SELECTING SUSTAINABLE PIPE MATERIALS

Pipeline running across millions of acres of Native American land in the Southwest demonstrates the opportunity to design water pipeline systems to minimize pollution.
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U.S. Public Health Service engineers reviewed years of lifecycle analysis data to develop best practices for selecting buried water and wastewater piping materials in order to reduce toxicity and impacts.

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As civil and environmental engineers designing and managing construction of water and wastewater systems, Commissioned Corps officers working for the Indian Health Service and the National Park Service are responsible for specification of the types and sizes of hundreds of buried piping systems that get installed each year in Native American communities and our National Parks. Moreover, federal agencies are directed through laws and executive orders to take action and implement technology and processes to reduce energy demand, eliminate waste, and prevent pollution.

To help meet the intent of these requirements, a workgroup of U.S. Public Health Service engineers of the Public Health Engineering Practice Subcommittee of the Engineering Professional Advisory Committee reviewed numerous published materials from around the world on what the most sustainable pipe materials should be for use in the installation of buried water and wastewater pipelines. The findings of this work group are applicable across a wide spectrum of water and wastewater utilities in both developed and developing countries.

Information was reviewed on the cradle-to-grave impacts of five commonly specified pipe materials: ductile iron, polyvinyl chloride (PVC), high density polyethylene (HDPE), reinforced concrete, and vitrified clay. Initial data was examined that compared the impacts of each pipe material in six life phases: resource

extraction, manufacturing, transportation, installation, use, and end-of-use fate. Sustainability was defined as one, contributing the least amount of greenhouse gases throughout the lifetime of the material; and two, minimizing toxicity impacts.

The amount of greenhouse gases contributed was termed global warming potential. Resource extraction and manufacturing were combined into production. End-of-use-fate was eliminated as there is little evidence that buried pipe is recycled in meaningful quantities or that it would markedly lower global warming potential. This reduced the number of phases to four: Production, Transport, Installation, and Use.

COMPARING TWO OPTIONS

A situation in which upsizing pipe may be appropriate is in circulating systems. For instance, in Alaska Native communities in the Arctic, potable water distribution systems are comprised of a circulating loop with a heat add component.

The environmental condition that drives this requirement is quite often because these systems are installed in permafrost, so as the water travels through the distribution system the water temperature continues to decrease. This creates the need to continually circulate the water and add heat periodically to keep distribution lines from freezing.

We can simplify the energy use comparison based on a few assumptions.

- It is a loop system, so the net static lift is zero.
- Assuming the pipe material and length are held constant, the friction loss equation can be reduced to a comparison of the velocities (ft/s) taken to the exponent 1.85, while being divided by the associated pipe diameter (feet) taken to the exponent 1.165.
- Since specific gravity and the volumetric flow rate will be the same, a comparison of the hydraulic horsepower (kilowatt) can be reduced to a comparison of friction losses.

Compare a 4-in pipe to a 6-in pipe. In order to move the same quantity of water, say approximately 79-gal/min, the 4-in pipe velocity would be 2-ft/sec. For the 6-in diameter pipe, the velocity would be 0.9-ft/sec. Plugging in these velocities along with the associated pipe diameters, the calculated ratio of headloss for the 4-in and 6-in pipes is 12.96 and 1.85, respectively. This is a seven-fold difference.

Increasing the pipe size and reducing the velocity lowers the energy use requirement approximately 85 percent. This leads to lower global warming potential over the lifecycle of the system. Keep in mind the difference will not be as dramatic in the larger pipe sizes.

INSIDE THE ANALYSES

Of note in the research, only pressure conveyance is considered. Gravity conveyance is not. Additionally, only open trench installation techniques were considered. The discussion also does not include benefits inherent to some materials that would lend themselves to other installation techniques such as directional drilling. In addition, the work group did not consider the inherent benefits of certain pipe material such as the ability to mold HDPE pipe into unique fittings inexpensively. Ultimately, these were considered as separate design considerations and did not find evidence they would significantly impact global warming potential or toxicity.

Lifecycle analysis data on the toxicity related to raw material extraction and base material production were not covered due to the complexities involved. Manufacturing of the many pipe materials have all evolved over time to involve processes and industrial hygiene practices that meet laws and regulations put in place to protect the environment and worker health and safety. The one area where toxicity can be a concern is when using diesel powered equipment during installation; however, relative to the entire lifetime of the pipe material, installation is an acute exposure. For pipes in the service phase of the lifecycle, the concern is release of any toxic material from the pipe itself to the environment. None of the pipe materials researched are presently known to have a toxicity to the environment when the pipes are utilized following manufacturers' recommendations.

A typical

LIFECYCLE ANALYSIS

Lifecycle analysis provides tools for quantifying the impacts of pipe materials. Studies reviewed identified the inputs (energy, raw materials) and outputs (impacts to air, water, solid wastes, other releases, and byproducts) for each phase of each pipe material's life cycle.

Production includes all processes required to produce the product, including resource extraction. Transportation comprises energy involved in conveying materials to markets and to the project site. Installation includes all energy expended installing the pipe including bedding. The Use Phase is the energy consumed to convey the liquid during the service life of the piping system.

PIPE MATERIALS IMPACT

In the analyses reviewed, global warming potential is measured in kilograms of CO_2 emitted per kilometer of pipe length. At the material production level there is great variability in the contributing factors. For instance, the composition of energy sources for a particular area of the country can vary significantly. The electrical power might come from a hydroelectric plant, a coal fired plant, a natural gas fired plant, or a nuclear power plant. The Pipe Workgroup

gravity flow wastewater collection system.

mitigated this variable by ignoring the energy source makeup and looking only at energy consumed for each phase of the analysis.

The Production Phase accounts for 92 percent to 99 percent of total global warming potential for the first three phases. The Installation and Transportation Phases are minor contributors to global warming potential when compared to the Production and Use Phases. In addition, considering the first three phases (Production, Transport, and Installation), concrete pipe shows the least global warming potential while ductile iron shows the greatest.

Within each material, differences exist at varying diameters. Iron pipe has the highest global warming potential at diameters less than 24-in. PVC has the highest for diameters greater than 30-in. This anomaly is created by the schedule of pipe thickness associated with different pipe material.

USE PHASE ASSESSMENT

In the past, several lifecycle analyses did not include the Use Phase. Incorporating this adds complexity as each application/project typically has unique requirements. A valid comparison can be determined when lifecycle analysis incorporates the Use Phase, if the scope is held consistent across pipe materials. Typically, pressure requirements and static lift are excluded. Only friction losses developed during conveyance were considered. What becomes clear when the Use Phase is included is that, unless fluids are conveyed by gravity alone, the energy used to transport water and wastewater through miles of pipe networks over typical lifetimes of 20 or more years may have as much global warming potential as the first three phases of the pipe's lifecycle. This leads to selecting pipe size to minimize global warming potential because of the effect that size has on energy requirements. Small diameter pipe sizes have lower global warming potential from production, transport, and installation; however, the energy consumed to convey a quantity of water/wastewater is increased.

Minimizing energy use becomes a critical practice for minimizing global warming potential. Lowering energy inputs has been a goal of designing these systems for decades, simply to keep down the operating cost. It was determined that keeping down operating costs to move water and wastewater has the greatest effect on reducing greenhouse gas emissions as well. Longer service life applications will favor larger diameter pipes.

For pressure water conveyance, global warming potential is minimized for all four phases over the service life when velocities are reduced to approximately 1-ft/sec versus previous standard velocities. Typically this cannot be applied to wastewater force mains since higher velocities are necessary to re-suspend wastewater solids.

BUILDING BEST PRACTICES

Studying the impact of our work stems from an imperative to do less harm than good. The information we use to make those determinations is available in the scientifically determined and relevant form of life cycle analyses.

Engineers should revise the design model to include environmental impact (global warming potential) as a factor in the pipe material and size selection for pressure water conveyance. Specifically, this includes potentially upsizing the pipe diameter to allow velocities to approach approximately 1-ft/sec. In addition, depending on project requirements (including pipe sizes) certain pipe materials will induce less environmental impact.

It remains the responsibility of the design engineer to determine if it is appropriate to incorporate these findings to their specific system. Typically, every design has its unique requirements and it may not be appropriate for every instance.

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