A BRIEF HISTORY OF DHE MATERIALS

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Author's Note: Not much information is recorded about DHE materials and life times. When good references existed, they were cited. Other than those, the information herein is based on conversations with drillers, installers, homeowners and observations over some 43 years.

KLAMATH FALLS, OREGON

The first downhole heat exchanger (DHE) in Klamath Falls, Oregon, perhaps the first in the world, was installed in 1931 by a local plumber, Charles B. "Charlie" Leib, as an experiment and as a favor to a friend. Charlie had worked as a plumber/pipe fitter in Pennsylvania, moved to Klamath Falls in 1928, and worked for a local plumbing shop. Much of his work was repairing pumps and piping, and cleaning out cast iron radiators in the geothermal systems then in use. They used the geothermal water directly in the systems at that time (Fornes, 1981).

Charlie knew from experience that hot water boilers would thermo syphon to circulate hot water in a system. He figured the geothermal resource could act as the fire in a water tube boiler or the steam in a steam-to-water tube and shell exchanger. Money was tight during the depression, so he used the cheapest materials available–black iron pipe and cast iron fittings to put a U-tube DHE in his friends artesian well. It worked. It lasted 25 years, when the well, cased only about 20 feet, caved in.

Before long DHEs were being installed in other wells and their success in reducing problems in the aboveground parts of the system led to increased drilling of the resource (Figure 1). In non-artesian wells, corrosion near the water level was the major problem; although, failures do occur at other locations (Figures 2 and 3). Non-artesian DHE life was generally on the order 10 - 15 years–in artesian wells, about twice as long.

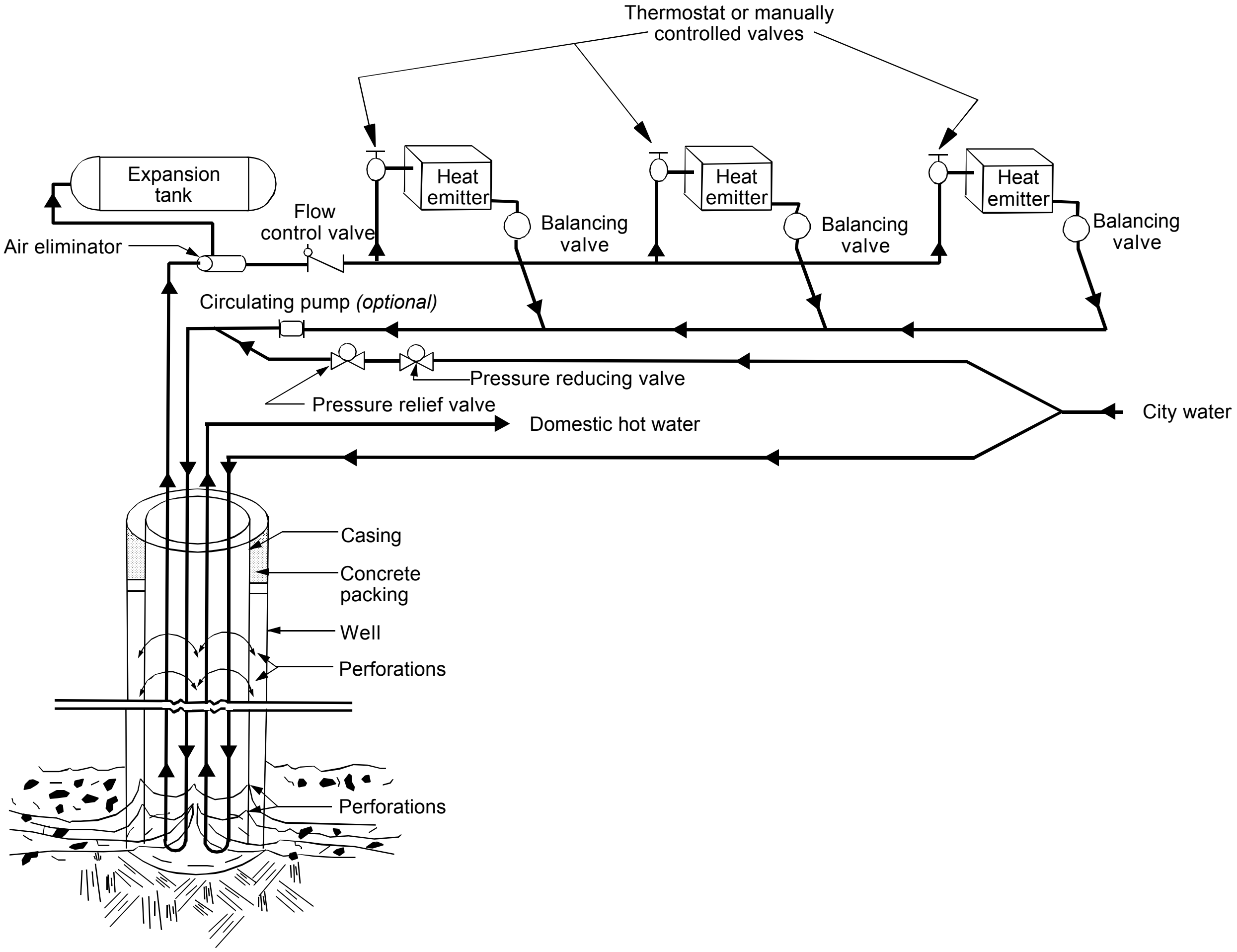

Figure 1. Typical downhole heat exchanger system (Klamath Falls, OR).

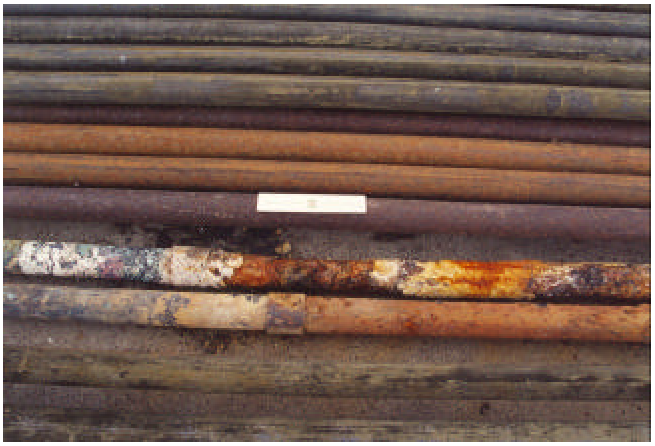

Figure 2. Corrosion and failure of a residential DHE at the air/water interface.

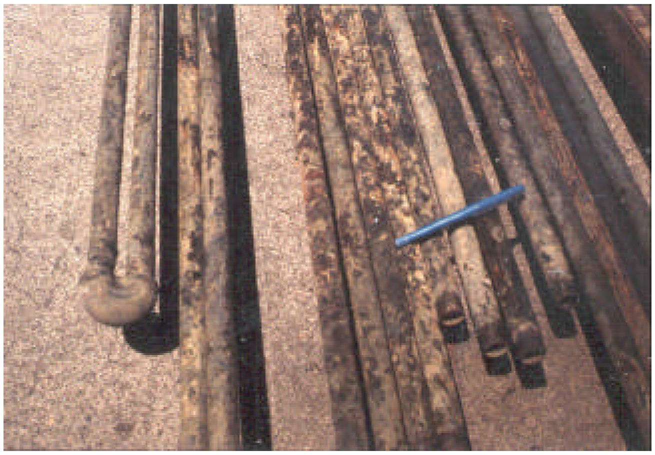

Figure 3. Corrosion and pitting of DHE replaced in 1974. Note the Reverse loop at the bottom of the heat exchanger.

Early efforts to solve the problem included use of galvanized pipe, brass pipe at the waterline, and dumping used motor oil down the well.

Use of zinc galvanized pipe was doomed to failure. We now know that geothermal water leaches zinc and at above 135°F, the anode cathode relationship of zinc and iron reverses. Any scratches in the galvanized coating caused by handling or pipe wrench jaws during tightening, caused rapid localized pitting rather than the slower general corrosion of bare pipe. Some of the installers were aware of this and only a very few galvanized DHEs were installed.

Use of brass pipe at the water level was a bit more successful. Although, no written records are known, installers estimate in some cases, life was extended 5-10 years. The main problem was that since the resource was being more fully utilized, including wells being pumped, water levels were fluctuating–up in summer and down in winter. Since brass pipe is about 10 times as expensive as black iron, only short 10-20 ft sections were installed. Unless the installer accurately predicted water level over the future 20 years, the brass section could be above or below the water level much of the time.

In one well, what appeared to be the tubes and header of a U-tube and shell exchanger had been used as a DHE. A well driller had been called in to replace a DHE. The black iron DHE had been pulled and the well was being bailed to clean out, when the object was encountered. It was fished out in good condition except for fishing damage. It appeared to be yellow brass or naval bronze tubes and header, 7-in. diameter and 8 ft long with four U-tubes. It appeared to have been hung on black iron pipes which had corroded where it was attached due to dissimilar metals. None of the local drillers or DHE installers knew about it; so, how long it was in service or laid on the well bottom, remains a mystery.

Because DHEs in capped artesian wells had about double the life of those with water levels below ground surface, it was summarize that water vapor was the culprit. Used motor oil, which would float on the surface and reduce vaporization, was dumped down wells. It was also believed that the oil would creep up the pipes some distance preventing water vapor contact. The practice was prohibited by state water resource rule; since, it contaminated the resource and some people were drinking, washing dishes and clothes, bathing and using it in swimming pools. There was also the potential for mixing with public water supply aquifers. Paraffin was substituted in many cases, but the practice probably continued in others.

In 1990, Swisher and Wright published results of experiments that showed that paraffin did in fact reduce corrosion above the water surface by a factor of a bit less than three - **but** - corrosion rate just above and below the surface was still unacceptable. The also showed that fairly rigorous exclusion of air reduced corrosion rate from 500 micro-meters per year, down to about 10 micro-meters per year, a factor of 50. Their recommendation, after the DHE is installed, was to seal the wellhead. Any oxygen in the well will be used fairly quickly and corrosion will cease (Swisher and Wright, 1990). This has been done on several wells by welding a cap or use of closed cell foam-in-place insulation material. We'll have the real results in 15 - 20 years–or when the well owners agree to inspecting their DHE.

All of the above failed to address the problem of corrosion well below the water level. This typically occurs at the very bottom of the DHE or where the DHE either contacts or is very near the well wall. It appears to be more pronounced in wells only partially cased. Wells are rarely drilled perfectly straight. DHEs never hang perfectly straight because of slight differences in pipe length, coupling tightening and the fact that the hot leg thermally expands more than the cold leg. One leg usually spirals around the other.

This type of corrosion is believed to be at least partially caused by stray induced electrical currents. Just how these are induced is unknown. Currents of several milliamps were measured between the DHE and a grounding rod at several residences with shorter than normal DHE life. In one case, over 30 milliamps were measured. This was traced to a faulty refrigerator with the electrical system grounded to water pipes–a common practice in older homes.

In an attempt to solve the problem of stray electrical currents supposedly accelerating the corrosion of DHE, an experiment with isolation junctions and a sacrifical electrode was tried (Newcombe, 1976). The thought was that commercially available unions using steel-on-neoprene could be used to electrically isolate the pipes suspended in the well from the residence. These unions can be installed at the top of the well in place of standard unions to couple the suspended hairpin loop to the pipes leading to the residence. In addition, any stray current originating in the well plumbing itself can be negated or rendered harmless when a sacrifical anode is attached to the suspended well pipes needing a cathodic protection. The anode is a preparation of sacrifical metals and chemical which, when wet and buried in the ground, forms a cell ("battery') causing a small current to flow from the pipes through the attached wire to the anode and, hence to ground. Normal current flow is thereby reversed. Commercial anodes which are sacrificed need to be periodically replaced– perhaps every five years. Cathodic protection generally can be installed on any existing well pipe without removing the pipe from the well. A rule of thumb is: "2 milliamperes of negative current is required to protect each square foot of surface pipe exposed to water." Very deep wells would require special consideration in that the bottom section receives less protective current.

The one well that we are aware of, that used the sacrificial electrode, had poor results in that the DHE failed again in a short period. Unfortunately, there is no documentation of the installation or results, thus the procedure is questioned and needs to be investigated further. Insulating unions in piping between the building and DHE at the wellhead and good connection (i.e., tack weld at DHE to casing) seems to reduce the problem.

One solution tried by a Klamath Falls homeowner was X-Tru-Coat. He installed it himself. X-Tru-Coat is a thin wall, black iron pipe coated with mastic, then with an extruded polyethylene cover. It was used as underground natural gas pipe. Polyethylene becomes very soft and the plasticizer migrates out at about 150°F causing brittleness and cracking. The DHE life was only a few years.

The formation of scale on DHEs forms a protective coating. The Langlier Saturation Index, a measure of water's tendency for scale deposition, ranged from +0.02 to 0.75 in Klamath Falls geothermal fluids. Non-artesian, with an index of +0.02, had a repair frequency of five years, wells with index between +0.45 and +0.75 repair frequency of 10 to 20 years. Artesian wells with index of +0.75 had lives between 29 and 34 years (Culver, 1974).

Inspection of DHEs after removal sometimes reveals long deeply corroded lines with little or no scale along one side of the DHE. Presumably, this is where a DHE lies against the well wall or casing and movement due to thermal expansion and contraction scrapes off the scale exposing fresh material for corrosion.

Today, there are over 500 geothermal wells in Klamath Falls, most have DHEs. Many of the old artesian wells that used geothermal water directly in the system have been converted to DHEs because of a city ordinance requiring injection of used water and the cost of a second well.

The latest innovation is an experiment by the Geo-Heat Center using PEX (cross-linked polyethylene) installed in October 2004. (See article by Andrew Chiasson in this issue of the *Bulletin*.)

RENO, NEVADA

The first DHE in the Moana area of Reno, Nevada, was installed in 1950 in a 167°F, 850-ft deep well. The material was a 2-in. copper pipe U-tube (locally called a trombone). Moana area geothermal water generally has less than 1,000 ppm total dissolved solids, pH 8.2, with 0.2 ppm H_2S (Bateman and Scheibach, 1975). This is quite similar to Klamath Falls geothermal water.

Only anecdotal estimates of the life of the copper DHEs is available. These range from 3 to 6 years average life with none lasting as long as 10 years. Based on the life of copper components in contact with similar geothermal water in other applications, this seems reasonable. Considering the homes were large, over 3000 sq ft, many had swimming pools heated and snow melt systems, and the cost of DHE repair compared to conventional fuel cost was not a great concern. Copper continued to be the material of choice until the mid-to-late 1970s.

The increasing cost of conventional fuel and especially the federal residential energy tax credit program combined with growth of the Reno area, prompted a greater than 4-fold increase in the number of homes using geothermal between 1975 and 1996 (Flynn, 2001). This, of course, increased the desire for longer life DHEs.

The first change was to substitute black iron pipe for the copper in the upper portion of the well with a copper tube helix in the lower hotter portion.

This reduced the initial cost, but not the repair frequency of the copper portion. Next, the entire U-tube was replaced with black iron pipe, which reportedly increased DHE life to about 10 years.

In about 1980, non-metallic U-tubes were installed, including polyethylene in a few lower temperature wells, as well as, polybutylene and CPVC (chlorinated polyvinyl chloride). All of these materials have reduced pressure ratings at elevated temperatures. Polyethylene's maximum temperature is 140°F; where, it has a pressure rating of 0.2 of the rating at 73°F. Polybutylene is similarly rated at 160°F. Even CPVC which has a maximum temperature rating of 210°F is derated to 46 psi at 200°F. This means that if the static water level exceeds 106 ft, its rating would be exceeded at 200°F. Some of the well bottom hole temperature exceeds 215°F. These materials are also subject to long-term creep, especially at elevated temperature, which could cause bursting.

In 1981, 1982 and perhaps 1983, fiberglass epoxy pipes were tried. This product was similar to its metal counterpart in that it had machine cut threads on the pipe and in the fiberglass epoxy couplings. It has seen extensive satisfactory use in aboveground and shallow burial in corrosive soils carrying hot brines in oil fields at temperatures above any encountered at Moana.

After a short time, many failures occurred, always at or very close to the couplings. This was attributed to water vapor entering the cut fiberglass fibers; so, the threads were epoxy coated similar to doping metal pipe threads and with an epoxy coating after make up. Failures still occurred. The final determination was that, in wells with low water levels, the threads were subjected to tensile stresses not present in aboveground use; where, stress was compressive due to pressure and thermal expansion. Happily, the manufacturers warranted the pipe, including labor.

In some wells, those with higher water levels, the pipe is still in service after 25 years. So far as is known, no one has attempted to determine the maximum depth to water for satisfactory service life.

The well drilling company doing most of the DHE business in Moana is now recommending threaded and coupled 304 stainless steel. Currently, SST is about $10 per ft for 1-½ in.–about three times the cost of black iron, but less than brass and some non-metallics.

Today, there are an estimated 250 geothermal wells in the Moana area of Reno, NV. Most of these have DHEs–many of which are pumped with small submersible pumps to increase temperatures. Nevada regulations prohibit pumping except when an injection well is utilized. No new wells have been drilled in the area in the last 10 years (Flynn, 2001).

NEW ZEALAND

The only other concentrated DHE use is in New Zealand at Taupo and Rotorura. There were about 500 geothermal wells in use in Taupo in 1987, about half utilizing DHEs (Curtis, 1988). Most wells in Rotorura historically were discharged to the surface. In 1985, the Geothermal Task Force recommended discharge be stopped an DHEs installed. Most wells were shut in and only less than a dozen DHEs were in use in Rotorura in 1990.

Well boreholes will not stand open in the softer formations; so, the convection flow outside the casing is not possible. Wells are equipped with a convection promoter (Figure 4) with the DHE either inside or outside the promoter–but the corrosion problems are the same–at the water level. As far as is known, black iron pipe is the only material used for the DHEs–the rigorous exclusion of air by sealing the top.

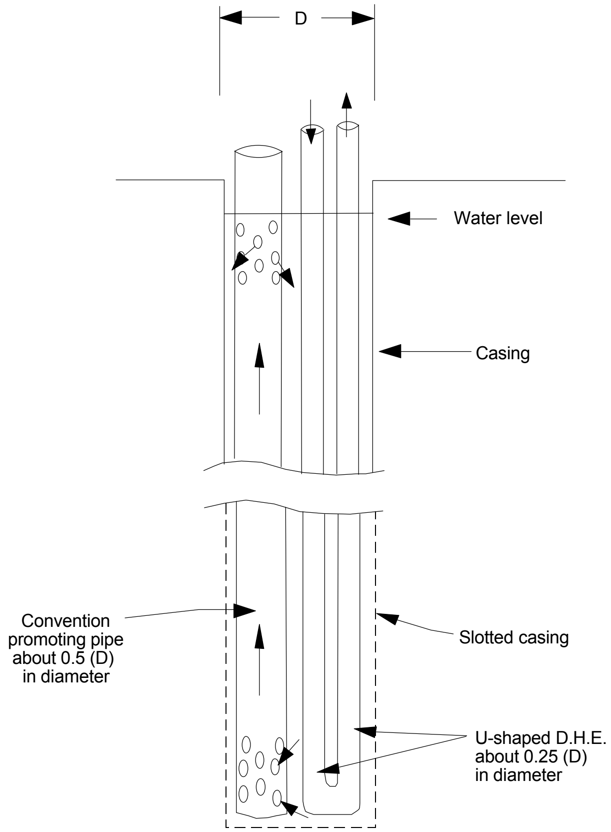

Figure 4. ***Convection promoter and DHE (New Zealand type).***

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