Town of Chebeague Island  
192 North Road  
Chebeague Island, ME  04017  
Phone: 207-846-3148  
Fax-207-846-6413  
www.townofchebeagueisland.org  

Homework!  
From 11/13/18 meeting

1. Bob:  
   a. Contact MMA regarding the legality, precedents, etc of requiring the following at point of sale of a property:  
      i. Fuel tank inspection  
      ii. Septic pumping and inspection  
   b. Also, discuss the potential of building code requirements regarding fuel oil tanks, such as double wall, sheathed tubing on / in concrete, etc.  
   c. Contact Ester: could the fuel assistance fund serve as a confidential collector of folks who would like a state visit to look at their fuel tank relative to possible subsidized replacement?  
   d. Writeup for Calendar: summary of the upcoming info / PR approach to aquifer protection; plus Bev site, FB B/S/B page

2. Nancy:  
   a. Check with school re: how to work with CIS/kids/curriculum to get info out there re: fuel tank issues  
   b. PR stuff to bulletin boards

3. Danny: mockup designs for bumper sticker

4. Public comment?

5. Adjourn

The public is welcome and encouraged to attend!
ANTI-FREEZE FLUID ENVIRONMENTAL AND HEALTH EVALUATION - AN UPDATE

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ABSTRACT

At Stockton College’s Geothermal Heat Pump Conference in August 1995, The University of New Mexico presented preliminary environmental and health data on fluids in use or proposed as anti-freeze solutions for ground-source heat pumps (GSHP). Since that time, we have completed work on a research project “Assessment of Anti-Freeze Solutions for Ground-Source Heat Pump Systems.” This paper presents final results from the project. It assesses the risks of using six different anti-freeze fluids (methanol, ethanol, aqueous potassium acetate, propylene glycol, aqueous calcium magnesium acetate, and aqueous urea). In addition to the environmental and health areas, fire, corrosion and leakage, life cycle cost, and potential regulatory controls were also assessed. For each area, the anti-freezes were rated as having either significant potential for problems, minor potential for problems, or little or no potential for problems. A final assessment of each anti-freeze solution is presented.

1. INTRODUCTION

At Stockton College’s Geothermal Heat Pump Conference (August, 1995), we presented environmental and health data on fluids in use or proposed as anti-freezes for ground-source heat pumps. At that time, we were just beginning work on an American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE) research project entitled the “Assessment of Anti-Freeze Solutions for Ground-Source Heat Pump Systems.” During the past 2-1/2 years, the project has been completed, and results were reported to the ASHRAE annual meeting in Boston in June 1997 (Heinonen 1997). In addition, a summary has been included on
An important environmental aspect of ground-source (ground-coupled) heat pump systems is the anti-freeze fluids required in closed loop systems for freeze protection in many applications. GSHPs use a refrigerant-to-liquid heat exchanger and a heat transfer fluid to exchange heat with the earth by means of a heat exchanger that is buried in the ground, either vertically in boreholes drilled up to a few hundred feet deep or horizontally in trenches. While the heat transfer fluid may be water in warm climates, anti-freeze solutions are required in colder climates to prevent freezing of the fluid during the heating season. Because the earth is used as a heat source/sink, a risk of leakage or spillage into soil, surface water, or groundwater, including aquifers, exists. Some anti-freezes are potentially toxic to humans and animals, while others are flammable, so that their use could pose a risk of fire or explosion, especially during installation when the fluids may be present in concentrated form. Because GSHPs are designed for many years of service, corrosion of piping and equipment could also pose a problem.

The research project assessed the fire, corrosion, health, environmental, and performance risks, and cost impacts of using six anti-freeze fluids. Four aqueous fluids are currently used—ethanol, methanol, potassium acetate and propylene glycol—while two—aqueous urea and aqueous calcium magnesium acetate (CMA)—have been proposed for possible use. While the focus of our previous presentation was strictly on environmental and toxicological impacts of the anti-freeze fluids, the results of the entire study are presented in this paper as the selection of proper anti-freeze fluids should be made with full cognizance of all impacts on the system.

2. DESCRIPTION OF THE INVESTIGATION

Six major aspects of the installation and use of anti-freezes were investigated. The assessment of potential impacts and risks in these areas involved the following steps:

2.1 Fire Hazard

The risk of fire and explosion of both the pure and dilute anti-freezes was assessed. First, standards and codes governing the use of flammable and combustible liquids were assessed for applicability to GSHP uses. Flash points were then determined for each pure anti-freeze fluid and for fluids at concentrations corresponding to three different freeze protection temperatures. Finally, attempts were made to ignite dilute fluids at room and elevated temperatures.

2.2 Corrosion and Leakage

Tests were performed to (1) assess the corrosion of metal parts both inside and outside the system and (2) determine whether components, such as joints, unions and valves, and elastomers would leak when used in a GSHP system. Stainless steel, black and cast irons, lead solder, copper, red and yellow brass, bronze, and galvanized coupons were tested in immersion and

* http://www.geoexchange.org/dsgntool/anti-freeze.htm
spray environments, and aluminum only in spray tests. Coupons of each metal were prepared and cleaned, and rates of corrosion were measured for immersion in fluids (to simulate corrosion inside the pipes) and in a spray apparatus (to simulate corrosion outside the system.)

To evaluate potential leakage, a loop consisting of components similar to those contained in a GSHP system was constructed, using brass and iron fittings, rubber and polyethylene hoses, and several types of sealants and elastomers. Each of the six anti-freezes was circulated through this loop for 7 days at 6.7°C (20°F) followed by 7 days at 43.3°C (110°F) to evaluate whether leakage would occur at the operational temperature limits.

2.3 Health Hazard

An assessment of the risk to humans as a result of the installation and use of the anti-freeze solutions was performed. First, five leakage and spillage scenarios associated with GSHP installation and use were developed to establish the amounts of fluid that could potentially be released by each scenario, and to determine potential routes of entry. Secondly, human responses caused by the anti-freezes for different routes of entry (including inhalation, ingestion, intravenous, and skin contact) were investigated. From these data, a median toxic dose was determined for a 70-kg (150-lb) human for intravenous and skin contact routes of exposure.

Occupational exposure limits and other guidelines imposed or recommended by the Environmental Protection Agency and industrial organizations to protect workers were identified and values determined. Health data were extracted from material safety data sheets (MSDS). Confirmed and experimental chronic effects (carcinogenicity, mutagenicity, reproductive effects, and teratogenicity) were identified, to the extent available, for each anti-freeze.

2.3 Environmental Assessment

Two major areas of environmental risk were evaluated. Electric power plant emissions of CO₂, SO₂, NOₓ, and mercury attributable to operation of GSHPs with each of the six anti-freeze solutions were estimated through the year 2015, using projections of power plant emissions along with projected numbers of installations. The emission estimates were obtained by multiplying annual energy use of the heat pump system for each of the anti-freeze solutions by the projected number of installed units and an emission factor per unit of energy used.

Secondly, the volume of ground and surface water that could be polluted as a result of spillage or leakage was quantified. The leakage and spillage scenarios developed in the health hazard task were combined with fish toxicity and proposed permissible limits for the anti-freezes to establish a volume of water that could potentially be contaminated. The Biochemical Oxygen Demand (BOD) was determined for each fluid to assess the capability to deplete oxygen and cause fish kills. Lastly, federal and state environmental regulations were investigated to determine those anti-freezes regulated by law (See Den Braven 1998).
2.4 Energy and Cost Analysis

A residential GSHP installation in a northern climate (Madison, Wisconsin) was modeled for the six anti-freeze solutions to estimate relative annual energy use, life cycle cost, and electric power plant emissions associated with operation of GSHP systems. A ground heat exchanger with vertical bore hole was modeled (Figure 1) and the thermal conductivity of the soil and the length and diameter of the ground loop pipe were varied, resulting in 10 separate scenarios for each fluid. The heat pump system includes a buried heat exchanger comprised of a header and three ground loops, each containing high density polyethylene pipe inserted into 12.7-cm (5-inch) diameter vertical bore holes. A dynamic system modeling software (Klein et al. 1979) was employed, which accounts for transient temperatures in the soil surrounding the ground loops, transient indoor and outdoor air temperatures, the temperature dependent properties of the ground loop fluid, and heat pump controls. Results were then used to determine energy use and resulting usage costs. The initial cost of the anti-freeze and other components was considered along with energy costs in determining life cycle costs.

Figure 1. Ground-Source Heat Pump System Schematic.

3. DISCUSSION

3.1 Risk Analysis

A risk of usage of each of the anti-freezes was determined, on a scale of 1, 2, or 3, for each area investigated. A risk level of 1 indicates potential problems, and caution in use is required; a risk
level of 2 indicates that there is minor potential for problems; and a risk level of 3 indicates that there is little or no potential for problems. A table summarizing risk for each of the areas is included for each factor (Tables 1-7), and a composite risk table (Table 8) summarizes all risks and includes a short narrative of the level 1 and 2 risks determined by the analyses.

**Fire risk (Table 1).** Methanol and ethanol present a serious fire risk if the pure fluids are added to the system in enclosed spaces. Testing indicated that dilute fluids in the concentrations required to provide freeze-protection could not be ignited by a flame even at 60°C (140°F), resulting in acceptable risk if dilute solutions only are added. Propylene glycol, which is flammable at a high temperature, is considered to have a low risk. Potassium acetate, CMA, and urea do not have a fire risk.

<table>
<thead>
<tr>
<th></th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene glycol</th>
<th>Potassium acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composite</strong></td>
<td>1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

<sup>a</sup>Pure fluids only. Diluted anti-freeze is rated 3.

**Corrosion risk (Table 2).** High corrosion rates (over 2.5 mils per year [mpy]) were observed in immersion for methanol with black and cast iron; potassium acetate with cast iron; ethanol with cast iron; urea with copper-based metals such as brass and bronze; and all anti-freezes with galvanized. (The immersion corrosion rate determined the risk). High corrosion rates were observed for the spray tests with methanol on black and cast iron; potassium acetate on cast iron; ethanol on yellow brass, bronze, cast and black iron; CMA on solder, black and cast iron; and urea on solder, black and cast iron, and copper-based metals.
Table 2. Corrosion Rates, Immersion Tests.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel</td>
<td>VL</td>
<td>VL</td>
<td>VL</td>
<td>VL</td>
<td>VL</td>
<td>VL</td>
</tr>
<tr>
<td>Solder</td>
<td>VL</td>
<td>L</td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>VL</td>
</tr>
<tr>
<td>Black Iron</td>
<td>H</td>
<td>M</td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>Copper</td>
<td>L</td>
<td>L</td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Red Brass</td>
<td>L</td>
<td>L</td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Yellow Brass</td>
<td>L</td>
<td>L</td>
<td>VL</td>
<td>L</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Bronze</td>
<td>L</td>
<td>M</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>H</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Galvanized</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Composite</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

VL = less than 0.1 mpy; L = over 0.1 but less than 1.0 mpy; M = between 1.0 and 2.5 mpy; and H = over 2.5 mpy corrosion rate.

Not used to determine composite number.

Leakage risk (Table 3): Methanol experienced no leaks. Ethanol and propylene glycol experienced minor leakage. Ethanol leaked from the top of a plastic valve during the cold cycle: non-critical leakage of propylene glycol occurred during the heating cycle. Moderate (although unacceptable) leakage of potassium acetate was observed at two threaded joints where pipe sealing compounds were used. CMA experienced leakage from three joints with one type of sealing compound and at a union. Urea experienced major leakage at tube joints and hose ends and minor leakage at joints with several different sealing compounds.

Table 3. Leakage Hazard Index.

<table>
<thead>
<tr>
<th>Material</th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Health hazard risk (Table 4). None of the anti-freezes is assessed to be dangerous if properly handled, and each can safely be used in a GSHP. Three areas were assessed: inhalation, ingestion, and chronic effects. Inhalation, which is unavoidable in confined spaces, was considered to be the major route of exposure. Continued high-level methanol exposure can lead to headaches, nausea, blindness and even death. Proper protective equipment is required. None of the other anti-freezes is considered as dangerous, although proper protective equipment is recommended. Ingestion requires intentionally drinking the fluid, which is highly unlikely. Even the methanol, the most toxic anti-freeze, would require a 70-kg (150-lb) installer to ingest 0.4 kg (almost 0.9 lbs) to achieve a 50 percent fatality rate (based on LD_{50} data, although lower doses
could result in blindness and other symptoms. For chronic effects, including carcinogenic, mutagenetic, and teratogenic potential, methanol was assessed to have high inhalation and ingestion risk, while ethanol has been confirmed to be a human carcinogen when taken orally. None of the other anti-freezes was assessed to have significant health risk when properly used.

Table 4. Health Hazard Index.

<table>
<thead>
<tr>
<th></th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingestion</td>
<td>H</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Inhalation</td>
<td>H</td>
<td>M</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Chronic Effects</td>
<td>L</td>
<td>M</td>
<td>L</td>
<td>M</td>
<td>a</td>
<td>M</td>
</tr>
<tr>
<td>Composite</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*aNo data available.

Environmental risk (Table 5). Air pollution resulting from the generation of electricity to run GSHPs did not vary significantly among the fluids. The small differences between the results for the fluids are consistent with the small differences in energy use discussed later.

Potassium acetate and CMA apparently have the highest risk for polluting water. However, this risk is based on results that may overstate the potential risk, and these two fluids should not be assumed to cause significantly greater water pollution than the other fluids. Methanol and ethanol have moderate risk of polluting water, with propylene glycol and urea having little risk. Methanol and ethanol were assumed to have a considerably higher risk than

Table 5. Environmental Hazard Index.

<table>
<thead>
<tr>
<th></th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Pollution</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Water Pollution</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Composite</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

the other anti-freezes for pollution based on proposed permissible limits. However, since similar limits have not been proposed for the other anti-freezes, the fish toxicity values referenced above, which were available for all anti-freezes, were used to determine the risk of water pollution.

Energy use and life cycle cost assessment (Table 6). To aid in assessing the effects of system parameters, results were obtained for the ten cases defined above. Consistent with intuition, energy use declined with increasing soil thermal conductivity. Surrounding the vertical ground loops with low thermal conductivity, thermally unenhanced grout, tends to reduce the effects of the soil thermal conductivity. The effect of increasing bore hole depth as well as ground loop
Pipe length is to reduce energy use by each of the energy-consuming components and therefore by the heat pump system. There is only a slight decrease in system energy use due to the use of larger pipe in the ground loops. The economic results reveal that the decrease in energy cost is not sufficient to offset the corresponding increased cost of larger pipe. An important feature of these results is that there are only small differences between energy use for the various cases. Figure 2 illustrates life cycle costs for the base case scenario (note truncated vertical scale).

Table 6. Life Cycle Cost Index.

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle Cost</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Risk of Future Use Index (Table 7). Current and proposed regulations were assessed to determine whether any of these anti-freezes could conceivably be banned at some time in the future. Because of its toxicity, the use of methanol is currently, or may in the future be, limited in many areas. Potassium acetate, because of its leakage problems, may face future regulation, although it is currently approved for use in many states. Ethanol is not explicitly approved in some locations, although it meets the criteria of non-toxicity and its use is widespread. Propylene glycol is approved in nearly all states. While urea and CMA have not been submitted for approval as GSHP anti-freeze solutions, they are used for other applications (urea as fertilizer and CMA as a road de-icer), and it is believed that usage would be allowed.

Figure 2. Comparison of Life Cycle Costs for Typical Installation Scenario.
Table 7. Risk of Future Use Index.

<table>
<thead>
<tr>
<th></th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

3.2 Regulations and approvals

A separate issue, not connected with any specific task, concerns the confusing array of regulations governing the installation of GSHP systems. A perception survey of manufacturers, users, installers, and others, conducted as part of this project, indicated that most members of the community believe that GSHP units are designed and manufactured to be installed safely for a trouble-free lifetime. However, state and local regulations governing the installation process are often confusing and regulators often do not understand the health, environmental, and fire risk differences among the anti-freezes. This situation could preclude the use of the most efficient and safe anti-freezes in GSHP applications.

4. CONCLUSION

Table 8 summarizes the results of the project for each of seven categories. Three stars indicate little or no potential for problems, two stars indicate a minor potential for problems, and one star indicates a major potential for problems. One or two star ratings are footnoted with the potential problem area described. Note that in several instances, the ratings would change with conditions. For example, while the fire risk for methanol and ethanol is denoted one star for the pure fluid, there is little risk for the dilute solution in the appropriate concentration.
Table 8. Composite Results.

<table>
<thead>
<tr>
<th>Category</th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle Cost</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Corrosion</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Leaks</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Health Hazard Risk</td>
<td>⬤10,11</td>
<td>⬤10,12</td>
<td>⬤10</td>
<td>⬤10</td>
<td>⬤10</td>
<td>⬤10</td>
</tr>
<tr>
<td>Fire Risk</td>
<td>⬤13</td>
<td>⬤13</td>
<td>⬤14</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Environmental Risk</td>
<td>⬤15</td>
<td>⬤15</td>
<td>⬤</td>
<td>⬤15</td>
<td>⬤15</td>
<td>⬤</td>
</tr>
<tr>
<td>Risk of Future Use</td>
<td>⬤16</td>
<td>⬤17</td>
<td>⬤</td>
<td>⬤18</td>
<td>⬤19</td>
<td>⬤19</td>
</tr>
</tbody>
</table>

Key:
- ⬤ Potential problems, caution in use required
- ⬤⬤ Minor potential for problems
- ⬤⬤⬤ Little or no potential for problems

**CATEGORY NOTES**

<table>
<thead>
<tr>
<th>Category</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. High black iron and cast iron corrosion rates.</td>
</tr>
<tr>
<td></td>
<td>3. High black iron and cast iron, copper and copper alloy corrosion rates.</td>
</tr>
<tr>
<td></td>
<td>4. Medium black iron, copper and copper alloy corrosion rates.</td>
</tr>
<tr>
<td></td>
<td>5. Medium black iron, high cast iron, and extremely high copper and copper alloy corrosion rates.</td>
</tr>
<tr>
<td>Corrosion</td>
<td>6. Minor leakage observed.</td>
</tr>
<tr>
<td></td>
<td>7. Moderate leakage observed. Extensive leakage reported in installed systems.</td>
</tr>
<tr>
<td></td>
<td>8. Moderate leakage observed.</td>
</tr>
<tr>
<td></td>
<td>9. Massive leakage observed.</td>
</tr>
<tr>
<td>Leaks</td>
<td>10. Protective measures required with use (See MSDS).</td>
</tr>
<tr>
<td></td>
<td>11. Prolonged exposure can cause headaches, nausea, vomiting, dizziness, blindness, liver damage, and death. Use of proper equipment and procedures reduces risk significantly.</td>
</tr>
<tr>
<td>Health Hazard Risk</td>
<td>13. Pure fluid only. Little risk when diluted with water in anti-freeze.</td>
</tr>
<tr>
<td></td>
<td>14. Very minor potential for pure fluid fire at elevated temperatures.</td>
</tr>
<tr>
<td>Fire Risk</td>
<td>15. Water pollution risk.</td>
</tr>
<tr>
<td>Environmental Risk</td>
<td>16. Toxicity and fire concerns. Prohibited in some locations.</td>
</tr>
<tr>
<td></td>
<td>17. Toxicity, fire, and environmental concerns.</td>
</tr>
<tr>
<td></td>
<td>18. Potential leakage concerns.</td>
</tr>
<tr>
<td>Risk of Future Use</td>
<td>19. Not currently used as GSHP anti-freeze solutions. May be difficult to obtain approval for use.</td>
</tr>
</tbody>
</table>
All of the factors evaluated during this program should be considered when making a decision as to which anti-freeze to use in a GSHP installation. Although energy usage and life cycle cost are significant, they do not greatly influence the selection of anti-freeze fluids due to their small differences. The fire, health hazard, and environmental risks, as well as local restrictions, are more critical in determining which anti-freeze fluids are appropriate for a specific application.

The four anti-freezes in current use (methanol, ethanol, propylene glycol, and potassium acetate) should continue to be used where possible. While methanol is currently the most widely used anti-freeze, it has higher fire, health, and environmental risks than other anti-freezes, so greater care must be taken with its use. Ethanol should be considered in cases where the fire risk can be managed and corrosion is not considered to be a major problem. Propylene glycol has extremely low environmental, health, and fire risk, and low corrosion risk; it may be a good choice if energy use and life cycle costs are not overriding concerns. Potassium acetate, likewise, has good environmental and health characteristics, but system component selection and installation must be monitored carefully to eliminate leakage risk. CMA and urea possess desirable environmental and health characteristics; however, they should be considered only after potential corrosion and leakage problems have been thoroughly addressed.

ACKNOWLEDGMENTS

Funding for this program was supplied by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and by the Geothermal Heat Pump Consortium through USDOE Grant DE-FG07-95ID13347. The support of the Project Monitoring Subcommittee, especially Pat Hughes, Bob Brown, Harvey Sachs, and Amanda Meitz, contributed to the success of the project, as did the efforts of Jeff Thornton, Thermal Energy Systems Specialists, in modifying TRNSYS to meet program goals. The efforts of Glenn Mattson in preparing the corrosion and leakage equipment and samples are greatly appreciated.

REFERENCES


The Environmental Effects of Ground-Source Heat Pumps—
A Preliminary Overview

Edward Mehnert, Illinois State Geological Survey

INTRODUCTION

Ground-source or geothermal heat pumps are a highly efficient, renewable energy technology for space heating and cooling. This technology relies on the fact that, at depth, the Earth has a relatively constant temperature, warmer than the air in winter and cooler than the air in summer. A geothermal heat pump can transfer heat stored in the Earth into a building during the winter, and transfer heat out of the building during the summer. These types of geothermal heat pumps are suitable for use throughout Illinois and the Midwest. Special geologic conditions, such as hot springs, are not needed for successful application of geothermal heat pumps.

A geothermal heat pump includes three principle components— an earth connection subsystem, heat pump subsystem, and heat distribution subsystem. The earth connection subsystem usually includes a closed loop of pipes that is buried, horizontally (Figure 1) or vertically (Figure 2). A fluid is circulated through these pipes, allowing heat but not fluid to be transferred from the building to the ground. The circulating fluid is generally water or a water/antifreeze mixture. Less commonly, the earth connection system includes an open loop of pipes connected to a surface water body or an aquifer, that directly transfers water between the heat exchanger and water source (pond or aquifer). For heating, the heat pump subsystem removes heat from the circulated fluid, concentrates it, and transfers it to the building. For cooling, the process is reversed. The heat distribution subsystem is the conventional ductwork used to distribute heated or cooled air throughout a building.

The U.S. Department of Energy (USDOE) estimated that over two-thirds of the nation’s electrical energy and greater than 40% of natural gas consumption is used inside buildings. In residential and commercial buildings, space heating and cooling and water heating consume greater than 40% of electrical power. The U.S. Environmental Protection Agency (USEPA) estimated that geothermal heat pumps can reduce energy consumption by up to 44% compared to air-source heat pumps and up to 72% compared to conventional electrical heating and air conditioning. For most areas of the U.S., geothermal heat pumps are the most energy efficient means of heating and cooling buildings (USGAO, 1994).

For vertical, closed loop systems, heat exchange between the fluid and ground depends upon the thermal properties of the material in the borehole. The borehole may be backfilled with soil cuttings or grout. In Illinois, the borehole must be backfilled with bentonite grout or neat cement. Standard bentonite grout has a thermal conductivity that is lower than most soils or geologic materials (0.43 BTU/ hr ft °F vs 0.8 to 1.8 BTU/ hr ft °F), thus it acts as an insulator around the heat exchange pipes (Smith and Perry, 1999). Thermally enhanced bentonite grouts have been developed and have thermal conductivities of 0.85 to 1.4 BTU/ hr ft °F (Rafferty, 2003), while retaining low hydraulic conductivity (<10⁻⁷ cm/sec), based on technical data from manufacturers. To boost the thermal conductivity of grouts, manufacturers mix silica sand and bentonite, and at times other materials such as cement and superplasticizer.
Figure 1. Residential geothermal heat pump with horizontal loop piping (from Geothermal Heat Pump Consortium)

Figure 2. Residential geothermal heat pump with vertical loop piping (from Geothermal Heat Pump Consortium)
ENVIRONMENTAL ASSESSMENT
Geothermal heat pumps can have positive and negative environmental effects. The USDOE and USEPA have encouraged the use of these heat pumps because of their energy efficiency, as discussed above. Increased energy efficiency for such a major use of energy will reduce the amount of fossil fuels burned, greenhouse gases such as carbon dioxide (CO₂) generated, and other air pollutants (NOₓ and SO₂) emitted (USEPA, 1997).

Heat Pump Antifreeze
A potential negative effect of all geothermal heat pumps is the release of antifreeze solutions to the environment. Antifreeze solutions are required in colder climates to prevent the circulating fluid from freezing. Antifreeze chemicals include methanol, ethanol, potassium acetate, propylene glycol, calcium magnesium acetate (CMA), and urea. These chemicals are generally mixed with water when used as a heat exchange fluid. These chemicals can be released to the environment via spills or corrosion of system components. In Illinois, closed-loop wells are regulated by the Illinois Department of Public Health under the Illinois Water Well Construction Code (Appendix). Approved antifreezes include methanol, ethanol, propylene glycol, calcium chloride, or ethylene glycol. These antifreezes must be mixed with water, at concentrations of 20% or less.

Geothermal heat pumps for a single family residence and the antifreezes for these units were evaluated by Heinonen et al. (1996). These authors evaluated total energy consumption, corrosion due to the antifreeze, and the operational and environmental effects of six antifreeze solutions (methanol, ethanol, potassium acetate, propylene glycol, CMA, and urea). These authors excluded salt solutions, such as sodium and calcium chloride, from their study because they pose serious potential corrosion problems. The differences in total energy consumption for these antifreezes were considered minimal. Heinonen et al. (1996) recommended that propylene glycol was a good choice based on its low health, fire, and environmental risks (Table 1). Unfortunately, these authors did not assess the leak potential of these antifreezes in the plastic pipe (e.g., HDPE & CPVC SDR-11) commonly used for the ground loop.
Table 1. Cost and Risk Factors for Heat Pump Antifreeze (from Heinonen et al., 1996)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Propylene Glycol</th>
<th>Potassium Acetate</th>
<th>CMA</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle Cost</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Corrosion Risk</td>
<td>2</td>
<td>2</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Leakage Risk</td>
<td>3</td>
<td>2</td>
<td>2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Health Risk</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Fire Risk</td>
<td>1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Environmental Risk</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Risk of Future Use</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Notes:
Ratings—1 means potential problems and caution required, 2 means minor potential for problems, 3 means little or no potential problems
a) DOWFROST HD
b) GS-4
c) Pure fluid only. Diluted antifreeze (25% solution) is rated 3.

**Vertical Boreholes**

Geothermal heat pumps with vertical boreholes may pose environmental threats. If these boreholes are not properly grouted or the grout fails, groundwater could be contaminated by surface water infiltration, interaquifer flow, or antifreeze leakage. These boreholes are usually grouted with bentonite, neat cement, or a mixture of these materials. Laboratory tests of the hydraulic conductivity of grout materials range from $10^{-10}$ to $10^{-7}$ cm/sec. Hydraulic conductivity values of $10^{-7}$ cm/sec are considered impermeable. For the grout and conductor pipe systems, values of hydraulic conductivity of $10^{-8}$ to $10^{-7}$ cm/sec have been reported (Allan and Philappacopoulus, 1999).

The low hydraulic conductivity of grout/pipe system can be compromised by poor bonding between the grout and the borehole or poor bonding between the grout and the heat conductor pipe (Allan and Philappacopoulus, 1999). The bond between the grout and conductor pipe is considered more likely to be compromised (Philappacopoulus and Berndt, 2001) and can fail by thermal contraction of the conductor pipe. Because the grout and pipe have significantly different coefficients of thermal expansion, the conductor pipe can contract from the grout at low temperatures, forming a conductive pathway for contaminant transport (Figure 3). Neat cement grouts with water/cement ratios of 0.4 to 0.8 failed in this manner during lab experiments where low temperature fluids were pumped through the pipe (Allan and Philappacopoulus, 1999). A thermally enhanced grout (Mix 111) did not fail, maintaining hydraulic conductivities of less than $10^{-7}$ cm/sec during these experiments. Mix 111 is a mixture of cement, water, silica sand, and small amounts of superplasticizer and bentonite.
Figure 3. Cracking of neat cement grout after thermal cycle testing of grout and U-loop pipe samples (from Brookhaven National Laboratory).

and has high thermal conductivity (1.4 BTU/hr ft °F). The bond between the grout and borehole can be compromised by dessication of the geologic materials near the borehole, as the heat from the borehole lowers the moisture content of the geologic materials and these materials contract. In areas with thick unsaturated zones, the bentonite grout may dry out over time, compromising the seal.

To improve heat exchange, some advocate the use of spacers which moves the heat conductor pipe to the side of the borehole, putting it in contact with the geologic materials. However, the use of spacers appears to increase the environmental risk of antifreeze leaking into groundwater, by reducing or removing the bentonite between the heat conductor pipe and geologic materials.

The risk of groundwater contamination is primarily controlled by the low hydraulic conductivity of the grout. Thus, grouts must be mixed and placed according to manufacturer’s specifications and those procedures defined by industry groups such as the International Ground Source Heat Pump Association, Electric Power Research Institute (EPRI and NRECA, 1997), and the National Ground Water Association (McCray, 1997).

**Antifreeze & Grout Compatibility**

The hydraulic conductivity of bentonite grouts can be altered by changes in the pore fluid, especially some of the fluids used as antifreeze. Salt solutions such as calcium chloride and magnesium chloride solutions, at concentrations used for antifreeze applications, can increase the hydraulic conductivity of bentonite by approximately three orders of magnitude (Jo et al., 2001). Pure organic liquids such as ethanol and heptane also can increase the hydraulic conductivity of bentonite and other clays by two to three orders of magnitude (Anandarajah, 2003). Mixtures of ethanol and water,
up to 60% ethanol solutions, were found to decrease the hydraulic conductivity of bentonite while 100% ethanol solutions (pure ethanol) increased the hydraulic conductivity of bentonite by more than two orders of magnitude (Petrov et al., 1999). The causes of this behavior involve differences in fluid viscosity and clay mineralogy, which are beyond the scope of this report. In summary, some antifreeze solutions, if leaked from piping, will alter the hydraulic conductivity of bentonite grouts which are designed to contain any leakage. Additional research is needed for some antifreeze solutions, such as CMA and propylene glycol, because data for their potential to alter the hydraulic conductivity of bentonite grouts is not known.

SUMMARY
USEPA (1997) concluded that, despite potential environmental problems, geothermal heat pumps pose little if any serious environmental risk when best management practices are applied during the installation, operation, and decommissioning of these systems. Grout selection and installation is a vital step in protecting groundwater quality or minimizing the environmental effects of geothermal heat pumps, especially those from vertical boreholes. Neat cement grouts crack and lose hydraulic integrity when exposed to thermal stresses and should not be used for grouting geothermal wells. Bentonite grouts appear to be an acceptable alternative to neat cement grouts. Thermally enhanced grouts appear to be a better option than spacers for improving the thermal connection between the borehole and geologic materials. Spacers reduce the amount of grout between the heat conductor pipe and groundwater, thus they appear to pose a higher risk for groundwater contamination. Finally, additional research is needed on the topic of compatibility of antifreeze solutions and bentonite grouts.

REFERENCES


**SOURCES OF ADDITIONAL INFORMATION**


Electric Power Research Institute—[www.epri.com](http://www.epri.com), EPRI and the National Rural Electric Cooperative Association produced several reports on cement and bentonite grouting in 1997 and 1998. Some of this material also has been released through the International Ground Source Heat Pump Association.

Geo-Heat Center—[http://geoheat.oit.edu/](http://geoheat.oit.edu/) This site has a focus on western U.S geothermal issues.

Geothermal Heat Pump Consortium– [www.ghpc.org/home.htm](http://www.ghpc.org/home.htm)

International Ground Source Heat Pump Association– [www.igshpa.okstate.edu](http://www.igshpa.okstate.edu)


U.S. Department of Energy (USDOE)– [www.eere.energy.gov/geothermal](http://www.eere.energy.gov/geothermal)

U.S. Environmental Protection Agency, Energy Star program– [http://134.67.99.43/Estar/consumers.nsf/content/ghp.htm](http://134.67.99.43/Estar/consumers.nsf/content/ghp.htm)
ACKNOWLEDGMENTS
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Beverly L. Herzog, Karan S. Keith, and Jonathan H. Goodwin, Illinois State Geological Survey, for reviewing this manuscript.
APPENDIX: Illinois Water Well Construction Code/ Closed-Loop Wells

SECTION 920.180 CLOSED-LOOP WELLS
Construction. Each closed-loop well shall be grouted as required in Section 920.90(h). Closed-loop wells shall not be located closer than 200 feet from a water well, except when the well is a private water system well and when the owner is the same for both the water well and the closed-loop well, in which case the water well shall not be closer than 75 feet from the closed-loop well.

Piping Pressure. The liquid in the closed-loop piping shall be maintained under pressure. The equipment shall be designed to shut down if there is any pressure loss in the system. The system must be pressure tested at a minimum pressure of 20 pounds per square inch by the installer after installation to ensure that there are no leaks in the piping or in the equipment system.

Coolant. The solution used as coolant or the liquid which is pumped through the closed-loop well piping must be methanol, ethanol, propylene glycol, calcium chloride or ethylene glycol. These chemicals may be used only in concentrations of 20% or less. When copper piping is utilized, the coolant shall be hydrochlorofluorocarbon-22, or any equivalent refrigerant with less ozone depletion potential.

Piping. All plastic piping shall be watertight and shall conform to ASTM D2666-89, D2447-89, D3035-91. All copper piping system and joints shall be watertight and conform to UL 1995. All joints in plastic piping shall be heat fusion welded.

Abandonment. All vertical piping in closed-loop wells which is abandoned shall be physically disconnected from the horizontal piping and sealed with neat cement grout or any bentonite product manufactured for water well sealing by pressure grouting. All horizontal piping which is abandoned shall be removed or the coolant must be drained from the piping and disposed of off-site in accordance with State and local laws.

Horizontal Piping Distances to Water Wells. Horizontal piping in a closed-looped system shall not be closer than 25 feet to any water well.

Distances to Sources of Contamination. Closed-loop wells shall not be closer to the sources of contamination listed in Section 920.50(b)(1) than the distances to water wells specified in this Section.

(Source: Amended at 22 Ill. Reg. 3973, effective April 1, 1998)
From the Planning Board:

Words to ponder: No Aquifer = No Island!

The Planning Board has begun working thru high level goals of the Comprehensive Plan. The first goal we're addressing is protection of the aquifer on Great Chebeague Island. As you may know, we have one aquifer on the island from which all wells draw water; this means it’s very important to the viability of our community that we protect that aquifer.

After our recent public workshop on Protecting the Aquifer we’ve outlined 4 major areas to address:

- Septic systems
- Oil tanks
- Pesticides, herbicides, and hazardous chemicals
- Leakage from cars & trucks (especially those no longer in use – “junk cars”)

Our efforts will focus, for now, on education regarding these topics, and, in some cases, improving our database of information (septic systems and wells come to mind). Look for future write-ups on these topics in this space in the months ahead. And thanks, in advance, for your help in protecting Chebeague’s aquifer.
Potential Workshop Discussion items:
Planning Board/Select Board

1) How to reduce the impact of old vehicles on Great Chebeague
   a) Context: current focus on aquifer protection
   b) Short term vs long term; one-time versus repeated...
   c) Should we require that car owners pay for removal when vehicle comes on island?
      i) Ironclad plan (ordinance) to be implemented January 1, 2020, after which it will cost $xxx to get rid of vehicle.
      ii) Some kind of amnesty program to get vehicles off before January 1, 2020.
      iii) Last round: DEP paid for the crusher to come to the island? Reach out to DEP again?
   d) Eventually enforce current restrictions for how many vehicles (including boats) can be on a property? Set this issue aside for now.

2) Should the Planning Board work to include a definition of, and codify the permitting of, “sheds”?
   a) Context: recent homeowner concerns regarding a structure built in the setback and classified as “shed”
   b) Range of structures recently built that were permitted as sheds
   c) Positives and negatives of current approach

3) Should we collaborate on a voluntary well testing program, as part of SB work on ‘protect the aquifer’
   a) Homeowners would pay the fee and would receive their results from Chebeague coordinator
   b) Chebeague coordinator would arrange to have results gathered and summarized, but all results would be kept anonymous
   c) Carol White has offered to coordinate distribution of vials and protocol sheets, pickup of samples, etc; goal is to make it easy for folks to participate

The public is welcome and encouraged to attend!