April 27, 2007

Mr. Jeff Wiese
Acting Associate Administrator for Pipeline Safety
PHMSA / Office of Pipeline Safety
U.S. Department of Transportation
400 7th Street, SW
Room 2103
Washington, DC 20590-0001

Subject: **Petition to Amend Title 49 Code of Federal Regulations Section 192.123 to Permit Use of Polyamide 12 at Higher Pressures**

Dear Mr. Wiese

Degussa AG and UBE Industries are pleased to submit the attached petition and supporting documentation to the Department of Transportation Pipeline Hazardous Materials Safety Administration for its positive consideration.

Specifically, the petition seeks to revise Title 49 Code of Federal Regulations Section 192.123 to permit the design pressure of Polyamide 12 (PA12) piping systems to be determined in accordance with the design formula contained within Section 192.121 as limited by its Hydrostatic Design Basis Rating (HDB). This would enable the use of PA12 piping systems at pressures up to 200 psig and is consistent with other pending regulatory initiatives before DOT for other Polyamide materials.

Since 2004, both Degussa and UBE have partnered with the Gas Technology Institute and other leading gas utility companies throughout the United States through the Operation Technology Development (OTD) group to validate the technical feasibility for the use of PA12 piping systems at higher operating pressures. The cumulative results of both laboratory testing and field evaluations have confirmed the safe operations of PA12 piping systems at pressures up to 250 psig. Moreover, based on the comprehensive test data developed as part of the GTI program, the PA12 material has been successfully integrated within applicable ASTM and other industry standards and specifications.

The similarities in the performance characteristics between the Polyamide 11 and Polyamide 12 materials are quite well known. For the intended high pressure gas distribution application, the results of the comprehensive testing effectively have shown that both materials can provide natural gas in a safe and reliable manner. The primary benefit of the PA12 material, as compared to the PA11, is that there is a multiplicity of suppliers capable of meeting the industries' needs, as evidenced by the joint petition.

It is the belief of the PA12 suppliers that the adoption of this following petition will permit local distribution companies to provide natural gas service to areas which were not economically feasible without sacrificing the safety and integrity of the gas distribution network. The PA12 materials can offer all of the common benefits associated with plastic piping system while being cost competitive to steel piping system in terms of total installed costs and overall life cycle costs. As a result, it is believed that the adoption of this petition will not result in any increase in the costs to operators, general public, and consumers.

If there are any questions or need for follow-up discussions by either yourself or your staff concerning this petition, then please do not hesitate to contact Richard Wolf at 610-804-9794 or Hitesh Patadia at 847-873-3139.

Sincerely,

i.V.

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PETITION OF POLYAMIDE 12 (PA12) SUPPLIERS TO REVISE THE PIPELINE SAFETY REGULATIONS

Revise Title 49 Code of Federal Regulations Section 192.123 to Allow the Design Pressure of Polyamide 12 Piping Systems as Determined by Section 192.121

Prepared and Submitted By:

Degussa Corporation
UBE Industries

April 27, 2007

BEFORE THE
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
UNITED STATES DEPARTMENT OF TRANSPORATION
WASHINGTON, D.C.

REVISE SECTION 192.123 TO ALLOW THE)
DESIGN PRESSURE OF POLYAMIDE 12 (PA12) PIPING SYSTEMS)
TO BE DETERMINED USING DESIGN FORMULA)
CONTAINED WITHIN SECTION 192.121)

PETITION TO REVISE THE PIPELINE SAFETY REGULATIONS

Pursuant to 49 CFR Section 106.31, the following petition is being respectfully submitted to the Research and Special Programs Administration (RSPA) of the United States Department of Transportation (DOT) to conduct a rulemaking to amend section 192.123 to allow the maximum design pressure for Polyamide12 (PA12) piping systems, pipe and fittings, to be determined by its dimensions and the materials' long term strength as stated by its hydrostatic design basis (HDB) rating in accordance with section 192.121. RSPA is respectfully requested to issue a proposed rule using the proposed language submitted herein.

This petition is intended for only PA12 piping materials and is not directly a part of or connected in anyway with previous petitions or efforts related to Polyethylene (PE) and/or Polyamide 11 (PA11) piping materials. However, this petition seeks to leverage and build upon the previously filed Notice of Proposed Rulemaking (NPRM) for the Polyamide 11 (PA11) materials given the inherent similarities with respect to performance characteristics for the range of intended operations between these two materials which are from the same family of Polyamide(s). These similarities and the performance characteristics are addressed in the subsequent sections of this petition.

To aid DOT RSPA in the development of the proposed amendments to the regulations, the following language is being respectfully submitted by Degussa and UBE (Petitioners) to amend section 192.123(a) by adding a new section within Section 192.123 – specifically, revising Paragraphs (a) and adding a new paragraph (g)[1].

[1] The use of 192.123(g) is the next section number which is contingent on the approval of the other proposed rulemaking initiative(s) already pending before DOT-RSPA

(New or revised language is shown underlined)
192.123 Design limitations for plastic pipe

(a) Except as provided for in (f) and (g) below, the design pressure may not exceed a gauge pressure of 689 kPa (100 psig) for plastic pipe used in –
(1) Distribution systems; or
(2) Classes 3 and 4 locations

(g) The design pressure for Polyamide 12 (PA12) piping may exceed a gauge pressure of 689 kPa (100 psig) provided:
(1) The material is a Polyamide12 (PA12) as specified in ASTM D2513; and
(2) The pipe size is nominal pipe size (IPS) 6 inches or less; and
(3) The design pressure is determined in accordance with the design equation defined in Part 192.121.
(4) This exception applies to only new construction utilizing polyamide 12 (PA12) piping materials produced after the effective date of this paragraph.

This petition seeks to amend Section 192.123 to allow the design pressure for Polyamide 12 (PA12) piping systems to be determined by its dimensions and its long term strength as stated by its hydrostatic design basis (HDB) rating in accordance with design formula contained within section 192.121. The intent is consistent with the previously filed NPRM for the Polyamide 11 (PA11) material. It is important to emphasize from the onset that any statements made with respect to the PA11 material throughout the document are for comparative purposes only. The petitioners believe that the PA11 material is a suitable material for gas applications; however, the PA12 offers gas distribution companies an additional alternative to steel piping systems over a greater range of operating pressures and capacity considerations.

As Department of Transportation Research Special Programs Administration considers the approval and integration of the PA11 piping material within Part 192 requirements, consideration should also be given to approve and incorporate the PA12 piping materials. For the intended applications, the performance characteristics of both PA11 and PA12 are identical. However, it should be noted that for certain key performance characteristics including long term performance characteristics, PA12 has greater hydrostatic strength as compare to PA11. Moreover, the PA12 piping systems have been extensively tested and evaluated to demonstrate their ability to safely be utilized for high pressure gas distribution applications – in all cases, the testing has either met or exceeded industry standards and specifications. As a result, ASTM F17 committee for Gas has approved the annexation of the Polyamide 12 within the same annex as Polyamide 11. This further underscores the complementary nature of both of these polymers with respect to performance characteristics for the intended applications at higher pressures.

The technical justifications for the aforementioned proposed changes have been extensively studied by the petitioners and leading research institution worldwide to validate that the proposed changes are justified, and there are no resulting adverse implications to both the safety and/or system integrity of the gas distribution network. Based on the cumulative results of both laboratory testing and field evaluations of PA12 piping systems at significantly more aggressive conditions than those experienced in the field, it can be inferred that there are no deleterious consequences to either public safety and/or overall integrity of the gas distribution network. The PA12 material, like the PA11 material, meets and/or exceeds industry accepted performance requirements and possesses all of the necessary listing and ratings for use in gas distribution applications. Moreover, the PA12 material satisfies all current code requirements with respect to design, construction, and maintenance provisions. Significant amount of testing and evaluation has been performed to ensure that all fittings, appurtenance, and methods of joining meet and/or exceed current code requirements and industry standards and specifications.

The following discourse sets forth the justification for the amendment of Section 192.123 by DOT-RSPA to allow PA12 piping systems to operate at pressures as determined using the design formula contained within Section 192.121. The adoption of the aforementioned proposed changes will help to ensure that the regulations are kept current with advancements in pipeline technologies while advancing overall pipeline safety considerations. In addition, adoption of this proposed rulemaking will allow gas distribution companies to utilize a safe and cost effective alternative to steel piping systems without minimizing flow capacity.

PETITION OF POLYAMIDE 12 (PA12) SUPPLIERS TO REVISE THE PIPELINE SAFETY REGULATIONS

TECHNICAL JUSTIFICATION

Background

Recent demographic changes and rapid urbanization have placed a significant burden on the United States gas distribution systems in order to safely and effectively satisfy the Nations' increasing energy needs. As a result, gas utility companies have expressed a strong need and a desire to identify, evaluate, and use new thermoplastic materials which can operate at significantly higher pressures and in larger diameters without sacrificing flow capacity.

Unlike the transmission pipelines, the gas distribution systems are comprised of several different types of materials and pipe sizes which operate over a range of pressures between 0.25 psig to 200 psig, and in some case up to 300 psig [1]. The choice of a particular material and the overall design is predicated on several factors including capacity considerations, company preference, and long term growth forecasts.

Historically, metallic piping materials have been the preferred material of choice – specifically, steel and cast iron piping materials. However, since the late 1960s, the use thermoplastic piping materials, primarily polyethylene (PE), has been growing at an exponential growth. In addition to their relative ease of use (lightweight, ability heat fuse, coiled pipe), plastic piping materials offer the additional advantage of eliminating the need for costly long-term corrosion control measures and the associated monitoring costs. As a result, PE is the preferred material of choice for distribution piping operating at pressures less than 124 psig. For pressures greater than 124 psig and less than 200 psig, steel piping is almost exclusively utilized. Figure 1 provides a comparison of the various materials used between 1990 and 2002.

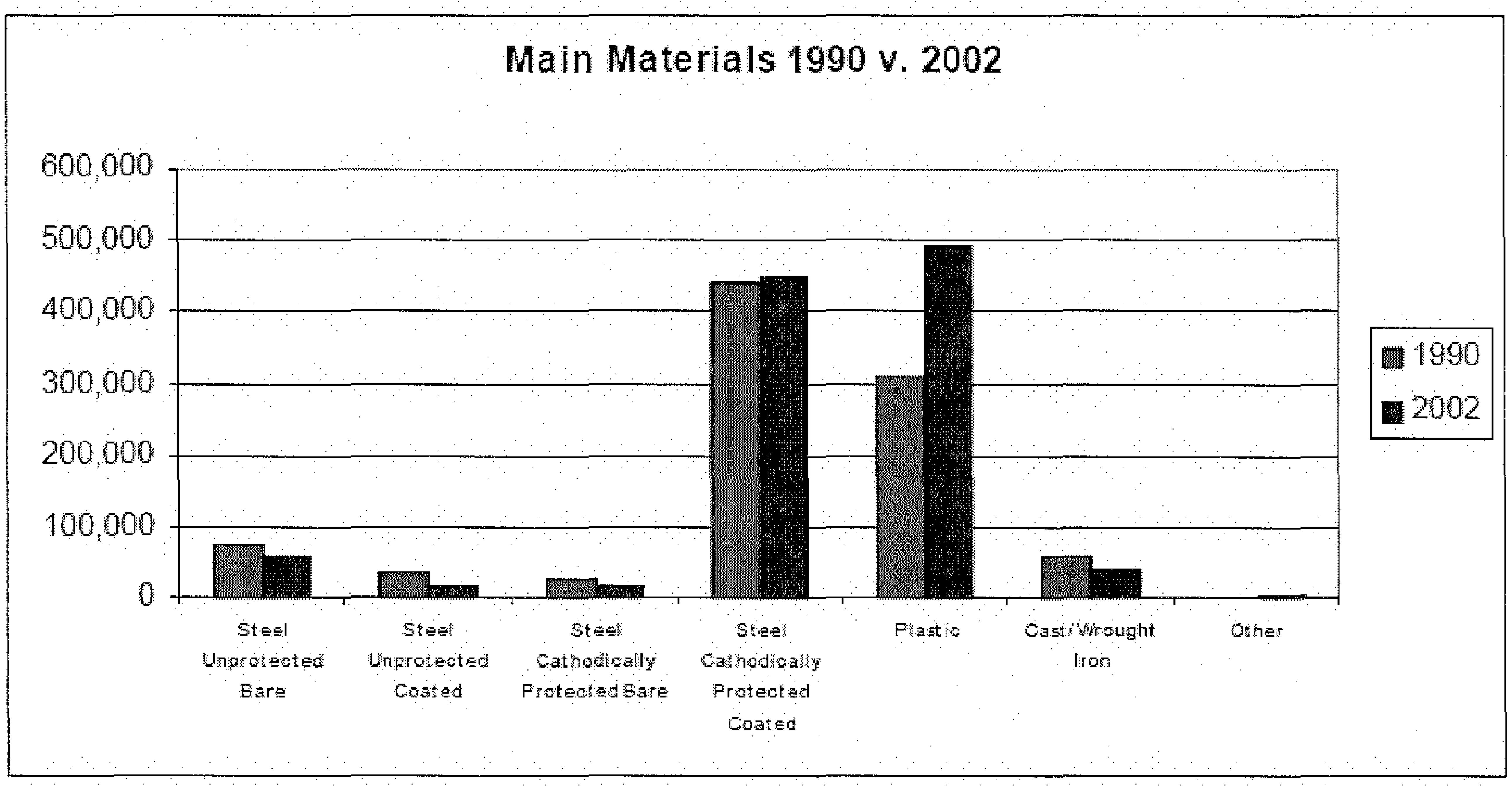

Figure 1: Comparison of materials used for "mains" between 1990 and 2002[2]

From Figure 1 above, it is clear that while the use of plastics has grown significantly over the past few decades, there is still a large segment of the overall gas distribution network which is comprised of steel piping. Recent changes to Part 192 requirements to permit the use of PE piping systems up to 124 psig have been positive advancement and will help to increase the use of PE materials; however, even with these changes current PE materials (medium density and high density PE) will still not be capable of operating at intermediate pressures ranging between 125 – 200 psig in order to effectively satisfy the much needed capacity considerations.

As a result there has been a tremendous interest and a desire on the part of gas utility companies to identify and evaluate promising candidate materials which offer the benefits of thermoplastic materials and can operate at higher pressures in larger diameters without adversely compromising flow capacity considerations.

The primary areas of interest for the use of these candidate materials by gas distribution companies include:

- Replacement of bare steel pipe with plastic piping to eliminate long term corrosion control issues provided that flow capacity is not significantly impacted
- Line extensions to areas experiencing high growth which are not being served by the gas companies due to the cost prohibitive nature of steel piping

Since the mid-1990's, gas utility companies have spent a significant portion of their R&D budgets to identify, evaluate, and validate the use of these materials at higher operating pressures. A few of the candidate materials have included Polyamide 11 (PA11), Reinforced Thermoplastic Pipe (RTP), and Cross-linked Polyethylene (PEX).

Since 2004, Degussa and UBE, in conjunction with the Operations Technology Development (OTD) and the Gas Technology Institute (GTI), have supported comprehensive research aimed at establishing the technical feasibility and validating the use of the Polyamide 12 (PA12) piping systems for high pressure gas distribution application in larger diameters without sacrificing flow capacity considerations. Given that the chemical make-up of the PA12 material closely resembles the PA11 material which has been proven as a safe material for gas distribution applications at higher pressures, the primary driver to validate the performance characteristics of the Polyamide 12 (PA12) piping systems was that

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[2] Reference: AGF Study: "Safety Performance and Integrity of Natural Gas Distribution Infrastructure" , January 2005

unlike the PA11 which is provided by only a single supplier, the PA12 material is sold by multiple suppliers. This multiplicity of suppliers lends itself to more market driven competition and pricing pressures which in turn can provide significant value and savings to gas operators and pipe/fitting suppliers.

Based on the results of both comprehensive laboratory testing and field experiments, the data effectively demonstrates that the PA12 material can be safely installed and used at higher operating pressures and in larger diameters without sacrificing the needed flow capacity[3]. The cumulative results have established the necessary technical foundation for the integration of PA12 within applicable industry and ASTM standards and specifications.

The following sections contain detailed discussions with respect to the performance characteristics of PA12, its history of use, conformity to industry standards and specifications, and technical data in order to demonstrate that overall safety and system integrity will not be adversely compromised with PA12 piping systems.

Polyamide 12 (PA12)

Polyamide 12 belongs to the general class of polymers called polyamides. Polyamides in general and polyamide 12 specifically are characterized by high strength, excellent toughness, excellent abrasion and chemical resistance and high thermal resistance as compared to conventional polymers such as polyethylene. The chemical formula for polyamide 12 is:

$$-(NH-(CH_2)_{11}-CO)_n-$$

The characteristic which gives polyamides their unique properties is the presence of the amide function (-(CONH)-) in the polymer chain. Differences in properties between polyamides can be attributed to the amide density or the frequency of occurrence of the amide function in the polymer backbone. The presence of the amide function causes intermolecular and intramolecular hydrogen bonding to occur which impact overall strength, flexibility, impact resistance, moisture absorption characteristics and thermal properties.

The development of high carbon number polyamides began in the 1940's with the development of PA 11 by ATO, a joint venture between three French oil companies. The development of Polyamide 12 began in the 1960's with the intent of developing a material with similar performance characteristics as compared to PA 11. The first commercial production of Polyamide 12 began in the 1970's at what is now Degussa in Marl, Germany. At the present there are four commercial suppliers of Polyamide 12 worldwide:

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[3] Patadia, H., "Technical Reference on the Mechanical, Physical, and Chemical Characteristics of the Polyamide 12 Material for High Pressure Gas Distribution Applications", November 2005. OTD Report.

- Degussa AG – Marl, Germany
- UBE Industries, Ltd. – Tokyo, Japan
- EMS-Grivory – Domat, Switzerland
- Arkema – Paris, France

In the late 1970's, The Australia Gas Light Company (AGL) identified a need to rehabilitate corroded cast iron service lines in New South Wales, Australia. At the time, polyamide 11 (PA11) was identified as a candidate material for this application due to a combination of high strength, excellent toughness and resistance to chemical degradation. It was found that the use of polyamide 11 allowed AGL to conveniently line the corroded cast iron pipe with a thin walled PA11 pipe without compromising the operating conditions of the system. A development program was initiated by AGL to develop a Polyamide 11 system suitable for rehabilitation.

During the early 1980's, a project was initiated to rehabilitate cast iron mains in Sydney with a Polyamide 11 solvent bonded system operating at low pressures. Concurrently, a program was initiated to introduce polyamide systems, up to pipe sizes of 110 mm, for new and replacement gas distribution systems operating at pressures up to 30 psig (210 kPa). As a result of the success of Polyamide 11 systems in the 1980's' a project was initiated to rehabilitate the entire low pressure cast iron pipe system in Sydney in 1988. The new polyamide system was designed to operate at 30 psig (210 kPa) with a future supply capacity of three times the existing load.

In the mid-1980s, AGL identified polyamide 12 as an alternative to polyamide 11 due to economic benefits, flexibility of supply, and multiplicity of suppliers.

In 1987, the Australian standards AS 2943, *"Plastics Pipes and Fittings for Gas Reticulation – Polyamide Compounds for Manufacture"* and AS 2944 , *"Plastics Pipes and Fittings for Gas Reticulation – Polyamide, Part 1 –Pipes, Part 2 – Fittings"* were developed. The standards outline the requirements for polyamide materials and pipe and fittings produced from polyamide materials operating at pressures up to 58 psig (400 kPa).

In the 1990's, polyamide distribution systems operating up to 58 psi (400 kPa) were installed in Poland and Chile.

In 1995, an evaluation was completed on a Polyamide 12 grade from UBE Industries, Ltd. The evaluation demonstrated that UBE PA12 was in compliance with the relevant Australian standards and was suited for the intended applications at lower costs.

Since 1991, the total consumption of polyamides for gas reticulation has been approximately 120 Mt/year. Approximately 50% of the total volume of pipe installed is Polyamide 12 . Most typically, 32 mm SDR 25 Polyamide 12 pipe is installed. Based on an annual volume of approximately 60 Mt/year, this translates to annual installed lengths of approximately 500 km/yr (approximately 300 miles/year).

Installation of polyamide pipe for gas distribution continues at AGL today with no significant problems. At present, approximately 80% of the distribution mains currently in service operate with a polyamide pipe installed by insertion.

Through extensive research performed at Agility Management Pty. Ltd. (Technical and Development Section) in Australia and through approximately 10 years of positive field service performance, Polyamide 12 has proven to be a viable candidate material for gas distribution systems.

Comparison Between PA11 and PA12

A comparison of PA 11 and PA 12 begins, of necessity by, noting the differences between the two polymers.

The monomer for the polymerization of PA 11 is undecanoicamino acid, a derivative of castor oil. The eleven carbon based amino acid is reacted under the appropriate conditions in a head to tail reaction the by-product of which is water of polymerization. The water of polymerization is continuously removed until the appropriate molecular weight of PA 11 is achieved at which point, the reaction is terminated.

The monomer for the polymerization of PA 12 is, most typically, lauryl lactam. Lauryl lactam is produced through the trimerization of butadiene, a by-product of the petroleum refining process. Unlike PA 11, the polymerization of PA 12 is a two step process. First, the lactam ring is opened under high temperatures and pressures and hydrolyzed to yield a twelve carbon amino acid, dodecanoic amino acid. The second step proceeds along the same path as the polymerization of PA 11.

The key difference between PA 11 and PA 12 is the presence of an additional methylene carbon in the repeating unit of the polymer backbone in PA 12. This additional methylene carbon, in addition to causing a slight decrease in the amide density, causes a difference in the polymer crystalline structure which accounts for the difference in properties between PA 11 and PA 12. Table 1 compares physical property data for grades of PA 11 and PA 12 intended for use in natural gas distribution systems.

Physical Property Comparison PA12 vs. PA11				
Property	**Test Method**	**Units**	**PA 12**	**PA 11**
Melting Point	ASTM D789	°C/°F	178/352	183-187/361-369
Density	ASTM D1248	g/ml	1.02	1.03
Moisture Absorption • 24 hour immersion @ 23°C/50%RH • 23°C/50%RH • Immersion - equilibrium		%	1.5	0.2 0.8 1.9
Tensile Strength • Stress @ yield • Strength @ break • Elongation @ yield • Elongation @ break	ASTM D638	psi/Mpa psi/Mpa % %	6090/42 >7830/>54 >250	5700/39 6200/43 14 240
Flexural Modulus	ASTM D790	psi/MPa	206,000/1420	180,000/1240
Impact Strength - notched	ASTM D256	J/m	78	
Heat Deflection Temperature • @ 66 psi/ 0.46 Mpa • @ 264 psi/ 1.8 MPa	ASTM D648	°C/°F	145/293 55/131	145/293 50/122
Coefficient of Linear Thermal Expansion • -30°C to 50°C • 50°C to 120°C	ASTM D	10^{-5}/°K	11 20-23	8.5 15
Volume Resistivity	ASTM D257	Ω*cm	10^{14}	10^{14}
Surface Resistivity	ASTM D257	Ω*sq.	10^{14}	10^{14}

Table 1. Physical Property Comparison of PA 12 and PA 11.

Due to the decreased amide density of PA 12 as compared to PA 11, PA 12 absorbs approximately 0.5% less moisture at equilibrium.

The melting point of PA 12 is also slightly lower than PA 11. This is typical of analogous pairs of polyamides. Typically, the even numbered polyamide exhibits a slightly depressed melting point when compared to its odd numbered partner. This is due to differences in the crystalline structure. For example, theoretically, while the pair of polyamides, PA 13 and PA 14 would be expected to have melting points lower than the polyamide pair, PA 11 and PA 12, due to a decrease in the amide density, PA 13 would be expected to have a slightly higher melting point than PA 14 due to differences in crystallinity. This has no impact on performance. A comparison of the heat deflection values and vicat softening point data for PA 11 and PA 12 indicates that both PA 11 and PA 12 have essentially the same continuous end use temperature performance.

Additionally, the tensile stress at yield and the flexural modulus data for PA 11 and PA 12 are slightly different due to slight differences in the nature of the polymers. The tensile stress at yield for PA 12 is higher than PA 11. This is reflected in both the short term tensile property comparison and by the fact that PA 12 possesses a higher HDB rating at both room temperature and elevated temperatures as compared to PA 11. PA 11 is approximately 50% stiffer than PE. Due to the aforementioned differences in the crystal structure between PA 11 and PA 12, PA 12 exhibits flexural modulus values approximately 15% higher than PA 11.

PA 12 and PA 11 were developed for use in markets requiring a material with:

- High strength
- Excellent toughness
- Excellent abrasion resistance
- Excellent chemical resistance

PA 12 and PA 11 have shown a long history of successful performance in applications requiring this balance of properties including:

- Automotive fuel lines
- Fuel tanks
- Heavy duty truck air brake tubing
- Hydraulic reservoirs
- Oil flowlines and control umbilicals
- Chemical storage tanks
- Various cable sheathing applications

When a comparison of the performance characteristics of PA 12 and PA 11 is made to the performance requirements of the applications where these polymers are used, the conclusion can be drawn that PA 12 and PA 11 are essentially interchangeable.

Conformity to Code Requirements and Industry Standards
Title 49, Part 192 of the Code of Federal Regulations governs the minimum requirements for the safe use of plastic piping systems. While all of the respective sections are important, Part 192, through reference, requires that all thermoplastic piping materials suitable for use in gas distribution applications must conform to the requirements contained within ASTM D2513-98[4] specification entitled *"Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings"* [1]. Within the main body of the ASTM D2513, there are several requirements that are applicable to all thermoplastic materials. Additional requirements are also contained within Annexes specific to each respective thermoplastic material, e.g. PE materials are in Annex A1, PA11 and PA12 materials are in Annex A5, etc. Finally, additional guidance for the introduction and use of new thermoplastic materials is also provided in a non-mandatory Appendix within ASTM D2513. These guidelines include the following:

- Conformity to ASTM D2513 requirements and establishing a ASTM product specification
- Establishing the materials' long term hydrostatic strength through comprehensive long term sustained pressure testing at elevated temperatures per ASTM D2837 requirements and PPI TR-3 policies and procedures used to establish the hydrostatic design basis (HDB) rating
- Demonstrating at least 3-years of service-related experience to demonstrate that a particular material can safely be used for underground gas pressure piping without significant changes to its long term performance characteristics

To that end, in the context of the joint R&D program between PA12 resin suppliers and leading gas utility companies, each of the aforementioned items were taken into account and have been resolved. To date, a complete PA12 system which has been validated through comprehensive testing is available for widespread use.

Specifically, on the basis of the technical data used to characterize the short term mechanical, chemical, and physical properties of the PA12 resins, the PA12 material has been successfully integrated within the most recent edition of ASTM D2513-06b. The PA12 materials from both of the resin suppliers meet the required cell designation codes referenced per ASTM D4066. As per ASTM and PPI TR-3 requirements, the material designation for PA 12 in ASTM D 2513-06b is PA 42316. The PA12 resins have an established long term strength rating, as represented by the HDB rating of 3150 psi at 73F, 2000 psi at 140F, and 1600 psi at 180F. These respective HDB values for the PA12 material are 25% greater than the HDB values of PA11 for a given temperature. Moreover, test data from both laboratory testing and field experiments have effectively demonstrated that the in-service performance characteristics of the PA12 piping systems. The

[4] Per the rule change issued during May 2004, and effective July 2004, the previous specified ASTM D2513-96a has been changed to ASTM D2513-98

cumulative test data supports the use of PA12 piping systems at pressures up to 250 psig under the combined influence of increased hoop stress and various forms of secondary stresses resulting from in-service conditions – detailed discussions presented in subsequent sections.

Design Considerations

In general, Polyamide 12 (PA12) offers significant potential given its inherent mechanical, physical, and long term performance characteristics. Based on empirical test data for its long term hydrostatic strength, PA12 has an established hydrostatic design basis (HDB) rating of 3150 psi at 73F, as discussed previously, which is greater than the HDB rating for the PA11 material of 2500 psi. Using these respective HDB ratings for an SDR 11 pipe size with both PA12 and PA11, the following maximum design pressure can be potentially realized:

Polyamide 12	Polyamide 11
$p = \frac{2S}{SDR-1} x0.32$	$p = \frac{2S}{SDR-1} x0.32$
$p = \frac{2(3150)}{11-1} x.32$	$p = \frac{2(2500)}{11-1} x.32$
$p = \frac{6300}{10} x.32$	$p = \frac{5000}{10} x.32$
$p = 200 psig$	$p = 160 psig$

From the above calculations, it is evident that PA12 piping systems can operate at 25% greater pressures, and in turn greater capacity, as compared to PA11 piping systems. As a result, PA12 can provide additional alternatives to gas utility companies as a replacement to steel piping and/or line extensions which are not possible with PA11.

Increased Performance Characteristics

While the recommendations contained within ASTM Appendix A provide excellent guidance to verify the effectiveness of new materials for natural gas applications, additional comprehensive testing was performed to validate the long term performance of PA12 piping systems taking into account various risks and threats at higher operating pressures. Specifically, comprehensive testing was performed to characterize the slow crack growth resistance and resistance to rapid crack propagation. The cumulative results effectively demonstrated the ability of the PA12 piping systems to operate at higher pressures, as outlined in the following sections.

Influence of Secondary Stresses and Slow Crack Growth Resistance

In general, there are three types of know failure mechanisms for gas distribution piping including short term ductile rupture, brittle failure through the slow crack growth mechanism, and more recently rapid crack propagation. Short term quality control testing as specified under ASTM D2513 help to characterize the mechanical and physical properties and failures which can occur in the ductile mode.

However, one significant implication of modern thermoplastic materials is that the failure strength is dependent on the duration of the loading and temperature. For safe and efficient long term service, the pressure rating must be established on the basis of the material's long term strength, as represented by its hydrostatic design basis (HDB), under anticipated service conditions.

The primary assumption in Part 192.121 is that plastic piping materials will behave in the "ductile" manner throughout its service life, i.e. the primary mode of failure is that of "bursting" due to internal pressure. The add-on effect of other stresses (localized stress intensifications) on the pipe while in service are considered negligible and can be effectively compensated through the use of a strength reduction factor or the *design factor.* Over 40 years of safe operating experience has demonstrated the efficacy of using plastic pipe in gas distribution applications, and the design approach has been effective in the prevention of catastrophic pipeline failures. Field experience has demonstrated that from a material perspective, the long term performance of plastic piping systems are dependent on the materials' ability to effectively resist localized stress intensifications generated by a number of installation and operational variables in addition to the internal pressure.

As a result, extensive testing was performed with the PA12 piping materials to verify its long term service performance under the combined influence of stresses resulting from internal pressure and various other add-on stresses including surface scratches, rock impingement, earth loading, and critical bending.

At the onset, it was recognized that the testing should simulate actual in-service conditions. Comprehensive long term sustained pressure testing at elevated temperatures were performed using test conditions which were significantly more aggressive. It was noted that while in-service, the line pressure is fixed regardless of the actual stress states to which the piping system is subjected. As a result, for each of the tests, the test pressure was the same as the pressure used to validate the long term hydrostatic strength. This is significant in that the design factor was assumed to equal unity.

The results of comprehensive testing at elevated temperatures for each of the critical in-service stress states (surface scratches, rock impingement, earth loading, and bending) demonstrated that the PA12 piping systems can safely and effectively operate at increased pressures over the intended 50-year design life [2].

Resistance to Rapid Crack Propagation

In addition to short term ductile rupture and slow crack growth considerations, another important failure mode includes Rapid Crack Propagation (RCP). It is important to emphasize that the occurrence of this particular threat for plastic piping systems is extremely low and there have been no documented cases of RCP failures in the United States.

In general, RCP considerations become more critical with increasing operating pressures, increasing diameters, increasing wall thicknesses, and decreasing temperatures. In order to effectively characterize the RCP resistance of plastic piping materials, several promising test methodologies have been developed including the small-scale steady state (S4 test) and full scale RCP test (FST). Given the cost effective nature of the S4 test as compared to the full scale test, the S4 test has been the preferred method to characterize the RCP resistance characteristics.

The S4 test is performed in accordance to ISO 13477 guidelines *"Thermoplastic pipes for conveyance of fluids – Determination of rapid crack propagation (RCP) – Small-scale Steady-state (S4 Test).* Per the test requirements, a specified length of the plastic piping material (usually 6 to 8 pipe diameters in length) is pressurized and maintained at a specified test temperature of 32°F in a test rig. The specimen is then impacted to initiate a fast growing longitudinal crack along the pipe length.

In order to establish the appropriate test conditions, a series of initiation tests are performed with un-pressurized pipe specimens at 32°F. Using a blade speed of 15m/s ± 5m/s, the pipe specimen is impacted and the crack growth is measured. For a given set of temperature and blade speed conditions, if the crack growth is greater than one (1) pipe diameter, the initiation conditions are considered to be satisfied and the same conditions are then used to determine the S4 critical pressure values.

Following the initiation testing, a series of iterative tests are performed using the initiation blade speed and constant temperature conditions (32F) at varying internal pressures. Crack propagation is then defined at pressure values where the measured crack exceeds 4.7 times the pipe diameter. The transition pressure from crack arrest to crack propagation then determines the S4 critical pressure value. It is important to note, the temperature is the most critical parameter. If the temperature of the pipe specimen is not closely monitored, then the S4 values obtained through this test can be overstated.

Based on a research program conducted on PE pipe by Imperial college in the UK and Becetel Institute in Belgium, the S4 critical pressure can be correlated to the full-scale test with the use of the following formula:

$$P_{c,FS} = 3.6(P_{c,S4})+2.6\text{bar} \qquad (1)$$

The design pressure to preclude RCP failures is then stated by the following:

$$P_C \geq 1.5 \times MAOP \qquad (2)$$

For the PA12, a series of S4 tests were performed to determine the S4 critical pressure. Based on the results of the testing, it was readily apparent that the current correlations (Equation 1) are specific to PE materials and do not hold true for PA12 materials.

In order to establish a correlation factor for PA 12 pipe a study was initiated by the PA 12 suppliers to perform both the S4 testing and full scale RCP testing in accordance to ISO 13477 and ISO 13478, respectively. For the purposes of this exercise, the decision was made to characterize the RCP properties of 110 mm X 10 mm pipe (4" SDR 11). S4 testing was conducted at Jana Laboratories in Canada and Imperial College in the UK. S4 crtical pressures at 0C were determined to be in the range of 41-49 psi. Good correlation on test values between the two laboratories was realized. Full scale testing was performed at Advantica in the UK. The full scale critical pressure was determined to in the range 406-435 psi. Based on the methodology used to determine the correlation factor for PE, the correlation factor between full scale critical pressure and S4 critical pressure for PA 12 pipes was determined to be:

$$P_{c,FS} = 7.8(P_{c,S4})+6.8\text{bar} \qquad (3)$$

It is important to note that this correlation factor (Equation 3) is in agreement with information published by Arkema on the correlation factor for PA 11. This further underscores the previous statements related to the similarities in the performance characteristics between PA 12 and PA 11.

Therefore, using the full scale RCP critical pressure values and applying a 1.5 factor of safety (Equation 2), PA12 piping systems can safely be used at the operating pressures up to 200 psig as proposed within this Notice of Proposed Rulemaking.

Impact to Operations

Based on the preceding technical discussions, it is clear that the PA12 material is a promising candidate material for high pressure gas distribution application. The test data supports that it can safely operate at the higher operating pressures over the intended design life. Based on the results of comprehensive testing and evaluation (more than any other material) to characterize the long term performance against known risks and threats, it is clear that there are no adverse implications to either safety or the integrity of the distribution network. While these results are promising, additional technical development work was performed to ensure the design and construction of a complete PA12 piping system consistent with the requirements contained in the Code of Federal Regulations. Extensive testing was performed to take into account system wide considerations, i.e. pipe, fittings, joints, and appurtenances.

Joining

Butt Heat Fusion Joining

A critical element includes the ability to join two PA12 pipe segments and fabricate a PA12 piping system. To promote the safe joining of plastic piping materials, Title 49CFR 192.283 and 192.285 prescribes specific guidelines for developing and qualifying approved joining procedures that must be in place at each utility for their thermoplastic piping materials. Specifically, per Part 192 requirements, joining procedures are qualified when heat fusion joints are made in accordance to those procedures and are then subjected to a combination of tensile strength tests and either the quick burst or long term sustained pressure tests.

It is generally accepted that there are several factors which govern the integrity of the joint including pipe preparation, heater (iron) temperature, applied force, and cooling times. In order to develop suitable ranges for these parameters, GTI performed comprehensive parametric testing using the UBE and Degussa PA12 material for 2-inch pipe sizes. On the basis of the test result, "qualified" PA12 joining procedures were developed. For the PA12 materials, the joining parameters were determined to be:

- Butt Fusion Interface Pressure Rang: 60 - 90 psi
- Heater Surface Temperature Range: 495 – 505°F
- Time of contact with Heater Face: 60 – 75 sec
- Melt Bead: 1/16" – 1/8"

Electrofusion Joining

In addition to butt heat fusion joining, another means of connecting pipe segments and extending service connections is through the use of electrofusion fittings.

The qualification for the use of electrofusion fittings is governed by ASTM F1055. Degussa and UBE, in conjunction with Friatec, developed the necessary electrofusion fittings made from PA12 resin for use on PA12 piping using the universal electrofusion box. It is important to note, the primary factor for performing this developmental activity is that given the inherent chemical make-up of PA12 materials, they will not bond with PE using heat. As a result, conventional PE electrofusion fittings will not work on PA12 piping systems. Moreover, the differences in the range of operating pressure also preclude the use of conventional PE electrofusion fittings.

Based on the results of comprehensive testing, the PA12 electrofusion fittings made at Friatec using the PA12 resin conform to all relevant requirements contained within ASTM F1055 requirements and produce strong joints.

Mechanical Joining
Another commonly used means of connecting pipe segments and extending lateral connections is through the use of mechanical fittings. The qualification and use of mechanical fittings for use in gas distribution applications is governed by ASTM F1924 and ASTM F2145 depending on the operating pressure and choice of material for the plastic mains. ASTM F1924 provides the qualification requirements for mechanical fittings to be installed on PE piping system, and ASTM F2145 provide qualification requirements for mechanical fittings to be installed on Polyamide (PA) mains. It is important to emphasize that the requirements for both of these standards is the same with the exception of minor changes to certain test conditions.

Like the case with the transition fittings, targeted tests were performed on 2-inch mechanical fittings made from injection molding trials at Continental Industries using the UBE and Degussa PA12 resin. Specifically, mechanical fittings installed on PA12 piping were subjected to long term sustained pressure tests at elevated temperatures and temperature cycling tests.

Six pipe/fitting assemblies were subjected to long term sustained pressure tests at 290 psig and 80C. The mechanical fittings were tapped prior to test to ensure that the entire joint is under test. The results of the testing were consistent with expectations. There were no failures that were observed in any of the test specimens at test times greater than 1000 hours.

In addition to the long term sustained pressure tests, six specimens from each supplier were subjected to temperature cycling testing. Like the previous testing on the transition fittings, the temperature cycling tests for mechanical fittings require that the mechanical joint be leak tight following exposure to 10 alternating temperature cycles ranging in temperature from 20F to 140F at pressures of 7 psig to 1.5 times MAOP. For the PA12 mechanical fittings, the MAOP was assumed to be 250 psig based on the use of a 3150 psi HDB rating and a 0.40 design factor. Again, as expected, there were no failures observed with any of the mechanical fittings that were tested.

Appurtenances

Transition Fittings

Given the intended range of operating pressures (greater than 124 psig), it was noted that there was a need to develop effective means of connecting the PA12 piping systems to steel piping systems. With the support of R.W. Lyall and Continental Industries, PA12 to steel transition fittings in both 2-inch and 6-inch sizes were developed to facilitate connection to steel piping systems.

The qualification and use of transition fittings is governed by ASTM F1973 requirements. Like the case of mechanical fittings, the primary objective is to validate a leak tight seal and the ability to withstand the increased internal pressures. Several tests were performed on the PA12 to steel transition fittings including pull out resistance testing and temperature cycling testing. The cumulative results of the testing demonstrated that the PA12 to steel transition can safely operate at the intended design pressures and provide a leak tight seal.

Field Demonstrations

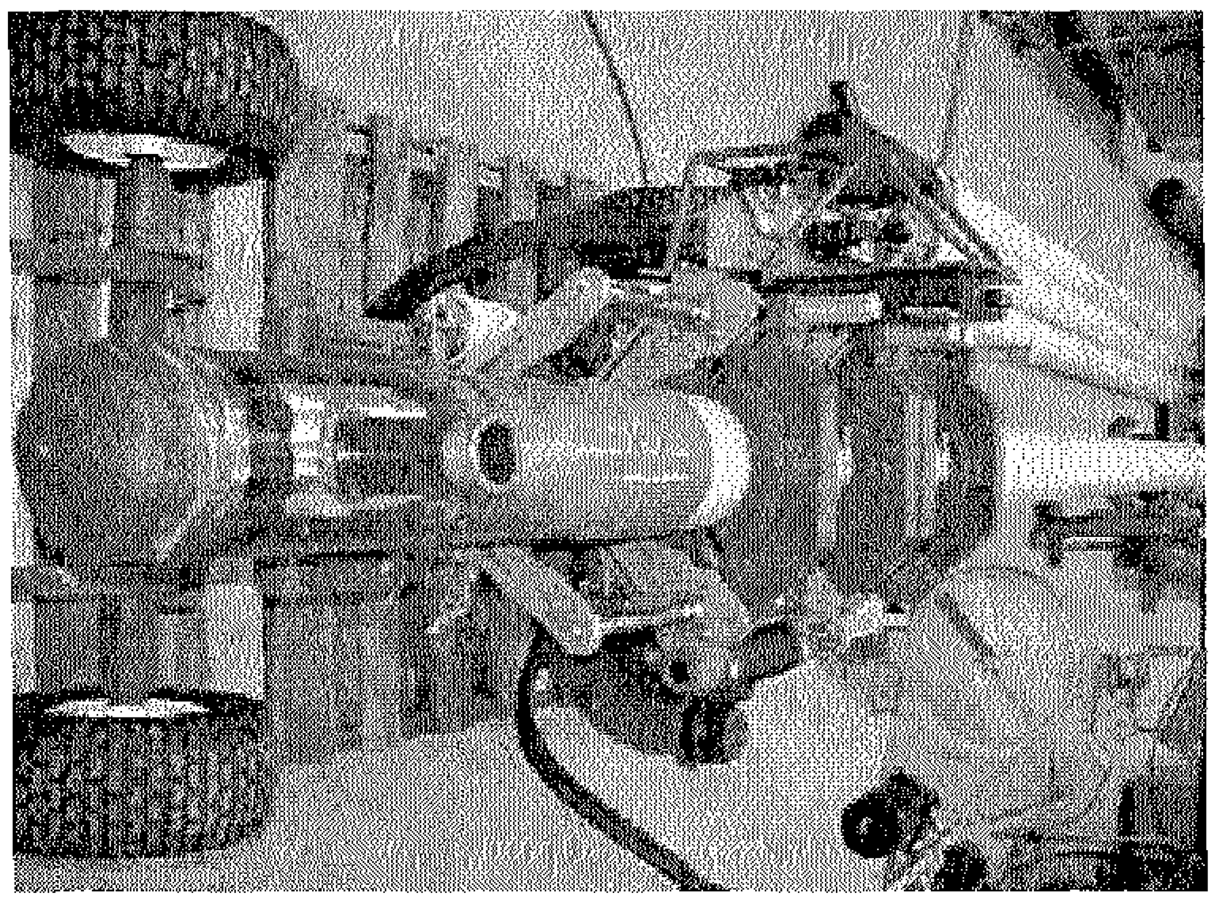
While the results of the laboratory testing were positive, it was critical to gain actual field experience and operator feedback using the PA12 piping systems. Several installations were successfully executed to validate the results of the laboratory testing and the safe installation and operations of the PA12 piping systems at high operating pressures. Moreover, these installations included testing several different pipe sizes and the use of a maximum design pressure resulting from the use of a 0.40 design factor, i.e. 250 psig.

GTI Installations

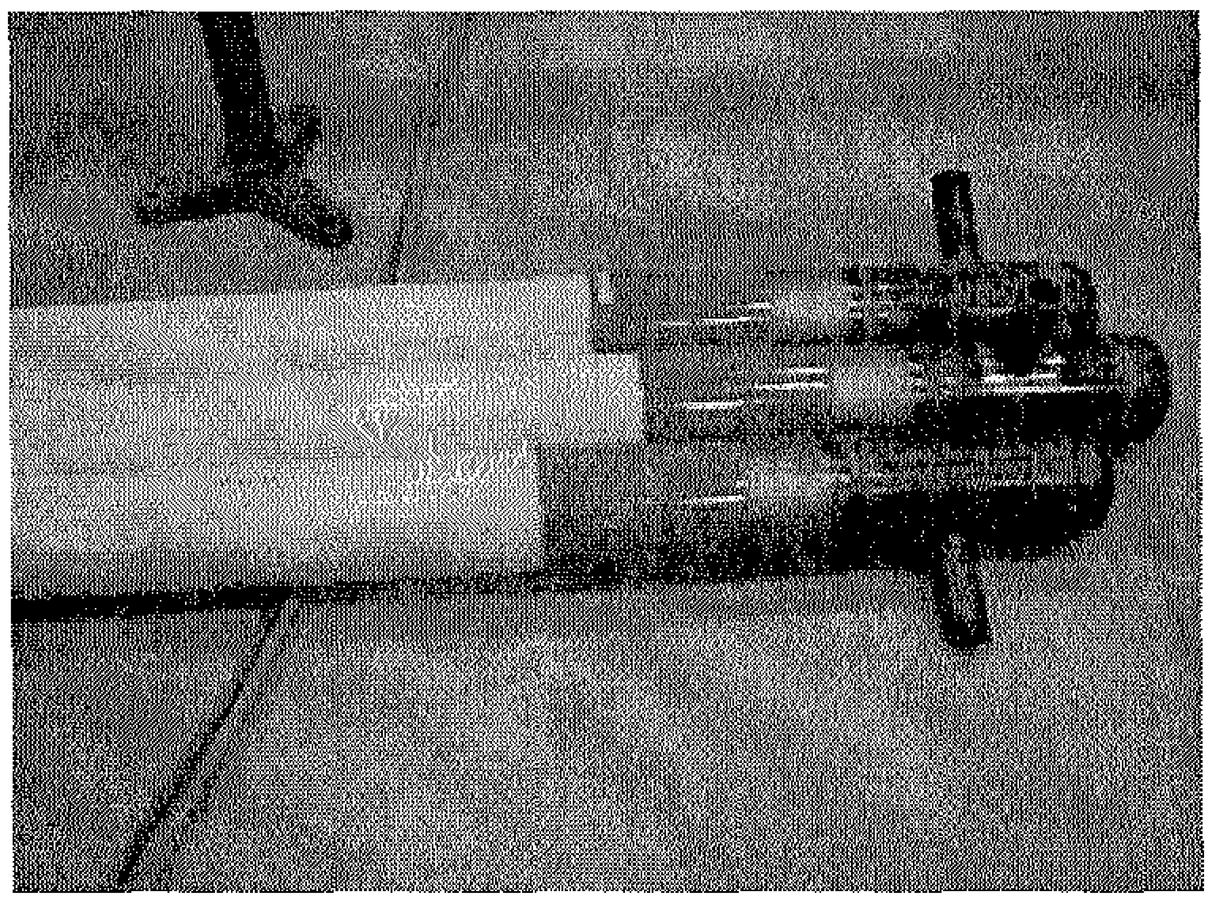
Three separate installations were performed at the GTI Plastic Pipe Farm. These installations included two different pipe diameters and various types of backfill:

- 2" IPS SDR 11 PA12 pipe operating at 250 psig with indigenous backfill
- 6" IPS SDR11 PA12 pipe operating at 250 psig with 80/20 rocky soil/clay mix using industry accepted compaction practices
- 6" IPS SDR11 PA12 pipe operating at 250 psig with "flowable fill" material to simulate aggressive compressive forces acting on the pipe

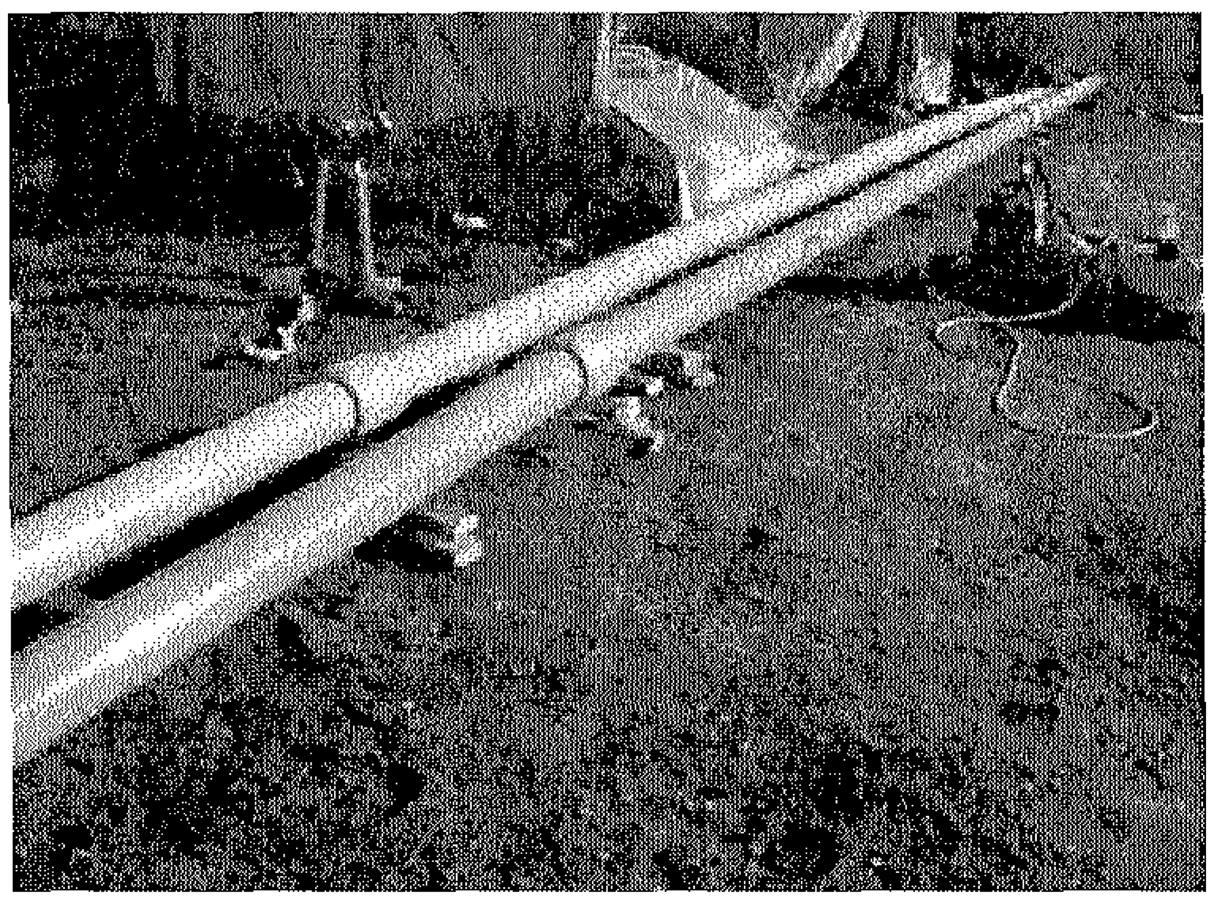
The installations utilized various methods of joining including PA12 butt heat fusion procedures and electrofusion couplings. Moreover, additional fittings and appurtenances were also installed, i.e. transition fittings. The installations were pressure tested at 375 psig for 4 hours and then the pressure was reduced to the 250 psig operating pressure. These installations proved the ability to safely install and operate the PA12 piping systems at high pressures using practices specific to PE piping systems which are commonly accepted and approved. The following figures illustrate the installation details for the respective GTI installations.



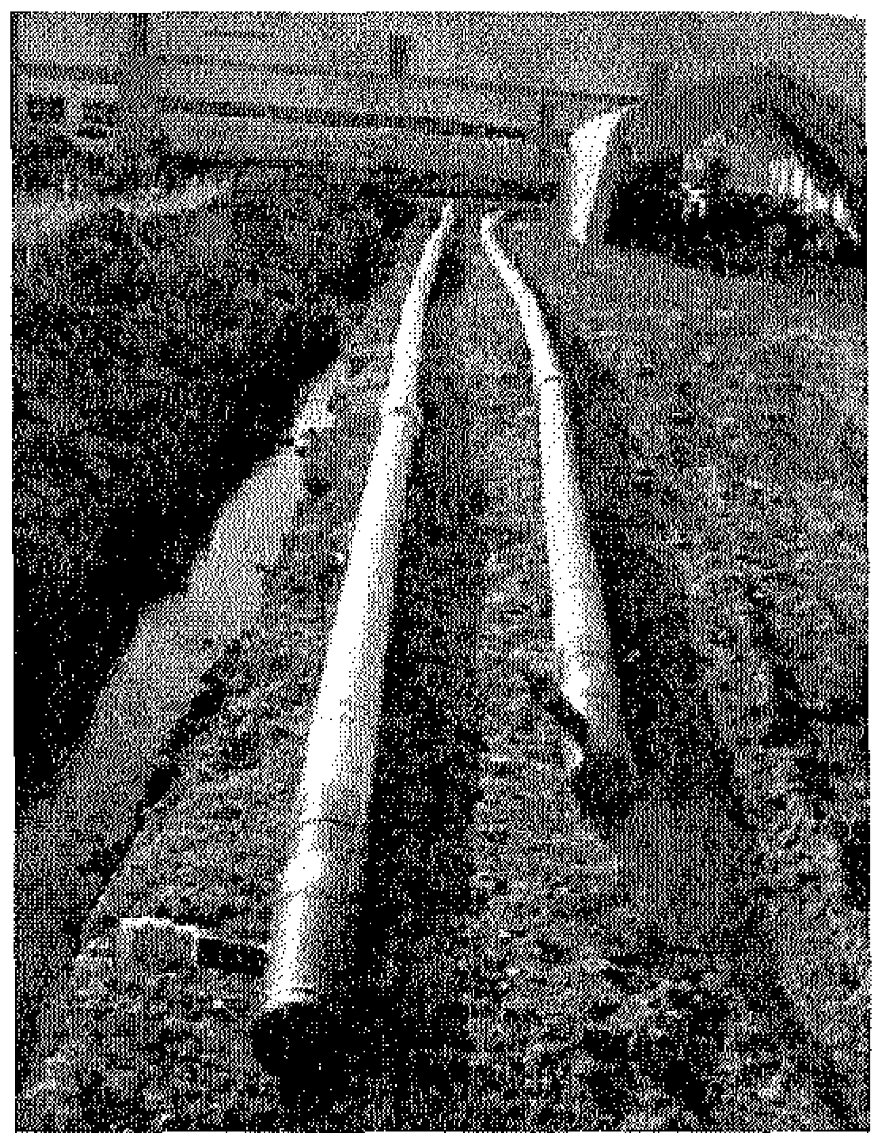
(a)



(b)



(c)



(d)

Figure 2: Representative illustrations of the 6" PA12 installation at GTI pipe farm during October 2006. (a): Illustration of the butt heat fusion using the McElroy 28 machine. (b): Illustration of end connections used to facilitate pressurization and tie-in. The end connections consist of a 6-inch PA12 transition fitting and schedule 40 steel fittings and end caps. (c): illustration of pipe connected using both PA12 electrofusion fittings and butt heat fusion joints. (d): Illustration of pipe to be installed using flowable fill as the backfill material.

Figure 3: Representative illustrations of installed PA12 pipe segments using both (a)flowable fill and (b)rock soil mixture

National Fuel Gas Distribution Company

In addition to the installations at GTI, National Fuel Gas Distribution Company performed an additional field installation at their Mineral Springs facility near Buffalo, New York to characterize the effects of extensive bending strain on the PA12 piping systems. PA12 piping systems were installed at both a 20 times the outside diameter bend radius on pipe sections with no joints or fittings, and a separate length of pipe containing a butt heat fusion joint was installed at 90 times the outside diameter bend radius. Each of these respective test conditions represents significantly more aggressive installation conditions than those found in routine practice. The intent was to evaluate the PA12 piping under worst case conditions. Like the GTI installation, the PA12 piping systems installed at National Fuel were installed using PA12 butt fusion procedures and electrofusion fittings, pressure tested at 375 psig, and then pressurized to 250 psig operating pressure using compressed natural gas. In addition, a 6x2" mechanical fitting was also installed and tapped at the line pressure – 250 psig.

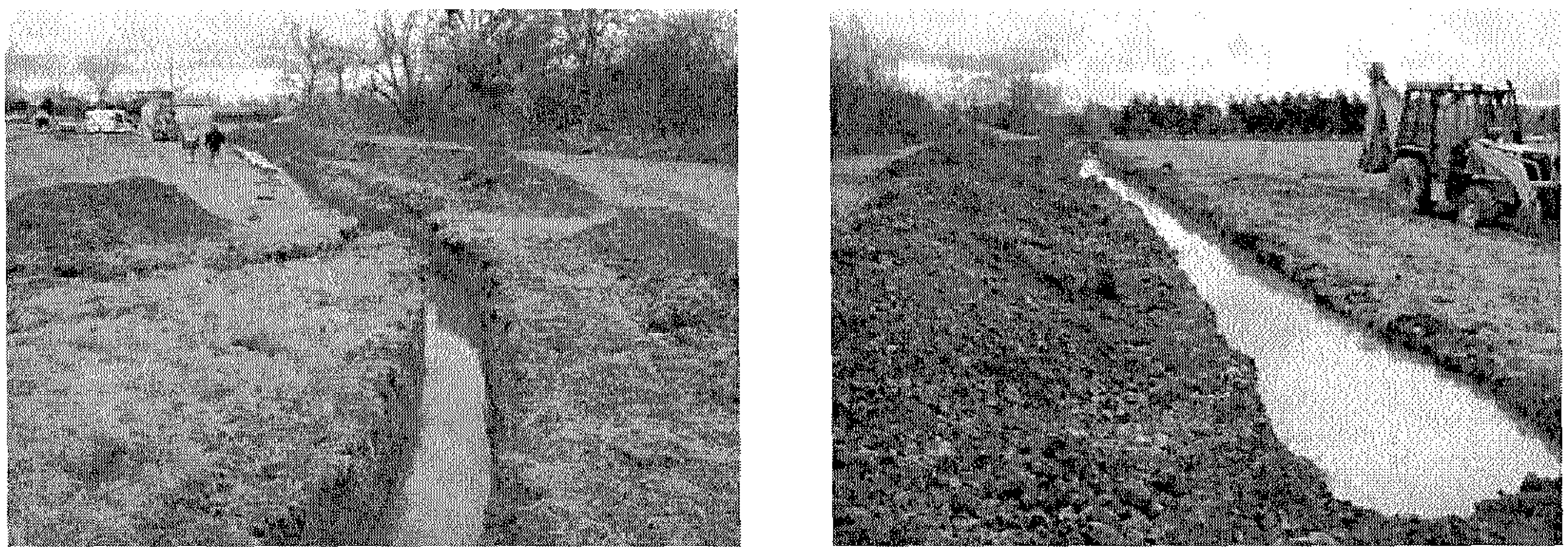


Figure 4: illustration of National Fuel installation with varying bend radii

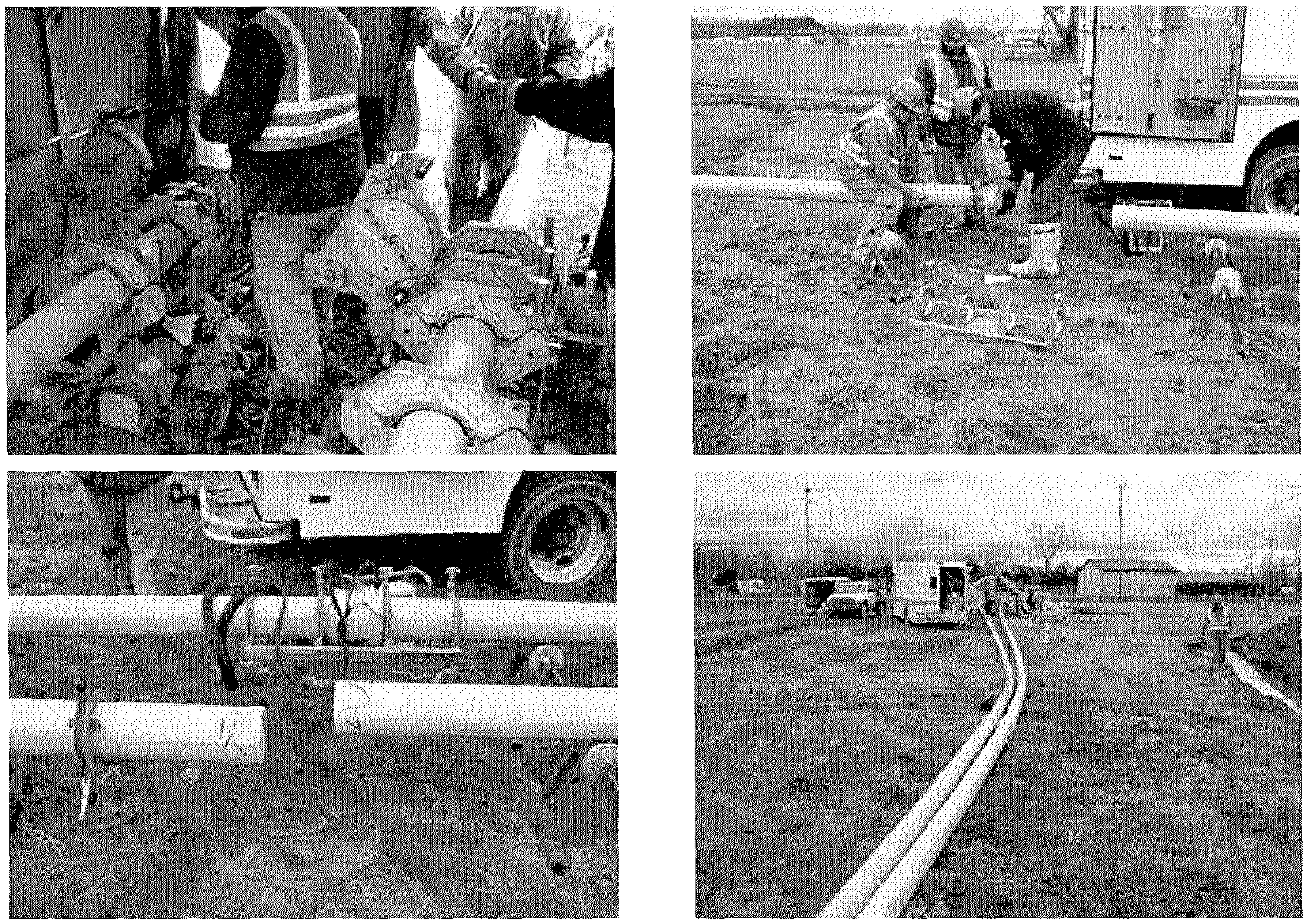


Figure 5: Representative illustrations of the National Fuel installation at its Mineral Spring facilities.

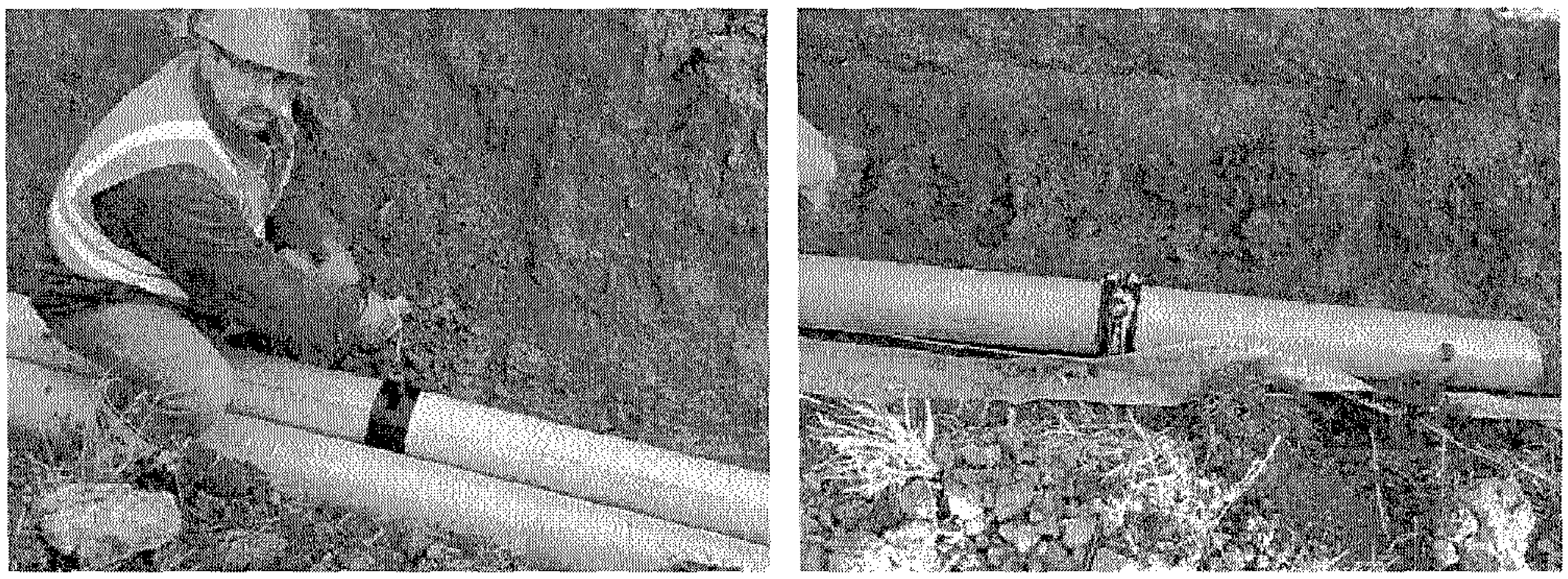


Figure 6: Illustration of the installation and leak testing of a 6x2" Continental Industries mechanical fitting. The mechanical fittings were installed at 250 psig and tapped with no observed issues.

Complete System
Based on the preceding discussions, it is shown that the PA12 piping material has been extensively tested and evaluated under all of the applicable code requirements and industry standards and specifications. The results of the testing have demonstrated that the PA12 piping system conforms to all of the relevant requirements contained within both the main body and specific annexes related to Polyamide materials within ASTM D2513. Moreover, the joining of PA12 piping segments conforms to Part 192.283 requirements, ASTM F1055, and ASTM F1924, ASTM F1973 requirements.

Expected Beneficiaries
Based on the preceding discussions, it is clear that PA12 piping systems offer all of the common benefits associated with plastic piping systems. In addition to being easier to handle, pipes can be supplied in coils, and PA12 piping systems eliminate the need for costly long term corrosion control measures. As a result, PA12 piping systems can offer a safe and cost effective alternative to steel piping systems with respect to total installed costs and life-cycle costs.

Most importantly however, the PA12 piping systems offer an effective alternative based on capacity considerations. Given the demographic changes and rapid urbanization, the current gas distribution network is in need of greater capacity to satisfy the Nations' ever growing energy needs. The recognition of this need has led the DOT to act on several other related petitions to satisfy the growing capacity considerations. The introduction and use of the PA12 piping systems can also offer a significant benefit with respect to this objective.

Specifically, as a result of adopting this petition, gas utility companies can:

- fully utilize high performance engineering polymers which meet and/or exceed exiting code and industry accepted standards and specifications
- serve customers in remote areas which were previously cost prohibitive using metallic piping materials which are susceptible to corrosion
- replace existing bare steel unprotected piping which could not be replaced using PE materials

In doing so, this will result in a significant benefit to company's operations and the general public. Moreover, the safety of the overall gas distribution network will be strengthed with the use of proven materials that have demonstrated excellent performance characteristics against know risks and threats – failures via the slow crack growth mechanism.

Conclusion

There has been a tremendous interest and a desire on the part of gas utility companies to identify and evaluate promising candidate materials which offer the benefits of thermoplastic materials and can operate at higher pressures in larger diameters without adversely compromising flow capacity considerations.

The primary areas of interest for the use of these candidate materials by gas distribution companies include:

- Replacement of bare steel pipe with plastic piping to eliminate long term corrosion control issues provided that flow capacity is not significantly impacted
- Line extensions to areas experiencing high growth which are not being served by the gas companies due to cost prohibitive nature of steel piping

Since 2004, Degussa and UBE, in conjunction with the Operations Technology Development (OTD) and the Gas Technology Institute (GTI), have supported research aimed at establishing the technical feasibility and validating the use of the Polyamide 12 (PA12) piping systems for high pressure gas distribution application in larger diameters without sacrificing flow capacity considerations.

The cumulative results of both comprehensive laboratory testing and field evaluations have effectively demonstrated that the PA12 piping material can safely operate at pressures up to 200 psig and provide an effective alternative to steel. The results demonstrate that the decision to incorporate PA12 within Title 49, Code of Federal Regulations Part 192 will not compromise safety and will provide a meaningful benefit to both the gas distribution operators and the general public.