GEO-HEAT CENTER

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Assessment of Downhole Heat Exchangers in Existing Wells in Puna County, Hawaii

This work has been funded and completed under Midwest Research Institute, National Renewable Energy Laboratory (NREL) Task Order No. KLDJ-5-55052-06, "*Assessment of Downhole Heat Exchangers in Existing Wells in Puna County, Hawaii*". Downhole heat exchangers (DHEs) have the potential for use in direct (non-electric) applications of geothermal energy. Their benefit is that no groundwater is extracted from wells. Some targeted uses of DHEs are low temperature agricultural applications such as greenhouse bottom heating and soil pasteurization.

Purpose and Scope

- Investigate the use of black iron and cross-linked polyethylene (PEX) DHEs
- Provide a specific design on the size and configuration of the DHEs, along with the cost of fabrication and installing a DHE in one or more available wells, and
- Assist with the fabrication and installation of DHEs in one or more wells, along with developing a monitoring program

Available Wells

With assistance from Andrea Gill of the Department of Business, Economic Development and Tourism (DBEDT) Energy Office, two available wells have been identified for possible DHE testing, and Geo-Heat Center staff visited and inspected these wells on October 24, 2006. These wells are referred to as Puna Geothermal Venture (PGV) well *MW-2* and the *Malama Ki* well, owned by the University of Hawaii, Hilo. Well *MW-2* is located on the PGV lease property and the *Malama Ki* well is located on a University of Hawaii agricultural research site. Details of the well construction are summarized in Table 1.

Table 1. Construction Details of Available Wells for DHE Testing

Well ID	Depth to Water (ft)	Total Well Depth (ft)	Height of Water Column in Well (ft)	Casing Diameter (in.)	Max. Well Temperature (^oF)
PGV MW-2	573	646	74	4	145
Malama Ki	272	319	47	8	133

DHE Design

There are a couple of main factors that dictate the DHE design. With regard to the available wells for this project, the limiting factors are well diameter and static water level.

The well diameter dictates the pipe diameter of the DHE, as there has to be allowable room for not only the DHE legs, but also for the U-bend at the bottom of the DHE. Deep static water levels in wells limit the use of PEX as a DHE. Water in a vertical DHE exerts increasing pressure on the pipe with increasing depth. Below the water table, the water pressure in the pipe is partially or fully offset by opposing pressure of groundwater in the well, but above the water table, this is not the case and the pipe has no confining pressure.

Figure 1 is a plot of pressure rating (converted to feet of water) for PEX pipe versus temperature, showing the static water levels of the Malama Ki and PGV MW-2 wells. As seen in Figure 1, the static water level in the Malama Ki well allows 140^{o}F water and lower in a PEX DHE. However, the static water level in PGV MW-2 is at a depth that would result in the rated PEX pressure to be exceeded.

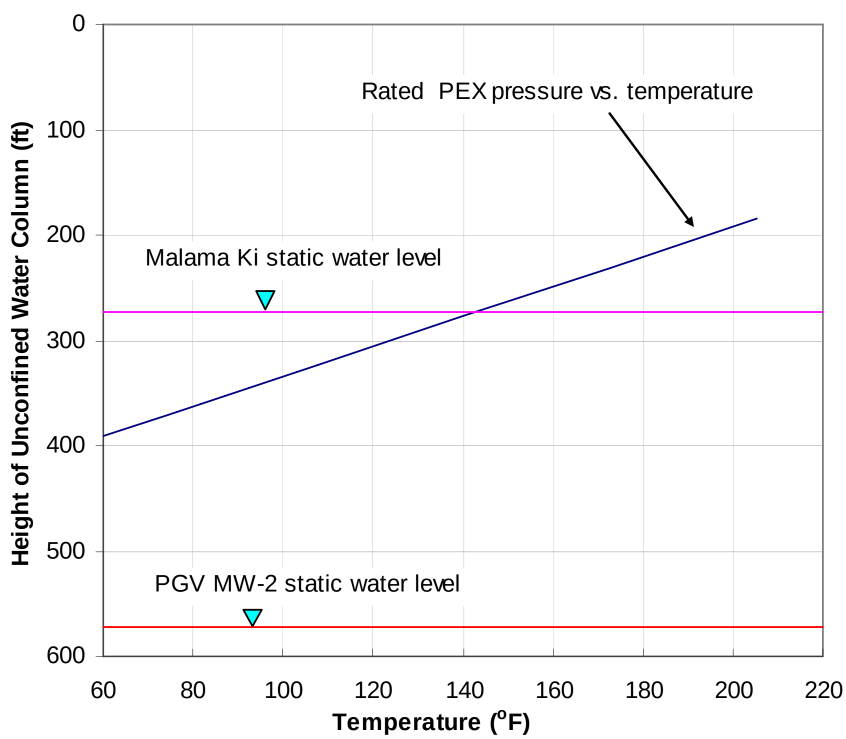

Figure 1. Pressure vs. temperature rating of PEX pipe

Given the well conditions mentioned above, PGV MW-2 is a good candidate for a black iron DHE, and the Malama Ki well is a good candidate for a PEX DHE. The diameter of MW-2 (i.e. 4-in.) would allow for only a 1-inch maximum nominal black iron DHE to be installed. The diameter of the Malama Ki well (i.e. 8-in.) would allow for either a 1-in. or a ¾–in. PEX DHE to be installed.

Estimate of Useful Heat Extraction Rates

The heat extraction rate of a DHE depends on its immersed length in the well in addition to many hydrogeological factors that are currently unknown in Puna County, HI. Part of this project includes field testing to determine actual heat extraction rates. Some of the important hydrogeologic factors that dictate heat extraction rate of a DHE are: subsurface thermal conductivity and volumetric heat capacity, groundwater flow rate, and groundwater temperature.

Perhaps the most important parameter that dictates the amount of *useful* heat that can be extracted from a DHE is the groundwater temperature. For example, if 120°F is the desired output temperature from a DHE, the required DHE length increases exponentially as the geothermal resource temperature approaches 120°F. To illustrate this point, Figure 2 is a plot of the required DHE length normalized to a 20°F temperature differential between the geothermal resource temperature and the desired DHE output temperature. Using the example, this would imply a geothermal resource of 140°F. As seen in Figure 2, if the geothermal resource temperature were decreased to 130°F (i.e. a temperature difference of 10°F), double the amount of DHE would be necessary to extract heat at the same rate as if the geothermal temperature were 140°F. On the contrary, if the geothermal resource temperature were 160°F, only half the amount of DHE would be required relative to a 140°F resource.

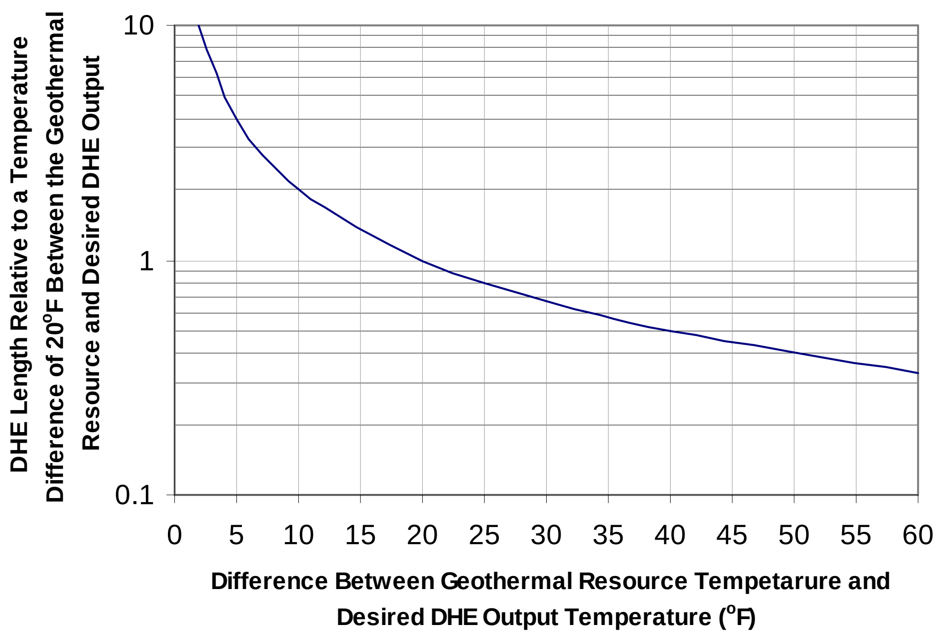

Figure 2. Semi-log plot of DHE length as a function of the temperature difference between the geothermal resource and the desired DHE output temperature. Note the curve is normalized to a temperature differential of 20°F.

From our experience, we cannot expect that a significant amount of heat can be extracted from the available wells. Assuming a design output temperature of 120°F for a greenhouse bottom heating application, about 250-500 Btu/hr/ft of submerged DHE can be expected from the

Malama Ki well and about 500 to 1000 Btu/hr/ft can be expected from PGV MW-2 well. Actual values, as mentioned above, depend on geological conditions. With the relatively short standing water columns in each well, we can expect heat extraction rates of only about 12,000 Btu/hr to 24,000 Btu/hr from the Malama Ki well and about 37,000 Btu/hr to 74,000 Btu/hr from the PGV MW-2 well. Based on heating load calculations from the Draft Feasibility Report for Geothermal Direct Use (Okahara & Associates, September 2006), greenhouse bottom heating requires about 25 Btu/hr/ft^2. Therefore the Malama Ki well could support only a small greenhouse operation of about 500 to 1,000 ft^2 and the PGV MW-2 well could support a small greenhouse operation of 1,500 ft^2 to 2,960 ft^2.

DHE Cost Estimates

The following cost estimate applies to installing a ¾ in. PEX DHE in the Malama Ki well and a 1-in. black iron DHE in the PGV well MW-2. A one-day field test is planned to measure the effective thermal conductivity of the subsurface. This will aid in calculating heat extraction rates under different field conditions.

Malama Ki Well:	800 ft of ¾-in. PEX @ $1/ft	=	$800
	Shipping to Hilo	=	$250
	PEX fittings	=	$100
	Generator rental (1 day) (5000 W, 230 V)	=	$200
	TOTAL		*$1,350*
PGV MW-2:	1,400 ft of 1-in. PEX @ $2.50/ft	=	$3,500
	Misc. fittings	=	$ 100
	A-frame/crane truck $750/day (2 days)	=	$1,500
	Generator rental (1 day) (5000 W, 230 V)	=	$ 200
	TOTAL		*$5,120*

The above cost estimate does not include shipping of tools and experimental apparatus to the project site. We estimate these costs at about $500.

A long-term field monitoring test is also being planned. This type of test involves creating a fictitious heating load, which will consist of either buried pipe or a water tank exposed to the atmosphere. A long-term test of this type with unattended equipment presents challenges of vandal-proofing the experimental apparatus. Details for this test have not yet been finalized.