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HDPE being staged for fusion joining. HDPE is another pipe material the design engineer should know when designing direct-buried piping.

HDPE Pipe for Corrosion- And Leak-Free Operation

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It is important to understand available pipe materials when direct-burying pipe underground. High-density polyethylene (HDPE) pipe has gained acceptance as a non-ferrous alternative to steel pipe in direct-bury applications for chilled and condenser water systems. While steel pipe can deliver unmatched temperature and pressure service levels, properly designed HDPE pipe can deliver corrosion- and leak-free operation.

Some unique challenges require special design considerations due to HDPE piping's viscoelastic nature, very low material allowable stress, thermal conductivity, large coefficient of thermal expansion, and relatively thick pipe walls. This month I will review these considerations to design and specify underground HDPE piping systems.

Underground Piping Objectives

In the past, most direct-buried chilled water systems used either carbon steel, ductile iron (DI), or polyvinyl chloride (PVC) pipe. These systems and modes of failure were presented in a previous *Journal* column.[1] Ductile iron and 12-in. (305 mm) and larger diameter PVC pipe are typically joined using gasketed push-on joints. These joints are restrained with either concrete thrust blocks or an external bolted-on mechanical coupling. The allowable leakage rate for these types of joints are specified in AWWA Standard C600-10[2] and AWWA Standard C605-13.[3] The author has found that monthly and annual allowable leakage on a large distribution system can be substantial and will result in loss of treated water. Excessive makeup water can also lead to loss of adequate levels of corrosion inhibitor in the circulating water. One objective is to design and install distribution piping that will not leak.

Pre-insulated carbon steel piping is also commonly used in direct-buried chilled water systems. The piping has unmatched temperature and pressure ratings but is subject to both internal and external corrosion. According to NACE International, corrosion of ferrous metals buried underground is a naturally occurring process and is the leading cause of underground piping system failures. Pre-insulated and jacketed steel

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pipe is protected from soil corrosion by providing a PVC or HDPE continuous barrier over the insulation. Joint installation errors or damage from subsequent excavation can cause the insulation jacket to be penetrated, leading to external corrosion and eventual pipe failure. Another design objective is to design and install distribution piping that will not experience corrosion and will provide a long service life (>50 years).

HDPE Piping

Engineering Properties

Several types of thermoplastics exist, and they are classified as amorphous or semicrystalline. Two thermoplastics are PVC, which is amorphous, and HDPE, which is semicrystalline.

HDPE is a polyethylene (PE) thermoplastic. It is more abrasion- and heat resistant than PVC. HDPE pipes are convenient to use in underground piping because they dampen and absorb shock waves, minimizing surges that can affect the system. Although both materials are strong and durable, they vary in strength and other aspects, including their pressure capacity for design stress.

Table 1 shows a physical and mechanical properties comparison of HDPE and carbon steel. The coefficient of thermal expansion is substantially higher for HDPE compared to steel pipe. This is usually not an issue with direct-buried chilled and condenser water systems since the temperature change is low and buried HDPE pipelines typically do not move due to soil friction.

HDPE is an electrically nonconductive polymer not adversely affected by naturally occurring soil conditions. As such, it is not subject to galvanic action and does not rust or corrode. PE has no nutritional value and will not support microbiological-induced corrosion and fouling compared to carbon steel. HDPE also has an extremely smooth surface compared to carbon steel, which provides minimal opportunity for the precipitation of minerals such as calcium carbonate onto the interior surface. This smoothness also reduces pressure drop and associated pump energy.

PE plastic pipes and fittings are classified by ASTM Standard D3350-14[4] in accordance with density, melt index, flexural modulus, tensile strength at yield, slow crack growth resistance, and hydrostatic strength classification. High-density typically refers to PE with a base resin density of 0.034 lb/in.^{3} to 0.0345 lb/in.^{3} (0.941 g/cm^3 to 0.955 g/cm^3). Base resin density refers to the density of the natural PE that has not been compounded with additives and/or colorants. Most high performance HDPE materials today will have a base resin density around 0.0343 lb/in.^{3} (0.950 g/cm^3).

TABLE 1 Carbon steel and HDPE physical and mechanical properties.

	MATERIAL	
	CARBON STEEL	POLYETHYLENE (HDPE)
Modulus of Elasticity (*E*)	27.9×10^6 psi	2.8×10^4 psi
Poison's Ratio (*v*)	0.3	0.4 to 0.45
Pipe Roughness Value (*e*)	0.00015 ft	0.000005 ft
Coefficient of Thermal Expansion	6.5×10^{-6} in/in·°F	67×10^{-6} in/in·°F
Thermal Conductivity (*K*)	25 Btu/h·ft·°F	0.26 Btu/h·ft·°F
Allowable Stress	15,000 psi	350 psi

There are currently AAWA and ISO standards that apply to PE pressure pipe and fittings: AWWA Standard C901-08,[5] AWWA Standard C906-15[6], and ISO 4427-2007,[7] Parts 1 to 5. The Plastic Piping Institute (PPI) trade association published additional guidance for the proper and effective use of plastic piping systems. The trade association develops policies and procedures for the recommendation of the estimated long-term strength for commercial thermoplastic piping materials and includes this in Technical Report-3, TR3.[8] Recent enhancements to PE materials have resulted in changes in ASTM Standard D3350-14 and PPI's TR3 to define, recognize, and categorize higher performance PE materials.

Working Pressure Rating and Pressure Class

The parameters that control the design of HDPE pipe for chilled and condenser water are the sustained internal pressure, the intermittent surges that may occur during operation, and the temperature of the operating liquid. The working pressure rating (WPR) accounts for all of these factors. The terms pressure rating (PR) and pressure class (PC) define the limits of the pipe for sustained and surge pressures at operating temperatures through 80°F (27°C).

The pressure class for HDPE pipe in AWWA Standard C906-15 includes allowances for surge pressures. The allowances for recurring surge is 50% of the PC and occasional surge is 100% of the PC. Where the operating temperatures are expected to be higher than 80°F (27°C) or the surge pressures are higher than those allowed by the PC definition, the WPR must be reduced below the PC. For instance, the WPR would be reduced to 80% of the PC if the maximum operating temperature is 91°F to 100°F (33°C to 38°C).

The pressure class rating is a function of both the PE material used and the standard dimension ratio (SDR). The SDR is the ratio of pipe diameter to pipe wall thickness. For a given PE material, as the SDR increases, the pipe wall thickness and pressure rating decrease. A pipe material designation with a higher hydrostatic design basis would provide for a higher pressure class for the same standard dimension ratio. For example, PE4710 at SDR 11 has a pressure class of 200 psi (1380 kPa) versus PE3608 at SDR 11 with a pressure class of 160 psi (1103 kPa). *Table 2* shows the pressure classes for pipe material designations PE3608 and PE4710 at various SDR ratios.

Heat Fusion Joining

An integral part of any pipe system is the method used to join the system components. There are two methods for producing heat fusion joints. The first and most common for underground distribution piping is conventional heat fusion where heat is applied with an external heating plate. *Photo 1* shows fusion welding equipment being used in a pipe trench. Conventional heat fusion includes butt, saddle, and socket fusion. ASTM Standard F2620-13[9] provides standard practice and procedures for joining PE pipe and fitting by means of heat fusion. The second method is electrofusion, where an electric heating element is integrated into the electrofusion fitting. Electrofusion is used to produce socket and saddle heat fusion joints. Heat fusion causes the materials to mix and fuse into a monolithic joint and becomes as strong as or stronger than the pipe itself in pressure properties.

TABLE 2 HDPE pipe pressure rating for water at 80°F.

SDR	PIPE PRESSURE RATING, PSI	
	PE3608	PE4710
7.3	265	315
9	200	250
11	160	200
13.5	130	160
17	100	125
21	80	100

Properly made heat fusion joints do not leak. Piping joined by heat fusion, electrofusion, flanges, and mechanical joint (MJ) adapters are fully restrained and do not require external joint restraints or thrust block joint anchors. Butt fusion produces a double-roll melt bead on the outside and inside of the pipe. AWWA indicates that internal bead removal is not necessary because its effect on hydraulic flow is negligible.

Selection and Design

Determining Pressure Rating Required

The first step is to determine the maximum

PHOTO 1 HDPE fusion welding equipment in trench.

anticipated, sustained operating pressure for the pipe. HDPE works well for underground systems that require less than 200 psi (1380 kPa). Steel pipe is typically required at higher pressures. The designer cannot select the HDPE pressure class by simply looking at the operating pressure. Pressure surges occur in piping systems when flow suddenly changes. These surges can result from starting and/or stopping a pump, opening or closing valves, or power failures. Using variable frequency drives when starting and stopping pump motors and not having quick operating valves are cost-effective solutions that reduce surges or hammering problems.

As indicated earlier, the HDPE pressure class has assumed 50% of the pressure class for recurring surge and 100% of the pressure class for occasional surge. The working pressure rating will need to be reduced if the maximum operating temperature is above 80°F (27°C). Surge calculations should be performed if anticipating a sudden change in velocity greater than 5 ft/s (1.5 m/s). Refer to AWWA Manual M55,[10] Chapter 4 for guidelines on pressure surge calculation and determining the working pressure rating of HDPE pipe since this is dependent on maximum operating temperature and occasional and recurring surge. Manual M55 provides the following equations to estimate the transient pressure surge. An abrupt change in velocity of the flowing liquid generates a pressure wave, the velocity of which is calculated with the following equation:

$$\alpha = \frac{4,660}{\sqrt{1 + \frac{K}{E_d}(DR - 2)}} \quad (1)$$

Where

α = wave velocity, ft/s

K = bulk modulus of fluid at working temperature (300,000 psi [2 million kPa] for water at 73°F [23°C])

E_d = dynamic instantaneous effective modulus of pipe material (150,000 psi [1 million kPa] for PE pipe)

DR = pipe dimension ratio

Using the above formula for water in SDR 11 PE pipe, the wave velocity would be 1,069 ft/s (326 m/s). The transient surge pressure can be calculated from the wave velocity and the change in fluid velocity with the following equation:

$$P_s = \alpha\left(\frac{\Delta v}{2.31g}\right) \quad (2)$$

Where

P_s = transient surge pressure, psig

Δv = velocity change occurring within the critical time 2L/α, in seconds, where L is the pipe length, ft

g = gravitation acceleration, 32.2 ft/s^2 (9.8 m/s^2)

A sudden velocity change of 3 ft/s (0.9 m/s) for SDR 11 pipe would have a transient surge pressure of 43 psig (297 kPa).

The WPR should always be less than or equal to the selected PC. Once the WPR is known, select the most cost-effective combination of HDPE pipe material and standard dimension ratio to provide the pressure class required.

HDPE Design and Installation Considerations

HDPE pipe diameter is typically specified by iron pipe size (IPS). This means HDPE pipe will have a significantly smaller inside pipe diameter than nominal pipe size (NPS) steel pipe; therefore, it is sometimes oversized to achieve the desired inside pipe diameter. For example, 12 in. IPS (300 mm) SDR 11 HDPE pipe has an inside diameter of 10.3 in. (262 mm), whereas A53 carbon steel STD NPS pipe would have an inside diameter of 12 in. (300 mm). This needs to be factored into the pipe sizing for the flow rates required. In some cases, depending on butterfly valve dimensions used in the system, flange adaptors with tapered ID spacers may be required for the valve to open and close freely.

The low thermal conductivity and wall thickness of HDPE pipe combined with the very small temperature difference between chilled water return and ground temperature allows for installing uninsulated direct-buried HDPE piping on chilled water return lines in most locations.

Unlike steel pipe, HDPE pipe may be cold bent in the field without affecting the working pressure rating. The minimum allowable long-term bend radius for pipe is determined by the pipe diameter and dimension ratio. The pipe will typically bend without great effort to about a 70-pipe diameter radius. The minimum cold bending radius for SDR 11 pipe is 25 pipe diameters. HDPE pipe can be used with horizontal directional drilling. PPI TR-46[11] provides guidance for using HDPE for horizontal directional drilling.

When determining the minimum depth to bury the pipe, the compressive wall stress on the pipe from exterior forces should be kept less than the allowable compressive stress of the HDPE material. Generally, if the pipe being used has a SDR of 21 or less, and the cover is equal to the greater of the pipe diameter or 3 ft (1 m) of cover, AASHTO H20 truck loading is met. The pipe embedment materials should be coarse-grained, stable, and compacted to 85% to 90% standard proctor density.

HDPE and PVC pipe have similar costs for the same pressure class. Both of these pipe materials are considerably less expensive than A53 STD steel pipe. The steel pipe material costs can be four to eight times more expensive than HDPE pipe for 4 in. to 12 in. (100 mm to 300 mm) pipe depending on pipe diameter. Smaller pipe diameters have a greater cost differential than larger diameters.

Connecting to Other Pipe Materials

In some instances HDPE piping will need to connect to other piping materials. HDPE pipe can be connected to PVC pipe using slip-joint anchor fittings, gasketed joint adapters, and flanged connections. Some manufacturers also provide HDPE to PVC transition fittings. HDPE flanges can be used to connect to steel and ductile iron pipe. HDPE mechanical joint (MJ) adapters can be used to connect to existing ductile iron pipe.

Commissioning

HDPE, like other piping materials, should be thoroughly flushed prior to testing to prevent damage to valves and other fittings from any material left in the pipe during construction. A minimum flush velocity of 3 ft/s (0.9 m/s) is recommended to move the material in the pipe. The piping system should also be tested using water. HDPE leak testing is usually done per ASTM Standard F2164[12] at a pressure specified by the designer, typically 1.5 times the design WPR. This is a field leak testing procedure since PE pipe is a lower modulus viscoelastic material that dilates in diameter (creep-strains) when subjected to higher stress during hydrotest.

This means for a fixed volume of clean fill water, the hydrostatic pressure will decline slightly during the test time, as the PE molecular chains stretch and align under high stress. During the test period, water is added to keep the pressure constant since the thermoplastic pipe will expand with pressure. Normally, if the pressure remains within 5% of the target value for one hour, the leakage test passes.

Fusible PVC Piping

While not the primary subject of this month's column, manufacturers now provide fusible AWWA C900 and C905 PVC pipe. This PVC pipe uses a proprietary material formulation with a combination of the required heat, time, and pressure that results in fully pressure rated butt fusion joints. To achieve the same pressure rating as HDPE pipes, PVC pipe walls are approximately 2.5 times thinner than HDPE pipes. The author is currently evaluating this material as an alternative to HDPE for underground chilled water distribution.

Concluding Remarks

Based on decades of experience with campus direct-buried chilled water and condenser water systems, it is best when pressure requirements allow using piping systems that do not corrode and do not allow joint leakage. HDPE is another pipe material the design engineer should know when designing direct-buried piping. An understanding of HDPE material characteristics is an inherent part of the design process for applying this material to underground piping systems. With such an understanding, the piping designer can use the properties of the material to design for optimum performance for the intended service.

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