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THE CHOICE OF PRESSURE RATINGS FOR POLYETHYLENE PIPE SYSTEMS FOR WATER SUPPLY AND SEWERAGE DUTIES

CONTENTS

1. SCOPE AND OBJECTIVES

This Information and Guidance Note provides guidance on the choice of pressure classifications or ratings for buried and above ground polyethylene (PE) pipe systems for the transmission of potable water and sewage. Close-fit PE liner pipes (independent or interactive) are not within the scope of this document. The document supports WIS 4-32-17: June 2001: Issue 2 (Polyethylene pressure pipes for pressurised water supply and sewerage duties) providing information for the application of polyethylene pipe manufactured to that specification. Further guidance on the use and installation of PE pressure pipe systems can be found in the joint WRc/ British Plastics Federation publication ‘The PE Pipe Manual’, Issue 3. This document may be accessed on the website of either organisation. Website addresses are given in Section 5.4 below.

The UK Water Industry is obliged to quote European standards where available in the purchasing of pipes under the rules of the European Public Procurement Directive. These standards generally address two distinct areas; that of general requirements for a pipeline system regardless of material, and also specific performance requirements for the pipeline system materials that may be used. They are not designed to describe how a particular material is best specified to meet the different operating and installation conditions of pipeline systems.

This Information and Guidance Note (IGN) seeks to redress this situation for polyethylene pressure pipe systems and is written to conform to European (CEN) Standards already published and to be generally in line with the most recent philosophy of determining pipe 'allowable pressure ratings' being evolved by CEN committees. At the time of publication of this issue, CEN product standards for PE pressure pipeline materials are still in development and therefore UK Water Industry specifications (WISs) are referenced in the text. This IGN will be revised and reissued when the relevant CEN standards for materials and pressure classification are formally issued as BS ENs.

It should be noted that these standards are concerned with the most frequent application and operational conditions encountered across Europe, and the committees concerned have evolved the concepts of maximum allowable continuous operating pressure (PFA), maximum allowable operating pressure (PMA) and maximum allowable site test pressure (PEA). However, product standards only require the manufacturer to mark pipes and fittings with a nominal pressure 'classification' or 'rating' (PN). This cannot be otherwise as it is rarely possible for the supplier to know the application and installation conditions in which product is to be employed. In the cast majority of cases the PN rating of polyethylene pipe systems more than adequately meets the requirements of PFA and PMA, which are the key factors that the pipeline systems operator requires to know for long term management and maintenance.

It is therefore of paramount importance that, where pipeline systems have allowable operating pressures that do not correspond to the marked PN rating, this is prominently recorded on the operator's asset records.

Much of the guidance contained in this document is based on work carried out by UK Water Industry Research Ltd. (UKWIR). A list of relevant reports is given in Section 5.

The UK's buried pipeline design methodology is incorporated in BS EN 1295-1 'Structural design of buried pipelines under various conditions of loading'. It is important to note that the UK method calculates "combined stresses" in the pipe wall arising from both internal pressure loading, ground loading and from imposed surcharge. In theory this can sometimes influence the maximum allowable continuous operating pressure (PFA). Several other countries in Europe also have their own unique Annexes to EN 1295 giving their national design procedures, and these vary in their approach and methodology. However, none of the methods properly differentiates between flexible thermoplastics pipes and rigid or semi-rigid pipes, such as concrete or ductile iron respectively, in terms of their material physical characteristics. A committee in CEN is current charged with seeking to agree a common European design standard for all buried pipes but it will be some years before the current BS EN 1295-1 is superseded. Another thermoplastics-based group is currently utilising high grade empirical data from a three-year European field project (funded by TEPPFA and APME, the European plastics pipe and fittings manufacturers and materials suppliers associations respectively) to produce a simple graphical method of establishing the structural design requirements of buried thermoplastics pipes. UK Water Industry Research (UKWIR) has produced a computer program, PErseus, which carries out calculations following the major European structural methods and includes the TEPPFA method.

As already implied, the other critical considerations for a pressure pipeline are maximum allowable operating (PFA, PMA) and site test pressures (PEA). For example, although most water pipes are laid in situations where pressure fluctuations are primarily diurnal, PE pipes are increasingly being used for pumped water or sewage, with their associated more onerous operating conditions. The relevant product standards prEN 12201 and prEN 13244 only state nominal pressure classifications, PN, for various PE grades and "wall thickness to diameter ratios" (SDRs). The component-related allowable pressure definitions PFA, PMA and PEA are introduced in the overall water system standard BS EN 805 (Water Supply – Requirements for Systems and Components Outside Buildings) which takes installation, commissioning and operational conditions into account. BS EN 773 is the parallel pressure sewage standard.

The function of this information and Guidance Note is to provide a simple procedure to establish the PE pipe PNs required for different applications and duties, in a way that complies with the structural and hydraulic requirements of the above

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standards, but that also reflects the particular needs of the UK Water Industry.

Information contained in this Information and Guidance Note is given in good faith. Neither UK Water Industry Research Ltd, Water UK, WRc plc nor Pipeline Developments Ltd can accept any responsibility for actions taken by others as a result.

2. PE PIPES: BASIC SPECIFICATION

2.1 Specification

During 2000, Water UK decided to produce a new specification to define requirements for PE pressure pipes, WIS 4-32-17. This document effectively replaces WIS 4-32-03, WIS 4-32-09, WIS 4-32-13, BS 6572 and BS 6730, and specifies the requirements for PE pipe for the following duties:

- Blue pipes for potable water supply for use below ground in diameters 20 mm to 1600 mm.
- Blue pipes with brown stripes (to indicate an external 'skin' of a different polymer – to provide resistance to scoring, use for contaminated land etc.) in diameters 20 mm to 250 mm (or above as demand dictates).
- Black pipes for above ground use for potable water supply in diameters 20 mm to 1600 mm.
- Black pipes for sewerage and general-purpose duties in diameters 20 mm to 1600 mm.
- Black pipes with brown stripes (to indicate the presence of an external 'skin' of different polymer – to provide resistance to scoring) in diameters 20 mm to 250 mm (or above as demand dictates).
- Black pipes with green stripes for grey water in diameters 20 mm to 1600 mm.
- Coiled pipe in diameter range 20 mm to 180 mm.

For all pressure duties there is no difference in mechanical property requirements for water supply and other applications.

WIS 4-32-17 will be superseded when the European Standards EN12201 and EN13244 are ratified as BS ENs in the future, probably late 2003.

It should be noted that the CEN product standards for PE pressure pipe systems vary from WIS 4-32-17 in certain important aspects such as the requirements for resistance to slow crack growth, electrofusion (EF) socket lengths, and spigot lengths for butt fusion. These differences will be noted in the National Forwards for these standards.

2.2 Preferred sizes of PE pipes

Historically, a large part of the Water Industry has adopted the size range of PE pipes that was used in the gas industry. Indeed, in WIS 4-32-03 (for MDPE), the only sizes quoted in the distribution range were 90, 125, 180, 250 and 315 mm. In WIS 4-32-13 (for 'Higher Performance Polyethylene') the size range was extended to include the common European sizes and some water companies decided to standardise on the near Imperial bore dimensions of 110, 160, 225 and 280 mm to give a more cost effective size range.

PE pipes are standardised in three size ranges:

Range 1 (Service Sizes):

For nominal sizes 20, 25, 32, 40, 50 and 63: pipe will be PE 80.

The preferred pressure rating is PN 12.5.

Range 2 (Distribution Sizes):

For nominal sizes 75, 90, 110, 125, 140, 160, 180, 200, 225, 250, 280, and 315: pipe can be either PE80 or PE100.

The preferred pressure ratings are generally:

PN5, PN6, PN8, PN10, PN12.5 and PN16.

Range 3 (Trunk mains):

For nominal sizes 355, 400, 450, 500, 560, 630, 710, 800, 900, 1000, 1200, 1400, 1600 the pipe can be either PE80 or PE100.

The preferred pressure ratings (dependent on diameter and material and application) are:

PN5, PN6, PN8, PN10, PN12.5 and PN16.

2.3 Materials Classification and Designation

2.3.1 General

Since the introduction of polyethylene pipeline systems the materials have often been referred to in terms of density as well as performance (see Appendix B for details). However the performance classification and designation system introduced by International Standards Organisation committee ISO/TC 138 is now being universally adopted. This is purely based on performance irrespective of density and is described in Section 3.1.

2.3.2. ISO Classification of Pipe Compounds

PE materials are now being classified by both ISO and European Standards in accordance with BS EN ISO 12162 and are designated a **PE 80** or **PE 100**, based solely on long term hydrostatic strength at 20^{o}C. The minimum required strength **(MRS)** at 50 years for PE 100 is 10.0 MPa and for PE 80 is 8.0 MPa. These values are used as a design basis and can be considered conservative as many PE materials exceed these significantly.

PE 100 compounds can only be HDPE grades which have full resistance to rapid crack propagation (RCP) (see below).
PE 80 compounds used in the UK are MDPE grades in accordance with WIS 4-32-17.

Sometimes HDPE materials of inferior performance not meeting the requirements of WIS 4-32-17 may be offered as PE 80. These materials should be viewed with caution and their performance thoroughly evaluated before acceptance (see below).

2.3.3 Performance Classification of Pipes

Although PE materials are classified by strength alone, pipe manufactured from these materials must achieve all the requirements of a performance specification. Arguably the most important part of the pipe specifications concern material toughness properties.

- **Long term resistance to crack growth** is assessed by pressure testing a pipe containing external notches machined to a nominal 20% of pipe wall thickness. Notched pipes must withstand a specified pressure for 1,000 hours at 80^{o}C without failure.

- **Rapid crack propagation resistance** is assessed by either the ISO 13478 Full Scale RCP test (carried out on either 250 mm or 500 mm pipe) or by the ISO 13477 S4 laboratory test (250 mm pipe) to ensure that there is no extended crack propagation when the PE pipe sample is subject to high pressure and low temperature ($\leq$3^{o}C). Propagation will not occur in pipe filled with water. To obtain failure **a significant volume of air** must be present in the pipe, thus these tests are carried out with the pipe containing air only or water with at least 5% air. **Materials which have been tested and are in compliance with the tests specified in WIS 4-32-17 are deemed to be suitable for the whole size range without de-rating the PN.**

Not all MDPE and HDPE materials will meet the requirements of WIS 4-32-17 in relation to resistance to long term crack growth and RCP. It is important to recognise this fact when specifying the pipe.

MDPE (PE 80) pipes meeting the requirements of WIS 4-32-17 **except for the RCP test requirements** are acceptable provided they are de-rated at sizes $\geq$ 355 mm, when significant air pockets cannot be excluded, see Table C.2 in Appendix C.

However, there are older generation ‘Type 2’ HDPE PE 80 materials still available and although they meet the 50 year LCL (lower confidence limit) strength of $\geq$ 8.0 MPa, they are inferior in both slow crack growth and RCP resistance and only marginally meet the CEN requirements in the draft prEN 12202 (potable

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water) and prEN 13244 (sewerage) documents. These do not meet the requirements of WIS 4-32-17 and it should be realised that contracts may arise where materials such as these are offered. To avoid this issue only PE pipes meeting WIS 4-32-17 should be specified.

3. CONVENTIONAL PN RATINGS FOR PE PIPES

3.1 Definition of PN

The PN rating of a plastics pipe is the nominal pressure rating of the pipe determined from the material design stress and wall thickness of the pipe. **The design stress is determined from the material MRS (Minimum Required Strength) using a design coefficient specified by ISO and European standards, which is 1.25 for polyethylene**. These PN ratings are determined on a 50-year design basis at 20°C. However, this does not mean that the pipe has a lifetime of 50 years. On the contrary the actual predicted lifetime for high quality PE materials will be well in excess of 100 years.

A more detailed explanation of methodology to determine PN is given in Appendix A.1.

The PN of a pipe relates directly to the wall thickness or SDR of the pipe (see note 1, Table 1) and the material MRS classification, i.e. PE 100 or PE 80. PN, SDR and the material classification, should always be marked on the pipe.

Table 1 gives a summary of pressure ratings for PE pipes.

Table 1: Summary of General Pressure Ratings for PE Pipes

Material	Nominal pressure ratings (PN in bar) for various SDRs					
PE-80	PN 5 (SDR 26)		PN 8 (SDR 17)		PN 12.5 (SDR 11)	
PE-100		PN 6 (SDR 26)	PN 8 (SDR 21)	PN 10 (SDR 17)		PN 16 (SDR 11)

Notes:
1. *SDR is defined as Standard Dimension Ratio, i.e. the ratio of diameter to wall thickness.*
2. *MDPE PE80s are re-rated for diameters ≥355 mm (see clause 4.2.2.3 and Table C.2).*
3. *If other SDRs are offered, the pipe supplier should mark these pipes with the appropriate nominal pressure rating PN.*

4. DETERMINATION OF PRESSURE CLASSIFICATION TO TAKE INTO ACCOUNT OPERATIONAL AND INSTALLATION ISSUES

4.1 Pressure in service

It is recognised that most pipes in service:

- may not operate at constant pressures,
- will generally be buried, and
- will be filled with water at temperatures other than 20°C.

It is important to ensure that all these aspects have been considered in the design in order to always choose an appropriate pipe **nominal** pressure rating PN (i.e. its pressure classification) with total confidence. The designations for various **allowable pressures** given in BS EN 805 have been adopted as the basis here.

- **PFA**: allowable continuous operating pressure for the main. See Section 4.2.
- **PMA**: maximum operating pressure (i.e. not to be exceeded, e.g. via a ‘surge event’). See Section 4.3.

- **PEA**: test pressure that must not be exceeded during commissioning. See Section 4.4.

The pressure classification selected for a PE pipe for a particular application should be the higher of the values determined for PFA and PMA using the methodologies outlined below. In the vast majority of cases, this will be equal to the nominal pressure rating PN.

4.2 Determination of Allowable Continuous Operating Pressure (PFA)

4.2.1 General

For the majority of Water Industry applications, the allowable continuous operating pressure (PFA) will be the same as the marked PN rating when pipe conforming to WIS 4-32-17 is used. However, there are some occasions where this may not apply, and for such cases designers should relate PFA to PN via re-rating factors, as follows.

The approach utilises an **Operational 'Factor' F(O)** and an **Installation 'Factor' F(I)** whereby the Allowable Continuous Operating Pressure (PFA) is defined as:

PFA = F(O) x F(I) x PN

The **Operational Factor F(O)** will equal 1 for most PE pressure systems. It will only have a reduced value where it is necessary to allow for the effects of temperature, cyclic loading (fatigue) and resistance to RCP for PE80 (when significant air pockets are anticipated). Issues relating to the value of F(O) are discussed in 4.2.2.

The **Installation Factor F(I)** is not an issue for most systems installed in accordance with accepted good practice and will therefore also be generally equal to 1. Where unexpected problems occur on site during installation, then advice is needed to allow sensible judgements to be made of serviceability.

The primary exceptions considered here are excessive wall 'damage', non-standard backfill and/or control of compaction. The minimum factor from this grouping should be taken as the operative value of F(I). Issues relating to the value of F(I) are discussed in 4.2.3.

When there are several exceptional factors, a recommended and conservative approach is to multiply the effects of these together to determine F(O) or F(I).

This is illustrated in the flow chart shown in Figure 1.

4.2.2 Issues relating to the Operational Factor F(O)

4.2.2.1 Average Operating Temperature

The design basis and lifetime prediction for polyethylene pipeline systems is based on a temperature of 20^{o}C. This is not the temperature of most potable water mains in the UK, where the average is typically between 10^{o}C and 15^{o}C (ref. 2). However, in some sewerage applications temperatures above 20^{o}C may be the norm. Although variations in ambient temperatures between 0^{o}C and 30^{o}C do not significantly limit the use of PE pipes, some advice is given. Polyethylene is a thermoplastic and in order to determine performance both time and temperature dependence need to be taken into account. ISO 13761 defines the changes in PE material strength that occurs as temperature changes. At low temperatures, PE pipes become stiffer and stronger (and vice versa at high temperatures). For PE pipes, the strength and hence the pressure resistance changes by 1.3% per ^{o}C change in temperature.

'Warm' Water Systems: When operating temperatures above 20^{o}C are foreseen, e.g. for sewerage or above ground applications where there is no flow for long periods, the factor F(O) should be reduced using the following equation.

F(O) = 1 – 0.013 x (Average operating temperature – 20)

NOTE: For mean temperatures above 45^{o}C the client is advised to consult the supplier.

'Cold' Water Systems: The above equation is equally applicable for average operating temperatures below 20^{o}C, by itself (i.e. provided other factors do not reduce F(O)) resulting in a F(O) factor which is greater than 1. This would make PFA > PN, and notionally the pipe could

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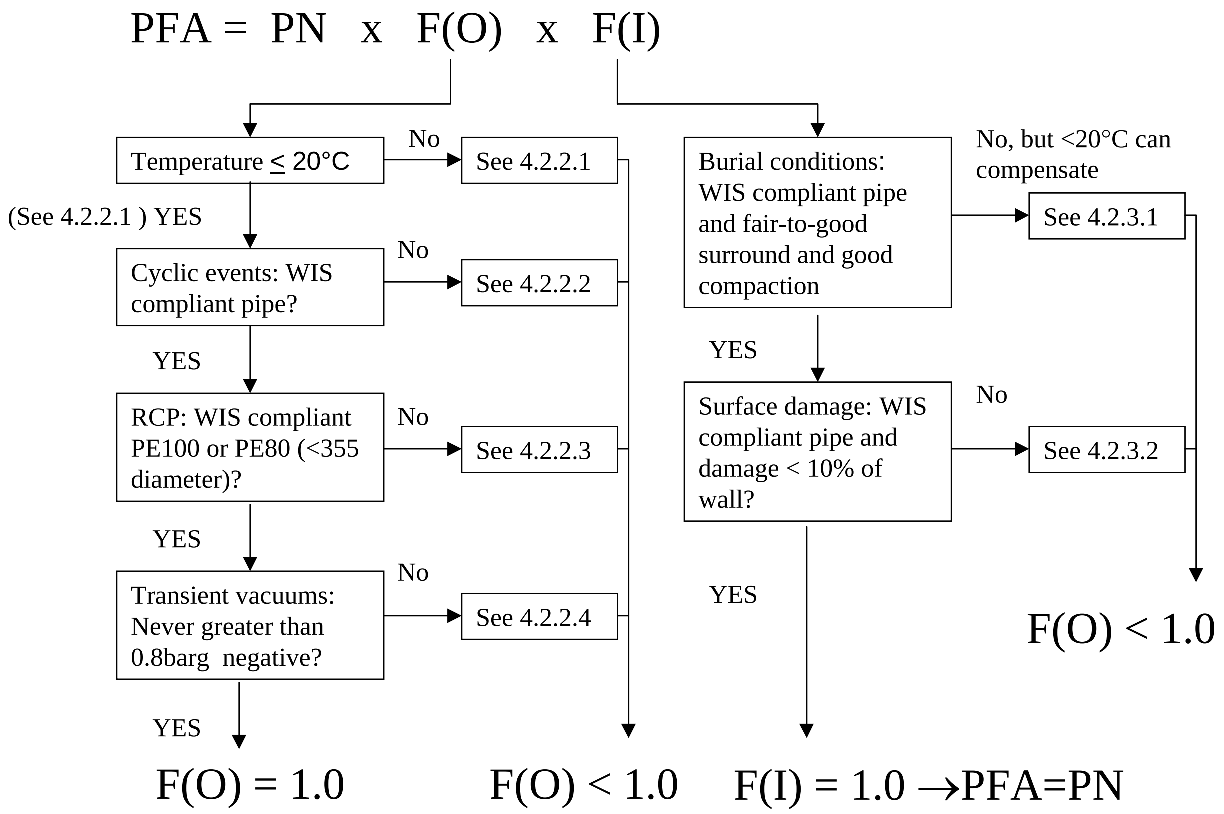

Figure 1 Calculation of PFA from PN, via the operational factor F(O) and the Installation factor F(I)

be operated at higher than its PN rating. However, it is usual practice in the UK to disregard this effect for clean water systems, and operate with F(O) = 1 and PFA = PN, resulting in an increased design coefficient above the specified minimum. However where another component factor of F(O) or F(I) is less than 1 for a particular application, consideration may be given to using the increased design coefficient to offset this. Pipe suppliers guidance should be sought in these circumstances.

4.2.2.2 Cyclic Pressure Regimes

The UK has issued an Information & Guidance Note (IGN 4-37-02 ‘Design against Surge and Fatigue Conditions for Thermoplastics Pipes’) to cover criteria for design against surge and fatigue. It specifies ratings to cope with maximum allowable pressure (PMA) and maximum allowable operating pressure (PFA) where there are cyclic variations in flow leading to the risk of fatigue damage. Surge can be treated as a separate phenomenon from fatigue and is addressed in Section 4.3 below.

Research by UKWIR (ref. 1) has shown that neither diurnal nor in fact cyclic pressures of any frequency (e.g. from pumps, valves etc.) will reduce the long-term performance of high toughness PE pipes. For materials meeting the notched pipe test requirements of WIS 4-32-17, cyclic pressures will not result in damage providing the associated peak values do not exceed 2 x PN. Hence the Operational Factor F(O) will usually [see above] be 1 for such materials.

NOTE: Materials not complying with WIS 4-32-17 will need to be substantially de-rated. The Operational Factors F(O) for such de-rating is defined in Appendix C.1.

4.2.2.3 Rapid Crack Propagation (RCP) Resistance

Research has shown that for a given set of test criteria it is possible to fracture steel or plastics pipes by the phenomenon known as RCP (Rapid Crack Propagation) when air is present in the pipeline. The proposed European PE product standards for clean water (prEN12201) and for sewage transport (prEN13244) contain test procedures defining criteria for total resistance to RCP. This IGN defines the applicable pressure ratings for the largest diameter range (Range 3) of PE 80 pipes in accordance with note 8 of Table 2 of part 1 of these European standards, when total RCP resistance cannot be assumed.

The guidance given in this document is applicable to materials meeting the requirements of WIS 4-32-17. Materials which do not meet these requirements or have not been assessed against this standard may be of poor performance with respect to RCP, surge and fatigue resistance. These characteristics are as vitally important as the material classification. It is therefore essential that the relevant data with respect to these characteristics are available to determine safe operating pressures.

Any pipe material offered which does not comply with WIS 4-32-17 will be of unquantified performance and therefore should not be used in both size ranges 2 and 3 unless adequate data to characterise performance are available.

For current MDPE (PE80) materials complying with WIS 4-32-17, re-rating of pipes in range 3 is considered necessary because small volumes of free air are inevitably entrapped in most pipelines. The effect on the Operational Factor F(O) is then given in Table C.2 in Appendix C.

The assumed volume of free air controls the pipe diameter at which re-rating is applied i.e.:

- If it is judged that 5% free air is present then re-rating starts at 355 mm.
- If it is judged that a maximum of 2% free air is expected, then pipes up to 560 mm may be used at their normal PN rating.

4.2.2.4 Vacuum Conditions

The European system standard BS EN 805 requires that all water supply pipes are able to resist transient negative pressures of up to 0.8 bar without collapse. IGN 4-37-02 presents a table of safety factors against collapse for various SDRs of PE pipe, conservatively assuming very poor burial conditions and high ovality in each case.

There should generally be no need to increase wall thicknesses above SDR26 values to cope with vacuum conditions. Advice on appropriate SDRs for extreme negative pressure conditions is given in IGN 4-37-02.

4.2.3 Issues relating to the Installation Factor F(I)

4.2.3.1 Burial conditions – Effect of Backfill and Traffic Surcharge

In many construction contracts, there may be little site supervision. It is essential to have readily achievable criteria for specifying the type and compaction of the backfill to be employed. There is also a need for advice on laying PE pipes at shallow depths to minimise installation costs, and/or for using 'as-dug' backfill. These issues are part of the structural design of the pipeline as codified in BS EN 1295-1. This is a complicated document, however UKWIR has produced the 'PErseus' software which will carry out the calculations. The program will also calculate deflections in accordance with the empirically proven TEPPFA method and these results can be compared (The software is free of charge and available from most PE pipe manufacturers or alternatively contact UKWIR).

For normal embedment conditions there is no need to rerate for pipe complying with WIS 4-32-17 and hence F(I) = 1.0 (i.e. there will be no effect on PN in such circumstances).

Experience with the BS EN 1295 design method has shown that re-rating may occasionally be necessary for poor native ground conditions and bad compaction (see Appendix C.3). Even in such cases, the re-rating that is necessary is

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usually very small and may be balanced by the increase in strength from operation at an average pipe wall temperature below 20°C, see 4.2.2.1 'Cold Water Systems'.

For both individual designs and global solutions for distribution networks, it is advised that the client should give details of the installation conditions to the supplier. The supplier cannot be expected to give any indication of reservations on performance unless he is aware of the intended burial policy.

4.2.3.1.1 Shallow Burial

Where water companies are considering laying pipes at reduced depths, greater controls are needed on pipe installation to ensure adequate containment and compaction of bed and surround. Restrictions against water freezing will be determined mainly by the shallow depth of cover on service connections. UKWIR research (ref. 4) has shown that it is mot unlikely that water will freeze at 750 mm or greater cover in UK conditions, especially if there is frequent water flow. However, even if freezing does occur the ductility of PE will allow pipes to accommodate without bursting any radial expansion resulting from freezing.

4.2.3.1.2 Use of Selected As-Dug Materials

The high toughness of PE pipes meeting the requirements of WIS 4-32-17 has led many Water Companies to consider relaxation of requirements for special bedding and surround materials for PE pipes. However, large angular or pointed stones which could possibly cause excessive pipe deformation should not remain, since in any case such spoil cannot be compacted adequately. However, WIS 4-08-01 does allow stones up to 10% of the pipe diameter to be used for side-fill. Suitable material should be provided for bedding pipes in trenches through rock or in carriageways. The use of excavated material in carriageways must conform with the HAUC specification of 'The New Roads and Streetworks Act'.

4.2.3.2 Surface Damage

Although good site practice should be followed at all times, it is acknowledged that some external scoring of PE pipes is inevitable during handling and installation, especially when using the trenchless techniques for which they are so well suited.

However, although scoring of up to 10% of wall thickness will not affect the predicted life of high toughness PE pipe (ref. 4), and therefore F(I) will not need to be reduced from unity in these circumstances, extensive scoring would indicate unacceptable site practice and should not be tolerated.

Furthermore, if defects greater than 10% deep are found in pipe after installation, the affected sections should be cut out and replaced. Where this is not possible the pipe supplier should be consulted for advice.

4.2.3.3 Jointing

Butt Fusion and Electro-Fusion are the two primary jointing methods for polyethylene pipe. WIS 4-32-08 provides guidance on methods of jointing and gives details of quality control tests. It is also recommended that operatives are accredited to the appropriate unit of the GWINTO (Gas and Water Industry National Training Organisation) Thermoplastic Jointing Assessment Scheme. Joint integrity is not an issue affecting pressure rating if carried out correctly and with due care and attention to the cleanliness of the pipe and fitting. However, if onsite quality control testing reveals problems with fused joints, these must be cut out and replaced.

The CEN standards, prEN 12201 and prEN 13244, specify minimum fusion lengths for electro-fusion fittings that are much shorter than those required by WIS 4-32-14. Also they allow spigot lengths on fittings for butt-fusion that are too short to allow clamping. When the CEN standards come into force particular care should be taken to select products with minimum fusion lengths appropriate to the operating pressure regimes of the application.

4.3 Determination of Maximum Operating Pressure (PMA)

The maximum allowable operating pressure (PMA) is defined in BS EN 805 as the maximum pressure occurring from time to time, including surge, that a component is capable of withstanding in service.

In cases where valves are operated or water or sewage is being pumped, it is possible that transient surge pressures will be encountered which are considerably in excess of PN. Comprehensive guidance on designing for surge in thermoplastics pipes is contained in IGN 4-37-02. This specification should be referred to when exceptionally high positive or negative transient pressures might occur.

However, PE pipe conforming to WIS 4-32-17 will safely withstand transient surge pressures of 2 x PN, i.e.

PMA = 2 x PN

4.4. Determination of Allowable Site Test Pressure (PEA) During Mains Commissioning

Following long-standing UK advice, the general maximum value of PEA should be:

PEA = 1.5 x PN

where PN is the lowest rated component of the system.

NOTE: In general, it should be assumed that all pipe systems will be subjected to a proof hydraulic pressure test at 1.5 times the nominal pressure rating PN of the lowest rated component in the system.

For SDR11 PE100 pipe systems which are rated at 16bar, it is recommended that there is a maximum test pressure of **no more than 18 bar**, since this is a limit imposed by the pressure resistance of service connections which are normally made using PE80 grades. It is recommended that the service pipe be assessed visually whilst pressurising via the end of the service connection (or the stem of a tapping tee) before the hole is cut through the mains wall. This test is detailed in WIS 4-32-08.

Site pressure test procedures suitable for plastics pipes are outlined in the WRc publication ‘A guide to testing of water supply pipelines and sewer rising mains’ (June 1999) and BS EN 805.

5. REFERENCES

5.1. List of Research References

1. Marshall, G.P., Brogden, S., Shepherd, M.: ‘Evaluation of the Surge and Fatigue Resistance of PVC and PE Pipeline Materials for use in the UK Water Industry’: Plastic Pipes X Conference, Gothenburg, 1998.

2. Birch, M.W., Marshall, G.P.: Report on Pipeline Innovation Contract to UKWIR (1998).

3. Birch, M.W., Marshall, G.P.: Report on Pipeline Innovation Contract to UKWIR (1996).

4. Marshall, G.P.: Report on Pipeline Innovation Contract to UKWIR (1995).

5.2 List of Referenced Standards

5.2.1 System Standards and Guidance Notes

WIS 4-08-01: 1994 Imported granular and selected as-dug bedding and sidefill materials for buried pipelines.

WIS 4-32-08: 2002 Specification for site fusion jointing of PE 80 and PE 100 pipe and fittings.

WIS 4-32-17: 2001 Polyethylene pressure pipes for pressurised water supply and sewerage duties.

IGN 4-37-02: 1999 Design against surge and fatigue conditions for thermoplastics pipes.

prEN 12201: 2002 Plastics piping systems for water supply – Polyethylene (PE).

prEN 13244: 2002 Plastics piping systems for buried and above ground pressure systems for

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water for general purposes, drainage and sewerage – Polyethylene (PE).

BS EN 773: 1999 General requirements for components used in hydraulically pressurised discharge pipes, drains and sewers.

BS EN 805: 1999 Water supply – requirements for systems and components outside buildings.

BS EN 1295-1: 1998 Structural design of buried pipelines under various conditions of loading – Part 1: General requirements.

5.2.2 Test Methods

BS EN ISO 12162: 1995 Thermoplastic materials for pipes and fittings for pressure applications – Classification and designation – Overall service (design) coefficient.

BS EN ISO 13478: 1997 Thermoplastics pipes for the conveyance of fluids (Determination of resistance to rapid crack propagation (RCP) – Full-scale test.

EN ISO 13479: 1997 Polyolefin pipes for the conveyance of fluids – Determination of resistance to crack propagation – Test method for slow crack growth on notched pipes (notch test).

ISO TR 9080: 1992 Thermoplastics pipes for the transport of fluids – Methods of extrapolation of hydrostatic stress rupture data to determine the long-term hydrostatic strength of thermoplastics pipe materials.

ISO 13477: 1997 Thermoplastics pipes for the conveyance of fluids – Determination of resistance to rapid crack propagation – Small scale test (S4).

ISO 13761: 1996 Plastics pipes and fittings – pressure reduction factors for polyethylene pipeline systems for use at temperatures above 20^{o}C.

5.3 Other Publications

PErseus: CD-ROM for the Hydraulic and Structural Design of PE Pipelines. : UKWIR and also available from most PE pipe manufacturers.

PE Pipes Manual Issue 3: WRc and British Plastics Federation. (Viewable on both companies' websites).

A Guide to Testing of Water Supply Pipelines and Sewer Rising Mains : 1999: WRc.

5.4 Useful Websites

WaterUK www.water.org.uk

UK Water Industry Research Ltd. www.ukwir.org

Gas and Water Industry National Training Organisation www.gwinto.co.uk

Bodycote Pipeline Developments Ltd. www.bodycote.com

WRc plc www.wrcplc.co.uk

British Plastics Federation Pipes Group www.bpf.co.uk

TEPPFA www.teppfa.com

BSi Ltd www.bsi-global.com

CEN www.cenorm.be

ISO www.iso.org

APPENDIX A

A.1 Establishing the PN Rating

The PN rating of the pipe is the nominal pressure rating of the pipe. This is determined on a 50-year design basis. This does NOT mean that the pipe will fail at 50 years. On the contrary the actual predicted lifetimes for high quality PE materials will be well in excess of 100 years because of the safety factors employed in the design basis.

The nominal pressure PN rating of a plastics pipe is derived from a design stress (σs) determined by applying an overall service design coefficient (C) of 1.25 to the MRS value of the material (Minimum Required Strengths: 8.0 MPa and 10.0 MPa for PE 80 and PE 100 materials respectively), in accordance with BS EN ISO 12162. This design basis is now well established in ISO, European and many national standards and industry specifications worldwide for polyethylene and other plastics pressure pipe materials.

The MRS value of the material is determined by analysis in accordance with ISO TR 9080 to predict the long term hydrostatic strength (LTHS) at 50 years, 20^{o}C, of data from a series of hydrostatic stress rupture tests at 3 temperatures carried out for in excess of a year. A 97.5% lower confidence limit (LCL) value predicted from this data is taken and rounded down to the nearest value in the Renard series to arrive at the MRS value. Hence the actual predicted LTHS of the material can be significantly higher than the MRS value applied, resulting in a higher overall service design coefficient.

Examples of the relationship between PN, MRS and SDR are:-

$$\sigma_s = [\ MRS\ ] / C \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$PN = 20\ \sigma_s / [SDR] - 1 \quad \ldots\ldots\ldots\ldots\ldots(2)$$

As shown above, the material design stress, σ_s, is determined dividing MRS by C.

Hence for PE 80 materials this will be 6.3 MPa and 8.0 MPa for PE 100 materials using the overall service design coefficient of 1.25.

It is from these values of design stress that the dimensions and nominal pressure rating PN are derived using equation 2.

A.2 Expected System Lifetimes

There is a strong case to be made for extending the asset life assumptions to beyond 100 years for the MDPE (PE80) pipe grades that comply with WIS specifications and which have now been in use for many years and been under continuous assessment by users and suppliers. The service performance of MDPE pipes since their introduction in 1982 has been excellent. There is no doubt that pipe produced from PE 100 materials to WIS specifications since 1989, and to the new WIS 4-32-17 specification in the future, will show similar performance.

Given close attention to the maintenance of quality, both in respect of pipe and fitting manufacture and site installation, it is believed that it is pertinent to review the estimation of system lifetime.

Some pipe stress rupture tests on MDPE (PE80) pipes have now continued beyond 13 years without failure at temperatures of 20^{o}C, 60^{o}C and 80^{o}C. Combining these tests with the required data up to 1 year and using the method of analysis in ISO TR 9080 it is permitted to allow data extrapolation to beyond 140 years.

Linear regression of standard results at 20^{o}C to 100 years from tests on the PE 80 material which has been in use for the longest time in the UK gives the mean and σ_{LCL} strengths as shown in Table 3.

Table A.1: Extrapolated Strengths of PE 80 Pipe Using ISO TR 9080 Criteria

Type	ISO Class	Data to (h)	Extrapolation Time (y)	Mean Strength (MPa)	σ_{LCL} (MPa)	Design Stress (MPa)	Effective Service Coefficient
MDPE	PE 80	115,416	100	8.8	8.37	6.3	1.33

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Both the mean and σ_{LCL} are in excess of the value of 8.0 MPa which is the standard design basis for PE 80 at 20^{o}C and 50 years, and thus a satisfactory lifetime of 100 years at temperatures of 20^{o}C and below may be assumed.

These test conditions simply determine time to failure by creep in unrestrained conditions and do not simulate buried pipes which in reality are constrained from creep by the backfill around the pipe which is a much less onerous condition. In reality the most likely ultimate failure mechanism may be slow crack growth, which is why it is important to ensure that product manufactured from materials with the highest possible resistance to crack growth are purchased, i.e. those conforming to WIS 4-32-17.

APPENDIX B - TYPES OF POLYETHYLENE USED FOR PRESSURE PIPE MANUFACTURE

B.1 High Density Polyethylene (HDPE)

Developed originally in Germany during the 1950s, the HDPE family of polyethylene has been the most common type used for pipe manufacture in Continental Europe. The materials are characterised by higher hoop strength and stiffness compared with the alternative low-density materials available at that time. These materials were known as ‘Type 1 HDPE’. However it was found that they were prone to the development of slow crack growth and instances of rapid crack propagation (RCP) are not unknown. These materials were improved in the mid 1970s and materials termed ‘Type 2 HDPEs’ were introduced. Such materials are still available today. Although some of these materials are classified PE 80 in terms of stress rupture performance they are generally inferior in resistance to slow crack growth and RCP, and **do not** meet the requirements of WIS specifications.

In the early 1990s, a new type of HDPE material was developed in Europe which had higher hoop strength meeting the PE100 classification but also had much higher tolerance to RCP. The UK WIS specification for these materials, WIS 4-32-13, introduced the term ‘HPPE’ for these materials supplied to the UK Water Industry. Effectively they are third generation HDPEs, sometimes termed bimodal as a result of the two-stage polymerisation process used to produce them. The UK Water Industry has been at the forefront in using these new PE 100 materials, attracted by the improved properties and potentially lower cost product achieved by savings on wall thickness.

B.2 Medium Density Polyethylene (MDPE)

This family of materials was developed in the UK and Europe in the early 1970s in response to the requirement of the gas distribution industry for improved resistance to slow crack growth, and flexibility to aid installation compared with the HDPE materials. In the early 1980s the blue pigmented MDPE material for potable water systems was developed in the UK for the water industry. Compared to traditional HDPEs, MDPE is considerably more tolerant of site abuse and is regarded as the most ‘forgiving’ materials for butt fusion welding. The outstanding reliability of MDPE has contributed to the success and growth of the use of polyethylene for distribution systems for both the gas and water utilities. These materials fall into the PE 80 classification.

British Gas and WRc carried out an extensive test programme to determine the RCP resistance of MDPE. It was found that it was not possible to produce RCP failures in MDPE pipes which were full of water. However, they did produce cracking when 5% free air was present. Although MDPE pipes in large diameters are not fully resistant to RCP cracking when they contain significant quantities of air, it is difficult to imagine how an RCP ‘event’ might initiate and there has been no recorded history of any rapid crack failures in these materials. Indeed, there have been no records of any significant pipe failures in either the gas or water industries, which reinforces the design philosophy applied.

B.3 Low Density Polyethylene (LDPE)

Until the early 1980s, this class of materials was used for service pipes in the UK produced to BS 1970. It was produced by a number of suppliers including ICI – using their tradename ‘Alkathene’. The stress crack resistance was poor and thicker walled pipe was required owing to the low MRS of 3.2 MPa. Mechanical fittings were used for jointing. Significant use of LDPE for water service pipes ceased in the 1980s.

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APPENDIX C - EXCEPTIONAL OPERATION AND INSTALLATION CONDITIONS THAT CAN AFFECT PFA

C.1 Effect of Cyclic Pressure on F(O)

If tough PE pipes with slow crack growth resistance meeting the requirements of WIS 4-32-17 are used, then F(O) = 1 irrespective of the frequency and total number of cyclic 'events' and hence PFA = PN.

However, experimental work conducted on PE pipes with poor slow crack growth resistance which do not meet the requirements of WIS 4-32-17, has shown that repeated pressure excursions (usually but not always above, and below, mean operating pressure) will reduce 'fatigue lifetimes' substantially.

It has been found that it is the pressure range (peak pressure – min pressure) in a cyclic event which controls the lifetime. When a formal dynamic pressure analysis has been conducted, this pressure range can be determined precisely.

However, in the absence of a formal surge analysis, it has been agreed in the preparation of IGN 4-37-02 that it should be assumed that the pressure range will be twice the static pressure.

All the aspects of this issue are covered in IGN 4-37-02, from which Table C.1 below is extracted, but the example below illustrates the extent of de-rating that can apply in the case of pipe materials not compliant with WIS 4-32-17.

Table C.1: Fatigue Re-rating Factors F(O) for Unproven PE Materials

Daily Frequency	Hourly Frequency	Total Cycles in 50 years	Re-rating Factor F (O)
4	0.2	73,000	**0.91**
24	1.0	438,000	**0.67**
48	2.0	876,000	**0.59**
120	5.0	2,190,000	**0.50**
240	10.0	4,380,000	**0.43**
1200	50.0	22,000,000	**0.33**

Example: If a PE material with unknown slow crack growth resistance is used and it is expected that there will be 120 cyclic pressure 'events' per day, then the nominal pressure rating, PN, will need to be 2 x the expected pressure range occurring during the cyclic event.

Therefore, if the expected pressure range is 2 x the mean pipeline operating pressure, as allowed from surge considerations, then the required pipe rating PN will be 4 (i.e. 2 x 2) x the mean pipeline operating pressure. F(O) will be the reciprocal of this, i.e. only 0.25.

This de-rating is severe and will mean that non-standard pipes without proof of compliance with WIS 4-32-17 will need to be 4 times thicker than those with known high toughness.

C.2 Re-rating Large Diameter MDPE Pipes for RCP Resistance (factor F(O))

Table C.2 below gives F(O) values that should be adopted for PE 80 MDPE pipes above 315 mm that comply with the requirements of WIS 4-32-17 and prEN12201 but do not have full RCP resistance. The values are based on the % volumes of air indicated.

Table C.2 RCP Resistance: F(O) values of large diameter MDPE pipes

	5% air in water			2% air in water		
Diameter (mm)	SDR11	SDR17	SDR26	SDR11	SDR17	SDR26
355	0.93	1.00	1.00	1.00	1.00	1.00
400	0.86	0.91	1.00	1.00	1.00	1.00
450	0.80	0.84	0.91	1.00	1.00	1.00
500	0.75	0.78	0.84	1.00	1.00	1.00
560	0.70	0.72	0.77	0.96	1.00	1.00
630	0.65	0.67	0.71	0.90	0.93	0.99
710		0.62	0.66		0.86	0.91
800		0.58	0.61		0.80	0.84
900		0.54	0.56		0.74	0.78
1000		0.50	0.52		0.70	0.73
1100			0.49			0.68
1200			0.47			0.65
1400			0.43			0.59
1600			0.39			0.54

C.3 Effect of Non Compliant Backfill on F(I)

It should always be recognised that bedding and surround may not be installed with care particularly in non-highway conditions. Where it is found that the compaction of the backfill is less than that required in BS EN 1295-1, the calculation from this standard (e.g. by means of the PErseus program) should be used to evaluate the predicted combined stress using the measured value of backfill modulus (see reference 3 for details of this measurement). In such cases:

F(I) = 8.0 ÷ predicted combined stress (for PE100)

F(I) = 6.4 ÷ predicted combined stress (for PE80)

Finding that there is improper backfill need not necessitate replacement if the slightly reduced PFA can be tolerated. Also, as described in 4.2.2.1, PFA may not need to be reduced if it is known that the mean operating temperature will be less then 20^{o}C.

Example: If a PE80 pipe is laid in a wide trench in low stiffness native ground with poor compaction of backfill such that the calculated combined stresses due to pressure and surcharge loading from backfill and traffic are 7.0 MPa (via BS En1295), then:

F(I) = 6.4 ÷ 7.0 = 0.91

and a PN8 pipe e.g. would have a reduced ‘safe allowable operating pressure’ (PFA) of 7.3 bar at 20^{o}C.

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APPENDIX D - ABBREVIATIONS AND DEFINITIONS

D.1 Abbreviations

FST	Full Scale Test for Rapid Crack Propagation Resistance
F(I)	Installation Factor in determining PFA
F(O)	Operational Factor in determining PFA
HDPE	High density polyethylene (>940 kg/m3)
HPPE	Former terminology for PE 100 meeting the requirements of WIS 4-32-13
LCL	Lower confidence limit for material classification
LDPE	Low density polyethylene (<930 kg/m3)
LTHS	Long term hydrostatic strength
MDPE	Medium density polyethylene (>930 <940 kg/m3)
MRS	Minimum required strength for material classification
NPT	Notched Pipe Test
OD	Outer diameter (sizing of PE pipe)
PE	Polyethylene
PE 80	Polyethylene compound classification for MRS 8 MPa
PE 100	Polyethylene compound classification for MRS 10 MPA
PEA	Allowable continuous operating pressure
PFA	Maximum operating pressure
PMA	Test pressure
PN	Pressure nominal
RCP	Rapid Crack Propagation
S4	Laboratory RCP test
SCG	Slow crack growth
SDR	Standard Dimension Ratio, diameter to wall thickness
UV	Ultra violet

D.2 Definitions

Independent Liners – Liners which are capable of resisting without failure all applicable internal and external loads throughout their design life, without relying on the existing pipeline for some measure of structural support.

Interactive Liners – Liners which are not capable on their own of resisting without failure all applicable internal and external loads throughout their design life, and which therefore rely on the existing host pipe for some measure of structural support.