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Underground Piping Systems

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One of the main components of heating and cooling systems serving multiple buildings such as at a university campus is the distribution or piping network that conveys the energy. The piping is often the most expensive portion of these types of systems. The piping usually consists of a combination of preinsulated and field-insulated pipe in both direct burial and concrete tunnel applications. These thermal utilities must supply sufficient energy at an appropriate temperature and pressure to meet the system heating and cooling needs.

There are many considerations when selecting and designing underground chilled water, heating hot water piping systems that will impact the life and thermal losses of the systems and components selected. This month's column includes some information for designing underground piping systems.

Utilidors/Tunnels vs. Direct-Buried

A utility tunnel is a passage built underground or aboveground to carry utility lines. Utility tunnels are generally large enough for maintenance access. Utilidors are smaller tunnels typically large enough for only the utility piping. Utilidors are usually connected together with manholes. Underground tunnels and utilidors provide an extra layer of protection for the underground utilities. If utilidors are installed with the tops at grade, they also allow maintenance of utility lines without disrupting the landscaping or streets above.

Underground utility tunnels and utilidors should be designed to keep groundwater out and manage water intrusion with drains and/or sump pumps. Many times these underground tunnels can provide a corrosive atmosphere for metals requiring corrosion-resistant selection of support and valve materials.

Utility tunnels and utilidors are generally best in "greenfield" facilities or campuses that do not already have an extensive direct-buried underground utility infrastructure. Piping utilidors generally have an additional cost of 10% to 20% over direct-buried options.

Direct-buried piping is required when utility tunnels or utilidors are not used. It is also easier to route direct-buried piping through existing underground infrastructure. Chilled water and heating hot water direct-buried piping is generally preinsulated with a vapor proof service jacket (HDPE, PVC, CPVC, etc.). Many campuses do not insulate the chilled water return pipe when using plastic pipe and operating at close to ground temperature.

Buried installations of distribution piping involve trench excavation, placing pipe in the trench, placing embedment backfill around the pipe, and then placing backfill to the required finished grade. Pipe application and service requirements, size, type, soil conditions, backfill soil quality, burial depth, and joining requirements will all affect the installation. The care taken by the installer during installation will dramatically affect system performance. A high quality installation in accordance with recommendations and engineered plans and specifications can ensure performance as designed, while a lack of attention to detail or low quality installation can cause substandard performance.

Service Pipe Materials

Many options exist for service pipe materials and joining methods. Pipe material selection and joining methods are governed by the utility service temperature and pressure ratings required. Commonly used direct-buried carrier pipes are shown in *Table 1*.

Corrosion of ferrous metals buried underground is a naturally occurring process and is the leading

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cause of underground piping system failures. "Underground Corrosion" Circular C-579"[1] shows that ferrous metals including carbon steel, wrought iron and ductile iron corrode at essentially the same rate underground. The apparent corrosion resistance of ductile iron is attributed to the fact that graphitized ductile iron retains its appearance as a pipe even when much of the iron is gone. Underground corrosion of ferrous metals occurs through electrolytic and galvanic corrosion. For more information on causes refer to "Causes of Underground Corrosion" Technical Paper 82."[2] Most of the underground exterior-piping corrosion failures witnessed by the author have originated at piping joints due to lack of corrosion protection or poor workmanship and inspection during installation.

Ductile iron (DI) and polyvinyl chloride (PVC) pipe and fittings may be joined to themselves and to other piping materials using various mechanical joining methods including gasketed push-on joints, flanges, mechanical joint (MJ) adapters, and transition fittings. All mechanical joint products used with pressure piping systems must provide restraint against pullout. Joining devices and components with joints that seal but do not restrain must be provided with additional external bolt-on restraints or thrust blocks.

It is important to caution that gasketed mechanical joints on PVC and DI pipe will experience leakage. This is normally acceptable in domestic water distribution systems but may not be desirable in large chilled and heating hot water systems. Allowable leakage from these joints can be calculated using AWWA C600[3] and C605.[4] Experience has shown that heating hot water systems will leak at a higher rate than chilled water systems when using gasketed push-on joints.

PVC and high-density polyethylene (HDPE) pipe resist typical aging effects because they do not rust, rot, corrode, tuberculate, or support biological growth, and they resist the adherence of scale and deposits. PVC and HDPE used in chilled water piping applications are electrically nonconductive polymers and not adversely affected by naturally occurring soil conditions. As such, they are not subject to galvanic action and do not rust or corrode. The surface characteristic of PVC and HDPE pipe are classified as "smooth" pipe and as such, they offer lower resistance to the flow of fluids compared to steel and iron pipe.

TABLE 1 Service pipe materials.

PIPE MATERIAL	SERVICE	RELATIVE COST	REFERENCE STANDARDS
Carbon Steel	CHW, HHW	$$	ASTM A53
Type K Copper	CHW, HHW	$$$$	ASTM B88
Ductile Iron	CHW, HHW	$$$	AWWA 151
PVC	CHW	$	AWWA C900 (4 to 12 in.), AWWA C905 (≥14 in.)
HDPE	CHW	$	AWWA C906
PEXa	CHW, HHW	$$	ASTM F877 (≤5 in.)

HDPE provides an additional benefit because it can be welded using heat fusion, not relying on a gasketed mechanical joint. The principle of heat fusion is to heat and melt the two joint surfaces and force the melted surfaces together, which causes the materials to mix and fuse into a monolithic joint. When fused according to the pipe and/or fitting manufacturers' procedures, the joint becomes as strong as, or stronger than, the pipe itself in both tensile and pressure properties (see "PE Pipe—Design and Installation" AWWA Manual M55[5]).

Crosslinked polyethylene (PEX) is a modified polyethylene material, typically high-density polyethylene (HDPE) that has undergone a change in the molecular structure using a chemical or a physical process whereby the polymer chains are permanently linked to each other. This crosslinking of the polymer chains results in improved performance properties such as elevated temperature strength, chemical resistance, environmental stress crack resistance, resistance to slow crack growth, toughness, and abrasion resistance. This piping provides a plastic alternative for heating hot water applications. The service temperature of PEXa can be 180°F to 203°F (82°C to 95°C) with short-term exposure to 210°F (99°C). The typical pressure rating is 100 psig at 180°F (690 kPa at 82°C).

Hydraulic shock is the term used to describe the momentary pressure rise in a piping system that results when the liquid is started or stopped quickly. The momentum of the fluid causes this pressure rise; therefore, the pressure rise increases with the velocity of the liquid, the length of the system from the fluid source, or with an increase in the speed with which it is started or stopped. Examples of situations where hydraulic shock can occur are valves that are opened or closed quickly. Surge pressures should be calculated for plastic piping systems. The surge pressure is added to the maximum operating pressure and should not exceed the short-term pressure rating of the pipe.

Pipe Insulation Materials

Insulation provides the primary thermal resistance against heat loss or gain in distribution systems. Insulation of piping in underground utilidors that could be subject to water intrusion should use closed cell insulation. Thermal properties and other characteristics normally used in thermal distribution systems can be found in Chapter 12, "District Heating and Cooling," of the *2012 ASHRAE Handbook*.[6]

Insulation used in most preinsulated chilled water and heating hot water applications is polyurethane. No insulation system is completely vapor tight. The best way to minimize corrosion is to make the system highly water resistant by using closed-cell insulation material coupled with a good vapor retarder. Preinsulated ferrous piping should have polyethylene heat shrinkable end caps or similar method to prevent moisture from penetrating the preinsulated casing. Carbon steel welded exposed joints should be protected with a polyethylene tape coating system on the pipe prior to bridging the preinsulated casings with a polyethylene sleeve and insulating the joint. Do not assume that the preinsulated jacketing system will provide complete protection against corrosion of ferrous materials.

Copper wires can be installed during fabrication to aid in detecting and locating liquid leaks in the preinsulated piping system. These systems can monitor the entire length of the underground piping system by looking for a short in the circuit using Ohm's law or monitor the impedance change using time-domain reflectometry. The copper wires can also be used as a tracer wire for locating the buried pipe in the future using a metal detector.

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Examples of Underground Pipe Failures

Photo 1 shows corrosion on a pre-insulated heating hot water supply ductile iron joint after being buried for 18 years. The joint was field insulated with flexible foam insulation and covered with a heat shrink polyethylene sleeve. The majority of heating hot water supply joints showed similar corrosion. None of the heating hot water return joints showed corrosion. The corrosion was due to excessive leakage at the supply joints.

PHOTO 1 Ductile iron pipe joint corrosion (18 years).

PHOTO 2 Ductile iron pipe joint failure (10 years).

Photo 2 shows corrosion on a pre-insulated heating hot water supply ductile iron joint after being buried for 10 years at a different site. This installation had the joints exposed to the backfill with no insulation. The author has witnessed many similar failures of ductile iron pipe used in heating hot water systems.

Photo 3 shows a failed section of 24 in. (0.6 m) SDR 26 Class 160 PVC chilled water pipe. Roughly 70 ft (21 m) of the pipe failed when the plant automatically closed the main return valve against a full-speed 350 hp (261 kW) secondary pump. The operating pressure plus surge pressure exceeded the short-term pressure rating of the 22-year-old SDR 26 piping.

PHOTO 3 SDR 26 PVC pipe failure (22 years).

Concluding Remarks

Underground piping systems should be designed for near zero leakage, and must account for thermal expansion, degradation of material, high-pressure and hydraulic shock, heat loss/gain, and corrosion. A fundamental understanding of material characteristics is an inherent part of the design process for any underground piping system. With such an understanding, the piping designer can use the properties of the material to design for optimum performance for the intended service.

Based on decades of experience with campus direct-buried chilled water and heating hot water systems, it is best to use piping systems that do not corrode and do not allow joint leakage. If ferrous metals must used in underground applications, they should be installed in utilidors or designed with corrosion protection.

References

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5. AWWA. 2005. "PE Pipe—Design and Installation." AWWA Manual M55, 1st Edition, American Water Works Association.

6. *2012 ASHRAE Handbook—HVAC Systems and Equipment*. Chapter 12, "District Heating and Cooling." ■