps. Recently, ISO and ARI produced a joint Standard. The new standard also includes the fan work and the fluid pressure drop through the heat exchanger in the unit efficiency calculations. It is important that the designer specify which standard is being used as the same heat pump will yield different performance. It is highly recommended that the designer use the new ISO standard because it is the standard used to certify equipment and it provides a more thorough estimate of energy consumption.

☺ *Tip: The ISO rating conditions for heat pumps do not necessarily represent the actual operating conditions. It is not necessarily a good idea to design the loop on ISO rating conditions.*

Table 7 – ARI and ISO Test Conditions

Standard	System	Cooling Rating Point (°F)	Heating Rating Point (°F)
ARI 320-93	Boiler/Tower	85	70
ARI 325-93	Ground Water Open Loop	70	50
ARI 330-93	Geothermal Closed Loop	77	32
ISO 13256-1	Boiler/Tower	86	68
	Ground Water Open Loop	59	50
	Geothermal Closed Loop	77	32

Note that the rating conditions do not represent the ***actual*** conditions a heat pump will operate under. This is particularly true for geothermal applications. It is very important that the designer realize that the ISO rating conditions are not necessarily good design conditions.

Loop Flow Rates and Temperatures

Table 8 – Flow Rates vs. Temperature Range

System Flow US gpm/ton	Temperature Range in Cooling (°F)	Temperature Range in Heating (°F)
3.0	10	6
2.5	13	7-8
2.0	15	9

Heat pumps operating in cooling reject the heat collected from the space and another 25% of the heat from the compressor. For this reason, loop flow is more like chiller condenser flow than chilled water flow. Most geothermal systems are designed with 3.0 US gpm flow rates. Lower flow rates will reduce the pump and piping size, but they will also de-rate the performance of the heat pump.

☺ *Tip: Most geothermal loop designs are based on 3.0 US gpm.*

In heating, the heat absorbed from the loop is added to the compressor heat to meet the space requirements. Hence the temperature range is smaller. It is important to note that if 3.0 US gpm is used as a design flow rate and all of the heat pumps are in heating, the loop temperature will drop by 6°F. If only water is used, then the supply water temperature must not drop below 42°F to avoid freezing. If temperatures below 42°F are likely, then antifreeze should be added. Adding antifreeze may change the design flow rate requirement. See ***Fluid Properties,*** page 12.

Constant vs. Variable Flow Systems

For water source heat pumps, the flow rate is based on the *connected* tonnage. For constant flow systems, this means a high flow rate is required to operate every hour of the year. Pump work is significant. Variable flow rate systems will vary the flow based on the actual load at any given time. This can cut the pump work by as much as two thirds. While downsizing the pumps and piping system to the design load flow rate is a good idea in chilled water systems (resulting in large capital savings), this is not recommended for heat pump systems. There are periods where all the heat pumps could actually be operating at the same time (morning warm-up, for example). Designing the heat pump loop on the design load flow rate would result in many heat pumps being short of flow during these periods and many would lock out. ASHRAE Standard 90.1-2001 requires variable flow for systems larger than 10 pump horsepower (Refer to ***ASHRAE Std 90.1-2001***, page 24).

Variable flow systems require two-way isolating valves at each heat pump that shut off the flow when the compressor is not running. These valves can be supplied with the heat pump, along with the controls to operate them. Since the system flow is variable, the pump must be able to modulate. Variable Frequency Drives (VFDs) are the most common method. A bypass that maintains the minimum flow rate at 33% of design is recommended. There is little pump horsepower savings below 33% (20 Hz), and the lower frequencies tend to cause undue wear on the motor and VFD.

Table 9 – Minimum Flowrate In Pipe

Pipe Size (in.)	Min Flowrate (US gpm)	Pipe Size (in.)	Min Flowrate (US gpm)
¾	4	1 ½	12
1	6	2	18
1 ¼	9	3	40

As the flow is reduced, the loop tube velocities may drop into the laminar region. This is acceptable since the plastic pipe thermal resistance is dominant. The flow only needs be non-laminar at design conditions. The oversized loop for part load conditions will offset the reduced heat transfer process. Table 9 shows the minimum flow rate in SDR 11 pipe for water to achieve 2 fps. This should provide non-laminar performance.

Design Fluid Supply Temperature

> ☺ *Tip: A good starting point for loop design temperature is that the supply fluid temperature should be 20°F to 30°F warmer than the undisturbed ground temperature for cooling and 10°F to 20°F colder for heating.*

Selecting the design inlet water temperature is an iterative process. The key is to find the balance between the supply water temperature (which improves heat pump performance as it is lowered) and ground loop size (which becomes larger and more costly as the supply water temperature is decreased). Raising the temperature will have the opposite effect. A good starting point is the supply fluid temperature should be 20°F to 30°F warmer than the undisturbed ground temperature for cooling and 10°F to 20°F colder for heating. Looping sizing software can then be used to calculate the required loop size and a balance between capital cost and operating performance found.

Design Load Analysis

Calculating the design (peak, block) cooling and heating loads is accomplished in the same manner as for any other building. Heat pumps are a decentralized system so the installed capacity is based on the *connected* load rather than the *design* load. It is not possible to move heat pumps from the East side of the building to the West side as the sun moves around! Dividing the design load by the connected load will yield the diversity, which can be 80 percent or more. The loop will respond to the *design* load. If the designer only uses the connected load when designing the loop, then the loop could be 25% larger than necessary. Since the ground loop is a major cost, proper load calculations that take into account diversity are warranted.

Safety factors should also be carefully applied as well. Oversizing the heat pumps is one thing. Oversizing the design flow rate and load will increase the piping, pumps and the ground loop – all of which result in a detrimental impact on the capital cost of the project.

Rules of Thumb

A rule of thumb is derived from a specific type of building in a given location. They are very popular in residential applications where there is no diversity (i.e. one heat pump in a house) and they tend to be based on connected load. While it is quite common in geothermal projects to talk about "bore hole feet per ton," this and other rules of thumb should be carefully weighed with a clear understanding about connected capacity vs. design capacity when applying them to commercial design.

Piping Details

The piping within the building for a Geothermal system is the same as for a Boiler/Tower system with the exception that the piping will need to be insulated if the minimum temperature is expected to be 50°F or less. Refer to McQuay's Catalog 330-1, ***Water Source Heat Pump Design Manual*** for more details on building piping design.

> ☺ *Tip: Only use HDPE piping with thermal fused joints for ground loops. SDR 17 is rated for 100 PSI, SDR 11 is rated for 160 PSI and SDR 9 is rated for 200 PSI.*

Ground loops use high-density polyethylene piping (HDPE) that is thermal fused. This is the same piping used by the gas utilities for natural gas lines. The ASTM number is 3408. More specific standards for ground loops are available from the International Ground Source Heat Pump Association (IGSPHA). These are 345434C, 345534C or 355434C. Driscoplex™ 5300 series Climateguard is a common brand name for HDPE.

Table 10 – HDPE Pressure vs. Temperature Rating[14]

Temperature (°F)	Pressure Rating (PSI) SDR 11	SDR 9
73	160	200
80	151	189
90	138	173
100	126	157
110	114	142
120	102	128
130	91	114
140	80	100

Figure 15 – HDPE Pipe With Thermal Fused U-Bend[15]

HDPE piping uses Standard Dimension Ratio (SDR) for pipe sizing rather than the traditional Schedule sizes. Thermally fused piping must be SODR, which is based on the outside diameter. SIDR piping is based on the inside diameter and is meant for use with barb-type connections and a hose clamp.

An advantage of SDR ratings is the pressure rating is consistent, regardless of pipe diameter. For instance, SDR 17 is generally rated at 100 PSI for all diameters. SDR 11 is rated at 160 PSI and SDR 9 is rated at 200 PSI.

Appendix 2 – Pipe Properties, on page 37 provides pressure loss tables for various SDR piping and fittings. Table 11 provides maximum flow rates for water based on 4 ft. WPD per 100-ft. pipe.

Table 11 – Maximum Recommended Water Flow Rates (US gpm)[16]

Nominal Dia. (in.)	SDR 11 HDPE	SDR 17 HDPE	Sched 40 Steel	Sched 80 Plastic	Copper Type L
¾	4.5	-	4	3	3.5
1	8	-	7	6	7
1 ¼	15	-	15	13	13
1 ½	22	-	23	21	20
2	40	-	45	40	44
3	110	140	130	125	130
4	220	300	260	250	260
6	600	750	800	750	800
8	1200	1500	1600	1500	-
10	2200	2600	3000	-	-
12	3500	4200	4600	-	-

Based on ASHRAE recommended head loss of 4 ft water per 100 ft pipe
Multipliers for antifreeze mixtures:
20% propylene glycol = 0.85
20% methanol = 0.90

[14] Driscoplex™ 5300 Climate Guard Systems, Bulletin PP 650, CP Chem. Plano Texas.
[15] Performance Pipe CP Chem. Plano Texas
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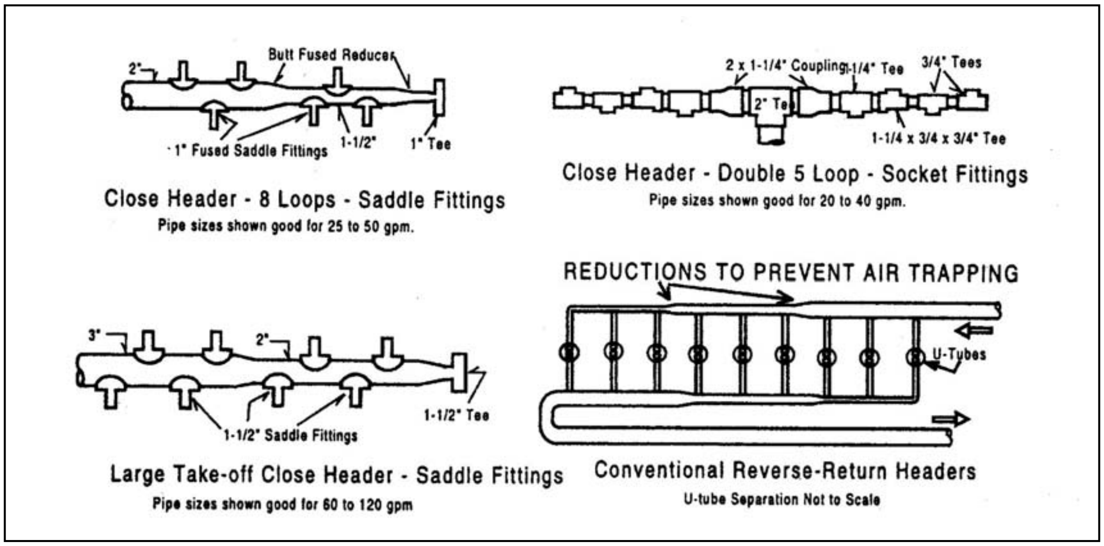
Reverse vs. Direct Return Piping

Reverse return piping is inherently self-balancing. However, it adds another leg and cost. The designer should strive to achieve a piping system that will balance to within 15% of the design flows without the use of balancing valves. If less than 30% of the ground loop head loss occurs in the longest run, direct return piping should suffice. If the head loss is greater, then reverse return piping is recommended.

Header Design

For small projects, the supply and return runouts for each loop can be brought directly to the pump room within the building. For projects over 20 tons, arranging the loops into subgroups and providing each subgroup with it's own header will be easier to manage. The subgroup headers can be fed from the pump room and each header should have its own butterfly-type isolating valve. This will also assist with flushing (See ***System Flushing,*** page 23).

Figure 16 – Header Configurations[17]



An alternative to bringing each subheader back to the pump room (which involves multiple penetrations) is that they can be fed from a vault installed in the bore hole field. A single header can then be brought back to the pump room. A vault makes sense when there are a lot of subheaders or the return distance is over 100 feet.

Another approach is to section the building and fields into smaller groups. For instance, have the East side on the building served by a ground loop on the East side. A dedicated mechanical room would need to be provided. While requiring more mechanical rooms and pumps, there are several advantages:

- Headers can be brought to the closest mechanical room, reducing pipe runs.
- Parts of the building operating on different schedules can be separated. Spaces with longer operating hours can have dedicated pumps that will not penalize the rest of the building.
- There is built-in redundancy to the system.

To assist in making the system self-balancing, the designer should reduce the headers to even the pressure drops through the loops.

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Mechanical Room Layout

Figure 17 – Typical Mechanical Room Layout[18]

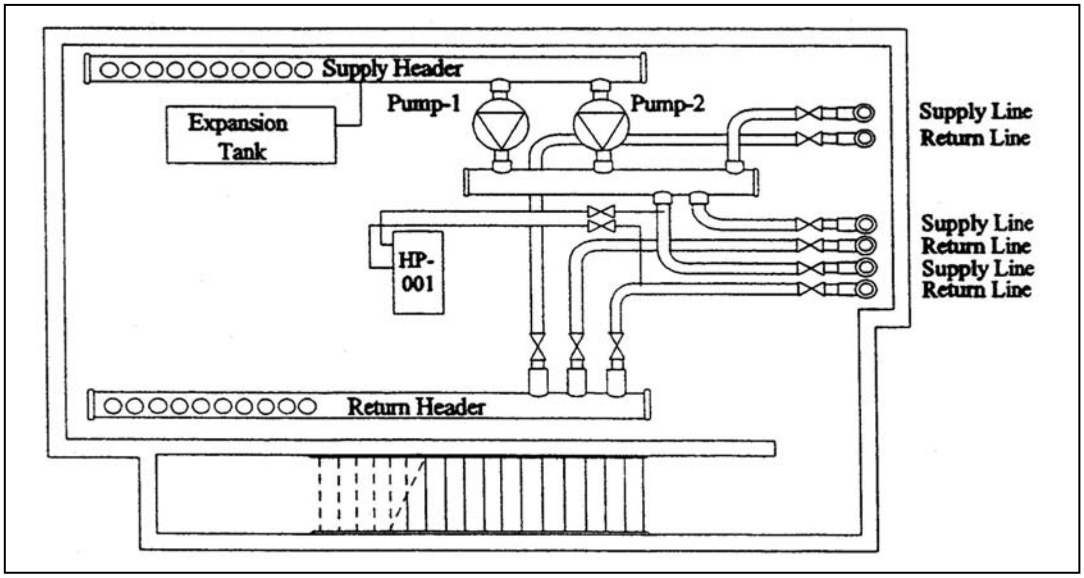

Figure 17 shows a plan view of a mechanical room with three headers. The Supply and Return headers are located where the field loops are attached. Individual loops would be isolated here. The third header allows multiple loops within the building to serve the heat pumps.

System Flushing

Removing all the air from a ground loop is more involved than with other piping systems. In most cases, additional pumps are required to get the necessary velocity to clear the pipes. Taps should be added to allow the contractor to hook up temporary pumps for flushing. The contractor can only do 10 to 20 tons of loop at a time, so valves are required to isolate loop sections. Even with small loops, it will be difficult to remove all the air. Air separators should be installed to help remove the remaining air.

Pumping Design

By their nature, geothermal projects are meant to be energy efficient. To accomplish this, the pumping system must be designed properly. Without flow, no heat pump can operate. It is typical to have a 100% redundant pump for backup. Alternatively, three pumps can be used, each sized for 50% of the design flow. At least two pumps will be required to meet the design flow. For variable flow systems, the pumps should be controlled with Variable Frequency Drives (VFDs).

Check valves are required on each circulating pump. Triple duty valves are common for flow control, but the pump impellers should be trimmed rather than relying on the valve to balance flow.

The following recommendations are given to help the designer:

- Limit design flowrate to 3.0 US gpm/ton of the design load
- Select pipe sizes at 4 ft WPD/100 ft. Try to minimize fitting losses.
- Select pumps within 5% of maximum efficiency. During commissioning, have the pump impellers trimmed, if necessary, rather than using a balancing valve to reduce flow.

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- ❑ Minimize the use of antifreeze.
- ❑ Consider multiple ground loops serving various parts of the building, particularly if the building use is different in each area.

The potentially cold fluid can cause condensation to form on the pump and motor windings. The pump should be designed to handle the minimum expected loop temperature.

Water Make-up

A backflow preventer is required by most local codes. This is particularly true if antifreeze is used. An alarm that senses abnormal make-up is recommended in case there is a leak in the field. A routine check of the antifreeze is recommended in the Fall (prior to the Winter season) to make sure water make-up has not diluted the concentration.

Pump Control

Constant flow systems require the design flow at all times, even if only one heat pump is operating. If constant flow systems are being used, then a control system that recognizes when no heat pumps are operating and can shut down the circulating pumps is recommended. A DDC system can handle this. A less expensive method is to use the pump restart feature in the Mark VI board of McQuay heat pumps. Refer to ***McQuay Heat Pump Product Catalogs*** for details.

Variable flow systems will require a pressure transducer to measure the pressure drop across the loop. This signal can be used to control the speed of the pumps and maintain the required system pressure. If the minimum pump speed is reached and the pressure begins to climb, the bypass valve should open and maintain minimum flow.

A method to control the redundant pumps is also required. Should a pump fail, the spare pump must be started immediately or all of the heat pumps serviced by the loop will trip on a safety.

ASHRAE Std 90.1-2001

ASHRAE 90.1-2001 requires the following for pumps:

- ❑ The hydronic system be proportionally balanced in a manner that first minimizes throttling losses and then trims the impeller or adjusts the speed to meet the design flow conditions (6.2.5.3.3)

Exceptions include:

  - ❑ Pumps with motors less than 10 hp.
  - ❑ When throttling results in no greater than 5% of nameplate horsepower or 3 hp, whichever is less.

- ❑ Systems with a total pump nameplate horsepower exceeding 10 hp shall be variable flow and able to modulate down to 50%. (6.3.4)
- ❑ Individual pumps with over 100-head and a 50-hp motor shall be able to operate at 50% flow with 30% power.
- ❑ The differential pressure shall be measured at or near the furthest coil or the coil requiring the greatest pressure differential.

  Exceptions include:

  - ❑ Where minimum flow interferes with proper operation of the equipment (i.e., the chiller) and the total pump horsepower is less than 75.
  - ❑ Systems with no more than 3 control valves.

- ❑ Each heat pump shall have its own two-way isolating valve to shut off flow when the compressor is not operating. (6.3.4.4)

Estimating Loop Fluid Volume

Estimating the loop fluid volume is important for sizing the expansion tank and calculating the amount of antifreeze. Table 12 shows the volume per 100 ft. of pipe for various types and diameters.

Table 12 – Fluid Volume Per 100 ft Pipe

Pipe Type	Nominal Size (in)	ID (in)	Volume (US gpm/100 ft)
SDR 17	2	2.09	17.8
	3	3.09	39.0
	4	3.98	64.5
SDR 11	¾	0.86	3.0
	1	1.08	4.7
	1 ¼	1.36	7.5
	1 ½	1.55	9.8
	2	1.94	15.4
	3	2.86	33.4
	4	3.69	55.4
Schedule 40	¾	0.82	2.8
	1	1.05	4.5
	1 ¼	1.38	7.8
	1 ½	1.61	10.6
	2	2.07	17.4
	3	3.07	38.4
	4	4.03	66.1

Estimating Pipe Pressure

Elevation changes, particularly in vertical loop systems, can lead to high hydrostatic pressures. Designing a system with 200 ft deep bore holes is equivalent to working on a 20 story project! The maximum pressure in the pipe is equal to:

$$P_{max} = p_o + h \cdot \rho / 144 + 0.5 \cdot p_h$$

Where

P_{max} is the maximum pressure (psi)

p_o is the static pressure (psi)

h is the maximum height difference in the fluid loop (ft)

ρ is the fluid specific weight (density times acceleration due to gravity) (lb/ft^3)

p_h is the pump head (psi)

Pipe Pressure Calculation Example
Consider a 4-story building with vertical bore hole field drilled to 200 feet. The pump head is 80 feet and the fluid is 20% ethanol. The system static pressure is 10 PSI. What pressure rating of pipe should be used?

Solution
A 20% ethanol solution has a specific gravity of 61 lb/ft³

The pump head is 80 feet, which converts to (80 ft) x (61 lb/ft³)/(144) = 33.9 PSI

The maximum height difference is assumed to be from the top of the building to the bottom of the bore hole. In this case, 4 stories x 12 ft + 200 ft bore hole = 248 ft.

The maximum pressure is:
= 10 PSI + (248 ft) x (61 lb/ft³)/144 + (0.5) x (33.9 PSI)
= 132 PSI

Therefore SDR 17 (100 PSI rating) is not acceptable. However, SDR 11 (160 PSI rating) is acceptable.

Ground Testing

Figure 18 – Field Testing Apparatus[19]

Ground testing provides the designer with accurate information on the thermal conductivity. With this information, the loop design can be optimized (in most cases) and the length of piping reduced. If the bidding contractors will test bore data and drilling conditions on the site, this will remove some of the uncertainty and they may provide a price with less of a hedge in it.

The tests are generally conducted by drilling a bore hole and adding a loop. Hot water from a portable electric heater is circulated. A data log is run over 48 hours and the energy absorbed by the ground is measured. From this, the conductivity and diffusivity can be calculated.

Ground tests can cost $2000 per bore hole depending on site conditions. They make sense for projects over 50 tons, or if the site conditions are not well understood.

☺*Tip: Ground tests cost about $2000 per borehole. They should be done for projects over 50 tons or if the site conditions are not well understood.*

[19] Performance Pipe C.P Chem., Plano TX.

Horizontal Loop Design

Figure 19 – Horizontal Loop

Horizontal loops are installed in trenches 3 to 5 feet deep. Deeper trenches may require sidewall supports, which would increase the installation cost. Several circuits can be installed, one on top of the other, in the same trench.

The shallow depths place the loops where the undisturbed ground temperature would naturally change with the seasons. This lowers the efficiency and increases the total pipe length required. The typical loop temperature operating range is 35°F to 100°F.

Horizontal loops are generally easier to install than either vertical or surface water systems.

Horizontal loops require large areas, typically 2500 ft² per ton. The trenches are about 150 to 220 ft per ton. The installed cost runs around $600 to $800 per ton.

Figure 20 – Installing Horizontal Loop[20]

The large area requirement makes horizontal loops more applicable to smaller projects. or projects with large land areas available. Running the loop under parking areas (particularly paved areas) is not recommended.

[20] Courtesy of Loop Group, Fort Wayne, Indiana

Vertical Loop Design

Figure 21 – Vertical Loop

Vertical loops are installed in bore holes 200 to 400 feet deep. The holes are typically backfilled with grout (see ***Backfill and Grouts***, page 9).

Each hole requires about 250 ft² of surface area. Vertical systems use much less land than horizontal systems. The range is 180 to 250 ft of borehole per ton. The cost is about $900 to $1300 per design ton.

The undisturbed ground temperatures at the depth vertical systems operate remains constant throughout the year. Typical loop temperature operating range is 35°F to 90°F in Northern climates. In Southern climates, the loop temperatures can climb to 100°F.

Figure 22 – Installing Pipe and Backfilling a Vertical Hole

Drilling Process

Figure 22 shows a drilling rig boring a hole. Once the hole is drilled the HDPE pipe is lowered into the hole along with the grout pipe. As the grout pipe is removed, the hole is backfilled.

Bore hole Layout

Bore hole layout is a key component of a good geothermal design. If the bore holes are placed too close together, the heat will not dissipate and the ground temperature will rise over time (The opposite will happen if the system is an annual net heat consumer). A second risk is that bore holes will run into each other. It only takes a small angle over the large depths involved to cause two holes to run into each other.

Approximately 25 foot centers are required to provide enough core volume for the heat to dissipate from a typical hole without having a long term effect on the average ground temperature. Most economical systems are based on 15 to 20 foot centers. The actual spacing should be found using computer program.

Bore holes on the perimeter of the field can dissipate heat better than those in the core area. Designs that increase the number of holes on the perimeter (long narrow layouts) are more effective. Bore holes can be under a paved parking lot.

Figure 23 – Typical Vertical Loop Piping Arrangement[21]

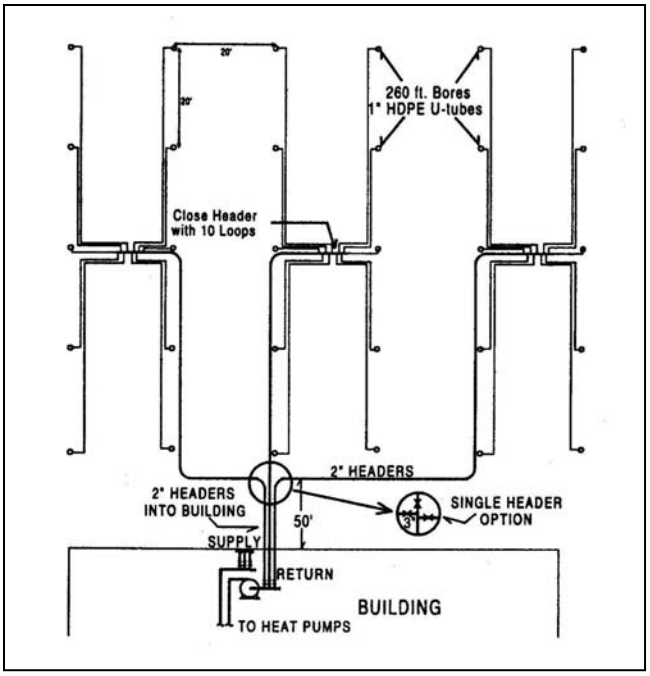


Figure 23 shows a typical reverse return vertical loop layout.

Information for sizing piping is covered in ***Piping Details***, page 20 and **Appendix 2 – Pipe Properties**, page 37. For initial sizing and evaluation, Table 13 lists guidelines for selecting vertical loop pipe size. Most return headers are 2 inch. If subheaders or vaults are used, then the pipe should be sized at 4 ft WPD per 100 ft or less.

Table 13 – Guidelines for Vertical Loop Pipe Sizing

Range Of Bore Length per Parallel Circuit			
U Tube Dia (in)	**Desired Pumping Efficiency**		
	High	Med	Low
¾	100-200 ft	Up to 250 ft	Over 250 ft
1	150-300 ft	Up to 350 ft	Over 350 ft
1 ¼	250-500 ft	Up to 600 ft	Over 600 ft
1 ½	300-600 ft	Up to 1000 ft	Over 1000 ft

Software Design

Software is now readily available to size horizontal and vertical ground loops. While somewhat different in format, most require the same basic inputs from the designer.

- **Design Fluid Supply Temperatures.** For cooling try 20°F to 30°F above the undisturbed ground water temperature and 10°F to 20°F colder for heating. ***Do not use the ISO rating conditions for heat pumps.***
- **Ground Temperature.** This is the undisturbed ground temperature that can be found in ***Appendix 1 – Ground Temperatures*** (Page 36) for many cities. Horizontal loops will require data to account for seasonal ground temperature changes near the surface. In some instances, ambient air conditions are used to estimate ground temperature changes.
- **System Flow Rate.** ton / gpm.
- **Fluid Properties.** If antifreeze is required, the properties need to be entered. Do not unnecessarily use too much antifreeze.

[21] Copywrite 1997, Americal Society of Heating, Air-Conditioning and Refrigeration Enginners Inc., www.ashrae.org. Reprinted by permission from *Ground-Source Heat Pump Systems: Design of Geotermal Systems for Commercial and Institutional Buildings*

- **Soil Properties.** Both conductivity and thermal diffusivity are required. These should come from either a site test or an accurate estimate.
- **Pipe Properties.** These include pipe thermal resistance, diameter, flow type (turbulent vs. Laminar) number of pipes per hole, placement in hole, backfill properties, etc.
- **Field Arrangement.** Number of rows across and down, separation distance, number of bores per parallel circuit, etc.
- **Design Day Load Profiles.** Design programs require both a design cooling and design heating day load profile. It may be 24-hour or grouped into smaller (4 hour) periods. In addition, the annual equivalent full load heating and cooling hours are required.

Fine Tuning the Design

The designer is challenged to strike a balance between capital cost (a large bore field) and operating performance (reduced heat pump EER due to a smaller bore hole field). The best balance may take a few iterations. Fortunately, the use of computer software to design the loops allows several iterations in a short period of time. The following is a list of possible changes to the design and their impact.

- **Increase the Design Loop Supply Temperature.** Raising the supply temperature will reduce the loop size but penalize the heat pumps. Raising the loop temperature 5°F can decrease the loop size by 10 to 15%. However, the heat pump design performance can drop 5 to 10%. The heat pumps are only penalized when the loop is at the design temperature. It is not possible to estimate the annual operating penalty associated with increasing the temperature. Energy Analyzer™ can be used to evaluate a high loop design condition.
- **Change Bore Hole Distance.** Increasing the bore hole distance will allow energy to dissipate better. It will also minimize the long term effect. This approach will only be effective if there is a large difference between annual heating and cooling loads. Bore hole centers beyond 25 feet will not provide much improvement. Reducing bore hole separation will reduce the required land but increase the thermal interference between holes. For instance, reducing the center distance from 20 to 15 feet saves over 40% in land, but it increases the pipe length by over 20%
- **Use a Hybrid System.** A hybrid system will allow the loop to be sized for the smaller of either the cooling or heating requirement. Refer to ***Hybrid Designs,*** page 33.
- **Test the Ground Conductivity.** When a test is performed, the designer can reduce the design safety factor with more confidence. In most cases (for systems over 50 tons) the test will pay for itself in reduced bore holes.
- **Test the Hydrological Conditions.** Ground water movement can help dissipate energy and reduce annual and long-term temperature changes in the ground. Allowing for minimized annual loop temperature changes can reduce the loop size by 20%.
- **Change Tube Diameter.** Larger tube diameters have better thermal performance, but they are more difficult and expensive to install.
- **Change Bore Hole Depth.** Increasing the depth will reduce the number of bore holes, but it may require larger pipes to carry the increased flow.

Surface Water Design

Figure 24 – Surface Water Loop

Surface water loops require a pond or lake. These can be natural or man made. In some locations, there are code requirements to catch and store rain water runoff on the property. In these cases, the storage pond can be the geothermal pond.

Pond depths are usually 10 to 12 feet minimum. The pond size depends on many factors (see ***Surface Water Fundamentals,*** page 16). Heating dominated loads are generally more demanding. Pond sizes can vary from 10 to 50 tons per acre.

The typical operating range for surface water systems is 35°F to 87°F. This is better than either vertical or horizontal loops, particularly in hot climates. The advantage surface water systems have in cooling is the evaporative effect of the water.

Figure 25 – Installing Pond Loop[22]

Piping Design

Piping systems are generally made up of 300 to 350 ft coils of ¾ in. HDPE pipe. Each coil will reject about 1 ton of heat to the water. To improve heat transfer, the turns of the coil are separated with spacers.

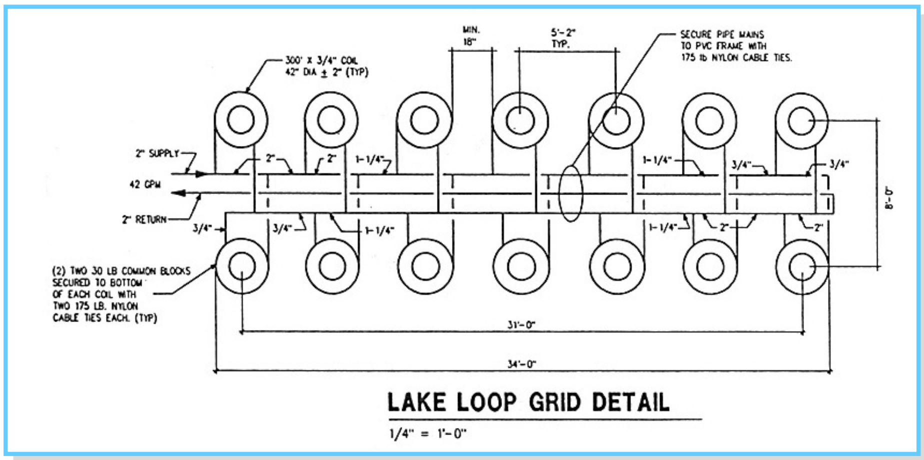
The coils are assembled in frames, either at the jobsite or remotely. They are attached to 2-inch headers and floated into the pond as shown in Figure 25. Once in place, the coils are filled with water and allowed to sink to the bottom.

Antifreeze is common even in warm climates. Pond water temperatures can reach as low as 42°F, which can lead to freezing conditions in the heating mode. Special attention should given to where the pipes leave the pond to reduce the possibility of mechanical damage and potential freezing.

[22] Courtesy of Loop Group, Fort Wayne, Indiana

***Figure 26 – Coil Spacers*[23]**

***Figure 27 – Typical Pond Loop Piping Arrangement*[24]**



Software Design

Software for surface water design will require the following information.

- **Design Fluid Supply Temperatures.** For cooling, try 20°F to 30°F above the undisturbed ground water temperature and 10°F to 20°F colder for heating. Do not use the ISO rating conditions for heat pumps.
- **Ground Temperature.** This is the undisturbed ground temperature and can be found in ***Appendix 1 – Ground Temperatures*** (Page 36) for many cities. Ambient air conditions may also be requested since the headers are similar to a horizontal ground loop system.
- **System Flow Rate.** Try 3 US gpm / ton.
- **Fluid Properties.** If antifreeze is required, the properties need to be entered. Do not unnecessarily use too much antifreeze.
- **Surface Water Properties.** The average summer and winter water temperatures at the depth where the bundles will be located. Also, the pond surface area and circuit depth are required.
- **Pipe Properties.** These include pipe thermal resistance, diameter, flow type (turbulent vs. Laminar), number of pipes per hole, placement in the hole, backfill properties, etc.

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[23] Courtesy of Loop Group, Fort Wayne, IN.
[24] Courtesy of Loop Group, Fort Wayne, IN.

Hybrid Designs

It is rare that the annual heating and cooling loads are equal. When the cooling load exceeds the heating load annually, the average ground temperature will climb over time until an equilibrium is reached. This will either lower the performance of the system from design conditions, or pipe length must be added to account for the long-term performance drop.

An alternative solution is to use a hybrid system. Hybrid systems consist of both a ground loop and supplementary cooling equipment – such as a closed circuit cooler. Hybrid designs come in many forms, but the goal is to balance out the annual load on the ground loop. Consider a building with a net heat addition to the loop. In other words, the loop size is dominated by the cooling load. One hybrid solution would be to size the ground loop to meet the heating load only. A closed circuit cooler handles the difference between the actual heat of rejection and the ground loop capacity. The cooler design conditions must be based on the ground loop design water temperatures and the local design wet bulb. These conditions may be different than conventional Boiler/Tower design conditions.

Ventilation System Design

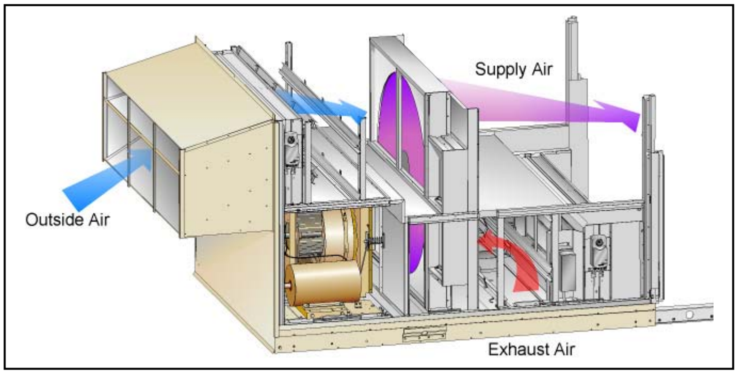
The ventilation load in a commercial building can range from 15% of an office building design load to over 30% in a school. Ventilation air represents a large part of the annual heating and cooling operating cost. How the ventilation load is handled will have a major impact on the overall operating performance.

Proper treatment of the ventilation air has a large impact on humidity control and indoor air quality. Since heat pumps are on-off devices that cycle to meet part load conditions, humidity control by the ventilation unit is critical. If the ventilation unit does not control humidity properly, humidity will enter the occupied space during periods when the heat pump is off.

Most efficient Geothermal designs include some method to minimize humidity by using electricity or natural gas to condition the ventilation air. General approaches include using energy recovery (such as enthalpy wheels) and attaching the ventilation load to the ground loop. For more information on ventilation system design, refer to McQuay Application Guide ***AG 31-004, HVAC School Design***.

Enthalpy Wheels

Figure 28 – McQuay Rooftop Unit with Enthalpy Wheel



Enthalpy wheels can transfer both sensible and latent energy. In cold weather, the enthalpy wheels can warm outdoor air into the 40°F range or better. They can also humidify the outdoor air, typically cutting the humidity load in half. In warm weather, enthalpy wheels can lower both the sensible and latent levels of the outdoor air. Typical leaving air conditions from an enthalpy wheel are around 80°F db, 67°F wb. For many climates, no further cooling is required. Any additional load can be handled by the heat pumps.

An enthalpy wheel ventilation unit alone, even with natural gas or electric heat, can provide a major improvement in the operating cost of a building. The systems are available pre-packaged (see Figure 28) and they are straightforward to design and operate. They are an excellent choice for schools.

Templifiers™

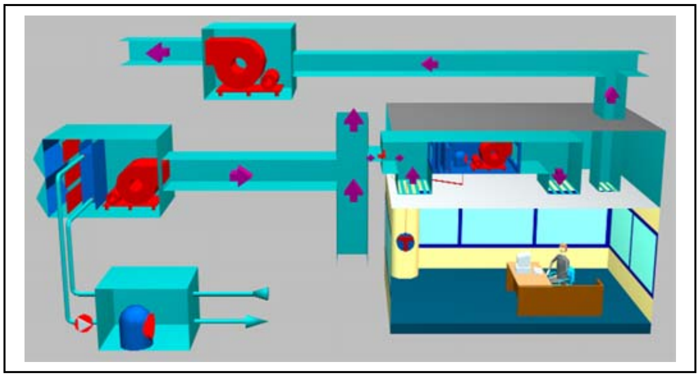
Figure 29 – McQuay Templifier™

A Templifier™ is a water-to-water heat recovery device. It can take low-grade heat in a *source* loop and use it to heat a hot water loop 70°F to 80°F warmer than the source loop. For Geothermal applications, the Templifier™ can heat a hot water loop from the ground loop. The hot water loop can be used for the ventilation load, for entrance heaters and for other heating loads that are not easily handled by a heat pump. The hot water loop can have antifreeze at concentrations appropriate to avoid freezing when used in 100% outdoor air systems.

Using a Templifier™ with an Enthalpy wheel can avoid the use of natural gas or electricity to directly heat or cool the ventilation air. A natural gas line can also be avoided. In some cases, the Templifier™ can handle the domestic hot water load as well.

Water-to-Water Heat pumps

Figure 30 – Water-to-Water Heat pump Ventilation Air Application



Water-to-water geothermal heat pumps can be used to produce either hot water or chilled water from the ground loop. The water produced by the water-to-water unit can be used to either heat or cool the ventilation air as required.

Water-to-water units avoid the use of electricity and natural gas to directly condition the ventilation air. However, compressor work is required in cooling mode, so they are not as efficient as a Templifier™/ enthalpy wheel arrangement. They are, however, generally less expensive.

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Appendix 1 – Ground Temperatures

State	City	GWT (F)	State/Country	City	GWT (F)	State/Country	City	GWT (F)
Alabama	Birmingham	65	South Carolina	Charleston	66	Germany	Frankfurt	52
Alabama	Mobile	70	South Carolina	Columbia	64	Germany	Hamburg	51
Alabama	Montgomery	67	South Carolina	Greenville	62	Germany	Munich	49
Alaska	Anchorage	40	South Dakota	Sioux Falls	51	Germany	Stuttgart	51
Alaska	Fairbanks	0	Tennessee	Knoxville	61	Greece	Athens	67
Arizona	Phoenix	73	Tennessee	Memphis	63	Hungary	Budapest	53
Arkansas	Little Rock	64	Tennessee	Nashville	60	Indonesia	Jakarta	83
California	Fresno	68	Texas	Austin	71	Ireland	Dublin	52
California	Los Angeles	64	Texas	Dallas	68	Israel	Jerusalem	63
California	Sacramento	67	Texas	Houston	71	Italy	Genova	60
California	San Diego	64	Texas	San Antonio	72	Italy	Milan	57
California	San Francisco	60	Utah	Salt Lake City	53	Italy	Naples	63
Colorado	Denver	52	Vermont	Burlington	46	Italy	Palermo	66
Connecticut	Hartford	51	Virginia	Norfolk	61	Italy	Rome	61
Delaware	Dover	57	Virginia	Richmond	60	Italy	Torino	58
Florida	Daytona Beach	70	Virginia	Roanoke	59	Italy	Trieste	58
Florida	Jacksonville	71	DC	Washington	57	Italy	Venice	58
Florida	Miami	78	Washington	Seattle	53	Japan	Nagoya	62
Florida	Tallahassee	69	Washington	Spokane	49	Japan	Osaka	63
Florida	Tampa	75	West Virginia	Charleston	58	Japan	Sapporo	51
Georgia	Atlanta	62	Wisconsin	La Crosse	48	Japan	Tokyo	64
Georgia	Savannah	67	Wisconsin	Milwaukee	47	Korea	Inch'on	56
Hawaii	Honolulu	79	Wyoming	Cheyenne	48	Korea	Pusan	59
Idaho	Boise	47	Alberta	Calgary	42	Korea	Seoul	57
Illinois	Chicago	51	Alberta	Edmonton	40	Kuwait	Kuwait City	80
Illinois	Springfield	56	British Columbia	Vancouver	53	Libyan Arab Jamahiriya	Tripoli	71
Indiana	Fort Wayne	53	Manitoba	Winnipeg	40	Malaysia	George Town	84
Indiana	Indianapolis	55	New Brunswick	Moncton	42	Malaysia	Kuala Lumpur	83
Iowa	Des Moines	53	Newfoundland	Saint John's	43	Mexico	Acapulco	78
Kansas	Wichita	59	Nova Scotia	Halifax	45	Mexico	Mexico City	65
Ohio	Cincinatti	57	Ontario	Ottawa	45	Mexico	Veracruz	75
Kentucky	Lexington	60	Ontario	Toronto	48	Morocco	Casablanca	66
Kentucky	Louisville	60	Prince Edward Island	Charlottetown	42	Netherlands	Amsterdam	52
Louisiana	New Orleans	70	Quebec	Montreal	46	New Zealand	Auckland	56
Louisiana	Shreveport	66	Saskatchewan	Regina	39	New Zealand	Christchurch	54
Maine	Caribou	46	Argentina	Buenos Aires	64	New Zealand	Wellington	57
Maine	Portland	48	Australia	Adelaide	64	Norway	Oslo	46
Maryland	Baltimore	57	Australia	Brisbane	72	Paraguay	Asuncion	64
Massachusetts	Boston	50	Australia	Canberra	67	Peru	Lima	70
Massachusetts	Worchester	50	Australia	Melbourne	59	Philippines	Manila	67
Michigan	Detroit	50	Australia	Perth	67	Poland	Krakow	48
Michigan	Flint	49	Australia	Sydney	67	Poland	Warsaw	49
Michigan	Grand Rapids	46	Austria	Salzburg	51	Portugal	Porto	64
Minnesota	Duluth	41	Austria	Vienna	50	Puerto Rico	San Juan	84
Minnesota	Minneapolis	47	Bahrain	Manama	80	Qatar	Doha	83
Mississippi	Jackson	67	Belgium	Brussels	52	Romania	Bucharest	54
Missouri	Kansas City	58	Bolivia	La Paz	50	Saudi Arabia	Riyadh	82
Missouri	St. Louis	58	Brazil	Belem	82	Singapore	Singapore	82
Montana	Billings	49	Brazil	Brasilia	80	Spain	Barcelona	62
Montana	Helena	47	Brazil	Recife	78	Spain	Madrid	60
Nebraska	Omaha	53	Brazil	Sao Paulo	78	Spain	Sevilla	67
Nevada	Las Vegas	69	Bulgaria	Sofia	55	Spain	Valencia	65
Nevada	Reno	50	Chile	Santiago	61	Sweden	Stockholm	47
New Hampshire	Concord	50	China	Beijing	58	Switzerland	Geneva	53
New Jersey	Trenton	55	China	Guangzhou	77	Syria	Damascus	71
New Mexico	Albuquerque	59	China	Harbin	53	Taiwan	Taipei	75
New York	Albany	50	China	Hong Kong	77	Thailand	Bangkok	85
New York	Buffalo	50	China	Shanghai	62	Tunisia	Tunis	69
New York	New York City	52	China	Shenyang	55	Turkey	Ankara	52
North Carolina	Asheville	59	Colombia	Bogota	58	Turkey	Istanbul	60
North Carolina	Charlotte	62	Cuba	Havana	77	Turkey	Izmir	64
North Carolina	Greensboro	60	Czech Republic	Prague	50	United Arab Emirates	Abu Dhabi	80
North Carolina	Raleigh	62	Denmark	Copenhagen	47	United Arab Emirates	Dubai	80
North Dakota	Bismarck	44	Ecuador	Quito	60	United Kingdom	Aberdeen	49
North Dakota	Fargo	42	Egypt	Aswan	78	United Kingdom	Belfast	51
Ohio	Cleveland	51	Egypt	Cairo	73	United Kingdom	Birmingham	52
Ohio	Columbus	55	Finland	Helsinki	47	United Kingdom	Edinburgh	50
Ohio	Dayton	50	France	Bordeaux	61	United Kingdom	Liverpool	54
Oklahoma	Oklahoma City	62	France	Lyon	57	United Kingdom	London	54
Oregon	Portland	54	France	Marseille	59	Uruguay	Montevideo	64
Pennsylvania	Harrisburg	52	France	Nantes	56	Venezuela	Caracas	78
Pennsylvania	Philadelphia	55	France	Paris	54	Vietnam	Hanoi	84
Pennsylvania	Pittsburgh	52	Germany	Berlin	52	Yugoslavia	Belgrade	55

Appendix 2 – Pipe Properties

Heat Transfer Fluid= Water @ 50 F	Pressure Drop per 100 ft of PVC Piping (Using D'arcy-Weisbach Equation)								
Fluid Viscosity= .0012 (lb/ft*s) Fluid Density= 63 (lb/ft^3)	3/4" SDR 11 ID (in)= .61"			1" SDR 11 ID (in)= .92"			1 1/4" SDR 11 ID (in)= 1.13"		
Flow Rate (GPM)	Rd	PD (ft of H2O)	Vel (f/s)	Rd	PD (ft of H2O)	Vel (f/s)	Rd	PD (ft of H2O)	Vel (f/s)
1	2930	1.60	1.10	1943	0.23	0.48	1582	0.09	0.32
1.5	4395	3.25	1.65	2914	0.46	0.72	2373	0.17	0.48
2	5860	5.38	2.20	3886	0.76	0.97	3163	0.29	0.64
2.5				4857	1.13	1.21	3954	0.42	0.80
3				5828	1.55	1.45	4745	0.58	0.96
3.5				6800	2.03	1.69	5536	0.77	1.12
4				7771	2.57	1.93	6327	0.97	1.28
4.5				8742	3.16	2.17	7118	1.19	1.44
5				9714	3.79	2.41	7909	1.43	1.60
5.5				10685	4.48	2.65	8700	1.69	1.76
6				11657	5.22	2.90	9490	1.97	1.92
6.5							10281	2.26	2.08
7							11072	2.57	2.24
7.5							11863	2.91	2.40
8							12654	3.25	2.56
8.5							13445	3.62	2.72
9							14236	4.00	2.88
9.5							15026	4.39	3.04
10							15817	4.81	3.20
10.5							16608	5.23	3.36
11							17399	5.68	3.52

Heat Transfer Fluid= Water @ 50 F	Pressure Drop per 100 ft of PVC Piping (Using D'arcy-Weisbach Equation)								
Fluid Viscosity= .0012 (lb/ft*s) Fluid Density= 63 (lb/ft^3)	3/4" SDR 9 ID (in)= .58"			1" SDR 9 ID (in)= .88"			1 1/4" SDR 9 ID (in)= 1.07"		
Flow Rate (GPM)	Rd	PD (ft of H2O)	Vel (f/s)	Rd	PD (ft of H2O)	Vel (f/s)	Rd	PD (ft of H2O)	Vel (f/s)
1	3066	1.98	1.20	2033	0.28	0.53	1670	0.11	0.36
1.5	4599	4.03	1.80	3050	0.57	0.79	2506	0.23	0.54
2	6132	6.67	2.40	4067	0.95	1.06	3341	0.37	0.71
2.5				5083	1.40	1.32	4176	0.55	0.89
3				6100	1.93	1.59	5011	0.76	1.07
3.5				7117	2.52	1.85	5846	0.99	1.25
4				8134	3.19	2.12	6682	1.25	1.43
4.5				9150	3.92	2.38	7517	1.54	1.61
5				10167	4.71	2.64	8352	1.85	1.78
5.5				11184	5.57	2.91	9187	2.19	1.96
6				12200	6.48	3.17	10023	2.55	2.14
6.5							10858	2.93	2.32
7							11693	3.34	2.50
7.5							12528	3.76	2.68
8							13363	4.21	2.85
8.5							14199	4.69	3.03
9							15034	5.18	3.21
9.5							15869	5.69	3.39
10							16704	6.23	3.57
10.5							17539	6.78	3.75
11							18375	7.36	3.93

Appendix 3 – Antifreeze Properties

Ethylene Glycol Correction Factors			Propylene Glycol Correction Factors		
Cooling Capacity	10%	0.9950	**Cooling Capacity**	10%	0.9900
	20%	0.9920		20%	0.9800
	30%	0.9870		30%	0.9700
	40%	0.9830		40%	0.9600
	50%	0.9790		50%	0.9500
Heating Capacity	10%	0.9910	**Heating Capacity**	10%	0.9870
	20%	0.9820		20%	0.9750
	30%	0.9770		30%	0.9620
	40%	0.9690		40%	0.9420
	50%	0.9610		50%	0.9300
Pressure Drop	10%	1.0700	**Pressure Drop**	10%	1.0700
	20%	1.1300		20%	1.1500
	30%	1.1800		30%	1.2500
	40%	1.2600		40%	1.3700
	50%	1.2800		50%	1.4200

Methanol			Ethanol		
Cooling Capacity	10%	0.9980	**Cooling Capacity**	10%	0.9910
	20%	0.9720		20%	0.9510
	30%			30%	
	40%			40%	
	50%			50%	
Heating Capacity	10%	0.9950	**Heating Capacity**	10%	0.9950
	20%	0.9700		20%	0.9600
	30%			30%	
	40%			40%	
	50%			50%	
Pressure Drop	10%	1.0230	**Pressure Drop**	10%	1.0350
	20%	1.0570		20%	1.0680
	30%			30%	
	40%			40%	
	50%			50%	

Appendix 4 – Equivalent Full Load Hours[25]

City	State	EFLH[1] School Occupancy		EFLH[2] Office Occupancy		EFLH[3] Retail Occupancy		EFLH[4] Hospital Occupancy	
		Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Atlanta	GA	290 - 200	690 - 830	690 - 480	1,080 - 1,360	600 - 380	1,380 - 1,860	430 - 160	2,010 - 2,850
Baltimore	MD	460 - 320	500 - 610	890 - 720	690 - 1,080	770 - 570	880 - 1,480	590 - 300	1,340 - 2,340
Bismarck	ND	500 - 460	150 - 250	990 - 950	250 - 540	900 - 810	340 - 780	730 - 530	540 - 1,290
Boston	MA	520 - 450	300 - 510	1,000 - 960	450 - 970	870 - 760	610 - 1,380	680 - 420	1,020 - 2,330
Charleston	WV	440 - 310	430 - 570	840 - 770	620 - 1,140	730 - 620	820 - 1,600	550 - 320	1,260 - 2,560
Charlotte	NC	320 - 200	650 - 730	780 - 530	1,060 - 1,340	670 - 420	1,350 - 1,830	490 - 180	1,990 - 2,820
Chicago	IL	470 - 390	280 - 410	920 - 820	420 - 780	810 - 670	550 - 1,090	640 - 400	870 - 1,780
Dallas	TX	200 - 120	830 - 890	520 - 340	1,350 - 1,580	440 - 280	1,660 - 2,090	310 - 100	2,320 - 3,100
Detroit	MI	480 - 400	230 - 360	1,020 - 970	390 - 820	900 - 790	530 - 1,170	710 - 460	870 - 1,950
Fairbanks	AK	630 - 560	26 - 54	1,170 - 1,050	64 - 200	1,090 - 930	110 - 320	930 - 690	210 - 600
Great Falls	MT	430 - 360	130 - 220	890 - 820	210 - 490	800 - 680	290 - 710	640 - 420	500 - 1,210
Hilo	HI	1 - 0	1,360 - 1,390	23 - 13	2,440 - 2,580	14 - 8	2,990 - 3,370	0 - 0	4,060 - 4,910
Houston	TX	130 - 90	940 - 1,000	350 - 250	1,550 - 1,770	300 - 190	1,870 - 2,290	200 - 70	2,540 - 3,320
Indianapolis	IN	480 - 400	380 - 560	920 - 840	560 - 1,000	820 - 690	730 - 1,410	640 - 390	1,120 - 2,250
Los Angeles	CA	160 - 80	780 - 910	580 - 370	1,280 - 1,670	440 - 250	1,740 - 2,350	180 - 20	2,740 - 3,770
Louisville	KY	430 - 290	550 - 670	830 - 710	770 - 1,250	720 - 570	1,000 - 1,720	550 - 300	1,480 - 2,690
Madison	WI	470 390	210 - 310	900 - 840	320 - 640	800 - 700	420 - 900	640 - 440	680 - 1,490
Memphis	TN	240 - 170	700 - 830	600 - 420	1,090 - 1,350	510 - 330	1,350 - 1,780	370 - 140	1,910 - 2,680
Miami	FL	12 - 6	1,260 - 1,300	46 - 34	1,980 - 2,150	37 - 25	2,350 - 2,740	12 - 1	3,110 - 3,890
Minneapolis	MN	500 - 420	200 - 300	950 - 860	320 - 610	860 - 720	430 - 870	700 - 470	680 - 1,420
Montgomery	AL	180 - 120	840 - 910	470 - 330	1,260 - 1,510	400 - 250	1,550 - 1,990	260 - 90	2,170 - 2,950
Nashville	TN	320 - 250	570 - 740	680 - 590	830 - 1,280	590 - 470	1,030 - 1,710	450 - 240	1,490 - 2,620
New Orleans	LA	110 - 67	920 - 990	320 - 230	1,500 - 1,720	260 - 160	1,820 - 2,240	160 - 46	2,500 - 3,280
New York City	NY	440 - 350	360 - 550	870 - 790	540 - 1,040	760 - 630	720 - 1,480	590 - 330	1,160 - 2,440
Omaha	NE	400 - 330	310 - 440	800 - 720	480 - 820	720 - 600	610 - 1,130	570 - 360	920 - 1,780
Phoenix	AZ	110 - 65	950 - 1,020	290 - 210	1,340 - 1,610	250 - 170	1,630 - 2,090	140 - 34	2,220 - 3,040
Pittsburgh	PA	500 - 470	300 - 530	950 - 910	440 - 920	840 - 750	600 - 1,310	650 - 420	960 - 2,160
Portland	ME	480 - 400	190 - 300	980 - 880	310 - 630	870 - 710	410 - 900	690 - 420	700 - 1,520
Richmond	VA	410 - 270	630 - 730	820 - 660	880 - 1,310	710 - 520	1,110 - 1,770	530 - 250	1,650 - 2,760
Sacramento	CA	360 - 220	680 - 850	990 - 640	1,080 - 1,430	830 - 480	1,460 - 2,020	540 - 120	2,250 - 3,180
Salt Lake City	UT	540 - 520	410 - 710	1,060 - 1,040	510 - 1,090	930 - 830	660 - 1,520	720 - 440	1,060 - 2,470
Seattle	WA	650 - 460	260 - 460	1,370 - 1,270	440 - 1,200	1,170 - 960	710 - 1,860	850 - 360	1,340 - 3,270
St. Louis	MO	400 - 280	460 - 550	800 - 710	680 - 1,100	700 - 570	850 - 1,500	550 - 320	1,260 - 2,330
Tampa	FL	58 - 35	1,050 - 1,110	190 - 140	1,800 - 2,000	160 - 100	2,170 - 2,580	90 - 22	2,910 - 3,710
Tulsa	OK	300 - 240	580 - 770	620 - 560	830 - 1,300	540 - 450	1,030 - 1,730	410 - 220	1,470 - 2,630

General Table Notes:

1. The ranges in values are from internal gains at 0.6 W/& (6.5 W/m^2) and *2.5* W/& (27 W/m^2).
2. Operating with large temperature setbacks during unoccupied periods (effectively turning off the system) reduces heating EFLHs by 20% and cooling EFLHs by 5%.

[1] School:

Sizing ratio of peak daily load to daily capacity was maintained at 0.25.

Heating EFLH =

At 0.6 W/ft^2: 0.09 x HDD_{65} [for HDD_{65} < 5,000] & EFLH = 500 [for HDD_{65} > 5,000]
At 2.5 W/ft^2: 0.06 x HDD_{65} [for HDD_{65} < 10,000]
(At 6.5 W/m^2: 0.16 x HDD_{18} [for HDD_{18} < 2,800] & EFLH = 500 [for HDD_{18} > 2,800])
(At 27 W/m^2: 0.11 x HDD_{18} [for HDD_{18} < 5,500])

Cooling EFLH =

At 0.6 W/ft^2: 160 + 0.28 x CDD_{65}
At 2.5 W/ft^2: 320 + 0.25 x CDD_{65}
(At 6.5 W/m^2: 160 + 0.50 x CDD_{18})
(At 27 W/ m^2: 320 + 0.45 x CDD_{18})

Weekday occupancy from 8 a.m. until 3 p.m., summer break June through August.

[2] Office:

Sizing ratio of peak daily load to daily capacity was maintained at 0.40.

Heating EFLH =

At 0.6 W/ft^2: 0.20 x HDD_{65} [for HDD_{65} < 5,000] & EFLH = 1,000 [for HDD_{65} > 5,000]
At 2.5 W/ft^2: 0.15 x HDD_{65} [for HDD_{65} < 6,000] & EFLH = 900 [for HDD_{65} > 6,000]
(At 6.5 W/m^2: 0.36 x HDD_{18} [for HDD_{18} < 2,800] & EFLH = 1,000 [for HDD_{18} > 2,800])
(At 27 W/ m^2: 0.27 x HDD_{18} [for HDD_{18} < 3,300] & EFLH = 900 [for HDD_{18} > 3,300])

Cooling EFLH =

At 0.6 W/ft^2: 225 + 0.45 x CDD_{65}
At 2.5 W/ft^2: 670 + 0.40 x CDD_{65}
(At 6.5 W/m^2: 225 + 0.81 x CDD_{18})
(At 27 W/ m^2: 670 + 0.72 x CDD_{18})

Weekday occupancy from 8 a.m. until 5 p.m.

[3] Retail:

Sizing ratio of peak daily load to daily capacity was maintained at 0.40.

Heating EFLH =

At 0.6 W/ft^2: 0.17 x HDD_{65} [for HDD_{65} < 5,000] & EFLH = 850 [for HDD_{65} > 5,000]
At 2.5 W/ft^2: 0.13 x HDD_{65} [for HDD_{65} < 5,500] & EFLH = 715 [for HDD_{65} > 5,500]
(At 6.5 W/m^2: 0.31 x HDD_{18} [for HDD_{18} < 2,800] & EFLH = 850 [for HDD_{18} > 2,800])
(At 27 W/ m^2: 0.23 x HDD_{18} [for HDD_{18} < 3,100] & EFLH = 715 [for HDD_{18} > 3,100])

Cooling EFLH =

At 0.6 W/ft^2: 360 + 0.50 x CDD_{65}
At 2.5 W/ft^2: 1,000 + 0.46 x CDD_{65}
(At 6.5 W/m^2: 360 + 0.90 x CDD_{18})
(At 27 W/ m^2: 1,000 + 0.83 x CDD_{18})

Weekday occupancy from 8 a.m. until 10 p.m.

[4] Hospital:

Sizing ratio of peak daily load to daily capacity was maintained at 0.40.

Heating EFLH =

At 0.6 W/ft^2: 0.12 x HDD_{65} [for HDD_{65} < 6,000] & EFLH = 720 [for HDD_{65} > 6,000]
At 2.5 W/ft^2: 0.06 x HDD_{65}
(At 6.5 W/m^2: 0.22 x HDD_{18} [for HDD_{18} < 3,300] & EFLH = 720 [for HDD_{18} > 3,300])
(At 27 W/ m^2: 0.11 x HDD_{18})

Cooling EFLH =

At 0.6 W/ft^2: 690 + 0.75 x CDD_{65}
At 2.5 W/ft^2: 1,770 + 0.57 x CDD_{65}
(At 6.5 W/m^2: 690 + 1.35 x CDD_{18})
(At 27 W/ m^2: 1,770 + 1.03 x CDD_{18})

Continuous Occupancy

Appendix 5 – Antifreeze MSDS

ASTRO PRODUCT CODE # 10094

MATERIAL SAFETY DATA SHEET

HUNTSMAN

READ AND UNDERSTAND MATERIAL SAFETY DATA SHEET BEFORE HANDLING OR DISPOSING OF PRODUCT

PRODUCT CODE AND NAME	:	***PGUSP PROPYLENE GLYCOL - USP***
DATE ISSUED	:	**5/20/97**
DATE PRINTED	:	**9/4/97**

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MATERIAL IDENTITY

PRODUCT CODE AND NAME

PGUSP PROPYLENE GLYCOL - USP

Chemical Name and/or Family or Description:

Glycol

COMPANY INFORMATION

Huntsman Specialty Chemicals Corporation
500 Huntsman Way
Salt Lake City, UT 84108

TELEPHONE NUMBERS
Transportation Emergency
Company: (409) 727-0831
CHEMTREC: (800) 424-9300
Medical Emergency: (409) 722-9673 (24 Hour)
General MSDS Assistance: (713) 235-6432
Technical Information: (512) 459-6543

2. COMPOSITION AND INFORMATION ON INGREDIENTS

THE CRITERIA FOR LISTING COMPONENTS IN THE COMPOSITION SECTION ARE AS FOLLOWS: CARCINOGENS ARE LISTED WHEN PRESENT AT 0.1 % OR GREATER; COMPONENTS WHICH ARE OTHERWISE HAZARDOUS ACCORDING TO OSHA ARE LISTED WHEN PRESENT AT 1.0 % OR GREATER; NON-HAZARDOUS COMPONENTS ARE LISTED AT 3.0 % OR GREATER. THIS IS NOT INTENDED TO BE COMPLETE COMPOSITIONAL DISCLOSURE. REFER TO SECTION 14 FOR APPLICABLE STATES' RIGHT TO KNOW AND OTHER REGULATORY INFORMATION.
Product and/or Component(s) Carcinogenic According to:

OSHA IARC NTP OTHER NONE X

Composition:

Chemical Name	CAS Number	Exposure Limits	Range in %
1,2-propanediol	57-55-6		100.00

THIS PRODUCT IS CONSIDERED NON-HAZARDOUS ACCORDING TO OSHA (1910.1200).

1

ASTRO PRODUCT CODE # 10094

PRODUCT CODE AND NAME	**:**	***PGUSP PROPYLENE GLYCOL - USP***
DATE ISSUED	**:**	***5/20/97***
DATE PRINTED	**:**	***9/4/97***
COMPANY	**:**	**HUNTSMAN**

3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

Appearance:

Colorless mobile liquid

Odor:

Mild odor

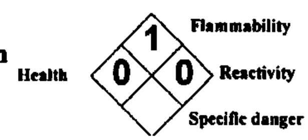
WARNING STATEMENT

CAUTION! ASPIRATION HAZARD IF SWALLOWED - CAN ENTER LUNGS AND CAUSE DAMAGE

Hazardous Material Information System (United States)

Health	0
Fire	1
Reactivity	0
Personal protection	0

National Fire Protection Association NFPA (United States)



POTENTIAL HEALTH EFFECTS

Primary Route of Exposure

Eye X **Skin** X **Inhalation** X **Ingestion**

Effects of Overexposure

Acute:

Eyes: May cause minimal irritation, experienced as temporary discomfort.

Skin: Brief contact is not irritating. Prolonged contact, as with clothing wetted with material, may cause defatting of skin or irritation, seen as local redness with possible mild discomfort.

Other than the potential skin irritation effects noted above, acute (short term) adverse effects are not expected from brief skin contact; see other effects, below, and Section 11 for information regarding potential long term effects.

Inhalation: Vapors or mist, in excess of permissible concentrations, or in unusually high concentrations generated from spraying, heating the material or as from exposure in poorly ventilated areas or confined spaces, may cause irritation of the nose and throat, headache, nausea, and drowsiness.

Ingestion: If more than several mouthfuls are swallowed, abdominal discomfort, nausea, and diarrhea may occur. Aspiration may occur during swallowing or vomiting resulting in lung damage.

Sensitization Properties: Unknown

Chronic:

No adverse effects have been documented in humans as a result of chronic exposure. Section 11 may contain applicable animal data.

Medical Conditions Aggravated by Exposure:

There is no evidence that this product aggravates an existing medical condition.

Other Remarks:

2

ASTRO PRODUCT CODE # 10094

PRODUCT CODE AND NAME	**:**	***PGUSP PROPYLENE GLYCOL - USP***
DATE ISSUED	**:**	***5/20/97***
DATE PRINTED	**:**	***9/4/97***
COMPANY	**:**	**HUNTSMAN**

None

4. FIRST AID MEASURES

Eyes:

Flush eyes with plenty of water for several minutes. Get medical attention if eye irritation persists.

Skin:

Wash skin with plenty of soap and water for several minutes. Get medical attention if skin irritation develops or persists.

Ingestion:

If person is conscious and can swallow, give two glasses of water (16 oz.) but do not induce vomiting. If vomiting occurs, give fluids again. Have medical personnel determine if evacuation of stomach or induction of vomiting is necessary. Do not give anything by mouth to an unconscious or convulsing person.

Inhalation:

If irritation, headache, nausea, or drowsiness occurs, remove to fresh air. Get medical attention if breathing becomes difficult or respiratory irritation persists.

Other Instructions:

Aspiration of this product during induced emesis may result in severe lung injury. If evacuation of stomach is necessary, use method least likely to cause aspiration, such as gastric lavage after endotracheal intubation. Contact a Poison Center for additional treatment information.

5. FIRE-FIGHTING MEASURES

Ignition Temperature - AIT (degrees C):

371.1 (700 F)

Flash Point (degrees C):

100 (212 F) CC

Flammable Limits % (Lower-Upper):

Lower: 2.6
Upper: 12.5

Recommended Fire Extinguishing Agents And Special Procedures:

Use water spray, dry chemical, foam, or carbon dioxide to extinguish flames. Use water spray to cool fire-exposed containers. Water or foam may cause frothing.

Unusual or Explosive Hazards:

None

Special Protective Equipment for Firefighters:

No special equipment or procedures required.

6. ACCIDENTAL RELEASE MEASURES (Transportation Spills: CHEMTREC (800)424-9300)

Procedures in Case of Accidental Release, Breakage or Leakage:

Contain spill if possible, contain with absorbent materials such as clay or soil, and shovel up. Avoid skin and eye contact.

3

PRODUCT CODE AND NAME	:	***PGUSP PROPYLENE GLYCOL - USP***
DATE ISSUED	:	**5/20/97**
DATE PRINTED	:	**9/4/97**
COMPANY	:	**HUNTSMAN**

7. HANDLING AND STORAGE

Precautions to be Taken in

Handling:

Minimum feasible handling temperatures should be maintained.

Storage:

Periods of exposure to high temperatures should be minimized. Water contamination should be avoided.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Protective Equipment (Type)

Eye/Face Protection:

Safety glasses, chemical type goggles, or face shield recommended to prevent eye contact.

Skin Protection:

Workers should wash exposed skin several times daily with soap and water. Soiled work clothing should be laundered or dry-cleaned.

Respiratory Protection:

Airborne concentrations should be kept to lowest levels possible. If vapor, mist or dust is generated and the occupational exposure limit of the product, or any component of the product, is exceeded, use appropriate NIOSH or MSHA approved air purifying or air supplied respirator after determining the airborne concentration of the contaminant. Air supplied respirators should always be worn when airborne concentration of the contaminant or oxygen content is unknown.

Ventilation:

Local exhaust ventilation recommended if generating vapor, dust, or mist. If exhaust ventilation is not available or inadequate, use MSHA or NIOSH approved respirator as appropriate.

Exposure Limit for the Total Product:

None established for product.

Appearance:

Colorless mobile liquid

Odor:

Mild odor

Boiling Point (degrees C):

187.2 (369 F)

Melting/Freezing Point (degrees C):

< -60 (< -76 F)

Specific Gravity (water=1):

1.0381

pH:

6

Vapor Pressure:

< 1 mm Hg at 25 C (77 F)

Viscosity:

< 20 cSt at 40 C (104 F)

VOC Content:

28% by ASTM D 2369

Vapor Density (Air=1):

2.6

Solubility in Water (%):

> 10

Other:

None

10. STABILITY AND REACTIVITY

This Material Reacts Violently With:

Air Water Heat Strong Oxidizers Others None of these X

Comments:

None

Products Evolved When Subjected to Heat or Combustion:

Toxic levels of carbon monoxide, carbon dioxide, irritating aldehydes and ketones.

Hazardous Polymerizations:

DO NOT OCCUR

11. TOXICOLOGICAL INFORMATION

TOXICOLOGICAL INFORMATION (ANIMAL TOXICITY DATA)

Oral:
LD50 > 5.00 g/kg (rat) practically non-toxic
Inhalation:
Believed to be practically non-toxic
Dermal:
LD50 > 2.00 g/kg (rabbit) practically non-toxic

IRRITATION INDEX, ESTIMATION OF IRRITATION (SPECIES)

Skin:
(Draize) Believed to be < .50 /8.0 (rabbit) no appreciable effect
Eyes:
(Draize)Believed to be < 15.00 /110 (rabbit) no appreciable effect
Sensitization:
Not determined.

Other:

None

PRODUCT CODE AND NAME	:	***PGUSP PROPYLENE GLYCOL - USP***
DATE ISSUED	:	**5/20/97**
DATE PRINTED	:	**9/4/97**
COMPANY	:	**HUNTSMAN**

12. DISPOSAL CONSIDERATIONS:

Waste Disposal Methods:

This product has been evaluated for RCRA characteristics and does not meet the criteria of a hazardous waste if discarded in its purchased form. Under RCRA, it is the responsibility of the user of the product to determine at the time of disposal, whether the product meets RCRA criteria for hazardous waste. This is because product uses, transformations, mixtures, processes, etc. may render the resulting materials hazardous.

Remarks:

None

13. TRANSPORT INFORMATION

Transportation

DOT:

Proper Shipping Name:
Not regulated

Hazard Class:
Not regulated

Identification Number:
Not regulated

Packing Group:
Not regulated

Label Required:
Not regulated

IMDG

Proper Shipping Name:
Not regulated

ICAO

Proper Shipping Name:
Not regulated

TDG

Proper Shipping Name:
Not regulated

Hazard Class:
Not regulated

Identification Number:
Not regulated

Label Required:
Not regulated

ASTRO PRODUCT CODE # 10094

PRODUCT CODE AND NAME	:	***PGUSP PROPYLENE GLYCOL - USP***
DATE ISSUED	:	***5/20/97***
DATE PRINTED	:	***9/4/97***
COMPANY	:	**HUNTSMAN**

14. REGULATORY INFORMATION

Federal Regulations:

SARA Title III:

Section 302/304 Extremely Hazardous Substances

Chemical Name	CAS Number	Range in %	TPQ	RQ
None.				

Section 311 Hazardous Categorization:

Acute Chronic Fire Pressure Reactive N/A X

Section 313 Toxic Chemical

Chemical Name	CAS Number	Concentration
None.		

CERCLA 102(a)/DOT Hazardous Substances:

Chemical Name	CAS Number	Range in %	RQ
None.			

States Right-to-Know Regulations:

Chemical Name	State Right-to-know
None.	

State list: **CT (Connecticut), FL (Florida), IL (Illinois), MI (Michigan), LA (Louisiana), MA (Massachusetts), NJ (New Jersey), PA (Pennsylvania), RI (Rhode Island)**

California Prop. 65:
The following detectable components of this product are substances, or belong to classes of substances, known to the State of California to cause cancer and/or reproductive toxicity.

Chemical Name	CAS Number
None.	

INTERNATIONAL REGULATIONS:

TSCA Inventory Status:

This product, or its components, are listed on, or are exempt from the Toxic Substance Control Act (TSCA) Chemical Substance Inventory.

WHMIS Classification:

Not regulated.

Canadian Inventory Status:

This product, or its components, are listed on or are exempt from the Canadian Domestic Substance List (DSL).

EINECS Inventory Status:

This product, or its components, are listed on or are exempt from the European Inventory of Existing Chemical Substances (EINECS) or the European List of Notified Chemical Substances (ELINCS).

Australian Inventory Status:

This product, or its components, are listed on or are exempt from the Australian Inventory of Chemical Substances (AICS).

Japan Inventory Status:

ASTRO PRODUCT CODE # 10094

PRODUCT CODE AND NAME	:	***PGUSP PROPYLENE GLYCOL - USP***
DATE ISSUED	:	**5/20/97**
DATE PRINTED	:	**9/4/97**
COMPANY	:	**HUNTSMAN**

This product, or its components, are listed on or are exempt from the Japanese Ministry of International Trade and Industry (MITI) inventory.

15. ENVIRONMENTAL INFORMATION

Aquatic Toxicity:

LC50-96hr Aquatic toxicity rating is believed to be > 100.00 mg/liter practically nontoxic

Mobility:

Not determined.

Persistence and Biodegradability:

This product is reported to have a moderate (>= 30%) rate of biodegradation in a test for ready biodegradation.

Potential to Bioaccumulate:

This product is reported to have a low potential to bioconcentrate.

Remarks:

None

16. OTHER INFORMATION 5/20/97

This product is currently on the FDA's GRAS (generally regarded as safe) list.

THE INFORMATION CONTAINED HEREIN IS BELIEVED TO BE ACCURATE. IT IS PROVIDED INDEPENDENTLY OF ANY SALE OF THE PRODUCT FOR PURPOSE OF HAZARD COMMUNICATION AS PART OF HUNTSMAN'S PRODUCT SAFETY PROGRAM. IT IS NOT INTENDED TO CONSTITUTE PERFORMANCE INFORMATION CONCERNING THE PRODUCT. NO EXPRESS WARRANTY, OR IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE IS MADE WITH RESPECT TO THE PRODUCT OR THE INFORMATION CONTAINED HEREIN. DATA SHEETS ARE AVAILABLE FOR ALL HUNTSMAN PRODUCTS. YOU ARE URGED TO OBTAIN DATA SHEEETS FOR ALL HUNTSMAN PRODUCTS YOU BUY, PROCESS, USE OR DISTRIBUTE AND YOU ARE ENCOURAGED AND REQUESTED TO ADVISE THOSE WHO MAY COME IN CONTACT WITH SUCH PRODUCTS OF THE INFORMATION CONTAINED HEREIN.

TO DETERMINE APPLICABILITY OR EFFECTS OF ANY LAW OR REGULATION WITH RESPECT TO THE PRODUCT, USER SHOULD CONSULT HIS LEGAL ADVISOR OR THE APPROPRIATE GOVERNMENT AGENCY. HUNTSMAN DOES NOT UNDERTAKE TO FURNISH ADVICE ON SUCH MATTERS.

Date Issued: 5/20/97. **Verified by Phillip B. Valkovich.**

Inquiries regarding MSDS should be directed to:

HUNTSMAN
Coordinator, Product Safety
P.O. Box 27707
Houston, TX 77227-7707

For the latest Propylene Glycol MSDS go to www.huntsman.com

ETHYLENE GLYCOL

MSDS Number: E5125 --- *Effective Date: 02/25/99*

1. Product Identification

Synonyms: 1,2-Ethanediol; glycol; 1,2-Dihydroxyethane; Ethylene Alcohol; Ethulene Dihydrate
CAS No.: 107-21-1
Molecular Weight: 62.07
Chemical Formula: CH2OHCH2OH
Product Codes:
J.T. Baker: 5387, 5845, 9140, 9298, 9300, 9346, 9349, 9356, L715
Mallinckrodt: 5001, 5037

2. Composition/Information on Ingredients

Ingredient	CAS No	Percent	Hazardous
Ethylene Glycol	107-21-1	99 - 100%	Yes

3. Hazards Identification

Emergency Overview

WARNING! HARMFUL OR FATAL IF SWALLOWED. HARMFUL IF INHALED OR ABSORBED THROUGH SKIN. MAY CAUSE ALLERGIC SKIN REACTION. MAY CAUSE IRRITATION TO SKIN, EYES, AND RESPIRATORY TRACT. AFFECTS CENTRAL NERVOUS SYSTEM.

J.T. Baker SAF-T-DATA(tm) Ratings (Provided here for your convenience)

Health Rating: 2 - Moderate
Flammability Rating: 1 - Slight
Reactivity Rating: 1 - Slight
Contact Rating: 2 - Moderate
Lab Protective Equip: GOGGLES; LAB COAT; VENT HOOD; PROPER GLOVES

Storage Color Code: Orange (General Storage)

Potential Health Effects

Inhalation:
Vapor inhalation is generally not a problem unless heated or misted. Exposure to vapors over an extended time period has caused throat irritation and headache. May cause nausea, vomiting, dizziness and drowsiness. Pulmonary edema and central nervous system depression may also develop. When heated or misted, has produced rapid, involuntary eye movement and coma.
Ingestion:
Initial symptoms in massive dosage parallel alcohol intoxication, progressing to CNS depression, vomiting, headache, rapid respiratory and heart rate, lowered blood pressure, stupor, collapse, and unconsciousness with convulsions. Death from respiratory arrest or cardiovascular collapse may follow. Lethal dose in humans: 100 ml (3-4 ounces).
Skin Contact:
Minor skin irritation and penetration may occur.
Eye Contact:
Splashes may cause irritation, pain, eye damage.
Chronic Exposure:
Repeated small exposures by any route can cause severe kidney problems. Brain damage may also occur. Skin allergy can develop. May damage the developing fetus.
Aggravation of Pre-existing Conditions:
Persons with pre-existing skin disorders, eye problems, or impaired liver, kidney, or respiratory function may be more susceptible to the effects of this substance.

4. First Aid Measures

Inhalation:
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call a physician.
Ingestion:
Induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention.
Skin Contact:
Remove any contaminated clothing. Wash skin with soap and water for at least 15 minutes. Get medical attention if irritation develops or persists.
Eye Contact:
Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

Note to Physician:
Give sodium bicarbonate intravenously to treat acidosis. Urinalysis may show low specific gravity, proteinuria, pyuria, cylindruria, hematuria, calcium oxide, and hippuric

acid crystals. Ethanol can be used in antidotal treatment but monitor blood glucose when administering ethanol because it can cause hypoglycemia. Consider infusion of a diuretic such as mannitol to help prevent or control brain edema and hemodialysis to remove ethylene glycol from circulation.

5. Fire Fighting Measures

Fire:
Flash point: 111C (232F) CC
Autoignition temperature: 398C (748F)
Flammable limits in air % by volume:
lel: 3.2; uel: 15.3
Slight to moderate fire hazard when exposed to heat or flame.
Explosion:
Above flash point, vapor-air mixtures are explosive within flammable limits noted above. Containers may explode when involved in a fire.
Fire Extinguishing Media:
Dry chemical, foam or carbon dioxide. Water or foam may cause frothing. Water spray may be used to extinguish surrounding fire and cool exposed containers. Water spray will also reduce fume and irritant gases.
Special Information:
In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode. Toxic gases and vapors may be released if involved in a fire.

6. Accidental Release Measures

Ventilate area of leak or spill. Remove all sources of ignition. Wear appropriate personal protective equipment as specified in Section 8. Isolate hazard area. Keep unnecessary and unprotected personnel from entering. Contain and recover liquid when possible. Use non-sparking tools and equipment. Collect liquid in an appropriate container or absorb with an inert material (e. g., vermiculite, dry sand, earth), and place in a chemical waste container. Do not use combustible materials, such as saw dust. Do not flush to sewer! US Regulations (CERCLA) require reporting spills and releases to soil, water and air in excess of reportable quantities. The toll free number for the US Coast Guard National Response Center is (800) 424-8802.

7. Handling and Storage

Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage. Separate from acids and oxidizing materials. Containers of this material may be hazardous when empty since they retain product residues (vapors, liquid); observe all warnings and precautions listed for the product.

8. Exposure Controls/Personal Protection

Airborne Exposure Limits:
-OSHA Permissible Exposure Limit (PEL):
50 ppm Ceiling

-ACGIH Threshold Limit Value (TLV):
50 ppm Ceiling (vapor)
Ventilation System:
A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, *Industrial Ventilation, A Manual of Recommended Practices*, most recent edition, for details.
Personal Respirators (NIOSH Approved):
If the exposure limit is exceeded, a half-face respirator with an organic vapor cartridge and particulate filter (NIOSH type P95 or R95 filter) may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest. A full-face piece respirator with an organic vapor cartridge and particulate filter (NIOSH P100 or R100 filter) may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest. Please note that N series filters are not recommended for this material. For emergencies or instances where the exposure levels are not known, use a full-face piece positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.
Skin Protection:
Wear protective gloves and clean body-covering clothing.
Eye Protection:
Use chemical safety goggles. Maintain eye wash fountain and quick-drench facilities in work area.

9. Physical and Chemical Properties

Appearance:
Clear oily liquid.
Odor:
Odorless.
Solubility:
Miscible in water.
Specific Gravity:
1.1 @20C/4C
pH:

No information found.
% Volatiles by volume @ 21C (70F):
100
Boiling Point:
197.6C (388F)
Melting Point:
-13C (9F)
Vapor Density (Air=1):
2.14
Vapor Pressure (mm Hg):
0.06 @ 20C (68F)
Evaporation Rate (BuAc=1):
No information found.

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10. Stability and Reactivity

Stability:
Stable under ordinary conditions of use and storage.
Hazardous Decomposition Products:
Carbon dioxide and carbon monoxide may form when heated to decomposition. May produce acrid smoke and irritating fumes when heated to decomposition.
Hazardous Polymerization:
Will not occur.
Incompatibilities:
Strong oxidizing agents. Reacts violently with chlorosulfonic acid, oleum, sulfuric acid, perchloric acid. Causes ignition at room temperature with chromium trioxide, potassium permanganate and sodium peroxide; causes ignition at 212F(100C) with ammonium dichromate, silver chlorate, sodium chloride and uranyl nitrate.
Conditions to Avoid:
Heat, flames, ignition sources, water (absorbs readily) and incompatibles.

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11. Toxicological Information

Toxicological Data:
Oral rat LD50: 4700 mg/kg; skin rabbit LD50: 9530 mg/kg.
Irritation - skin rabbit: 555mg(open), mild; eye rabbit: 500mg/24H, mild.
Investigated as a tumorigen, mutagen, reproductive effector.
Reproductive Toxicity:
Has shown teratogenic effects in laboratory animals.

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--------\Cancer Lists\------------------------------------------------------
-

                                        ---NTP Carcinogen---
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  Ingredient                                 Known    Anticipated    IARC
Category

  -----------------------------------    -----    -----------    ------------
-

  Ethylene Glycol (107-21-1)                  No          No             None
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12. Ecological Information

Environmental Fate:
When released into the soil, this material is expected to readily biodegrade. When released into the soil, this material is expected to leach into groundwater. When released into the soil, this material is not expected to evaporate significantly. When released into water, this material is expected to readily biodegrade. When released into the water, this material is expected to have a half-life between 1 and 10 days. This material is not expected to significantly bioaccumulate. This material has a log octanol-water partition coefficient of less than 3.0. When released into water, this material is not expected to evaporate significantly. When released into the air, this material is expected to be readily degraded by reaction with photochemically produced hydroxyl radicals. When released into the air, this material is expected to have a half-life between 1 and 10 days.
Environmental Toxicity:
The LC50/96-hour values for fish are over 100 mg/l.

13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

Not regulated.

15. Regulatory Information

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  --------\Chemical Inventory Status - Part 1\-------------------------------
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  Ingredient                                        TSCA  EC   Japan  Australia

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Ethylene Glycol (107-21-1)	Yes	Yes	Yes	Yes

--------\Chemical Inventory Status - Part 2\---------------------------------

Ingredient	Korea	--Canada-- DSL	NDSL	Phil.
Ethylene Glycol (107-21-1)	Yes	Yes	No	Yes

--------\Federal, State & International Regulations - Part 1\----------------

Ingredient	-SARA 302- RQ	TPQ	------SARA 313------ List	Chemical Catg.
Ethylene Glycol (107-21-1)	No	No	Yes	No

--------\Federal, State & International Regulations - Part 2\----------------

Ingredient	CERCLA	-RCRA- 261.33	-TSCA- 8(d)
Ethylene Glycol (107-21-1)	5000	No	No

Chemical Weapons Convention: No TSCA 12(b): No CDTA: No

SARA 311/312: Acute: Yes Chronic: Yes Fire: No Pressure: No

Reactivity: No (Pure / Liquid)

Australian Hazchem Code: No information found.
Poison Schedule: No information found.
WHMIS:
This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

16. Other Information

NFPA Ratings: Health: **1** Flammability: **1** Reactivity: **0**
Label Hazard Warning:
WARNING! HARMFUL OR FATAL IF SWALLOWED. HARMFUL IF INHALED OR ABSORBED THROUGH SKIN. MAY CAUSE ALLERGIC SKIN REACTION. MAY CAUSE IRRITATION TO SKIN, EYES, AND RESPIRATORY TRACT. AFFECTS CENTRAL NERVOUS SYSTEM.
Label Precautions:
Do not breathe vapor or mist.
Use only with adequate ventilation.
Keep container closed.
Avoid contact with eyes, skin and clothing.
Wash thoroughly after handling.
Label First Aid:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. In case of contact, immediately flush skin or eyes with plenty of water for at least 15 minutes. Call a physician if irritation develops or persists. If swallowed, give water or milk to drink and induce vomiting. Never give anything by mouth to an unconscious person. In all cases call a physician.
Product Use:
Laboratory Reagent.
Revision Information:
MSDS Section(s) changed since last revision of document include: 8.
Disclaimer:
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Prepared by: Strategic Services Division
Phone Number: (314) 539-1600 (U.S.A.)

For the latest Ethylene Glycol MSDS go to www.varian.com

MATERIAL SAFETY DATA SHEET

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT IDENTIFIER:	**Methanol**
PRODUCT SYNONYMS:	Methyl Alcohol, Methyl Hydrate, Wood Alcohol
GENERAL USE:	Methanol has wide industrial use as a solvent and is extensively employed as a paint and varnish remover, as a chemical intermediate, and in the preparation of stains, enamels, plastics, and films. It is used to manufacture formaldehyde and methyl esters of organic and inorganic acids; chemical synthesis; automotive antifreeze; denaturant for ethyl alcohol; dehydrator for natural gas.
PRODUCT DESCRIPTION:	Clear, colorless, flammable, poisonous, mobile, highly polar liquid with slight alcohol odor; miscible with water, alcohol, ether, ketones and most other organic solvents. Burns with a nonluminous, bluish flame.

MANUFACTURER:
Dakota Gasification Company
P. O. Box 1149
Beulah, North Dakota 58523
(701) 873-6677

EMERGENCY TELEPHONE NUMBERS:
Dakota Gasification (701) 873-6600
CHEMTREC (800) 424-9300

2. COMPOSITION / INFORMATION ON INGREDIENTS

INGREDIENTS	WT. %	CAS Registry #
Methanol	98	67-56-1
Water	1.8	7732-18-5

OSHA HAZARDOUS COMPONENTS (29 CFR 1910.1200):EXPOSURE LIMITS 8 hrs. TWA(ppm)

	OSHA PEL	ACGIH TLV
Methanol	200 ppm	200 ppm
Water	Not Established	Not Established

3. HAZARDS IDENTIFICATION / EMERGENCY OVERVIEW

Routes of entry for methanol are primarily absorption through the skin, eye contact, inhalation, or ingestion. Industrial exposures are primarily vapor exposures and skin contact. Initial symptoms from ingestion or inhalation may be only mild intoxication, but may become severe after 12-18 hours. Toxic effects from repeated over exposure to methanol have an accumulative affect the central nervous system, especially the optic nerve. These symptoms may linger for several days after exposure. Methanol can seriously impair vision and may cause blindness.

POTENTIAL HEALTH EFFECTS:

EYE CONTACT: Methanol can seriously impair vision and may cause blindness. Immediate signs and symptoms include the following: vapors are slightly uncomfortable and splashes very irritating; irritation with painful burning or stinging sensation; watering of eyes; inflammation of the eyelids; eyes are sensitive to and painful in the light.

SKIN CONTACT: Direct skin contact with methanol may cause irritation, dermatitis, erythema, and scaling. Methanol is highly volatile and will produce a feeling of cold. Alcohols remove oils form the skin, which becomes dry and eventually develops cracks or dermatitis. Methanol which can be absorbed by the skin, causes headache, fatigue, and reduction of visual acuity.

INHALATION: Sign and symptoms of acute poisoning include the following: slight irritation of the nose and eyes; head feels hot and face is flushed; excitability and talkativeness; drunken behavior; staggering and lack of coordination; headache; mental confusion and visual disturbance; tiredness.

INGESTION: Signs and symptoms of acute poisoning are gastrointestinal irritation; head feels hot and face is flushed; excitability and talkativeness; drunken behavior; staggering and lack of coordination; headache; mental confusion and visual disturbance; tiredness.

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4. FIRST AID MEASURES

EYES: Remove the victim from the source of contamination and take him to the nearest eye wash, shower, or other source of clean water. Gently rinse the affected eye(s) with clean, lukewarm water for at least 15 minutes. Have the victim lie or sit down and tilt his head back. Hold the eyelid(s) open and pour water slowly over the eyeball(s) at the inner corners, letting the water run out of the outer corners. Ask the victim to look up, down and side to side as you rinse in order to better reach all parts of the eye(s). If the victim cannot tolerate light, protect his eye(s) with a clean, loosely tied handkerchief or strip of clean, soft cloth or bandage. Seek medical attention immediately.

SKIN: Remove the victim from the source of contamination. Remove clothing, shoes, socks, and jewelry from the affected areas. Be careful not to get any of the chemical on your skin or clothing. Wash the affected area with tepid water. Dry the skin gently with a clean, soft towel. Seek medical attention immediately.

INHALATION: Remove the victim from the contaminated area while protecting yourself from exposure by wearing an appropriate respirator. Put a similar respirator on the victim. Remove contaminated clothing and equipment, while wearing gloves, being careful not to contaminate yourself. Administer CPR if necessary. Seek medical attention immediately.

INGESTION: Remove the victim from the contaminated area to a quiet, well ventilated area. Call a poison control center, inform them of the chemical swallowed and follow their advice. Seek medical attention immediately.

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5. FIRE FIGHTING MEASURES

FLASH POINT:	54°F (Tagliabue / Tag Closed Tester)
AUTO-IGNITION TEMPERATURE:	725°F
FIRE AND EXPLOSION HAZARDS:	Methanol burns with a clean, clear flame, being almost invisible in daylight.
UPPER EXPLOSIVE / FIRE LIMITS:	36.50%
LOWER EXPLOSIVE / FIRE LIMITS:	6.72%
EXTINGUISHING MEDIA:	Use dry chemical alcohol foam, or carbon dioxide; water spray may be ineffective as an extinguishing agent, but water should be used to keep fire-exposed containers cool.
SPECIAL FIRE FIGHTING PROCEDURES:	Vapors are slightly heavier than air and may flow along surfaces to ignition sources. Water may be ineffective in "in-depth methanol fires". Fire fighters should use self-contained breathing apparatus and protective clothing.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES:	Eliminate all ignition sources. Stop spill source. If spill is small use absorbent material to soak up spill. Dike large spill areas. Recover large spills by recovering the methanol or by diluting with water to reduce the fire hazard. Salvage the liquid by using a recommended absorbent material. Prevent methanol from entering sewers, drains, or waterways. Always notify proper authorities of spills.
WASTE DISPOSAL METHOD:	Dispose of material in accordance with your local, state, federal or other applicable regulations.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE:	Keep cool.
SHELF LIFE:	Unknown.
SPECIAL SENSITIVITY:	Methanol is a flammable substance.
HANDLING / STORAGE PRECAUTIONS:	Store containers in well-ventilated place. Large volume storage should be remote from inhabited buildings or structures. Keep away from all sources of ignition. Wear chemical goggles or face shield, supplied-air or self contained breathing apparatus, rubber gloves, aprons and boots.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

RECOMMENDED WORK / HYGIENE PROCEDURES:	Adequate ventilation. Wear chemical goggles or face shield, supplied-air or self contained breathing apparatus, rubber gloves, aprons and boots.
EYE PROTECTION REQUIREMENTS:	Chemical safety goggles or face shields should be worn.
HAND PROTECTION REQUIREMENTS:	Natural rubber gloves.
PROTECTIVE CLOTHING REQUIREMENTS:	Appropriate protective clothing, including gloves, aprons, suits, boots, and face shields that are impervious to methyl alcohol should be worn to prevent repeated or prolonged skin contact.
RESPIRATORY REQUIREMENTS:	Supplied-air or self contained breathing apparatus operated in the positive pressure mode.
WASH REQUIREMENTS:	Soap and water should be available to clean contaminated skin. Wash thoroughly prior to consuming food or beverage, smoking, or using restroom facilities.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE:	Clear, colorless liquid.
ODOR:	Alcohol odor.
PHYSICAL STATE:	Liquid.
VAPOR PRESSURE:	(at 20°C) 96 mmHg
VAPOR DENSITY:	(air = 1) 1.11
MELTING POINT:	-97.6°C
BOILING POINT:	(at 760 mmHg) 64.5°C
SPECIFIC GRAVITY:	(water = 1) 0.7915 at 68°F
EVAPORATION RATE:	(Butyl Acetate = 1) 4.6
PERCENT VOLATILES:	100% (by volume)
BULK DENSITY:	6.63 lbs. per gallon
SOLUBILITY IN WATER:	Miscible.
SOLVENT SOLUBILITY:	Solubility in alcohols, ketones, esters, and halogenated hydrocarbons - Miscible.
MOLECULAR WEIGHT:	32.04
CHEMICAL FORMULA:	CH_3OH
CHEMICAL FAMILY:	Alcohols

10. STABILITY AND REACTIVITY

INSTABILITY CONDITIONS:	Stable.
INCOMPATIBILITIES:	Beryllium hydride: Intense reaction at 200°C Bromine: Intense exothermic reaction Calcium carbide: Violent reaction Chloroform and sodium hydroxide: Explosive reaction Chromic anhydride: Possible explosion Cyanuric chloride: Uncontrollable violent reaction Magnesium: Violent reaction Nickel: Possible ignition in the presence of nickel catalyst
DECOMPOSITION:	Formaldehyde and carbon monoxide.
HAZARDOUS POLYMERIZATION:	Will not occur.

11. TOXICOLOGICAL INFORMATION

ROUTES OF ENTRY:	A human poison by ingestion. Poison experimentally by skin contact. Moderately toxic experimentally by intravenous and intraperitoneal routes. Mildlly toxic by inhalation.
EFFECTS OF ACUTE EXPOSURE:	The main toxic effect is exerted upon the nervous system, particularly the optic nerves and possible the retina which can progress to permanent blindness. Once absorbed, methanol is only very slowly eliminated. Coma resulting from massive exposures may last as long as 2-4 days. In the body, the products formed by its oxidation are formaldehyde and formic acid, both of which are toxic. Because of the slow elimination, methanol should be regarded as a cumulative poison. Though single exposures to vapors may cause no harmful effect, daily exposure may result in the accumulation of sufficient methanol in the body to cause illness.
SYMPTOMS:	Gastrointestinal irritation; slight irritation of nose and eyes; head feels hot and face is flushed; excitability and talkativeness; drunken behavior; staggering and lack of coordination; headache; mental confusion and visual disturbance; tiredness.
EYE EFFECTS:	Methanol can seriously impair vision. It may cause blurred vision, constricted visual fields, blindness, changes in color perception, double vision, and general visual disturbances. Eye examinations have shown sluggish pupils, pallid optic discs, retinal edema, papilledema, hyperemia to the optic discs with blurred edges and dilated veins. 1200 ppm to 8300 ppm: visual disturbances, dilated unreactive pupils and dim vision.
SKIN EFFECTS:	Skin exposure may cause irritation and dermatitis. Poison experimentally by skin contact. Skin - rabbit: LD_{50}: 15,800 mg/kg
ACUTE ORAL EFFECTS:	Ingestion of methanol may cause acidosis, headache, visual disturbances, dizziness, nausea and vomiting, severe upper abdominal pain, dilated nonreactive pupils and death. Death from 2 to 8 ounces has been reported.
ACUTE INHALATION EFFECTS:	May cause headache, dizziness, nausea, vomiting, weakness, vertigo, chills shooting pains in the lower extremities, unsteady gait, numbness, prickling, shooting pain in the back of the hands and forearms, nervousness, gastric pain, insomnia, acidosis, and formic acid in the urine. Inhalation - human: TCL_0 = 86,000 mg/m^3 (lowest published toxic concentration). Concentrations of 200-375 ppm may cause severe, recurrent headaches. IDLH - 25,000 ppm.
CHRONIC EFFECTS / CARCINOGENICITY:	This agent is not considered a carcinogen by NTP, IARC or OSHA. Effects from repeated over-exposure to methanol are considered to be harmful . Because of the slow elimination, methanol should be regarded as a cumulative poison. Though single exposures to fumes may cause no harmful effect, daily exposure may result in the accumulation of sufficient methanol in the body to cause illness.
MUTAGENICITY:	Reproductive effects: an experimental teratogen in rats exposed to 20,000 ppm. Reported to cause birth defects.
ORGANS AFFECTED BY LONG-TERM EXPOSURE:	Repeated exposure to methanol vapor may be manifested by conjunctivitis, headache, giddiness, insomnia, gastric disturbances, and bilateral blindness.

12. ECOLOGICAL INFORMATION

Aquatic Toxicity Rating: Tlm 96: Over 1000 ppm

Toxicity threshold (cell multiplication inhibition test):

Trout: Tlm (48 hr) 8,000 mg/l

Bacteria (*Pseudomonas*) LD_0: 0.6 g/l
Algae (*Chlorella pyrenoidosa*) toxic: 31,100 mg/l

Low concentrations are biodegradable; therefore, long-term ecological effects are not anticipated.

13. DISPOSAL CONSIDERATIONS

Recycling/reuse of all methanol residuals is recommended. Discarded or spill cleanup material may be considered hazardous waste as defined under RCRA 40 CFR 261 (Methanol F003, U154).

Please be advised that state and local requirements for waste disposal may be more restrictive or otherwise different from federal regulations. Consult state and local regulations regarding the proper disposal of the material.

14. TRANSPORTATION INFORMATION

D.O.T. SHIPPING NAME:	Alcohol, N.O.S. (Contains Methanol)
D.O.T. HAZARD CLASS:	Flammable Liquid, 3
U.N. NUMBER:	1987
D.O.T. PLACARD:	Flammable Liquid
D.O.T. LABEL CODE:	Flammable Liquid
PACKAGING CLASSIFICATION:	Packing Group 2
D.O.T. REPORTABLE QUANTITY:	5000 lbs

15. REGULATORY REQUIREMENTS

EPA DETERMINATIONS

CERCLA, 40 CFR 302
The material contains the following hazardous substance which, when released in quantities equal to or exceeding the Reportable Quantity, triggers National Response Center notification requirements.

Hazardous Substance	Reportable Quantity
Methanol	5000 lbs.

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986,
TITLE III - SECTIONS 302, 304, 311, 312, 313

SECTION 302 / 304 - Extremely Hazardous Substances (40 CFR 355)
The material does not contain extremely hazardous substances at greater than 1.0 % concentration; however, it is possible that this material may contain extremely hazardous substances at a lower concentration so that a large enough spill could warrant an Emergency Release under section 304.

SECTION 311/312 - MSDS and Chemical Inventory Reporting Requirements (40 CFR 370)
The material should be reported under the following EPA Hazard categories.

- ✔ Immediate (Acute Health Hazard)
- ✔ Delayed (Chronic Health Hazard)
- ✔ Fire
- Sudden Release of Pressure
- Reactive
- Not Applicable

SECTION 313 - List of Toxic Chemicals (40 CFR 372)
The material contains the following chemical(s) at a level of 1.0% or greater (0.1% for carcinogens) on the list of toxic Chemicals and is subject to toxic chemical release reporting requirements.

Toxic Chemical:	Methanol
CAS Registry Number:	67-56-1
Approximate Concentration (Upper Bound):	98 wt %

TOXIC SUBSTANCES CONTROL ACT (TSCA) (40 CFR 710)
The chemical ingredients in this material are in the Section 8(b) Chemical Substance Inventory (40 CFR 710) and / or are otherwise in compliance with TSCA. In the case of ingredients obtained from other manufacturers, Dakota Gasification Company relies on the assurance of responsible third parties in providing this statement.

For the latest Methanol MSDS go to www.dakotagas.com

MATERIAL SAFETY DATA SHEET

ETHYL ALCOHOL USP - 190 PROOF

AAPER MSDS NUMBER: E190 — EFFECTIVE DATE: JUNE 1, 2001

AAPER Alcohol and Chemical Company
1101 Isaac Shelby Drive, P. O. Box 339
Shelbyville, Kentucky 40066-0339
Telephone: (502) 633-0650

For chemical emergency – spill, leak, fire, exposure, or accident, call CHEMTREC at 1-800-424-9300 day or night. Outside the continental United States, call CHEMTREC at 1-703-527-3887 (collect calls accepted).

AAPER Alcohol and Chemical Company urges the customer receiving this Material Safety Data Sheet (MSDS) to study it carefully to become aware of hazards, if any, of the product involved. In the interest of safety, you should: (1) notify your employees, agents, and contractors of the information on this sheet, and (2) furnish a copy to each of your customers to inform their employees and customers as well.

SECTION I – IDENTIFICATION

PRODUCT NAME:	Alcohol USP, Ethyl Alcohol, 190 proof
SYNONYMS:	Ethyl Alcohol - 190 proof, Ethanol
CHEMICAL FAMILY:	Alcohol
MOLECULAR WEIGHT:	46.07
FORMULA:	C_2H_5OH

Section II – INGREDIENTS

COMPOSITION	CAS RN.	NOMINAL WT/WT%	PEL/TLV	HAZARD
Ethyl Alcohol	64-17-5	92.42	1000 ppm	Flammable/Nervous System Depressant
Water	7732-18-5	7.58		

SECTION III – HEALTH INFORMATION

INHALATION:	Exposure to over 1000 ppm may cause headache, drowsiness and lassitude, loss of appetite, and inability to concentrate. Irritation of the throat.
INGESTION:	Can cause depression of central nervous system, nausea, vomiting, and diarrhea.
EYE CONTACT:	Liquid or vapor may cause irritation.
SKIN CONTACT:	May cause irritation and defatting of skin on prolonged contact.

SECTION IV – OCCUPATIONAL EXPOSURE LIMITS

PEL (OSHA Permissible Exposure Limit):	Mixture – See Section II
TLV (ACGIH Threshold Limit Value):	Mixture – See Section II

SECTION V – EMERGENCY FIRST AID PROCEDURE

FOR OVEREXPOSURE BY:

SWALLOWING: If victim is conscious and able to swallow, have victim drink water or milk to dilute. Never give anything by mouth if victim is unconscious or having convulsions. CALL A PHYSICIAN OR CHEMTREC (POISON CONTROL) IMMEDIATELY. Induce vomiting only if advised by physician or Chemtrec (Poison Control).

INHALATION: Immediately remove victim to fresh air. If victim has stopped breathing, give artificial respiration, preferably mouth-to-mouth. GET MEDICAL ATTENTION IMMEDIATELY.

CONTACT WITH EYES OR SKIN: Immediately flush affected area with plenty of cool water. Eyes should be flushed for at least 15 minutes. Remove and wash contaminated clothing before reuse. GET MEDICAL ATTENTION IMMEDIATELY.

SECTION VI – PHYSICAL DATA

BOILING POINT:	173° F
MELTING POINT:	-173° F
VAPOR PRESSURE:	44.6 mm Hg @ 68° F
SPECIFIC GRAVITY:	0.8158 @ 60°/60° F
VAPOR DENSITY (AIR = 1):	1.59*
SOLUBILITY IN WATER:	Complete
APPEARANCE AND COLOR:	Clear and colorless

SECTION VII – FIRE AND EXPLOSIVE HAZARDS

FLASH POINT:	**60° F ASTM D-56 (Tag Closed Cup)**		
AUTO-IGNITION TEMPERATURE:	685° F		
FLAMMABLE LIMITS IN AIR, % BY VOLUME:	LOWER: 3.3	UPPER: 19	
NFPA (National Fire Protection Association) RATING:	HEALTH (0)	FIRE (3)	REACTIVITY (0)

(Does not apply to exposure hazards other than during a fire.)

*For pure ethyl alcohol

FIRE FIGHTING PROCEDURES:	(Note: Individuals should perform only those fire-fighting procedures for which they have been trained.) Use dry chemical, "alcohol" foam, or carbon dioxide; water may be ineffective, but water should be used to keep fire-exposed containers cool. If a leak or spill has not ignited, use water spray to disperse the vapors and to protect men attempting to stop a leak. Water spray may be used to flush spills away from exposures and to dilute spills to nonflammable mixtures.
UNUSUAL FIRE & EXPLOSION HAZARDS:	Firefighters should wear self-contained breathing apparatuses in the positive pressure mode with a full face piece when there is a possibility of exposure to smoke, fumes, or hazardous decomposition products.

SECTION VIII – REACTIVITY

STABILITY:	Generally stable.
HAZARDOUS POLYMERIZATION:	Not likely.
CONDITIONS & MATERIALS TO AVOID:	Contact with acetyl chloride and a wide range of oxidizing agents may react violently.

SECTION IX – EMPLOYEE PROTECTION

CONTROL MEASURES:	Handle in the presence of adequate ventilation.
RESPIRATORY PROTECTION:	Where exposure is likely to exceed acceptable criteria, use NIOSH/MSHA approved respiratory protection equipment. Respirators should be selected based on the form and concentration of contaminant in air and in accordance with OSHA (29 CFR 1910.134).
PROTECTIVE CLOTHING:	Wear gloves and protective clothing which are impervious to the product for the duration of the anticipated exposure if there is potential for prolonged or repeated skin contact.
EYE PROTECTION:	Wear safety glasses meeting the specifications of ANSI Standard Z87.1 where no contact with the eye is anticipated. Chemical safety goggles meeting the specifications of ANSI Standard Z87.1 should be worn whenever there is the possibility of splashing or other contact with the eyes.

SECTION X – ENVIRONMENTAL PROTECTION

ENVIRONMENTAL PRECAUTIONS:	Avoid uncontrolled releases of this material. Where spills are possible, a comprehensive spill response plan should be developed and implemented.
SPILL OR LEAK PROCEDURES:	Wear appropriate respiratory protection and protective clothing as described in Section IX. Contain spilled material. Transfer to secure containers. Where necessary, collect using absorbent media. In the event of an uncontrolled release of this material, the user should determine if the release is reportable under applicable laws and regulations.
WASTE DISPOSAL:	All recovered material should be packaged, labeled, transported, and disposed of, or reclaimed in conformance with applicable laws and regulations and in conformance with good engineering practices.

SECTION XI – REGULATORY CONTROLS

DEPARTMENT OF TRANSPORTATION (DOT):	
DOT CLASSIFICATION:	3 (Flammable Liquid)
DOT PROPER SHIPPING NAME:	Ethyl Alcohol
OTHER DOT INFORMATION:	Identification No. UN1170 P.G. II Emergency Response Guide No. 127
ATF DISTILLED SPIRITS ACT:	Use of ethyl alcohol without prior payment of applicable excise tax is strictly controlled by regulation promulgated and enforced by the Bureau of Alcohol, Tobacco, and Firearms (ATF), Department of the Treasury. Governing regulations have been defined in Title 27, Code of Federal Regulations.
TOXIC SUBSTANCE CONTROL ACT (TSCA):	This product is listed in the TSCA Inventory of Chemical Substances.

SECTION XII – PRECAUTIONS: HANDLING, STORAGE, AND USAGE

Protect container against physical damage. Detached or outside storage is preferred. Inside storage should be in an NFPA approved flammable liquid storage room or cabinet. All ignition sources should be eliminated. Smoking should be prohibited in the storage and usage areas. Electrical installations should be in accordance with Article 501 of the National Electrical Code. NFPA 30, Flammable and Combustible Liquids Code, should be followed for all storage and handling. Frequent careful leakage inspections should be done. An automatic sprinkler system should be provided. Isolate from oxidizers, chemicals capable of spontaneous heating, materials reacting with air or moisture to liberate heat, ignition sources and explosives. Consult local fire codes for additional storage information.

When contents are being transferred, the metallic container must be bonded to the receiving container and grounded to avoid static discharges. Never use pressure to empty. Replace closure securely after each opening.

Keep material packaged in drums or bottles out of sun and away from heat. Remove closure carefully; internal pressure may be present. Keep closure on to prevent leakage.

Container hazardous when empty. Since emptied containers retain residual product (vapor and liquid), all precautions described on this MSDS must be observed.

CAUTION: For manufacturing, processing, repackaging, or industrial use.

The information contained herein is furnished without warranty of any kind. Employers should use this information only as a supplement to other information gathered by them and must conduct testing and/or make independent determinations of suitability and completeness of information from all sources to assure proper use of these materials and the safety and health of employees.

AAPER ALCOHOL AND CHEMICAL COMPANY — Ethyl Alcohol USP - 190 proof
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