

HISTORY OF CROSSLINKED POLYETHYLENE (PEX) TUBING IN NORTH AMERICA AND THE EVOLUTION OF ASTM STANDARD SPECIFICATION F876 FROM 1984 - 2024

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Foreword

This technical report was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). These members have shown their commitment to developing and improving quality products by assisting standards development organizations in the development of standards, and also by developing design aids and reports to help engineers, code officials, specifying groups, contractors and users.

The purpose of this technical report is to provide a history of crosslinked polyethylene (PEX) tubing in North America, based on the introduction and evolution of ASTM Standard Specification F876.

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For further information, contact: The Plastics Pipe Institute
105 Decker Court
Suite 825
Irving, Texas, 75062
469.499.1044
www.plasticpipe.org

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PREFACE

The Terminator. Purple Rain. Jeopardy. Floppy discs. Ronald Reagan. Pagers. Ghostbusters. 1984, the album by Van Halen. All launched in 1984, the year.

The year 1984 was forty-plus years ago, and while most of the technology of that year has been replaced by devices that we could not imagine back then, one of the newer technologies of the time, crosslinked polyethylene, was just getting started. It was 1984 when ASTM Standard Specifications **F876** and **F877** were first published, beginning the journey for crosslinked polyethylene tubing to be introduced into the North American market after 10+ years of successful use in Europe as a flexible, high-temperature plastic pipe for heating and plumbing applications.

This report is intended to describe the history of crosslinked polyethylene (PEX) tubing in North America and provide a timeline of the evolution of ASTM Standard Specification F876 from 1984 to 2024.

Note 1: In the piping industry, the term "tubing" refers to products whereby the actual outside diameter (OD) is 1/8 inch larger than the nominal size, such as with copper tubing. Products with an OD that matches copper tubing are sometimes referred to as "nominal tubing size" (NTS) or "copper tube size" (CTS). Most PEX products used for plumbing applications in North America are copper tube sized and are referred to as "tubing". The term "pipe" refers to products whereby the actual outside diameter matches that of iron or steel pipe of the same nominal size. Those products are sometimes referred to as "iron pipe size" (IPS) or "nominal pipe size" (NPS).

Within this technical report, the terms "tubing" and "pipe" may be used interchangeably, although the technically accurate term for the PEX products described in this report is "tubing".

1.0 INTRODUCTION

Crosslinked polyethylene, known as "PEX", is a polyethylene (PE) material which has undergone a change in molecular structure using a chemical or a physical process whereby a majority of the polymer chains are chemically linked, or crosslinked (X). In the PEX pipe industry, high density polyethylene (HDPE) is the type of polyethylene used to produce PEX.

Crosslinking of the polymer chains of polyethylene into PEX for pipes results in a high-temperature pressure-resistant, yet flexible, plastic (polymer) pipe that is rated for use at 180°F (82°C) or higher.

As compared with standard HDPE pipes, PEX has improved properties such as elevated temperature strength and performance, chemical resistance, environmental stress crack resistance (ESCR), and resistance to slow crack growth (SCG), and abrasion. Crosslinking makes PEX a "semi-thermoset" polymer, providing excellent long-term stability.

PEX tubing is approved for potable hot- and cold-water plumbing systems and hydronic heating and cooling systems, as well as several other applications, in all model plumbing, mechanical, and geothermal codes across the USA and Canada. PEX tubing systems are durable, provide security for drinking water, and use reliable connection systems.

Crosslinking technology for polyethylene was developed in Europe in the late 1960s, with the first PEX radiant heating systems installed in 1972 in Europe and has since had a more than fifty-year history of successful use around the world for a variety of demanding applications.

This technical report is intended to provide a history of the use of PEX tubing in North America and the timeline of the development of ASTM F876 *Standard Specification for Crosslinked Polyethylene (PEX) Tubing*, one of the most referenced and active standards published by the ASTM International Technical Committee F17 for Plastic Piping Systems, over its first forty years of publication from 1984 to 2024.

2.0 ACRONYMS AND TERMINOLOGY

- API American Petroleum Institute
- ASME American Society of Mechanical Engineers
- ASTM American Society for Testing and Materials (former name)
- AWWA American Water Works Association
- BOCA Building Officials and Code Administrators
- CSA Canadian Standards Association
- IAPMO International Association of Plumbing and Mechanical Officials
- ICC International Code Council
- ISO International Organization for Standardization
- NSF National Sanitation Foundation (former name)
- PPI Plastics Pipe Institute
- SBCCI Southern Building Code Congress International

3.0 BACKGROUND – THE INVENTION OF PEX TUBING

Polyethylene (PE), a product formed by the joining or polymerization of ethylene molecules into long chains, was first pioneered in the 1930s and developed in the 1940s as an insulation material for radar wiring during WW II. Today, polyethylene is the most widely used type of plastic (i.e., polymer) in the world.

High-density polyethylene (HDPE) is made by the copolymerization of ethylene and a small amount of another hydrocarbon. The resulting base resin density, before additives or pigments, is greater than 0.941 g/cm³, per ASTM D3350 *Standard Specification for Polyethylene Plastics Pipe and Fitting Materials*. HDPE resin is used to produce many different products, including piping through a process known as extrusion.

The idea for crosslinking of polyethylene pipe material to improve its temperature resistance and toughness was first developed and patented by the German inventor Thomas Engel. As reported to and documented by author Dan Holohan, Thomas Engel shared that, "In 1965, I was together with various scientists of the Phillips Petroleum Company in Bartlesville, Oklahoma, and we were discussing the cross-linking of polyethylene. It was possible at that time to cross-link polyethylene by means of highly active radiation.

The problem, however, lay not only in the extremely expensive, and somewhat dangerous, equipment, but also because this method of cross-linking was feasible only for wall thicknesses of up to 0.5 mm. The important uses for cross-linking polyethylene would, however, always be for thick-walled parts, having a wall thickness of 1 to 10 mm."

"I began my studies using an extruder and I very rapidly found that this technique was not feasible. This was followed by lengthy experiments with laser beams. Finally, I decided in favor of a compression method, with intermolecular friction, telling myself that the cross-linking of the molecules would have to be easier if I could heat them rapidly and bring them closer together by high pressure, so as to then cross-link them in the presence of a catalyst.

"Years of intensive research followed, finally culminating in success. The result was a handful of glittering white plastic, which came out of the autoclave.

"With this small treasure in my pocket, I flew back to Phillips Petroleum in the U.S., where we carried out analysis. We found I had actually obtained 97% cross-linking. And as a result, the thread-shaped chains of molecules connected directly to each other. We heated the polyethylene and the plastic simply would no longer melt into a shapeless mass. The joy was immense, but what was to be done with this new plastic, and into what could it be fabricated?"

In the late 1960s, Thomas Engel met with Wirsbo in Sweden (which became Uponor and now Georg Fischer Building Flow Solutions) and REHAU in Germany, and soon licensed his patent to these firms for the production of piping.

However, according to Tomas Lenman, who joined Wirsbo in 1971, "The patent did not include a 'ready to go' production process. Thomas Engel had just been able to produce a few yards at a time. However, the samples produced proved to be very heat resistant and did not melt or deteriorate when exposed to temperatures well above the crystalline melting point of over 130°C [266°F]. A limited number of tubing samples were put under pressure at close to boiling temperature to find out more about long-term resistance.

“Those tests were soon expanded to many more samples and temperatures as soon as funding became available.”

In 1982, Mr. Lenman emigrated to the United States with the goal of introducing PEX tubing to this market. He began by contacting PPI to learn about the development process for plastic piping standards, then he joined ASTM and initiated a project to develop the first ASTM standard for PEX tubing.

4.0 DEVELOPMENT OF PEX STANDARDS

ASTM F876 *Standard Specification for Crosslinked Polyethylene (PEX) Tubing* and ASTM F877 *Standard Specification for Crosslinked Polyethylene (PEX) Hot- and Cold-Water Distribution Systems* were first published in 1984. F876 contained the primary requirements for the tubing itself, while F877 contained performance requirements for fittings to be used as a system with PEX tubing, as well as other requirements specific to tubing used in hot- and cold-water plumbing systems.

Development of these standards began in 1982 within ASTM Technical Committee F17 “Plastic Piping Systems”, under the leadership of Mr. Lenman. PPI staff was involved in providing guidance for the development of plastic piping standards, and other F17 Technical Committee members provided input to the development of these standards.

Since that time, other industry standards have also been developed which apply to PEX tubing or piping in plumbing and mechanical applications, although these standards are not the focus of this technical report. Two of these standards are **CSA B137.5** *Crosslinked Polyethylene (PEX) Tubing Systems for Pressure Applications* first published in 1989, and **AWWA C904** *Crosslinked Polyethylene (PEX) Pressure Tubing, 1/2 In. (13 mm) Through 3 In. (76 mm) for Water Service* first published in 2006.

Several other PEX standards for different applications (e.g., API Spec 15PX “for the production and transportation of oil, gas, and non-potable water”, ASTM F3253 for “hydronic heating and cooling systems”, ASTM F2788 for “industrial and general-purpose pipelines, potable water pipelines, and fire-extinguishing pipelines”, ASTM F2905 for “oil and gas producing applications”, and ASTM F2968 for “buried gas distribution and gas transmission pressure piping applications”) have also been developed, based on F876.

5.0 EVOLUTION OF ASTM F876 FROM 1984 – 2024

Thanks to its inherent flexibility, toughness, and resistance to high temperatures, the initial applications for PEX tubing were in heating systems such as radiator connections, hydronic radiant floor heating, and snow and ice melting. Growth in uses for PEX led to new testing requirements to ensure that PEX tubing was suitable for all applications. By the 1990s, PEX was adopted by plumbers who liked its flexibility, long lengths, and ability to use home-run or parallel style plumbing systems in houses.

The original “Engel” method for producing PEX employs organic peroxides that, when heated, generate reactive free radicals that splice HDPE chains together during extrusion. This is sometimes referred to as the “PEXa” process.