CHAPTER 1

Introduction

Since its discovery in 1933, PE has grown to become one of the world's most widely used and recognized thermoplastic materials.(1) The versatility of this unique plastic material is demonstrated by the diversity of its use and applications. The original application for PE was as a substitute for rubber in electrical insulation during World War II. PE has since become one of the world's most widely utilized thermoplastics. Today's modern PE resins are highly engineered for much more rigorous applications such as pressure-rated gas and water pipe, landfill membranes, automotive fuel tanks and other demanding applications.

Figure I Joining Large Diameter PE Pipe with Butt Fusion

PE's use as a piping material first occurred in the mid 1950's. In North America, its original use was in industrial applications, followed by rural water and then oil field production where a flexible, tough and lightweight piping product was needed to fulfill the needs of a rapidly developing oil and gas production industry. The success of PE's pipe in these installations quickly led to its use in natural gas distribution where a coilable, corrosion-free piping material could be fused in the field to assure a "leak-free" method of transporting natural gas to homes and businesses. PE's success in this critical application has not gone without notice and today it is the material of choice for the natural gas distribution industry. Sources now estimate that nearly 95% of all new gas distribution pipe installations in North America that are 12" in diameter or smaller are PE piping.[2]

The performance benefits of polyethylene pipe in these original oil and gas related applications have led to its use in equally demanding piping installations such as potable water distribution, industrial and mining pipe, force mains and other critical applications where a tough, ductile material is needed to assure long-term performance. It is these applications, representative of the expanding use of polyethylene pipe that are the principle subject of this handbook. In the chapters that follow, we shall examine all aspects of design and use of polyethylene pipe in a broad array of applications. From engineering properties and material science to fluid flow and burial design; from material handling and safety considerations to modern installation practices such as horizontal directional drilling and/or pipe bursting; from potable water lines to industrial slurries we will examine those qualities, properties and design considerations which have led to the growing use of polyethylene pipe in North America.

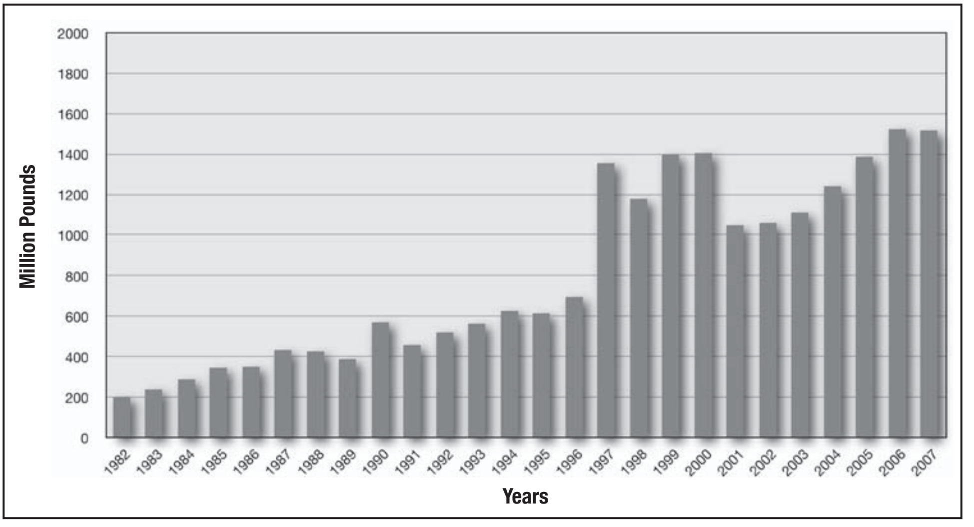

Figure 2 Historical Growth in North American HDPE Pipe Shipments(3)

Features and Benefits of PE Pipe

When selecting pipe materials, designers, owners and contractors specify materials that provide reliable, long-term service durability, and cost-effectiveness.

Solid wall PE pipes provide a cost-effective solution for a wide range of piping applications including natural gas distribution, municipal water and sewer, industrial, marine, mining, landfill, and electrical and communications duct applications. PE pipe is also effective for above ground, buried, trenchless, floating and marine installations. According to David A. Willoughby, P.O.E., "… one major reason for the growth in the use of the plastic pipe is the cost savings in installation, labor and equipment as compared to traditional piping materials. Add to this the potential for lower maintenance costs and increased service life and plastic pipe is a very competitive product."[4]

Natural gas distribution was among the first applications for medium-density PE (MDPE) pipe. In fact, many of the systems currently in use have been in continuous service since 1960 with great success. Today, PE pipe represents over 95% of the pipe installed for natural gas distribution in diameters up to 12" in the U.S. and Canada. PE is the material of choice not only in North America, but also worldwide. PE pipe has been used in potable water applications for almost 50 years, and has been continuously gaining approval and growth in municipalities. PE pipe is specified and/or approved in accordance with AWWA, NSF, and ASTM standards.

Some of the specific benefits of PE pipe are discussed in the parargraphs which follow.

- **Life Cycle Cost Savings** – For municipal applications, the life cycle cost of PE pipe can be significantly less than other pipe materials. The extremely smooth inside surface of PE pipe maintains its exceptional flow characteristics, and heat fusion joining eliminates leakage. This has proven to be a successful combination for reducing total system operating costs.
- **Leak Free, Fully Restrained Joints** – PE heat fusion joining forms leak-free joints that are as strong as, or stronger than, the pipe itself. For municipal applications, fused joints eliminate the potential leak points that exist every 10 to 20 feet when using the bell and spigot type joints associated with other piping products such as PVC or ductile iron. All these bell and spigot type joints employ elastomeric gasket materials that age over time and thus have the potential for leaks. As a result of this, the "allowable water leakage" for PE pipe is zero as compared to the water leakage rates of 10% or greater typically associated with these other piping products. PE pipe's fused joints are also self-restraining, eliminating the need for costly thrust restraints or thrust blocks while still insuring the integrity of the joint. Notwithstanding the advantages of the butt fusion method of joining, the engineer also has other available means for joining PE pipe and fittings such as electrofusion and mechanical fittings. Electrofusion fittings join the pipe and/or fittings together using embedded electric heating elements. In some situations, mechanical fittings may be required to facilitate joining to other piping products, valves or other system appurtenances. Specialized fittings for these purposes have been developed and are readily available to meet the needs of most demanding applications.
- **Corrosion & Chemical Resistance** – PE pipe will not rust, rot, pit, corrode, tuberculate or support biological growth. It has superb chemical resistance and is the material of choice for many harsh chemical environments. Although unaffected

by chemically aggressive native soil, installation of PE pipe (as with any piping material) through areas where soils are contaminated with organic solvents (oil, gasoline) may require installation methods that protect the PE pipe against contact with organic solvents. It should be recognized that even in the case of metallic and other pipe materials, which are joined by means of gaskets, protection against permeation is also required. Protective installation measures that assure the quality of the fluid being transported are typically required for all piping systems that are installed in contaminated soils.

- **Fatigue Resistance and Flexibility** – PE pipe can be field bent to a radius of about 30 times the nominal pipe diameter or less depending on wall thickness (12" PE pipe, for example, can be cold formed in the field to a 32-foot radius). This eliminates many of the fittings otherwise required for directional changes in piping systems and it also facilitates installation. The long-term durability of PE pipe has been extremely well researched. PE has exceptional fatigue resistance and when, operating at maximum operating pressure, it can withstand multiple surge pressure events up to 100% above its maximum operating pressure without any negative effect to its long-term performance capability.
- **Seismic Resistance** – The toughness, ductility and flexibility of PE pipe combined with its other special properties, such as its leak-free fully restrained heat fused joints, make it well suited for installation in dynamic soil environments and in areas prone to earthquakes.

Figure 3 Butt Fused PE Pipe "Arched" for Insertion into Directional Drilling Installation

- **Construction Advantages** – PE pipe's combination of light weight, flexibility and leak-free, fully restrained joints permits unique and cost-effective installation methods that are not practical with alternate materials. Installation methods such as horizontal directional drilling, pipe bursting, sliplining, plow and plant, and submerged or floating pipe, can greatly simplify construction and save considerable time and money on many installations. At approximately one-eighth the weight of comparable sized steel pipe, and with integral and dependable leakfree joining methods, installation is simpler, and it does not need heavy lifting equipment. PE pipe is produced in standard straight lengths to 50 feet or longer and coiled in diameters up through 6". Coiled lengths over 1000 feet are available in certain diameters. PE pipe can withstand impact much better than PVC pipe, especially in cold weather installations where other pipes are more prone to cracks and breaks. Because heat fused PE joints are as strong as the pipe itself, it can be joined into long runs conveniently above ground and later, installed directly into a trench or pulled in via directional drilling or using the re-liner process. Of course, the conditions at the construction site have a big impact on the preferred method of installation.
- **Durability** – PE pipe installations are cost-effective and have long-term cost advantages due to the pipe's physical properties, leak-free joints and reduced maintenance costs. The PE pipe industry estimates a service life for PE pipe to be, conservatively, 50-100 years provided that the system has been properly designed, installed and operated in accordance with industry established practice and the manufacturer's recommendations. This longevity confers savings in replacement costs for generations to come. Properly designed and installed PE piping systems require little on-going maintenance. PE pipe is resistant to most ordinary chemicals and is not susceptible to galvanic corrosion or electrolysis.

Figure 4 PE Pipe Weighted and Floated for Marine Installation

- **Hydraulically Efficient** – The internal surface of PE pipe is devoid of any roughness which places it in the "smooth pipe" category, a category that results in the lowest resistance to fluid flow. For water applications, PE pipe's Hazen Williams C factor is 150 and does not change over time. The C factor for other typical pipe materials declines dramatically over time due to corrosion and tuberculation or biological build-up. Without corrosion, tuberculation, or biological growth PE pipe maintains its smooth interior wall and its flow capabilities indefinitely to insure hydraulic efficiency over the intended design life.
- **Temperature Resistance** – PE pipe's typical operating temperature range is from 0°F to 140°F for pressure service. However, for non-pressure and special applications the material can easily handle much lower temperatures (e.g., to – 40°F and lower) and there are specially formulated materials that can service somewhat higher temperatures. Extensive testing and very many applications at very low ambient temperatures indicates that these conditions do not have an adverse effect on pipe strength or performance characteristics. Many of the PE resins used in PE pipe are stress rated not only at the standard temperature, 73° F, but also at an elevated temperature, such as 140°F. Typically, PE materials retain greater strength at elevated temperatures compared to other thermoplastic materials such as PVC. At 140° F, PE materials retain about 50% of their 73°F strength, compared to PVC which loses nearly 80% of its 73° F strength when placed in service at 140°F.(5) As a result, PE pipe materials can be used for a variety of piping applications across a very broad temperature range.

The features and benefits of PE are quite extensive, and some of the more notable qualities have been delineated in the preceding paragraphs. The remaining chapters of this Handbook provide more specific information regarding these qualities and the research on which these performance attributes are based.

Many of the performance properties of PE piping are the direct result of two important physical properties associated with PE pressure rated piping products. These are ductility and visco-elasticity. The reader is encouraged to keep these two properties in mind when reviewing the subsequent chapters of this handbook.

- **Ductility**

  Ductility is the ability of a material to deform in response to stress without fracture or, ultimately, failure. It is also sometimes referred to as increased strain capacity and it is an important performance feature of PE piping, both for above and below ground service. For example, in response to earth loading, the vertical diameter of buried PE pipe is slightly reduced. This reduction causes a slight increase in horizontal diameter, which activates lateral soil forces that tend to stabilize the pipe against further deformation. This yields a process that produces a soil-pipe Introduction 11 structure that is capable of safely supporting vertical earth and other loads that can fracture pipes of greater strength but lower strain capacity.

  Ductile materials, including PE, used for water, natural gas and industrial pipe applications have the capacity to safely handle localized stress intensifications that are caused by poor quality installation where rocks, boulders or tree stumps may be in position to impinge on the outside surface of the pipe. There are many other construction conditions that may cause similar effects, e.g. bending the pipe beyond a safe strain limit, inadequate support for the pipe, misalignment in connections to rigid structures and so on. Non- ductile piping materials do not perform as well when it comes to handling these types of localized high stress conditions.

Materials with low ductility or strain capacity respond differently. Strain sensitive materials are designed on the basis of a complex analysis of stresses and the potential for stress intensification in certain regions within the material. When any of these stresses exceed the design limit of the material, crack development occurs which can lead to ultimate failure of the part or product. However, with materials like PE pipe that operate in the ductile state, a larger localized deformation can take place without causing irreversible material damage such as the development of small cracks. Instead, the resultant localized deformation results in redistribution and a significant lessening of localized stresses, with no adverse effect on the piping material. As a result, the structural design with materials that perform in the ductile state can generally be based on average stresses, a fact that greatly simplifies design protocol.

To ensure the availability of sufficient ductility (strain capacity) special requirements are developed and included into specifications for structural materials intended to operate in the ductile state; for example, the requirements that have been established for "ductile iron" and mild steel pipes. On the other hand, ductility has always been a featured and inherent property of PE pipe materials. And it is one of the primary reasons why this product has been, by far, the predominant material of choice for natural gas distribution in North America over the past 30 plus years. The new or modern generation of PE pipe materials, also known as high performance materials, have significantly improved ductility performance compared to the traditional versions which have themselves, performed so successfully, not only in gas but also in a variety of other applications including, water, sewer, industrial, marine and mining since they were first introduced about 50 years ago.

For a more detailed discussion of this unique property of PE material, especially the modern high performance versions of the material, and the unique design benefits it brings to piping applications, the reader is referred to Chapter 3, Material Properties.

Visco-Elasticity

PE pipe is a visco-elastic construction material.(6) Due to its molecular nature, PE is a complex combination of elastic-like and fluid-like elements. As a result, this material displays properties that are intermediate to crystalline metals and very high viscosity fluids. This concept is discussed in more detail in the chapter on Engineering Properties within this handbook.

The visco-elastic nature of PE results in two unique engineering characteristics that are employed in the design of PE water piping systems, creep and stress relaxation.

- **Creep** is the time dependent viscous flow component of deformation. It refers to the response of PE, over time, to a constant static load. When PE is subjected to a constant static load, it deforms immediately to a strain predicted by the stressstrain modulus determined from the tensile stress-strain curve. At high loads, the material continues to deform at an ever decreasing rate, and if the load is high enough, the material may finally yield or rupture. PE piping materials are designed in accordance with rigid industry standards to assure that, when used in accordance with industry recommended practice, the resultant deformation due to sustained loading, or creep, is too small to be of engineering concern.
- **Stress relaxation** is another unique property arising from the visco-elastic nature of PE. When subjected to a constant strain (deformation of a specific degree) that is maintained over time, the load or stress generated by the deformation slowly decreases over time, but it never relaxes completely. This stress relaxation response to loading is of considerable importance to the design of PE piping systems. It is a response that decreases the stress in pipe sections which are subject to constant strain.

  As a visco-elastic material, the response of PE piping systems to loading is time-dependent. The apparent modulus of elasticity is significantly reduced by the duration of the loading because of the creep and stress relaxation characteristics of PE. An instantaneous modulus for sudden events such as water hammer is around 150,000 psi at 73°F. For slightly longer duration, but short-term events such as soil settlement and live loadings, the short-term modulus for PE is roughly 110,000 to 130,000 psi at 73° F, and as a long-term property, the apparent modulus is reduced to something on the order of 20,000-30,000 psi. As will be seen in the chapters that follow, this modulus is a key criterion for the long-term design of PE piping systems.

This same time-dependent response to loading also gives PE its unique resiliency and resistance to sudden, comparatively short-term loading phenomena. Such is the case with PE's resistance to water hammer phenomenon which will be discussed in more detail in subsequent sections of this handbook.

Summary

As can been seen from our brief discussions here, PE piping is a tough, durable piping material with unique performance properties that allow for its use in a broad range of applications utilizing a variety of different construction techniques based upon project needs. The chapters that follow offer detailed information regarding the engineering properties of PE, guidance on design of PE piping systems, installation techniques as well as background information on how PE pipe and fittings are produced, and appropriate material handling guidelines. Information such as this is intended to provide the basis for sound design and the successful installation and operation of PE piping systems. It is to this end, that members of the Plastics Pipe Institute have prepared the information in this handbook.

References:

1. *The History of Plastics.* (2005, May). www.americanplasticscouncil.org.
2. Mruk, S. (1985, November). Plastic Pipe in Gas Distribution Twenty-Five Years of Achievement, *Gas Industries.*
3. Shipments of PE Pipe, PPI Statistics Report. (2007). Plastics Pipe Institute, Irving, Texas.
4. Willoughby, D. A. (2002). *Plastic Piping Handbook*, McGraw-Hill Publications, New York.
5. PVC Pipe – Design and Installation. (2004). *AWWA Manual M-23*, American Water Works Association, Denver.
6. PE Pipe – Design and Installation. (2006). *AWWA Manual M-55*, American Water Works Association, Denver.