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Built to Last: Underground Piping for District Heating and Cooling

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ABSTRACT

Underground thermal distribution pipelines are common at institutional facilities where thermal energy is generated at a central utility plant and is distributed to various buildings (otherwise known as district energy or district heating and cooling). Chilled water, hot water, or steam is created and distributed through a network of underground pipelines to provide building heating or cooling.

The high range of pressures, temperatures, fluid properties, and other design considerations observed in these underground thermal piping systems can present many technical challenges. There are many factors to consider in selecting and specifying the appropriate underground thermal piping system including service pipe material, insulation material and thickness, corrosion protection and jacket material, expansion and contraction considerations, field-insulated vs. factory-insulated, and constructability/cost considerations.

INTRODUCTION TO DISTRICT HEATING AND COOLING

District energy systems are an efficient and reliable means of delivering heating and cooling medium to buildings. A central utility plant generates chilled water, hot water, or steam and delivers the thermal energy to various buildings through a network of pipelines. Providing heating and cooling from a central location can reduce fuel consumption, increase efficiency, reduce building footprint, streamline maintenance, and offers the potential to provide mass energy to multiple buildings utilizing “low-carbon” fuels such as natural gas or bio-fuels. There are currently more than 6,000 district energy systems in the United States primarily located in downtown districts, colleges, hospitals, airports, and military bases.

The creation, expansion, conversion, maintenance, or renewal of a district energy distribution system often requires the design and specification of an underground thermal distribution piping system.

Historically, the design of building heating and cooling systems, including high pressure or high temperature piping systems, has been performed by mechanical engineers. However, the challenges associated with designing an underground piping system, including excavating, navigating existing underground utilities, slopes and gravity drainage, and corrosion resistance are typically the responsibility of a civil engineer.

There are many similarities and many differences between underground thermal distribution piping systems and those traditionally classified as civil piping systems such as stormwater sewer piping, sanitary sewer piping, and domestic water piping.

Figure 1 – District Energy Distribution System
(Image Courtesy of International District Energy Association)

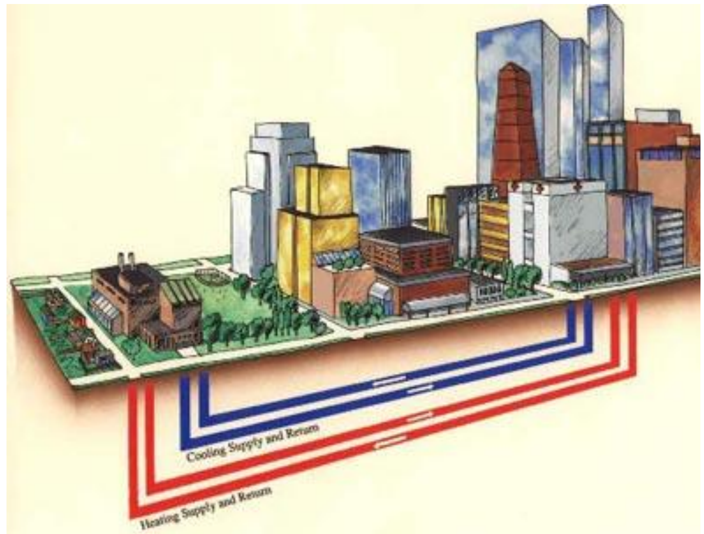

Figure 2 – Underground Thermal Distribution Pipelines
(Image Courtesy of International District Energy Association)

CHILLED WATER

There are many similarities between the design of an underground domestic water piping system and an underground chilled water piping system. Most notably, the restraint of joints, fittings and depth below the frost line are all important (and similar) considerations for both types of systems. The use of concrete thrust blocks, compression gaskets, and/or wedge-action gland restraints are all different (and acceptable) ways to restrain both a domestic water and chilled water piping system.

The first (and most notable) difference between a typical domestic water piping system and typical chilled water (or hot water) system is the presence of a 2nd (or “return”) pipe. When chilled water is created at a plant (for example 42°F) it is distributed to a user building through a “supply” pipe. The thermal energy is extracted at the building and the chilled water is returned to the plant through a “return” pipe at a higher temperature (for example 53°F). This water is returned to the plant because it is more economical than purchasing new treated “make-up” water and because it is more economical to re-cool water from 53°F back to 42°F than it is to cool new water (for example from 60°F down to 42°F).

The second distinction is the use of insulation which slows the thermal loss of the chilled water energy within the piping system. Distribution pipe diameters typically range from 2” to as much as 60” and have significant external surface area to conduct heat. If there is a high temperature difference (or delta T) between the chilled water (42°F) and the surrounding ground temperature (for example 60°F) it may be cost beneficial to provide insulation with the chilled water piping. If there is a low delta T between the chilled water temperature and the surrounding ground, insulation may not provide the most cost-benefit. There are some instances where insulation is recommended on the supply and not on the return. A project specific cost-benefit analysis should be completed to determine if piping insulation should be provided. If insulation is ultimately utilized, the type of insulation and outer waterproof “jacket” should be carefully considered to minimize deterioration of the insulation from moisture within the ground.

The third distinction (and arguably the most critical) between a domestic water and chilled water system is the design pressure. Residential or domestic water pressures tend to range between 45 and 80 psi. At this pressure range, many different piping materials are available for use. However, at an increased pressure (sometimes as high as 200 psi in certain chilled water systems), pressure limits can be reached at gaskets, flanges, or mechanical (bolted) joints. A higher chilled water system pressure typically pushes a designer to specify a seamless piping system such as welded steel or fused HDPE piping. While welded steel is an acceptable choice for an underground chilled water system, the introduction of steel requires a protective system against corrosion. Depending on the material type and ground temperature, underground anchors may also be required to limit contraction of the piping system once energized.

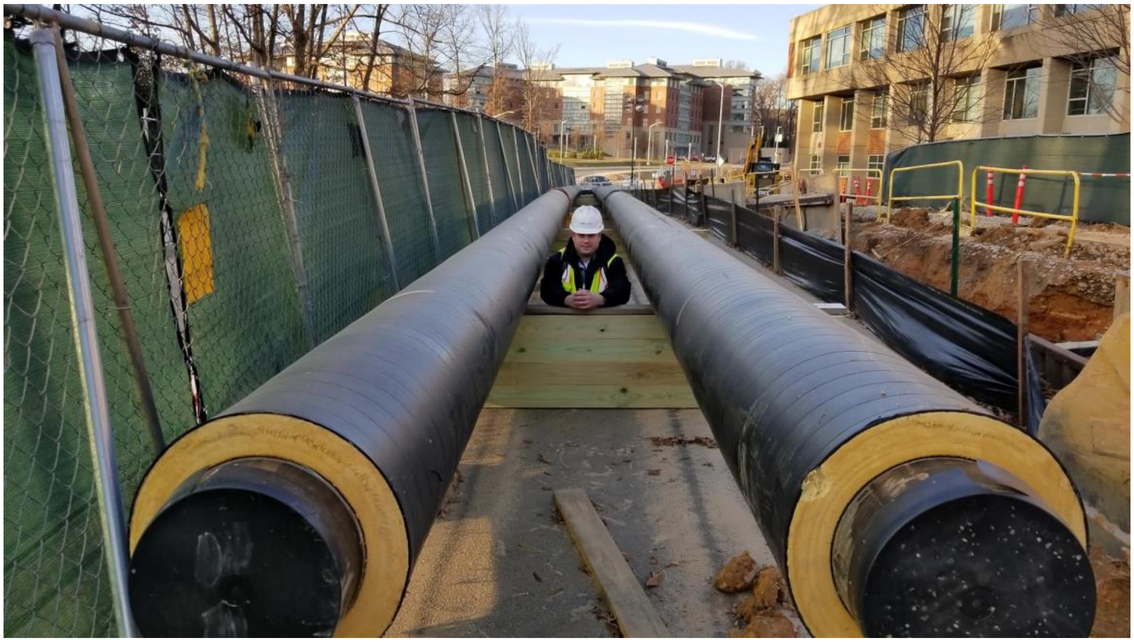

Figure 3 – Insulated and Jacketed Chilled Water Supply and Return Piping

LOW TEMPERATURE HOT WATER (BELOW 250°F)

As discussed in the chilled water section, the limiting factor on many types of piping systems are the pressure rating of the joints and gaskets. These pressure ratings can decrease drastically with the introduction of heat or hot water. As the design temperature of a piping system increases, fewer options are available for the service pipe (for example HDPE piping is typically not recommended for a system above 180°F). Because of the larger delta T between hot water and the ground, insulation is typically recommended for hot water piping systems. As the options available for hot water piping begin to narrow towards welded steel, the insulation thickness and protective outer jacket need to be examined more closely. Typically, an underground, welded-steel, insulated piping system, includes some sort of corrosion resistant protective outer jacket, such as HDPE, FRP, PVC, or a cathodic protection system. The temperature rating (melting point) of this outer jacket is the limiting factor of this type of system. This will determine the maximum temperature of the system and guide a designer towards recommending an insulation thickness.

Again due to the larger delta T between the hot water and ambient temperature, the expansion of a hot water system always needs to be considered. Different materials grow and expand at different rates as a function of temperature. If the pipe material, expansion coefficient, length between two fixed points, and delta T is known, then the growth or expansion of the system can be calculated. This growth must be accommodated both in an above ground and below ground hot water system. In an underground system, this can be accomplished through the use of expansion loops with expansion pads or expansion compensators (expansion joints). If this growth is restricted (by compacted soil for example), safety and maintenance issues will be created due to the trapped thermal stresses.

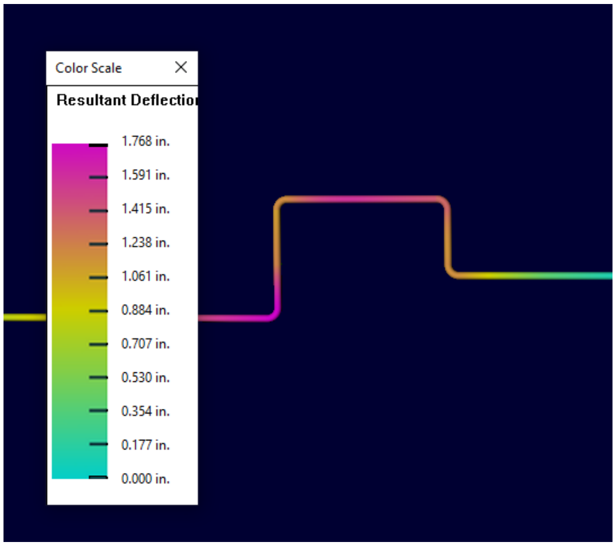

Figure 4 – Expansion Loop Deflections

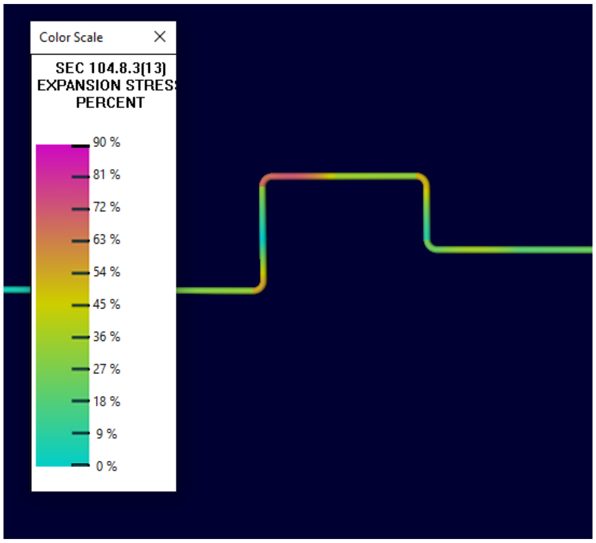

Figure 5 – Code Allowable Expansion Stress

HIGH TEMPERATURE HOT WATER AND STEAM (ABOVE 250°F)

With the temperature rating of the outer jacket setting the limit for a low temperature system, additional provisions must be provided for a high temperature system. When the hot water gets above a certain temperature (generally 250°F), an annular space can be provided between the service pipe and the outer most jacket. One way to accomplish this is through the use of a secondary outer conduit commonly known as a "double-walled" system. This type of system is comprised of a service pipe, service pipe insulation, an annular space, the outer conduit, conduit insulation, and finally the outer corrosion-resistant protective jacket. With this type of system, the outer conduit can be sized to accommodate the thermal expansion discussed in the previous section.

The introduction of this annular space and outer conduit introduces new design challenges that must be taken into consideration. The presence of an annular space creates an opportunity and area for water or water vapor to collect. Low point drains and high point vents can be provided on the outer conduit to remove this moisture from the system. In order for the low point drains and high point vents to be most effective, the entire length of piping should be sloped or pitched to encourage water to the drains and vapor to the vents.

High pressure steam is also a process fluid that is commonly distributed in district energy systems. It has a high thermal energy and does not require pumps which can make it an attractive energy system. Underground high pressure steam piping is very similar to high temperature hot water "double-walled" piping in both system expansion and conduit venting and draining. Another very important factor needs to be considered when designing a high pressure steam piping system: with steam, not only is the slope of the system required for removal of the vapor and water from the outer conduit, it is mandatory for the removal of condensed steam vapor (condensate) within the service pipe. When a steam system is energized (or under normal operating conditions), the hot steam can come into contact with the cold piping system and flash into condensed water. If not safely removed from the service piping, this condensed water can collect at low points (or behind valves) and create safety and maintenance "hammer" issues. A sloped steam piping system allows the condensate to gravity drain to a low point where it can be safely removed from the system.

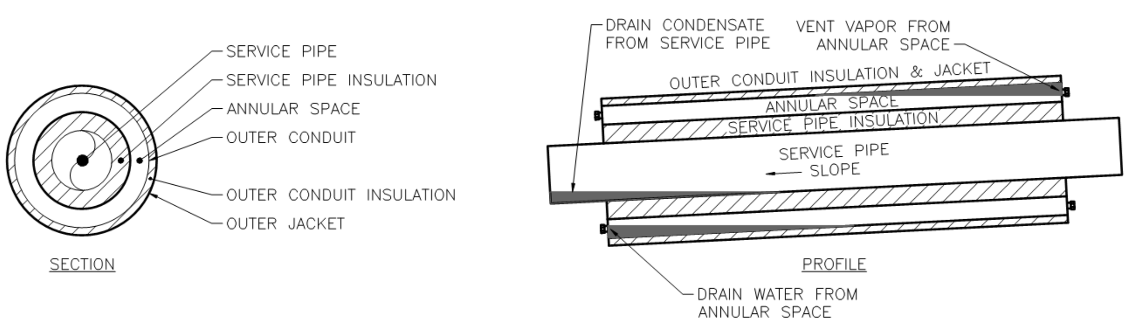

Figure 6 – Double-Walled Piping

ALTERNATIVE DISTRIBUTION METHODS

The types of piping systems described above can be provided by a pre-insulated piping manufacturer (where the pipe arrives to the site with the specified service pipe, insulation, and jacketing already assembled) or certain types of systems can be field-insulated on-site where a field-fabricated annular space is constructed with concrete and forms. Another alternative is a hydrophobic, insulating, poured in place insulation where guides, supports, anchors, and expansion pads are fabricated in the field.

Another common means of distributing thermal pipelines is by way of an underground concrete utility tunnel or utility trench/coffer. These types of systems are similar to piping systems within a building in terms of piping material, insulation, jacket, and expansion compensation. The design of the tunnel or trench/coffer can be customized for access from grade or at other key locations.

Figure 7 – Thermal Piping in Trench/Coffer and Walkable Tunnel

CONCLUSION

There are many different means of distributing thermal energy in a district energy system. Each piping system has specific components such as service pipe, insulation, and jacket selection that need to be carefully considered and specified. Failure to consider joint restraint, burial depth, design pressures, design temperatures, expansion, corrosion protection, and water removal can create maintenance issues, safety concerns, and decrease the service life of the system. It is important to understand how each of these considerations interact with each other to ensure proper operation and longevity of the system when evaluating a thermal distribution piping system.