Project Title: Greener and More Energy Efficient Renewable Energy Resource – Geothermal Heat Pumps
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Recent Milestones: **September 11, 2011** – ACTA applied for a non-provisional patent for their novel nanofluid with the USPTO. The application has been made special for quicker review. ACTA's CTO is a patent attorney and has worked for the PTO.

August 2011 – Improved the heat transfer of propylene glycol by 48%. This new nanofluid is stable and does not require a surfactant.

Small Business: ACTA Technology is a small business.

EPA Focus Area: This application is under focus area (3) **the design of greener chemicals.**

Location: All the work was performed in the USA. This work was partially funded by a Small Business Innovation Research contract from the EPA (Contract number - SBIR EPA-EP-D-11-034).

ABSTRACT

Given the need to rein in our nation's energy consumption and carbon emissions, there is a need for increased use of Geothermal Heat Pumps (GHPs). GHPs are a proven renewable energy resource that provides significant energy savings in the range of 30 to 60% as compared to typical heating and air conditioning units. The greatest barriers to GHPs implementation is their high initial cost and long payback period. The building environment accounts for nearly 40 % of U.S. energy consumption and greenhouse gas emissions. Today's GHPs systems use propylene or ethylene glycol water mixtures in their ground loop. Ethylene glycol is a toxic chemical and therefore has an environmental risk and a disposal problem.

ACTA developed nanofluids with improved heat transfer efficiency over both propylene and ethylene glycol water mixtures, thereby reducing the life cycle cost of GHPs by 17%. Subsidies are not good for any green technology in this time of budget cutting. This proposal addresses the largest barriers to acceptance: high initial cost and long payback period. ACTA's nanofluids increase the heat transfer rate of the ground source loop; thereby reducing the life cycle cost, need for subsidies, and the initial cost because the ground loop can be smaller and less fluid is pumped.

ACTA's propylene water mixture nanofluid improved the heat transfer properties of propylene glycol water mixtures by 48%. The nanofluids are stable. Paratherm, food grade heat transfer oil, was also improved to be a better heat transfer fluid than both the ethylene and propylene mixtures.

Manufacturers of GHPs and automobiles can benefit from this product and jobs in nanotechnology manufacturing would grow because of the use of these particles in more industries. Expanding GHP's market has the potential of reducing our dependence on foreign oil and reducing green house gas emissions because of improved energy efficiency.

This project covers greener circulating fluids for GHPs and automobiles that do not possess the harmful effects of ethylene glycol. These greener nanofluids can also improve automobiles' fuel economy because the car's radiator could be smaller with less fluid needing to be pumped. ACTA's research covers a greener chemical.

a) ***CHEMISTRY OF THE NEW TECHNOLOGY***

ACTA has developed new nanofluids with increased heat transfer over their initial base fluid. The specific heats and thermal conductivities of the nanofluids are higher than their base fluid.

Our heat transfer results were confirmed by thermal modeling and by two different test methods. Our approach relied on taking physical property readings (pH, viscosity, specific heat, thermal conductivity, and specific gravity) as well as pumping the nanofluids in a heat transfer apparatus where flow rates, pumping power and temperatures were recorded. We observed good correlation between our thermal model and apparatus test results.

Figure 1 illustrates that Paratherm ® LR (PLR), a FDA food grade oil (CAS 8042-47-5), has a higher heat transfer coefficient than ethylene (EG, CAS 107-21-1) and propylene glycol (PG, CAS 55-57-6) water mixtures (50:50) when nanoparticles are suspended into the fluid.

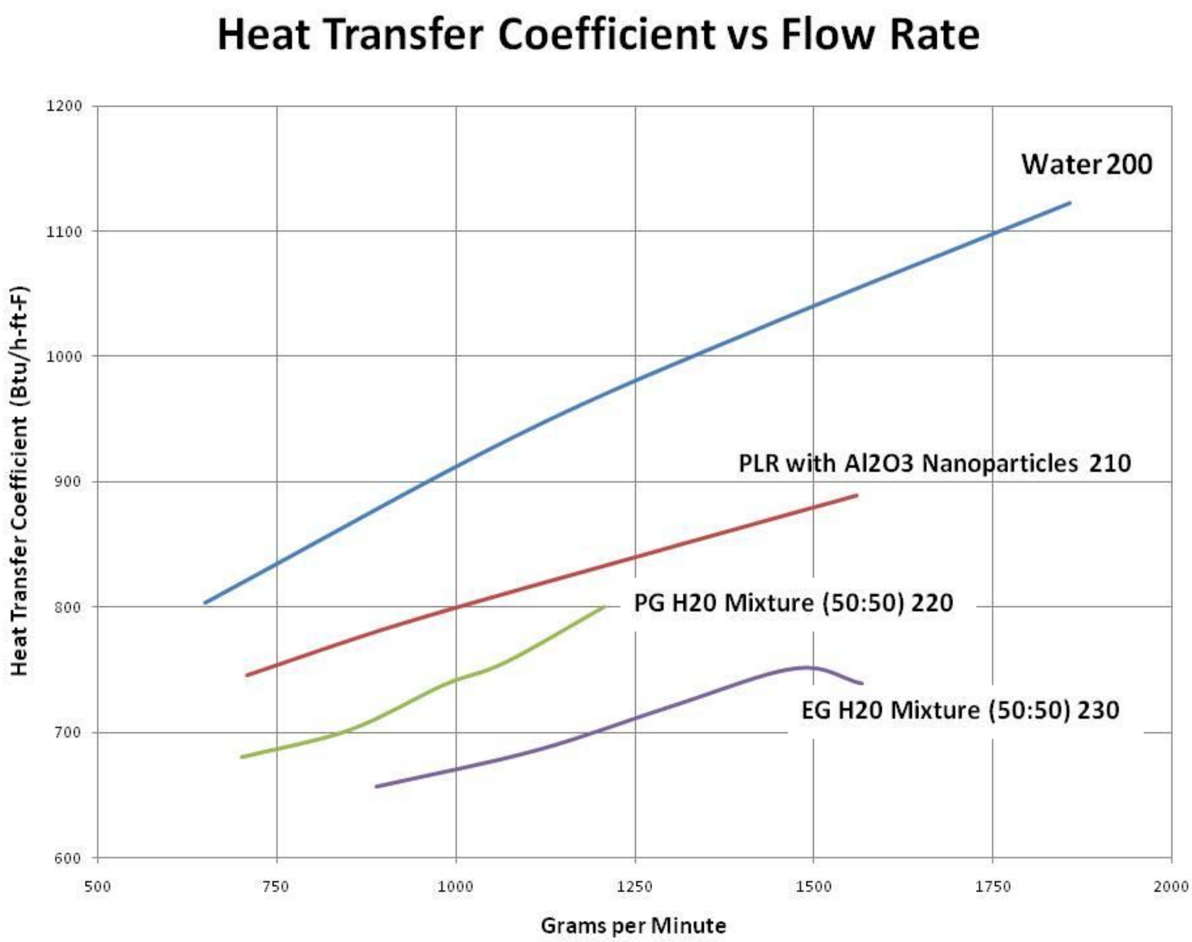

Figure 1 - PLR Nanofluid out-performed ethylene (EG) and propylene glycol (PG) water mixtures

Table 1 – Summary of Results for New Nanofluids

Heat Transfer Nanofluid	Heat Transfer Improvement over the base fluid	Heat Transfer capability (water =100)	Pumping Efficiency (water = 100)	Nano-particles	Viscosity increase <15% over the base fluid	Comments
Propylene glycol water nanofluid (50:50) with Al_2O_3	48%	120	107	1%	Yes	No surfactant
PLR with Al_2O_3	19%	79	98	2%	Yes	Sodium dioctyl sulfosuccinate (CAS 577-11-7)
Paratherm LR (PLR)	Base Fluid	60	97	Base Fluid	Base Fluid	PLR is a low viscosity fluid
Propylene Glycol (50:50) H_2O mixture	Base Fluid	62	107	Base Fluid	Base Fluid	
Ethylene Glycol (50:50) H_2O mixture	Base Fluid	72	107	Base Fluid	Base Fluid	

ACTA improved the heat transfer of Paratherm ® LR by adding a surfactant and alumina nanoparticles (2% wgt.) and had superior heat transfer properties over both ethylene and propylene glycol water mixtures. Therefore the nanofluid Paratherm ® LR could replace ethylene glycol water mixtures and the result would be a smaller ground cooling loop (7% improvement in heat transfer). The flow rate in the cooling loop could be reduced, thereby reducing the operating cost of the GHP. The surfactant (AEROSOL OT ®) is safe and is permitted under 21 CFR 178.3400 of the Food Additives Regulations to be used as a food additive.[1]

ACTA has also improved the heat transfer properties of propylene glycol water mixture without using a surfactant. **This is novel**. We used nanoparticles that were produced by a pyrogenic (flame) process that consists of microscopic droplets of amorphous particles fused into branched, chainlike, three-dimensional secondary particles which then agglomerate into tertiary particles. The resulting powders have an extremely low bulk density and high surface area. The pyrogenic nanoparticles are not spherical nanoparticles as often used by other researchers. During sonication the larger chainlike agglomerates are broken into smaller, more uniformly sized aggregates. These fumed nanoparticles have large surface area to volume ratios. Spectra AL® 100

[1] https://www.cytec.com/specialty-chemicals/downloads/PRT%20073-I%20PDS%20AEROSOL%20OT%20Surfactant%20(USA%20version).pdf

is an example of fumed alumina. This new nanofluid has superior heat transfer properties to water.

Fumed nanoparticles are not like spherical nanoparticles (NPs) that other researchers have used. Fumed nanoparticles are charged particles where the pH can vary the charge on the surface of the particles. The like charged NPs form a well dispersed nanofluid if the proper amount of energy is initially used to disperse the fumed particles. These fumed NPs are hydrophilic and are stable in propylene glycols mixture.

Reusing nanoparticles is also possible and important because the propylene glycol cooling fluid should be replaced every ten years according to ASHRAE.[2] ACTA filtered out the nanoparticles from the nanofluid for reuse with a removal efficiency of over 99.999%. Another way to remove the nanoparticles is to change the pH of the mixture. For example, for fumed silica oxide at a pH of 2.3 the iso-electric point of fumed silica is reached. When the pH is below 2.3; the surface chemistry changes charge. At a pH above 10.8 the fumed silica goes into solution. While at low pH the nanoparticles aggregate and can be separated out of solution. Hydroxyl groups cover approximately 40% of the surface of the nanoparticles making the surface hydrophilic.

ACTA has filed a non-provisional patent application for this technology. ACTA's CTO is a patent attorney who has worked for the PTO. The application was made special for quicker review.

b) ***PROBLEM THAT WE ARE SOLVING***

Conventional GHPs provide significant energy savings over typical air-source heat pumps or typical furnaces with air conditioners. GHPs are a proven renewable technology and savings in the range of 30 to 60% have been well documented.[3] But, the National Earth Comfort Program identified initial cost, confidence or trust in the technology, and design and installation cost as the primary barriers to GHPs acceptance in the U.S. market place. The greatest barrier being GHP's long payback periods and high initial installation costs.[4] Countries in Europe are accepting GHPs at a much higher rate than USA. GHPs have the potential to reduce our dependence on foreign oil and reduce greenhouse gas emissions because of their lower energy requirements and high efficiency. In summary, GHPs are a renewable energy source with high energy efficiency, but their high initial cost causes a drag on their acceptance into the US marketplace. These systems need utility, federal, and state subsidies in order to be accepted by the public. Subsidies are not good for any green technology in this era of budget cuts. Hence this proposal addresses the largest barrier to acceptance: high initial cost. Nanofluids increase the heat transfer rate of the ground source loop (borefield); thereby reducing the life cycle cost, need for subsidies, and initial costs of these systems. This improved heat transfer lowers the installation cost

[2] 1999 ASHRAE HVAC Applications Handbook ASHRAE. Atlanta, Ga
[3] Geothermal Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers", Prepared by Patrick J. Hughes, Energy and Transportation Science Division, Oak Ridge National Laboratory, 2008. http://www1.eere.energy.gov/geothermal/publications.hmtl
[4] Ground-Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers –Final Report, February 2008.

because the ground loop can be smaller and less fluid is pumped through the ground loop.

Prior work has already shown that using nanoparticles is an excellent method to improve heat transfer in water, ethylene glycol, engine oil and refrigerant applications.[5] Improved heat transfer efficiency enhancement of 40% or more has been reported with only a 0.10% particle concentration.[6]

Because of the larger surface area that nanoparticles (NP) possess, the heat transfer rate is greater and the thermal response time is less. It has been shown that higher wetting ability of nanoparticles can flatten the transverse temperature gradient of the fluid because of increasing effective liquid conductance in the pipe. Hence, the thermal resistance of the fluid is reduced for the same reason.[7]

The significance of this project is the need to develop new circulating fluids for GHPs that do not possess the harmful effects of ethylene glycol. A 5- ton residential GHP can produce 660 to 880 gallons of ethylene glycol waste over its 40 year lifetime. The installation cost for a horizontal loop is $600 to $800 per ton.[8]

The most common fluid used in GHPs is propylene glycol which is less hazardous than ethylene glycol. Ethylene glycol is extremely hazardous to pets and children and is water soluble. There is a potential risk of ethylene glycol entering the water supply via leaks in fixtures and leaky pipes in the ground loop. Therefore, ethylene glycol represents both a disposal and environmental risk.

Food grade heat transfer oils are not water soluble and are being used in many heat transfer applications today. But these heat transfer oils are not being used in GHPs because of their lower thermal conductivity as compared to glycols. Our project includes a food grade oil with significantly improved heat transfer efficiency over propylene and ethylene glycol water based fluids, and an improved propylene glycol nanofluid with superior heat transfer properties to even water. The nanoparticles used are able to be removed from the fluid and reused.

ACTA's project covers a greener and more energy efficient GHP system with a reduced payback period. Our technology will reduce the need for subsidies for this green technology.

c) ***COMPARISON TO OTHER TECHNOLOGIES***

GHPs are a renewable energy resource. Therefore a comparison must be made between other types of renewable energy sources (wind and photovoltaic) and other types of HVAC systems

- **Renewable Energy** - According to the Department of Energy, photovoltaic costs $6-10,000 per kWp or 20-40 cent per kWh.[9] Solar photovoltaic have long

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[5] H. Xie, J. Wang, T. Xi, Y. Liu, F. Ai, F. Wu, Q. Wu, Thermal Conductivity Enhancement of Suspensions Containing Nanosized Alumina Particles. J. Appl. Phys., 2002, 91(7), 4568-572
[6] P. Naphon, D. Thongkum, P. Assadamongkol, Heat Pipe Efficiency Enhancement with Refrigerant-Nanoparticles Mixtures. Energy Conversion and Management 50 (2009) 772-776.
[7]Shung-Wen Kang, Wei-Chiang Wei, Sheng-Hong Tsai, Chia-Ching Huang, Experimental investigation of nanofluids on sintered heat pipe thermal performance. Applied Thermal Engineering 29 (2009) 973-979.
[8] McQuay (GHP Manufacturer) Design Manual AG 31-008.
[9] US DOE Alternative Energy Cost http://www.eia.doe.gov/oiaf.aeo/assumption/pdf/renewable.pdf

payback periods and require backup energy resource. Wind turbines (10 kW to 2 Megawatts0 cost $3-4,000 per kWp or 10-15 cents per kWh.[10] This is lower that solar PV and the payback period is lower as well, but wind power can be located in a limited number of locations . Wind power also requires a backup power resource. Wind power also has a potential noise problem. GHP does not require a backup power source.

- **Alternative – Air Conditioning System Options**

The following air conditioning systems were used in the life cycle analysis:

1. Air-Cooled Chiller with Variable Air Volume Air Handling System
2. Water-Cooled Chiller with Constant Air Volume Air Handling System
3. Ground Source Heat Pump
4. Ground Source Heat Pump with a Nanofluid Cooling Medium

In this analysis each system is designed to meet a cooling load of 150 tons. The full-load heating profile was approximated to be 500 hours while the full-load cooling profile was estimated to be 700 hours. All systems were designed to meet ASHRAE Standard 62.1– 2007 which incorporates acceptable levels of outside air to maintain air quality.

A life cycle cost analysis was performed using the Building Life Cycle Cost (BLCC) software from NIST.[11] The present value in constant dollars is used with a 3.0% discount rate over a 40 year period to calculate life cycle costs. The life cycle analysis incorporates energy costs (gas and electric), water costs and annual maintenance costs for each system. The Department of Energy Price Escalation Rates is incorporated based on the region, utility rate type, and fuel type specified in the analysis. The annual maintenance costs implement a 1.5% price escalation rate during the analysis period. The Oak Ridge Study was performed using 1998 cost data therefore it was necessary to perform a life cycle cost analysis with adjustments to reflect present 2011 cost levels.[12] Reviewing inflation data for the last 11 years determined an average inflation rate of 2.85% which was used to adjust the 1998 costs to reflect 2011 price increases. Present gas and electric rates were obtained from the State of Nebraska's Public Utility website. [13,14]

The life cycle cost analysis indicates the GHP with nanofluid has the lowest life cycle cost at $2,778,768 over a 40 year period. Both GHP systems have a low life cycle cost when compared to the air-cooled and water-cooled chiller systems. When

[10] US DOE Alternative Energy Cost http://www.eia.doe.gov/oiaf.aeo/assumption/pdf/renewable.pdf

[11] NIST (National Institute of Standards and Technology). *Building Life-Cycle Cost Software BLCC 5.3-10*, April 2010.

[12] Shonder, John , Michaela Martin and Patrick Hughes (Oak Ridge National Laboratory), "Geothermal Heat Pumps in K-12 Schools", A Case Study of the Lincoln, Nebraska Schools, Oak Ridge National Laboratory, Oak Ridge Tennessee 37831-6285 ORNL/TM-2000/80.

[13] Official Nebraska Government Website, www.neo.ne.gov, Nebraska City Utilities 2011.

[14] Inflation Rate Data, www.fintrend.com, 2003-2011 Capital Professional Services, LLC.

comparing only the GHP systems the system incorporating nanofluid has a 17% lower life cycle cost than the conventional GHP system. The initial cost of the nanofluid system is also lower because of the reduction in the borefield size due to the increased heat transfer rate. A smaller borefield requires a smaller volume of cooling medium reducing material and pumping costs.

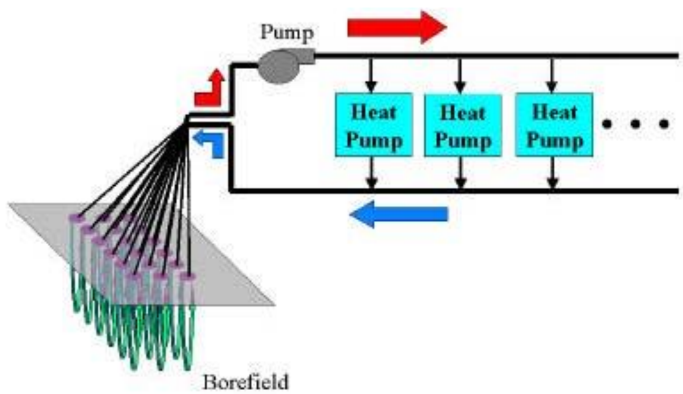
d) ***POTENTIAL BENFIT AND DRAWBACKS ACROSS ALL STAGES OF THE TECHNLOGIES LIFE CYCLE***

Manufactures of GHPs would benefit from this research and jobs in nanotechnology manufacturing would also grow because of the use of these particles in more industries. Expanding GHP's market has the potential of reducing our dependence on foreign oil and reducing green house gas emissions because of improved energy efficiency

Heat transfer fluids are used across a wide variety of industries including transportation, industrial processing, solar and geothermal applications. The market size for geothermal heat transfer fluids is estimated at $375M for 2011, and will continue to grow since heat pump systems are being more widely adopted.

A second large potential market for ACTA's propylene glycol nanofluid systems is vehicular radiator systems. Over the last five years, the average auto production worldwide was over 50 million units per year.[15] The global antifreeze is estimated as 1.3 million tons in 2006 with a grow rate of 3.7%.[16]

The continued drawback of this technology is the long payback period. Nanofluids can reduce the long payback period but not eliminate it. The initial cost is still higher than conventional HVAC systems. Installing borefields that can serve multiple units and be built during the initial construction of large residential and commercial sites can reduce the installation cost. This central building approach is used in Sweden to spread the initial is cost over a larger number of users. This strategy makes GHPs more economical.



GHPs do not require any cooling towers, therefore water usage is less. But GHPs do require a larger footprint to install the borefield. Borefields are commonly place under parking lots because of their larger footprint.

[15] [15] Source: worldometers.info/cars
[16] Frost and Sullivan – The Global Antifreeze/Coolant Market. 12 Mar 2007.