WATER INDUSTRY SPECIFICATION

WIS 4-01-03: [DATE] [ISSUE]

SPECIFICATION FOR HYDROSTATIC PRESSURE TESTING OF POLYETHYLENE AND POLYETHYLENE BARRIER WATER SUPPLY PIPELINES AND SEWER RISING MAINS

1. Introduction

Every pipeline should be tested before going into service to demonstrate the leaktightness of the installed system. This can be achieved by pressurising the constructed pipeline under controlled conditions.

The benefit of testing all new and renewed pipelines to eliminate leakage prior to putting the pipeline into service is evident by the significant proportion of hydrostatic pressure tests which fail to meet the acceptance criteria, requiring work to identify and repair potential leaks prior to a re-test.

This document specifies <u>the UK method for hydrostatic testing of pressure pipelines constructed from polyethylene or polyethylene barrier pipes.</u>

Supporting guidance is given on preparations for testing PE pipelines, choice of test section and apparatus for testing.

This document has been prepared on behalf of the Water UK Standards Board. Information contained in this specification is given in good faith. Water UK cannot accept any responsibility for actions taken by others as a result.

Note 1: For iron, steel and glass-reinforced polyester (GRP) pipelines, the water loss method for hydrostatic testing given in Section 10 of BS EN 805: 20xx (reference new version when published) applies. For PVC-O pipelines, advice should be sought from the pipe manufacturer.

Note 2: This document is called up by BS EN 805: 20xx as the UK method for testing of pipelines constructed from polyethylene or polyethylene barrier pipes. This WIS takes precedence over all clauses in EN 805 relating to pressure testing of polyethylene or polyethylene barrier pipes . The terms and definitions are consistent with BS EN 805: 20xx.

2. Scope

This document specifies the procedure for the hydrostatic pressure testing of water supply pipelines and sewer rising mains made of polyethylene pipes to BS EN 12201-2 or polyethylene barrier pipes to BS 8588.

It also specifies simplified procedures for the pressure testing of renewed sections of, and service connections to, water supply pipelines and sewer rising mains made of polyethylene and polyethylene barrier pipes.

Note 1: Pressure testing of pipelines designed to operate at temperatures above 20°C are not covered by this document. Pressure testing of plumbing systems inside premises are not covered by this document.

Note 2: All references to polyethylene pipe refer equally to polyethylene barrier pipes.

3. Principles of the test for PE pipelines

3.1 Visco-elastic behaviour of polyethylene pipes

When subjected to internal hydrostatic pressures, pipes made of a visco-elastic material such as polyethylene will creep under constant stress conditions (when internal pressure is applied and maintained) or will suffer stress relaxation (when initial pressure is applied but not maintained).

When an initial pressure is applied but not maintained, the pressure in a polyethylene pipe under test will naturally decay as the pipe expands, so the simple pressure loss method used for iron and steel pipes is not appropriate (Marshall et al, 1995).

However, the pressure decay in a leaktight polyethylene pipe system follows a linear relationship when plotted on a logarithmic scale, so any deviation from this line can be used as an indication that pipeline is not leaktight.

Analysis of the measured values of pressure over the test period is used to reveal whether there is likely to be a leak in the pipeline.

3.2 Terminology

The terminology used in this WIS is consistent with BS EN 805: 20xx and product standards for plastic piping systems.

Allowable operating pressure (PFA): maximum hydrostatic pressure that a component is capable of withstanding continuously in service.

Design pressure (DP): maximum operating pressure of the system or of the pressure zone fixed by the designer considering future developments but excluding surge.

Maximum Design Pressure (MDP): maximum operating pressure of the system or of the pressure zone fixed by the designer considering future developments including surge.

Nominal pressure (PN): numerical designation used for reference purposes related to the mechanical characteristics of the component of a piping system.

Static Head (P_0): height, relative to an arbitrary reference level, of a column of water that can be supported by the static pressure at a given point.

System test pressure (STP): the hydrostatic pressure applied to a newly laid pipeline in order to ensure its integrity and tightness.

Note: For polyethylene pipes, PN corresponds to the allowable operating pressure (PFA in bar), which can be sustained with water at 20°C with a design basis of 50 years and based on the minimum design coefficient. For most UK applications, PFA in bar corresponds to PN. Further information on this topic is given in IGN 4-32-18.

3.3 Overview of test methods

3.3.1 New pipelines

The System Test Pressure (STP) is calculated from the Design Pressure (DP) of the pipeline according to the system requirements determined by the designer.

The section of main under test is filled from the lowest point in a controlled manner and allowed to thermally stabilise.

The pressure is raised to STP, the pump is shut off and the section of main under test is isolated. The time to raise the pressure to STP determines the length of the test.

The pressure is measured and recorded over the test period.

The results are plotted on a logarithmic scale and the slope (n) of plot between time points is calculated using a simple equation. The slopes (n) are compared as a ratio. The test is considered 'a pass' if the ratio is within a defined range.

For the testing of new pipelines, see Sections 4, 5 and 8 of this WIS.

3.3.2 Renewed pipelines

The test described in 3.3.1 is only appropriate where the section of pipeline under test can be completely isolated. Where new pipes are installed as part of a working system, as for example is the case for most rehabilitation projects, a 10-minute test can be used. This short duration, high pressure test provides assurance when used in conjunction with visual inspection whilst recognising the need for a quick return to service.

The pressure is raised to STP and maintained by pumping over a period of 10 minutes. The pressure and flow are measured and recorded over the test period.

The reduction in flow as the test progresses is compared to reference data. The test is considered 'a pass' if the reduction in flow is within a defined tolerance.

After connection, the joints between the replacement section and the live main are visually inspected for signs of leaks.

For the testing of renewed pipelines, see Sections 4, 6 and 8 of this WIS.

Note: This test is intended for use on a replacement section of pipeline no more than 200m in length, typically coiled pipe up to and including DN180 installed using a trenchless technique. For longer lengths and larger diameters, the test described in 3.3.1 should be used. The replacement section is not connected to the live main until this test has been successfully completed. This is to avoid the risk of failure of components which are rated below that of the replacement polyethylene pipe either through design or wear and tear.

3.3.3 Service connections

Service connections to pressurised water mains or sewers are a potential source of leakage and should be visually inspected and tested. This shortened version of the test in 3.3.1 provides assurance when used in conjunction with visual inspection whilst recognising the need to minimise time to reconnect the services.

As much air as possible is removed by creating a vacuum and filling with water prior to testing. The pressure is raised to STP. The pump is shut off and the pressure is measured and recorded over a test period of 15 minutes.

The results are plotted on a logarithmic scale and the slope of plot (n) between time points is calculated using a simple equation. The slopes (n) are compared as a ratio. The test is considered 'a pass' if the ratio is within a defined range.

For the testing of service connections, see Sections 4, 7 and 8 of this WIS.

Note: This test is intended for use on service pipes up to DN 32. Service connections should be tested individually and not as part of the new pipeline. The services are made, but not tapped, until this test has been successfully completed.

3.3.4 Visual inspection leakage

For polyethylene or polyethylene barrier pipes, leaks generally only occur at joints or welds. The integrity of most connections in the pipeline are assessed during the pressure test. Where the pressure test indicates the presence of leakage, the pipeline should be depressurised to allow inspection.

Joints and welds which are not assessed during the pressure test, typically at each end of the test section, should be visually inspected for signs of leakage including damp patches on the surrounding ground. If there are no visible signs of water loss, a leak-noise correlator or other suitable leak detection method should be used.

4. General

4.1 Safety

In all hydraulic testing, there are dangers involved when high pressures are being employed. Only competent and trained staff who are aware of the risks should be allowed near any exposed part of the pipeline when it is under pressure. All applicable national health and safety regulations should be taken into account.

Appropriate safe systems of work and risk assessment should be in place.

Specific hazards include, but are not limited to:

- High pressures could be dangerous if there is an unexpected pipeline failure.
- Forces on end fittings or thrust blocks during testing are high and insecurely anchored ends could lead to the end caps disengaging from the pipeline.
- Air in the pipeline is compressed during testing and can lead to a massive and sudden release of stored energy if a failure occurs.

Care needs to be taken to manage these hazards:

- The whole section should be backfilled before testing, see 4.2.1.
- End-load resistant fittings, temporary strutting, thrust blocks, backfilling or other means of securing the ends should be used to guard against separation of the pipe and fittings during the test.
- Test sections should be filled slowly from the lowest point to avoid any entrapped air being pressurised and storing energy, see 4.2.5.
- Air in the pipeline should be minimised through swabbing and the correct operation of valves, see 4.2.7.

4.2 Preparations

4.2.1 Backfilling and anchoring

Prior to the pressure test, it is essential that:

- Any thrust blocks or other anchorages are sufficient to withstand the thrust forces generated at the test pressure.
- Concrete thrust blocks have been cured to develop adequate strength before testing begins.
- End caps and any temporary blanking fittings are fully end load bearing or adequately anchored to prevent separation from the pipe during the test.
- The section of pipeline to be tested has been backfilled and compacted prior to the test. This prevents any axial movement and minimises temperature variance due to weather changes.

Joints are the most probable source of leakage and should be left exposed for visual inspection, see 3.3.4.

Note: Temporary supports or anchorage at the ends of the test section should not be removed until the test is completed and the pipeline depressurised.

4.2.2 Choice of test section

The test sections should be selected so that:

- the System Test Pressure (STP) can be achieved at the lowest point of each test section; and
- the pressure at the highest elevation point of each test section is at least equal to the Design Pressure (DP), unless otherwise specified by the pipeline designer.

There is no theoretical limit to the maximum length of section that can be tested, but consideration should be given at the planning stage to:

- The availability of water for testing (see 4.2.5) and the point of discharge after the test (see Clause 8).
- The number of joints and fittings in the proposed test section and the ability to efficiently identify the source of any leak detected.
- The ability to minimise air content in the test section (see 4.2.7).
- The time available in which to obtain a valid test result. The time over which the test is undertaken is linked to the time (t_P) to pump the section up to STP.
- The pipe materials in the proposed test section. The details of the test method and analysis of test results can be more complicated where there is a mix of pipe materials.

Note 1: Where short lengths of pipe of other materials are present in a polyethylene pipeline, the detection of any leaks would be masked by the visco-elastic behaviour of polyethylene pipe. These lengths and any joints connecting them to the polyethylene pipeline should be left exposed and be visually inspected.

Note 2: For guidance on the test section for the 10-minute renewed pipelines test, see Note to 3.3.2.

4.2.3 Choice of STP

4.2.3.1 Values determined by the pipeline designer

When planning the pipeline project, the designer determines the design pressure (DP) and the maximum design pressure (MDP) for the system considering the intended use and future use of the pipeline.

Note: Where there is a short-term increase in pressure from a surge event, the associated energy is absorbed by the visco-elastic behaviour of the polyethylene material. IGN 4-37-02 shows that the maximum pressure that a PE pipe is capable of withstanding during a surge event is two times greater than its maximum rated pressure (PN) which it is capable of withstanding in long-term service. Therefore, when calculating MDP (MDP = DP + surge), for polyethylene pipes and polyethylene barrier pipes conforming to BS EN 12201-2 and BS 8588 respectively, no additional factors need to be included to account for the effect of surge on the pipe. Therefore, MDP and DP are the taken to be the same. Further information on choice of pressures ratings is given in IGN 4 -32-18.

Each component should be specified so that the maximum hydrostatic pressure that the component is capable of withstanding continuously in service (PFA) is greater than the design pressure (DP) for the system i.e. PFA > DP.

4.2.3.2 Calculation of System Test Pressure

The test is carried out at the System Test Pressure (STP).

To ensure the leak tightness of the pipeline is confirmed, the magnitude of STP needs to be greater than that of the design pressure of the system (DP).

(a) For a new pipeline

When testing a new polyethylene pipeline (see 3.3.1), STP is calculated as follows:

- STP = 1.5 x DP or DP + 5bar (whichever is least).

When planning a new polyethylene pipeline and at the design stage, STP should be calculated (as above) and the value checked against the pressure rating (PN) of the specified pipe.

Check:

- If STP ≥ 0.7 x PN, a test in accordance with this WIS would deliver valid results (see Note 1).
- If STP < 0.7 x PN, the results would be invalid (see Note 2) and suitable adjustments to the pipeline design or pressure test made (see Note 3).

Example calculations and selection of STP is given in Table 1.

Note 1: The visco-elastic behaviour of PE pipes occurs when the stress in the pipe wall exceeds a value determined by the strength of the PE material and the stiffness of the pipe. The correct application of the pressure test is achieved when STP (as calculated above) is greater than 0.7 x PN. This ensures that the visco-elastic response is achieved and the test delivers valid results.

Note 2: If the pressure rating of the polyethylene pipe is higher than needed to satisfy the maximum operating pressure of the pipeline, there is a risk that STP could be less than 0.7 x PN (in bar). The visco-elastic response is not achieved and the test delivers invalid results.

Note 3: If STP < 0.7 x PN, suitable adjustments should be made at the design stage to either: (a) the choice of pipe – review the pipe specification against the operating requirements or (b) the choice of STP – where it is not possible to reduce the pressure rating of the pipe, for example pipe strength / stiffness selected to meet structural design requirements, the value of STP would need to be increased to 0.7 x PN. In this case, STP might exceed 1.5 x PFA of other pipeline components, so great care would need to be taken to protect these by choice of test section to prevent damage during the pressure test.

(b) For a renewed pipeline

When testing a renewed pipeline (see 3.3.2) of polyethylene or polyethylene barrier pipe, SDR 11 or SDR17, up to DN 180: STP is 15 bar.

(c) For a service connection

When testing a service connection (see 3.3.3) of polyethylene or polyethylene barrier pipe, SDR 11, up to DN 32: STP is 18 bar.

Table 1: Examples showing selection of STP

Design Pressure DP determined by the pipeline designer (bar)	Pipe classification (shows typical selection for DP in Column 1)	Calculation of System Test Pressure (bar)		Pressure to activate visco-elastic response (bar)	Test Pressure selected (bar)
		1.5 x DP	DP + 5	0.7 x PN	
1	PN 6	1.5	6	**4.2**	4.2
2	PN 6	3	7	**4.2**	4.2
3	PN 6	**4.5**	8	4.2	4.5
4	PN 6	**6**	9	4.2	6
5	PN 6	**7.5**	10	4.2	7.5
6	PN 6	**9**	11	4.2	9
7	PN 8	**10.5**	12	5.6	10.5
8	PN 8	**12**	13	5.6	12
9	PN 10	**13.5**	14	7	13.5
10	PN 10	**15**	15	7	15
11	PN 12.5	16.5	**16**	8.75	16
12	PN 12.5	18	**17**	8.75	17
13	PN 16	19.5	**18**	11.2	18
14	PN 16	21	**19**	11.2	19
15	PN 16	22.5	**20**	11.2	20
16	PN 16	24	**21**	11.2	21

Notes to Table:
a) For design pressures greater than 16 bar, the polyethylene pipe manufacturer can advise on suitable pipe classification.

4.2.4 Elevations along section

When testing a pipeline with elevations along its section, the test equipment (gauge and logger) should ideally be located at the lowest point of the test section. Any air vents should be located at all high points of the test section.

The pressure at the lowest point is achieved by a combination of the static head (the pressure due to the weight of water in the pipeline above the lowest point) and raising the pressure using the pump.

The pressure at the lowest point should be:

- After filling the pipeline and before commencement of the test, equal to Static Head (P_0) in bar.
- After raising the pressure at the start of the test, equal to STP in bar (see 4.2.3.2).

If the test equipment (gauge and logger) is located higher than the lowest point on the pipeline, a correction needs to be made to ensure that the pressure at the lowest point meets but does not exceed these values.

The gauge pressure should be:

- After filling the pipeline and before commencement of the test, gauge pressure =

$$(P_0 - \frac{vertical\ distance\ between\ gauge\ and\ lowest\ point}{10})$$

where P_0 (static head) is in bar and distance in metres.

- After raising the pressure at the start of the test gauge pressure =

$$(STP - \frac{vertical\ distance\ between\ gauge\ and\ lowest\ point}{10})$$

where STP is in bar and distance in metres.

To ensure that the pressure at the lowest point does not exceed STP, the pressures at higher elevations are necessarily less than STP.

To ensure the leaktightness of the pipeline is confirmed, the test section should be selected so that, after raising the pressure at the start of the test, the pressure at the highest point in the test section is not less than maximum operating pressure of the system (DP), see 4.2.3.2). If this is not possible, the test section should be further divided.

4.2.5 Filling the test section

Sufficient water should be available to fill and complete the test without interruption.

The main should be filled from the lower end, with all air valves open and an open valve at the point of highest elevation.

Care needs to be taken that when filling the test section from the water supply system, the pressure at the lowest point of the test section does not exceed the static head (see 4.2.4).

If after filling, leaks are apparent, the test section should be depressurised slowly, emptied if appropriate, and the faults rectified prior to refilling.

After filling the test section and removing air (see 4.2.7), the valve at the point of highest elevation should remain open to ensure that the pressure is zero (i.e. no static head) at that point. The filled test section should be left in this unpressurised state for a minimum period of 2-3 hours to allow the temperature of the water and in the pipe wall to equalise.

Note 1: Guidance on the volume of water needed to fill and raise the pressure in the test section to the System Test Pressure is given in Annex A.

Note 2: If the pressure does accidentally exceed the static head at the lowest point, it is important that water is bled from the highest point of the test section to reduce the pressure prior to commencing the test. Holding the test section at the System Test Pressure prior to commencing the test (known as pre-conditioning) or starting the test at a raised pressure invalidates the test (see 5.1).

Note 3: Large diameter, thick-walled pipes might require a longer period to reach thermal stability. Advice may be sought from the pipe manufacturer.

4.2.6 Testing pipelines where the pipe surface is exposed

Wherever possible, the pipeline should be backfilled prior to testing (see 4.2.1). Where this is not possible, pressure testing should not be undertaken when there is a risk that the temperature on the outer surface of the pipe during the test might exceed 20°C.

Note: This is because the allowable operating pressure for the pipe (PFA) would temporarily be reduced due to the increased temperature. There is a slight risk that pressuring the system to STP determined in accordance with 4.2.3.2 could lead to rupture of the PE pipe.

4.2.7 Removal of air

The presence of air in a test section markedly increases the pressure rise time (t_P) and consequently the period over which pressure decay readings need to be taken. It will also distort the interpretation of pressure decay results.

As much air as possible should be removed from the test section during, and after, filling with water and before the start of the test procedure to keep the test time to a minimum.

To assist in this:

- Air valves should be functioning correctly.
- Air valves should not be closed during the test.
- Non-self-sealing air vents should be used to vent the pipeline and then closed before the start of the test.
- A foam swab should used ahead of the water column to assist the removal of air.
- Swabbing should be carried out as one continuous operation and at sufficient velocity to prevent the swab stalling and getting trapped in the pipeline.

Air content greater than 4% complicates the interpretation of the test data. The test times and test procedure described in Section 5 assume that air content is not greater than 4%.

Note: Every effort should first be made to reduce the air content to less than 4% but it is acknowledged that this will not always be possible. For air content greater than 4% and up to 6%, guidance on the adaptation of the test and the analysis is given in Annex B.2. Above 6% air, the test is not valid.

4.3 Test apparatus

Air valves: Valves to facilitate the removal of air during filling.

Data logger system: a calibrated pressure transducer and logger (Typically linked to meter to record flow). Accuracy ± 0.2% Full scale 0-50°C.

- For new pipelines (see 3.3.1), with pressure recording interval of 0.01 bar or better and time recording interval of 20 seconds or better
- For the 10-minute renewed pipeline test (see 3.3.2) and service connection test (see 3.3.3), with pressure recording interval of 0.01 bar or better and time recording interval of 10 seconds or better.

Flow meter:

- For new pipelines (see 3.3.1), a calibrated flow meter with a resolution of 1 litre or better to measure and record the volume of water added as the pressure is raised to STP.
- For the 10-minute renewed pipeline test (see 3.3.2), a calibrated flow meter with a resolution of 0.1 litre or better to measure and record the volume of water added as the pressure is raised to STP.

GPS: To allow test location to be identified and recorded. (Where required, this is typically fitted to the data logger).

Pipeline fittings: Fittings to facilitate the filling and pumping of the water, swabbing to purge air and water removal, typically tapped blank end plates, hydrants or ferrules.

Pump:

- For new pipelines (see 3.3.1), a pump with the capacity to raise the pressure smoothly to System Test Pressure within 30 minutes.
- For the 10-minute renewed pipeline test (see 3.3.2), a pump with the capacity to raise and hold the pressure at STP over the test period and measure the volume of water added using a flow meter.
- For the service connection test, a pump capable of delivering positive and negative internal pressure.

Pressure gauge: A calibrated digital pressure gauge with a 0.01 bar resolution or better. Accuracy ± 0.2% Full scale 0-50°C.

5. Test procedure for new pipelines

5.1 Raising test pressure and checking air content

Prior to commencement of the test and using Annex A, the volume of water required to raise STP shall be calculated for percentage volumes of air from 0% to 6% (see Note 1).

The pressure in the test section shall not be increased above the Static Head (P_0) prior to commencement of the test (see Note 2).

The pressure shall be raised to STP by pumping in a controlled manner.

The time to raise the pressure to STP shall be no longer than 30 minutes (see Note 3).

The pressure change (rise) and the volume of water added shall be continuously logged.

The volume of water added to raise the pressure to STP shall be compared to the volume of water calculated to raise STP.

If the actual volume of water added to raise the pressure to STP is more than predicted, it is likely that air is present.

The percentage of air in the system determines the next stage in the testing, as follows:

- For air content 0% - 4%, the test may proceed in accordance with 5.2 – 5.5.
- For air content > 4% - 6%, the test may proceed with caution using the adaptations given in Annex B.
- For air content > 6%, the test shall be abandoned as such large air volumes will confuse data analysis.

Note 1: This is used during the test to determine the volume of air present in the test section.

Note 2: Any pressure above static head before the start of the test would mean that the time to raise the pressure to STP (t_P) would be lower than the true value to raise pressure from zero to STP. Subsequent pressure readings would not be taken at the correct time intervals and the test outcome would not be valid. Calculation of air content would also be affected.

Note 3: A shorter 'ramp-up' time (t_P) is preferred as this minimise the length of the overall test.

5.2 Data collection

After the System Test Pressure (STP) has been reached, the test section shall be isolated and the pump shut off. Closed valves or 'squeeze off' shall not be used to isolate the test section.

The pressure change (decay) shall be continuously logged over a minimum pressure decay time, t_3, determined by the time to raise the pressure (t_P) as follows:

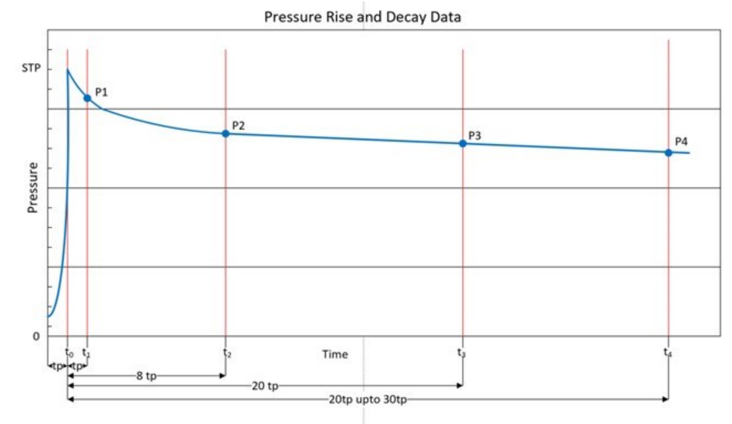
- Where air content ≤4%, t_3 is a minimum of 20 x t_P.
- Where 20 x t_P is less than 1 hour, the length of the test is extended to 1 hour by taking a further pressure decay time, t_4, see Annex B.2.
- Where air content is above 4% up to 6%, the length of the test is extended by taking a further pressure decay time, t_4, see Annex B.2.

The data shall be analysed whilst the test is in progress, i.e. as the pressure decays, to check for the presence of leaks.

5.3 Data use

Figure 1 shows a typical pressure v time graph.

Figure 1: Typical pressure v time graph



The static head on the pipeline (P_0), see 4.2.4, is a fixed value and does not decay over time. All pressures shall be displayed and analysed discounting the static head as follows:

$$Pressure\ P = Gauge\ Pressure - P_0$$

After STP has been reached and the test section isolated (time t_0), the pressure may fluctuate. Data collected in the period t_0 to t_1 (equal to t_p, see Figure 1) shall not be included in the analysis.

5.4 Analysis of results

5.4.1 Step 1 – Pressure data

The Pressures (P_1, P_2, P_3) are read from the graph at times (t_1, t_2, t_3). These pressures are used to calculate the rate of decay (see 5.4.3)

5.4.2 Step 2 - Correcting for creep during pressurisation time

During the time spent in raising the test section to STP (t_P), the polyethylene pipe creeps under the internal pressure. To account for this behaviour, a factor is added to each of the times (t_1, t_2, t_3) for calculating the rate of decay (see 5.4.3).

A factor of 0.4 x tP is added , such that the correct decay times (t_{c1}, t_{c2}, t_{c3}) are:

- $t_{c1} = (0.4 \times t_P) + (t_P)$
- $t_{c2} = (0.4 \times t_P) + (8t_P)$
- $t_{c3} = (0.4 \times t_P) + (20t_P)$

Pressures (P_1, P_2, P_3) against the corrected decay times (t_{c2}, t_{c2}, t_{c3}) shall be plotted on logarithmic axes.

The rate of decay is calculated using the pressure change between the times t_{c1} and t_{c2} (slope *n1*) and the pressure change between the times t_{c2} and t_{c3} (slope *n2*) as follows:

$n1 = [\log(P_1)-\log(P_2)] / [\log(t_{c2})-\log(t_{c1})]$

$n2 = [\log(P_2)-\log(P_3)] / [\log(t_{c3})-\log(t_{c2})]$

Note 1: Where a fourth reading is taken, see 5.2 and Annex B.3.

Note 2: The absolute value of n is dependent on numerous factors and cannot be used to determine leaktightness. For PE pipes, the value of n is typically in the range -0.07 and -0.1. A value of less than -0.06 might indicate pre-pressurisation of the pipeline. No great significance should be placed on the absolute value provided that it is within this range. For PE barrier pipes which exhibit less creep, the absolute values may be lower.

5.4.4 Step 4 – Checking results against pass / fail criteria

The ratio of *n2* to *n1* is used to indicate whether there is leakage in the system.

- **If the ratio of *n2* to *n1* lies between 0.75 (75%) and 1.25 (125%),** then the test is a pass (see Note 1 and Note 3).
- **If the ratio of *n2* to *n1* lies outside of this range,** the pressure decay is unacceptable and could indicate the presence of leaks or air. The test shall be stopped and the following action taken:
    - the test section shall be depressurised slowly (i.e. such that the pressure at lowest point of the test section does not exceed the static head, see 4.2.5);
    - the pipeline shall be inspected for signs of leaks and air content checked and action taken to rectify the problem; and
    - after a period of no less than 4 x t (where t is the total time to raise the pressure to STP and to carry out the first test), the test shall be repeated (see Note 2).
- **If the ratio of *n2* to *n1* is above 1.1 (110%)**, it is recommended that data is re-analysed using all pressure data and the results checked to confirm *n2* to *n1* does not exceed 1.25 (125%) as follows:
    - all logged pressure data between t1 and t3 shall be plotted using a spreadsheet program
    - power law trendlines shall be determined for the two time periods tc1 - tc2 and tc2 - tc3; and
    - the ratio of n2 to n1 shall be checked against the pass criteria above.

Note 1: The pressure decays with a constant power law slope. The slope is proportional to the leakage rate and computer analysis has shown that assuming air content of up to and including 4%, a 25% change in slope corresponds to the maximum allowable leakage rate specified in BS EN 805. The maximum value for the ratio of n2 to n 1 (or n3 to n2) is therefore 1.25 and the minimum value 0.75.

Note 2: This period between tests allows the pipe to recover its shape. If this is not done, the effect is the same as starting the test at a raised pressure and the test is invalid.

Note 3: Where a fourth reading is taken, see 5.2 and Annex B.3.

5.5 Recording of test results

A report shall be prepared for the test, containing as a minimum:

- The name, company and contact details of the person carrying out the test.
- The date, start and finish time, location including GPS co-ordinates.
- Plan of the site including elevations, and other significant features.
- Plan of the test section showing length, elevations, static head, location of air valves, test equipment and filling points.
- Details of the pipe under test – Pipe materials, dimensions, pressure rating, fittings.
- The System Test Pressure (STP).
- Test equipment records including maximum range, precision and calibration history of flow meter and pressure gauges.
- All logged measurements of the pressure and flow and the volume of water added during the pressure rise phase.

- All logged measurements of the pressure during the pressure decay phase.
- Details of any analysis carried out in accordance with the method described in this WIS.
- Outcome of test (pass / fail).
- Causes of failure and any remedial action taken, if appropriate.

6. Test procedure for renewed pipelines

6.1 Raising test pressure

The pressure shall be raised to System Test Pressure (STP) by pumping in a controlled manner.

The flow rate to hold the pressure at STP determines the next stage in the testing as follows:

- If after reaching STP, the flow rate drops to 0.06 litres / second (i.e. 0.6 litres in 10 seconds) or below, the test may proceed.
- If after reaching STP, the flow rate does not drop to 0.06 litres / second, there is almost certainly a leak in the system which shall be identified and rectified and the test repeated.

Note: This flow rate check ensures that flow rate measurements can be taken consistently over the test period.

6.2 Data collection

The pressure shall be maintained by pumping for 1 minute to stabilise the system prior to commencing the 10-minute test.

After stabilisation for 1 minute, the pressure shall be maintained by pumping for a test period of 10 minutes.

The pressure and the flow rate shall be continuously logged over the test period in 10-second increments.

The test is considered to be 'a fail' if during the test:

- the maintained pressure changes by more than 0.1 bar on 2 consecutive data points (10-second increments); or
- the test period of 10 minutes is not achieved and/ or data are not recorded for the full period.

In the case of a 'fail', the problems shall be identified and rectified before repeating the test.

6.3 Analysis of results

6.3.1 Volume of water

The data from the 10-minute test are analysed in three stages of equal times (i.e. 3 mins 20 secs per stage).

The total volume of water input in each stage is calculated using flow rate and time to give V_1, V_2 and V_3 for Stages 1, 2 and 3 respectively.

The test is considered to be 'a fail' and problems shall be identified and rectified and the test repeated, if any of the following occur:

a) either $V_2 > V_1$ or $V_3 > V_2$.

b) $V_1 < 0.2$ litres and V_2 is zero.

c) $V_2 < 0.2$ litres and V_3 is zero.

Note: The volumes in (b) and (c) above assume that each stage is 3 minutes 20 seconds. Where this is not the case, the total volume of water input in the stage should be corrected such that $V_c = (V * 3.33)/(\text{time taken for stage in minutes})$. The test is a fail if $V_{2c} < 0.2$ litres and V_3 is zero or $V_{1c} < 0.2$ litres and V_2 is zero.

6.3.2 Checking results against pass / fail criteria

The percentage reduction in total volume of water input between Stage 2 and Stage 3 is used to indicate whether there is leakage in the system.

The percentage reduction in total volume between Stage 2 and Stage 3 is calculated as follows:

$$\frac{(V_2 - V_3)}{V_2} \; x\, 100$$

For test sections up to and including 150 m in length, the minimum percentage volume reduction shall be 20%.

For test sections greater than 150m in length, the minimum percentage volume reduction shall be 18%.

If the percentage reduction is greater than or equal to these values and there is no visible leakage at the joints, then the test is a pass.

For values outside of this range, the reason should be established, and action taken to rectify the problem.

6.4 Recording of test results

A report shall be prepared for the test in accordance with 5.4.

7. Test procedure for service connections

7.1 Raising test pressure

This shortened test is effective only when there is minimal entrained air in the service pipe under test. This is achieved by creating a vacuum in the pipe.

A negative pressure of 0.8 bar (0.8 bar below atmosphere) shall be applied to the test section and held for a period of 60 sec.

The negative pressure shall be released and the test section is filled from a gravity feed until the reading on the gauge is positive.

The pressure shall be immediately raised to STP by pumping in a controlled manner. The time to raise pressure to STP (t_p) shall not exceed 60 seconds.

Note: If the negative pressure rises above 0.7 bar (< 0.7 bar below atmosphere), there is almost certainly a leak in the system which should be identified and rectified and the test repeated.

7.2 Data collection

After STP has been reached, the test section shall be isolated and the pump is shut off. The first pressure reading shall be taken 10 seconds after the pump is switched off. The pressure change (decay) is continuously logged for a further 15 minutes.

7.3 Analysis of results

7.3.1 Step 1 – Pressure data

The Pressures (P_1, P_2, P_3) are read from the graph at times (t_1, t_2, t_3) where t_1 = 2 min, t_2 = 6 min, t_3 = 15 min. These pressures are used to calculate the rate of decay.

7.3.2 Step 2 - Correcting for creep during pressurisation time

As described in 5.4.2, a factor of 0.4 x t_p is added to t_1, t_2, t_3 to account for creep in PE pipe.

For the service connection test, the corrected decay times (t_{c1}, t_{c2}, t_{c3}) are:

- t_{c1} = (0.4 x t_P) + 2 min
- t_{c2} = (0.4 x t_P) + 6 min
- t_{c3} = (0.4 x t_P) + 15 min

7.3.3 Step 3 - Calculating rates of decay

A graph of the pressures (P_1, P_2, P_3) against the corrected decay times (t_{c1}, t_{c2}, t_{c3}) is plotted on logarithmic axes.

The rate of decay is calculated using the pressure change between the times t_{c1} and t_{c2} (slope *n1*) and the pressure change between the times t_{c2} and t_{c3} (slope *n2*) as follows:

$n1 = [\log(P_1) - \log(P_2)] / [\log(t_{c2}) - \log(t_{c1})]$

$n2 = [\log(P_2) - \log(P_3)] / [\log(t_{c3}) - \log(t_{c2})]$

7.3.4 Step 4 – Checking results against pass / fail criteria

The ratio of *n2* to *n1* is used to indicate whether there is leakage in the system.

- If the ratio of *n2* to *n1* lies between 0.75 (75%) and 1.1 (110%), then the test is a pass.
- If the ratio of *n2* to *n1* lies outside of this range, the pressure decay is unacceptable and could indicate the presence of leaks or air. The test should be stopped.

7.4 Recording of test results

A report shall be prepared for the test in accordance with 5.4.

8. Pressure release and discharge of water

When the pressure test has been satisfactorily completed, the test section shall be depressurised slowly and the water discharged safely from the pipeline. Guidance on the disposal of water can be found in Water UK's Technical Guidance Notes (TGNs), available from www.water.org.uk/guidance/principles-of-water-supply-hygiene/.

9. References

Dated:

The development of a mains pressure test for PE and PVC pressure pipes. GP Marshall, MW Birch, K Morley. 1995. (https://plasticpipesconference.com/)

BS EN 805: [dated reference]. Water supply - Requirements for systems and components outside buildings. BSI, [date].

IGN 4-01-03: Issue 2: 2015 Pressure testing of pressure pipes and fittings for use by public water suppliers. Water UK, 2015.

Undated:

BS 8588 Polyethylene pressure pipe with an aluminium barrier layer and associated fittings for potable water supply in contaminated land. Size 20 mm to 630 mm. BSI.

BS EN 12201-2 Plastics piping systems for water supply, and for drainage and sewerage under pressure. Polyethylene (PE) – Pipes. BSI.

IGN 4-37-02 Design against surge and fatigue conditions for thermoplastic pipes. Water UK.

IGN 4-32-18 The choice of pressure ratings for polyethylene pipe systems for water supply and sewerage duties. Water UK.

ANNEX A ESTIMATE WATER INPUT VOLUME

A.1 Introduction

For new pipelines, the pressure should be raised smoothly to System Test Pressure (STP) within 30 minutes. The estimated water input volume can be calculated (see A.2) to assist in the choice of pump and projected test duration.

A.2 Volume of water to fill the test section (unpressurised)

Where there is no air present, the volume of water to fill the unpressurised test section is equal to the internal volume of the pipe.

Therefore,

volume of water to fill the test section (m^3), V0 = $\left(\pi \frac{d^2}{4}\ x\ L\right)$ (Equation A1)

Where:

d = internal diameter of pipe (m)

L = length of test section (m)

(1 m^3 = 1000 litres)

Table A.1 gives example values for maximum internal volume of a 100m length of polyethylene or polyethylene barrier pipe.

Using Table A.1, <u>where there is no air present in the pipeline prior to pressurisation</u>:

- the values in Table A.1 can be taken to be the volume of water to fill a 100m unpressurised test section. For example, the volume of water to fill an unpressurised test section of 100m of 63mm diameter, PE100, SDR 11 is 207 litres.
- volumes for other lengths of test section can be calculated on a pro-rata basis.

Note: Where air is present in the unpressurised test section, the combined volumes of water and air equates to the internal volume of the test section.

Table A1: Volume of water to fill a 100m length of test section (at 10°C, no air, unpressurised)

Nominal diameter DN / OD	Internal volume of 100m test section at 10°C[a] (litres) = Volume of water to fill test section (no air present, unpressurised), V_0		
	PE 100 SDR 11[b]	PE 100 SDR 17	PE 100 SDR 21
63	207	241	255
75	296	342	361
90	425	493	520
110	636	736	776
125	820	954	1003
140	1031	1196	1259
160	1344	1561	1642
180	1702	1976	2082
200	2102	2438	2567
225	2659	3085	3249
250	3288	3815	4019
280	4126	4784	5035
315	5220	6052	6379
355	6633	7685	8103
400	8419	9765	10281
450	10648	12354	13010
500	13151	15247	16060
560	16504	19136	20157
630	20879	24210	25518
710	26512	30758	32391
800	33675	39058	41146
900	42614	49440	52066
1000	52604	61015	64269
1200	-	87881	92561

Notes to Table:
a) 10°C has been selected as the reference temperature as this is a typical value for buried water supply pipelines.
b) For PE80 / SDR 11 pipe, the volume of water to fill a test section (100m long at 10°C) is 131 litres for DN50 and 208 litres for DN63.
c) Volumes have been calculated using values from BS EN 12201-2 and BS 8588 for minimum OD and minimum wall thickness. NOTE FOR CONSULTATION – Min OD and Min wall thickness have been used to maintain consistency with previous versions of the IGN whilst being able to extend the size range of the table. It would be more correct to use Max OD and Min wall thickness. What are your views?

A.3 Volume of water to raise pressure to STP

Once the test section has been filled (see A.2), the additional volume of water required to raise the pressure from the unpressurised state (i.e. gauge pressure equal to Static Head at the lowest point of the test section, see 4.2.4) to STP can be calculated from first principles using thin-walled cylinder theory but is complex and time-consuming.

Tables A.2 – A.4 therefore provide look-up tables of values established for IGN 4-01-03: Issue 2: 2015.

Using Tables A.2 – A.4 where there is no air present in the pipeline prior to pressurisation:

- **Column 2** gives the additional volume of water in litres to raise the pressure in a 100m length of polyethylene or polyethylene barrier pipe from the unpressurised state to 10 bar. For example, where there is no air present (0%) in the test section after filling, the volume of water to raise the pressure from the unpressurised state to 10 bar for a test section of 100m, 63mm diameter, PE100, SDR 11 is 2 litres.
- For other test section lengths and System Test Pressures, Equation A2 can be used to calculate the additional volume of water to raise the pressure to STP from the values provided in Tables A.2 – A.4

$$V_P = V_{P10} x \frac{STP}{10} x \frac{L}{100}$$ (Equation A2)

Where:

V_{P10} = volume of water to raise the pressure in a test section of 100m from zero to 10 bar, given in Table A2 (litres)

STP = System Test Pressure (bar)

L = length of test section (m)

($1m^3$ = 1000 litres)

A.4 Using volume of water added to estimate percentage of air in system

If air is present, a larger volume of water is required to raise the pressure from the unpressurised state (i.e. gauge pressure equal to Static Head at the lowest point of the test section, see 4.2.4) to STP as the air is compressed.

Tables A.2 – A.4 provides look-up tables of values for volume of water for air content (i.e. percentage air prior to pressurisation) of 1% - 6%.

Using Tables A.2 – A.4 where there is air present in the water prior to pressurisation:

- **Columns 3 - 8** give the additional volume of water in litres to raise the pressure in a 100m length of polyethylene or polyethylene barrier pipe from the unpressurised state to 10 bar.

  Example: where 1% of the internal volume of the test section after filling was air, the additional volume of water to raise the pressure from the unpressurised state to 10 bar for a test section of 100m, 63mm diameter, PE100, SDR 11 is 4 litres (Column 3 of Table A.2). Where 2% of the internal volume of the test section after filling was air, , the additional volume of water for the same test section is 6 litres (Column 4 of Table A.2).

- For other test section lengths and System Test Pressures, Equation A2 can be used to calculate the additional volume of water to raise the pressure to STP from the values provided in Tables A.2 – A.4.

The measured volume of water added can be used to estimate the volume of air in the test section. Further guidance is given in 4.2.7 and Annex B.

Prior to commencing the test, the volume of water corresponding to air content up to 6% should be calculated and recorded. A flow meter and logger should be used to monitor the volume of water being added during the pressurisation phase.

Where the monitoring shows that the volume of water added is reaching the value corresponding to air content up to 6% and STP has not been attained, the test should immediately be stopped as any results would be invalid.

Table A2 Additional volume of water to raise the pressure in 100m long test section to 10 bar in presence of air – PE 100 SDR 11

Nominal diameter DN / OD	**Volume of water to raise pressure in 100m long test section at 10°C[a] from 0 bar to 10 bar (litres)**						
	Percentage of the internal volume of the test section filled with air after filling (i.e. pre-pressurisation)						
	0%	1%	2%	3%	4%	5%	6%
63	2	4	6	8	10	12	14
75	3	6	9	11	14	17	19
90	5	8	12	16	20	24	28
110	7	13	19	24	30	36	42
125	9	16	24	31	39	46	54
140	11	21	30	39	49	58	67
160	15	27	39	51	63	76	88
180	19	34	49	65	80	96	111
200	23	42	61	80	99	118	137
225	29	53	77	101	126	150	174
250	36	66	96	126	155	185	215
280	45	83	120	158	195	233	270
315	57	105	152	199	247	294	342
355	73	133	193	253	314	374	434
400	92	169	245	322	398	474	551
450	116	213	310	406	503	600	696
500	144	263	383	502	622	741	860
560	181	331	481	630	780	930	1080
630	229	418	608	797	987	1176	1366
710	290	531	771	1012	1253	1494	1734
800	369	675	980	1286	1592	1898	2203
900	467	853	1240	1627	2014	2401	2788
1000	576	1053	1531	2009	2486	2964	3442

Table A3 Additional volume of water to raise the pressure in 100m long test section to 10 bar in presence of air – PE 100 SDR 17

Nominal diameter DN / OD	**Volume of water to raise pressure in 100m long test section at 10°C[a] from 0 bar to 10 bar (litres)**						
	Percentage of the internal volume of the test section filled with air after filling (i.e. pre-pressurisation)						
	0%	1%	2%	3%	4%	5%	6%
63	4	6	9	11	13	15	17
75	6	9	12	15	19	22	25
90	9	13	18	22	27	31	36
110	13	20	26	33	40	47	53
125	17	26	35	43	52	61	69
140	22	32	43	54	65	76	87
160	28	42	56	71	85	99	113
180	36	53	71	89	107	125	143
200	44	66	88	110	132	155	177
225	55	83	111	139	167	195	224
250	69	104	138	173	208	242	277
280	86	130	173	217	260	304	347
315	109	164	219	274	329	384	439
355	138	208	278	348	417	487	557
400	176	265	354	442	531	620	708
450	223	335	447	559	672	784	896
500	275	413	552	690	828	967	1105
560	345	519	693	867	1040	1214	1388
630	436	656	876	1096	1316	1536	1755
710	555	834	1114	1393	1672	1952	2231
800	706	1060	1415	1770	2124	2479	2834
900	894	1343	1791	2240	2689	3138	3587
1000	1101	1655	2209	2763	3317	3871	4425

Table A4 Additional volume of water to raise the pressure in 100m long test section to 10 bar in presence of air – PE 100 SDR 21

Nominal diameter DN / OD	Volume of water to raise pressure in 100m long test section at 10°C[a] from 0 bar to 10 bar (litres)						
	Percentage of the internal volume of the test section filled with air after filling (i.e. pre-pressurisation)						
	0%	1%	2%	3%	4%	5%	6%
63	6	8	11	13	15	17	20
75	8	12	15	18	21	25	28
90	12	17	21	26	31	36	40
110	18	25	32	39	46	53	60
125	23	32	41	50	59	68	78
140	29	40	52	63	75	86	97
160	37	52	67	82	97	112	127
180	48	67	86	105	123	142	161
200	59	82	105	129	152	175	199
225	74	104	133	163	192	222	251
250	93	129	166	202	239	275	312
280	116	161	207	253	298	344	390
315	147	205	263	321	379	437	495
355	187	261	334	408	481	555	628
400	236	330	423	517	610	703	797
450	299	417	535	653	772	890	1008
500	369	515	661	806	952	1098	1244
560	464	647	830	1013	1196	1380	1563
630	589	820	1052	1284	1516	1747	1979
710	745	1039	1333	1627	1922	2216	2510
800	949	1323	1696	2070	2444	2817	3191
900	1200	1673	2145	2618	3091	3564	4036
1000	1480	2064	2647	3231	3814	4398	4981

Annex B ADAPTATION TO THE TEST FOR AIR CONTENT ABOVE 4%

B.1 Calculation of air content

The air content (presented as a percentage volume) can be calculated from the actual water input volume obtained from the flow meter and other known data: see A4 of Appendix A.

Every effort should be made to reduce the air content to less than 4%. If this is not possible, the test section should be depressurised in a controlled manner (i.e. such that the pressure at lowest point of the test section does not exceed the static head, see 4.2.5). The test section should be held in this unpressurised condition for a minimum period of 4 x t (where t is the time to raise the pressure to STP and any further time over which the pressure as held prior to depressurisation, see 5.1). This allows the pipe to recover its shape prior to commencing the pressure test. If this is not done, the effect is the same as starting the test at a raised pressure and invalidates the test (see 4.2.5).

B.2 Adaptation to the test time for air content above 4%

If the air content so calculated is greater than 4% but less than 6%, the test may proceed with caution.

The pressure decay time needs to be extended to counteract the effect of air on the pressure decay and accurately determine whether the pipe is leaking. An additional (fourth) pressure reading (P_4) is taken at this extended time (t_4).

The minimum test time $t_4 = (30 \times t_P + 0.4 * t_P)$ where t_P is the time taken to reach the System Test Pressure.

If the air content so calculated is greater than 6% or if the test period cannot be extended, the test should be abandoned as such large air volumes would confuse data analysis. The pressure should be released so that it is reduced to zero at the highest point and efforts made to bleed air from the system. The test should be restarted after a minimum period of four times the period that the pipe was under pressure, including the initial rise time.

B.3 Adaptation of the analysis for air content above 4%

By taking a fourth pressure reading (P_4), a further n value (*n3*) can be calculated using the following formula:

$n3=[\log(P_3)-\log(P_4)] / [\log(t_{c4})-\log(t_{c3})]$

B.4 Pass / fail criteria for air content above 4%

If *n3/n1* and *n2/n1* lie between 0.75 and 1.25, then the test is a pass.

Note: If the slope of the pressure decay curve, n, is less than 0.04, there is probably air in the system. See 4.2.7 on air removal.