

“PE 100 at 100psig - 13 years of success”

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ABSTRACT

PE 100 has allowed Transco, the largest UK natural gas distribution company, to develop a 7 bar (100psig) polyethylene (PE) distribution network. This paper outlines the work that was undertaken in taking this technology from the polymer chemists laboratory to the gas engineers trench, from early work on long term strength, resistance to crack propagation, installation issues such as fusion welding, proximity distances to operational issues such as emergency flowstopping.

INTRODUCTION

Polyethylene (PE) pipe was first used as pressure pipe in the US in the 1950s. These first materials were high density polyethylenes (HDPEs), which were prone to stress cracking and had poor resistance to rapid crack propagation (RCP). Despite this, the benefits of PE over metallic systems were quickly proven. The PE systems were lightweight and easier to handle than metallic pipes, and were not at risk of corrosion. PE pipe could be supplied in coils, reducing the number of joints to be made, and was flexible enough to negotiate bends during installation. Jointing could be achieved above ground, allowing narrower trenches to be used. Developments such as electrofusion made jointing extremely reliable and rapid. The pipe could be squeezed to stop the gas flow without long term damage, giving emergency and routine flowstopping at minimum cost.

In 1969, Transco started construction of a PE gas distribution system, using Dupont Aldyl A material at pressures up to 4 bar (60psig). The majority of the UK distribution network operates at low pressure (<75mbar 1psig) with a small proportion at 2 bar (30psig). This second generation medium density polyethylene (MDPE) material was less crystalline than the first generation materials, giving improved resistance to slow crack growth (SCG) and RCP. Advantica carried out significant

work on stress crack resistance and RCP resistance of the MDPE resins, and established the critical pressures above which PE pipes are at risk of RCP, which limited the operational pressures of MDPE pipes to 5.5 bar (80psig). RCP resistance decreases with diameter, so Transco de-rated the operational pressures of MDPE pipes as the diameter increased in their codes of practice, so large diameter PE pipes are operated at pressures significantly lower than those permissible based on stress rupture design criteria alone.

Today, the PE mains network extends to almost 120,000 km (75,000 miles) in sizes up to 630 mm (24 inches) and is accepted as the prime material for gas distribution.

In the early 1980s, Transco engineers wanted to extend the pressure capability of PE pipes to allow the widely known benefits of PE to be used at pressures up to 7 bar (100psig). The materials available at this time were not capable of safely meeting these requirements, but polymer manufacturers were making significant steps in understanding how to control the polymerisation process to achieve the desired material properties.

Solvay made a breakthrough in the mid 1980s by producing an HDPE rated at PE 100 with excellent resistance to both SCG and RCP, and this was widely proclaimed as the ‘third generation’ of PE. PE 100 rated resins were the only PE materials that offered the balance of required properties to allow the use of PE at the pressures desired.

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MATERIAL ISSUES

What is PE 100?

The precise definition of PE 100 is covered with clarity elsewhere¹, but essentially PE materials that are classified as PE 100 are theoretically capable of operating at a stress of 10MPa for 50 years. This corresponds to a pressure of 20 bar (280psig) with SDR 11 pipe. ISO 4437² specifies a safety factor of 2, giving a maximum operating pressure of 10 bar (145psig). Due to the fact that pipelines above 7 bar (100psi) bar are subject to taxation in the UK, it was decided to limit the PE 100 pipe network to a pressure of 7 bar. This led to a safety factor of $20/7 = 2.9$.

Balancing the properties of PE 100 resins

For application at high operating pressures, PE pipes must have the required strength for the design life, resistance to SCG, and resistance to RCP. Changing the properties of a resin might improve one aspect of performance, but have a detrimental affect on the others.

Long term strength

Long term strength is usually measured by carrying out a series of long term hydrostatic tests at specific stresses at controlled temperatures and analysing the time to failure results following the protocol in ISO TR 9080³, which uses a lower confidence limit to determine the minimum required strength classification.

Stress crack resistance

Stress concentrations caused by environmental factors such as rock impingement or scratches will act as crack initiation points. Pipe materials for high pressure applications require excellent resistance to SCG. Advantica carried out extensive notch pipe testing at elevated temperature on the Solvay PE 100 material, to confirm the material had superior SCG performance.

Rapid Crack Propagation (RCP)

A fast running longitudinal brittle fracture can occur in a pressurized pipe subject to impact, and this is known as RCP. Extensive work on RCP in PE pipes was carried out by Advantica⁴ (Greig et al) in the 1980s and 1990s, and this determined the need to de-rate pressures as diameter increases. The issue of RCP resistance with a 7 bar pipeline, particularly with the large diameters (up to 400 mm) is obviously of paramount importance, given the fact that these pipelines usually run cross country between towns or villages. A fast running fracture could destroy a long length of pipeline, and this has happened on a number of occasions worldwide⁵ where designers have neglected to include the risk of RCP in their calculations.



Figure 1: Arrest of a fast running fracture in PE 100

Transco perform a hydrostatic strength test during commissioning at 1.5 times the operating pressure, followed by a leak test at the operational pressure. It is therefore necessary to ensure that the critical pressure for RCP is above 10.5 bar. Transco specify that all PE 100 resins are tested in a full scale RCP test at 0°C (32°F) at 14 bar (200psig), at the largest diameter in the size range. Additionally, campaign tests are carried out at 21 bar (300 psig) on each batch of resin supplied from the manufacturers, which ensures that there is an RCP safety factor of at least twice the highest pneumatic pressure encountered by the pipeline. Figure 1 illustrates the superior resistance to RCP of PE 100 (orange) in comparison to PE 80- (yellow). The propagating fracture, running from left to right, is arrested within a short distance in the PE 100 material.

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Use at low temperatures

Gas is supplied to distribution systems following pressure reduction from higher pressures. Typically, pressures will be reduced from around 20 bar (290 psig) to 7 bar (100psig). The process of reducing the pressure in a regulator causes Joule-Thompson cooling. In the relatively temperate UK winter, gas temperatures can be as low as 5°C (41°F). This can result in the gas temperature falling to as low as -20°C (-4°F) downstream of the regulator. Transco usually install water bath heaters to preheat the gas to an acceptable temperature, but these heaters can fail and are expensive to install and maintain. It is therefore important that the performance of any pipe connected downstream of a pressure reduction station is well understood at the low temperatures that can be experienced. The risk for PE pipe is that of brittle failure, either of the joints, or by impact on the pipe, which may lead to RCP. This can be mitigated by installing steel pipe immediately after the pressure reduction station, for sufficient length to allow the gas to warm up to an acceptable temperature before making the transition to PE pipe. Advantica undertook a test programme to determine the capability of various grades of PE material, temperatures down to -20°C (-4°F), at various diameters and pressures. This was carried out on both pipe and fittings, and acceptable performance criteria have been established. Advantica has developed a software package "HTREC" for Transco that calculates temperature recovery after pressure reduction.

CONSTRUCTION ISSUES

Butt fusion

Correctly made butt fusion joints are as strong as plain pipe. The control of melt temperature is highly critical to producing a good butt weld and to minimise the risk of poor welds, which is especially critical with higher pressures, fully automatic machines are used for all PE construction in Transco. Automatic machines minimise the time between hot plate removal and butting of the pipes, and this ensures that the melt temperature has not fallen below critical levels. The fusion procedures developed by Advantica for Transco are broadly similar for PE 100 and PE 80, with slight differences in applied pressure during bead up and heat soak.

Inspection of butt fusion welds

Advantica has evaluated a number of Non Destructive Techniques over the years, including radiography and ultrasonics for assessing the quality of butt joints. None has proved sufficiently reliable or cost effective for field implementation. Advantica developed a simple in-field butt fusion quality control technique, relying on removal and inspection of the external weld bead. External and hydraulically powered internal weld bead removal tools are available from a number of manufacturers. For PE 100 pipelines, it is common practice to remove the internal weld bead to improve the flow capacity, and remove the potential notch in the pipe bore, which reduces the risk of compromising the strength of the pipe. Removal and inspection of the external weld bead will reveal any pipe misalignment. The width of the external weld bead is checked using a standard min-max gap gauge. For PE 100, new butt fusion bead gauges had to be developed. The quality control of the fusion process is highly important, and both the weld beads and the print out records from each joint are kept for inspection on PE 100 pipeline projects.

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Figure 2: External debanding

Electrofusion

Electrofusion is also used as a jointing technique for PE 100 pipe, mostly for connection of tie-ins. A range of special fittings has been developed in conjunction with fitting manufacturers, and fully approved fittings up to 400 mm have been used in Transco. These fittings have been tested to a higher specification than fittings for the PE 80 system and are designated "Class C". Most of the Class C fittings are existing products for PE 80 pipe (Class B) that have achieved Class C rating, enabling them to be used on the PE 100 network. Fusion compatibility between PE 100 and PE 80 resins used in the fittings has been assessed, and found to be satisfactory. Larger fittings from European suppliers have recently been approved, and some of these are manufactured from PE 100 resins. The size range of fittings is more restricted than that available for the PE 80 system, due to the limited demand, but manufacturers are more inclined to develop new fittings for PE 100 pipe now it is clear that this is a well established technology.

Proximity distances and depth of cover

Advantica carried out both experimental and computational work to determine the effect of 7 bar (100psig) pipes failing at pressure, both in terms of the risk from the emanating projectiles, and the risk of ignition of the released gas. Due to the higher pressure of the gas within the pipe, proximity distances for 7 bar (100psig) PE pipe are significantly higher than those required for 4 bar (60psig) pipe. For pipes above 180 mm in diameter operating at 7 bar, the energy of escaping gas was judged to be high enough to warrant even greater

proximity distances. Where PE 100 pipe is laid in areas where it may be prone to impact damage, or where specified proximity distances cannot be maintained, reinforced concrete sections, welded mesh metal sheet or steel capping plate is used. In rural or cross-country locations, pipe is laid deeper than in urban environments, due to the increased risk of farming activities damaging the pipelines.

Position of valves

Valves are installed in PE 100 lines at operationally desirable locations, such as on the outlets of a tee, branches or connections. Special crossings, such as river crossings, are valved either side. Pressure points and rider points are also installed either side of valves, to allow their safe use and maintenance. Due to the volumes of gas likely to be released following a strike, regular positioning of valves is desirable, especially in urban environments.

Marking and protection

Marker tape is laid directly above the PE 100 mains to warn excavators of the position of the pipeline. Detectable marker tape is specified. Individual lengths of marker tape are connected together, and is in turn connected to marker posts and earthed to allow detection by induced current, but provision is made for electrical isolation to allow direct connection of cable location equipment, or for continuity testing. Marker posts are positioned at boundaries, such as hedges between fields, adjacent to fences, at special crossings, and along road sides at the extremity of the public highway. Marker posts are also used to identify changes in direction of the main.

Commissioning a new PE 100 pipeline

It is difficult to accurately measure leakage on large pipe volumes during commissioning pressure testing. For polyethylene pipe, a period of time must elapse to avoid viscoelastic creep affecting the measured pressure. This creep is significant when the pressures are high. Also small temperature variations can mask pressure changes resulting from leakage. Advantica has developed a solution to both these problems, which enables several miles of large diameter PE pipe to be accurately leakage tested in a fraction of the time required using conventional techniques⁶. The APT (Advanced Pressure Test) equip-

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ment incorporates software with built in creep compensation algorithms based on sound knowledge of polyethylene behaviour. The advanced pressure test system measures the temperature change of all the air in the pipe using acoustics. A loudspeaker and microphone is placed inside the pipe and a pulse echo technique is used to measure the sound speed. The speed of sound varies with temperature, and this is used to determine average changes down to 0.001°C. This data is then used to compensate the pressure readings. In addition to the pneumatic leakage test at the operational pressure, Transco perform a hydrotest on PE 100 pipelines at 1.5 times the operating pressure to test the strength of the pipeline.



Figure 3: Advanced Pressure Testing using acoustics and creep correction algorithms

OPERATIONAL ISSUES

Emergency procedures

Emergency flowstopping was a major concern in the early days of PE 100. Squeeze off is the standard Transco technique for flowstopping of PE pipelines, and this was used within Transco on PE 100 lines. There was concern over internal cracks that can develop when squeeze off is released from large diameter, thick wall PE 100 pipes, and for this reason, it was mandatory to cut out and replace PE 100 pipe sections that had been subject to squeeze off within 6 months. Advantica has recently developed squeeze off procedures for PE 100 that have been proven not to have an impact on the 50 year design life of PE 100 pipes. This has been achieved by close control of the squeeze off, and in particular, the squeeze release process. Up to 180 mm (6"), standard squeeze off equipment can be used. Above this size, specialist equipment has been developed⁷ which provides precise control over the squeeze off process, allowing squeeze off of pipes up to 355mm (12"). For sizes above 400 mm (14"), Advantica are working with equipment suppliers to develop folding head stopple fittings. Prototype fittings have been produced, and initial testing is proving encouraging.



Figure 4: Squeeze off trials on PE 100 at low temperature

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Branch connections

A range of 7 bar (100psig) rated branch saddles has been developed, allowing offtakes of 63 mm (2") and 90 mm (3") for pipe sizes up to 400 mm (14"). Further developments for large diameter flowstopping are likely to make larger offtakes available.

History of PE 100 use in Transco

The first 7 bar gas installation using PE 100 was undertaken in 1989 on the island of Mersea near Colchester in the South East of England. Mersea Island is separated from the mainland by saltmarshes and mudflats. The only access was by means of a road built on a causeway that was liable to flooding at high tide. There had been considerable interest from the 10,000 villagers of West Mersea in getting natural gas. A feasibility study undertaken in 1988 to establish whether it was economically feasible. Two identified options were to lay 7.1 km (x miles) of 4" and 6" steel pipe, operating at 4 bar (60psig) or to construct a 180 mm SDR 11 line, operating at 7 bar (100psig). The PE 100 solution was adopted. A number of issues were identified during this project, including that of how to conduct a pressure test on a pipe subject to viscoelastic creep. Since then, PE 100 has been widely used in the UK, with notable projects being a 7 km 355 mm reinforcement project around Swindon in 2001, which required several road and ditch crossings.

Success story

To date, over 400 miles (700 km) of PE 100 pipe has been installed in diameters up to 400 mm (14") in the UK. PE 100 is now the preferred material in the majority of 7 bar (100psig) installations in the UK. The initial reluctance of design engineers to specify the material has now been overcome, by tackling issues such as resistance to RCP, large diameter flowstopping and in field quality control of jointing.

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REFERENCES

- ¹ PE 100: Performance Plus- S D Sandstrum, 16th International Plastic Pipe Fuel Gas Symposium, November 1999, New Orleans
- ² ISO 4437- Buried Polyethylene (PE) Pipes for Supply of Gaseous Fuels- Metric Series- Specifications
- ³ ISO TR 9080 - Plastic Piping and Ducting Systems – Determination of Long Term Hydrostatic Strength of Thermoplastic Materials in Pipe Form by Extrapolation
- ⁴ Rapid Crack Propagation in Polyethylene Gas Pipes - J M Greig Plastics Pipes IX, Edinburgh UK, September 1995.
- ⁵ RCP, after 25 years of debates, finally mastered by two ISO tests- P Vanspeybroeck, Plastics Pipes XI, Munich, Germany, September 2001
- ⁶ Pressure testing of polyethylene pipes using acoustic temperature measurement – R Ashworth, Plastics Pipes XI, Munich, Germany, September 2001
- ⁷ Development of flowstop systems for large diameter polyethylene mains D Morgan & T Hill, Plastics Pipes XI, Munich, Germany, September 2001

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