WATER INDUSTRY INFORMATION & GUIDANCE NOTE

UK Water Industry

GUIDE TO PRESSURE TESTING OF PRESSURE PIPES AND FITTINGS FOR USE BY PUBLIC WATER SUPPLIERS

Contents

1. Introduction

One of the primary justifications for the refurbishment of water distribution, transmission and sewer pressure pipelines is to replace and renovate pipes that have been shown to have unsatisfactory leakage levels. It is paramount that new pipeline installations are fit for purpose and therefore follows that the new systems should be demonstrated to be as secure and leak-free as possible.

In 2000, BS EN 805 was published and, for the first time, there are now specified European criteria for assessing acceptability for different pipeline systems.

BS EN 805 gives advice on different test methods that may be used to assess pipelines for leakage. These methods are not mandatory; it is left to the Engineer / Client to choose the most appropriate procedure.

It has been decided to adopt one procedure to test all new PE and PVC water and sewerage pressure pipelines laid in the U.K. and another method for ductile iron, steel and GRP pressure pipelines. Note: This IGN is referenced by BS EN 1610 for testing of sewerage and drainage pressure pipelines.

This Information and Guidance Note (IGN) was originally published in March 2011 and has been extensively adopted by the UK Water Industry and its contractors. This revision has been prepared in the light of the experience gained from the use of the document. The principal technical change in this second edition of the document is in the manner in which the amount of air present in a main under test is calculated and the evaluation of its effect on test results. In addition, the document has been restructured so that the test methods to be used by contractors undertaking the testing are detailed in the main body of the IGN and additional background to the application and development of the method is included for reference in Appendices B, C and D.

2. Scope

This IGN details the procedure for the testing of PE and PVC water and sewerage pressure pipelines laid in the U.K. The procedure involves raising pressure in a controlled manner to the System Test Pressure (STP) and allowing the pressure to decay after isolating the main. The assessment follows the principle of specifying an acceptable limit of the pressure loss over test time and test length. The values of allowable pressure loss rate for different materials are given.

For PE and PVC pipelines, viscoelastic stress relaxation effects affect the simple linear decay in pressure since they will lose pressure without any leakage being present as the molecular structure relaxes, a phenomenon usually referred to as 'creep'. These effects dominate the pressure decay until some 24 hr. - 36 hr. after reaching STP. Therefore, to provide an earlier warning that pipelines are leaking at an unacceptable level, the analysis of results is modified for PE and PVC and is aligned with that successfully used for many years in the 1980s and 90s by the U.K. Water Industry.

This IGN also details the procedure for the testing of ductile iron, steel and GRP water and sewerage pressure pipelines laid in the U.K. The procedure is essentially the same as that detailed in BS EN 805 and the methods traditionally used on these materials.

Note: Some specifications advise that PVC pipelines are tested in the same manner as ductile iron but this is not recommended.

The test methods described above are only appropriate where a test section of the pipeline and associated fittings can be completely isolated. Where new pipelines are already installed as part of a working water system – as, for example, is the case for most rehabilitation projects – a 10 minute mains renewal test for use on short test lengths is provided in Section 7.

It is good practice to also test joints and connections to the pipeline to ensure a leak free system. A short, visual test is provided in Section 8 for this purpose.

This IGN applies only to pipes and fittings which form part of the system that is owned by the utility. Pipes and fittings which are part of privately owned pipelines or plumbing systems in premises, and which are supplied with water from the public supply system, come under the scope of The Water Supply (Water Fittings) Regulations 1999, as amended, in England and Wales, The Water Supply (Water Fittings) (Scotland) Byelaws (2014) in Scotland or The Water Supply (Water Fittings) Regulations (Northern Ireland) 2009 in Northern Ireland.

3. General considerations (all tests)

3.1 Safety

In all hydraulic testing, there are dangers involved when high pressures are being employed. All applicable national health and safety regulations should be taken into account.

Specific hazards:

- 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 blowing off.
- Air in the pipeline is compressed during testing and can lead to a massive and sudden release of stored energy.

Care needs to be taken:

- Only competent and trained staff who are aware of the risks should be allowed near to any exposed part of the pipeline when it is under pressure.
- The test area should be cordoned off and a warning notice erected when the test is in progress.
- When a long length of main is under test, staff involved in the test should be in radio / mobile phone contact at all times.
- Air in the pipeline should be minimised through swabbing and the correct operation of valves.

3.2 Choice of test section / length

There is no theoretical limit to the maximum length of main that can be tested, but there are a number of practical issues which limit the length. These are:

- The number of joints and fittings on the main.
- The availability of potable water to pre-charge the main.
- The point of discharge of water after the test.
- The differences in elevation on the main to meet the System Test Pressure.
- The ability to identify the source of any leak detected.
- The time available in which to obtain a valid test result.

The exception to this is the 10 minute test for renewed mains described in Section 7. This test is only suitable for short test lengths with a small number of joints. The maximum recommended length is 200 m comprising two jointed 100 m coils.

3.3 Choice of System Test Pressure (STP)

The method for choosing the System Test Pressure in BS EN 805 is that STP should be the lowest of:

- Surge calculated
    - MDP + 1 bar
- Surge not calculated
    - MDP * 1.5
    - MDP + 5 bar

MDP is defined by BS EN 805: 2000 (clause 3.1.5) as the maximum continuous operating pressure of the pipeline plus an allowance for surge pressures. The allowance for surge pressure (where this is not calculated) shall not be less than 2 bar.

The value of STP shall apply at the lowest elevation of the pipeline and should therefore include the static head due to elevation changes in the pipeline (P_0) i.e. Raised Pressure + P_0 together equate to STP.

The test pressure at the highest elevation should be at least the allowable maximum operating pressure, PMA, (defined in 3.1.1 of BS EN 805: 2000). If this is not possible due to the elevations involved then the line should be split prior to testing.

Note 1: Some water suppliers prefer to use an STP value of 1.5 * the pressure that designer expects the pipeline to see in service.

It is recommended that the minimum STP for PE pipelines should not be less than 0.7 * PN where PN is a numerical designation related to the mechanical characteristics of the component of a piping system.

Note 2: When testing PE pipelines, some water suppliers may prefer to use an STP value of 1.5 * PN of the lowest rated component in the system. Raising the pressure significantly above this STP will not affect the test analysis but may damage a plastic pipe or fitting if the pressure is maintained for more than 2 hours (however, the creep should reduce the pressure in the pipeline significantly within 2 hours). It is strongly recommended that STP is not raised above 1.5 * allowable maximum operating pressure (defined in 3.1.1 of BS EN 805: 2000) of the pipeline or 1.5 * PN of the lowest rated component in the system.

3.4 Pipeline testing set-up

To carry out a quantifiable assessment of leakage by a pressure decay test, it is essential that:

- The section of pipeline to be tested is isolated from the rest of the pipeline with end load bearing end fittings with sealed plates. End fittings should have pressure ratings of at least 1.5 * STP. For higher test pressures such fittings will, of necessity, be specialist re-useable items.
- Any thrust blocks or other anchorages are sufficient to withstand the forces generated by the pressure test and any concrete used has been adequately cured.
- Closed valves or 'squeeze-off' seals (for PE) are NOT used to isolate the test length.
- Any service connections should not be tapped prior to pressure testing, even if tapping tees have been bolted / welded to the main.
- Wherever possible, all joints made to the pipeline are in open trenches, visible for direct visual inspection.
- The section of pipeline to be tested has been backfilled and compacted prior to the test. This prevents any axial movement or thermal effects due to weather changes.
- Air valves are located at all high points to facilitate the removal of air during filling of the main. Air valves should not be closed during the test but non-self-sealing air vents should be closed.

It is recommended that an automatic air valve is included in all test sections of PE pipes with wall thicknesses thinner than SDR21, and for GRP pipes with a ring stiffness of lower than 5000 N/m^2, in order to avoid the risk of collapse under vacuum.

3.5 Test apparatus

3.5.1 Test fixtures

- A typical setup requires tapped blank end plates, and hydrants or ferrules at the lowest point of the pipeline to facilitate the filling and pumping of the water and its subsequent removal.
- Duckfoot hydrant bends may be used as a temporary measure to allow easier removal of swabs used to purge air from the system.

Note: This setup may be varied for the 10 minute test for renewed mains – see Section 7.

3.5.2 Pressurisation

The capacity of the pump varies according to the type of test carried out:

- **Type II test:** Where available and practical, a pump with the capacity to raise pressure smoothly to System Test Pressure (STP) in a time period between 1 min. to 30 min. should be used.
- **Water Loss / Water Added test:** A pump with the capacity to raise and control the System Test Pressure (STP). If the Water Added method is being used, a separate, specialised pump is required. This pump should be capable of maintaining the test pressure, measuring the volume of water pumped into the pipeline to achieve this, and should have data logging capabilities. This pump could also be used with the Water Loss method to accurately measure the water

required to bring the pipeline back to STP. Alternatively, a hand pump could be used for the Water Loss method.

- **10 minute test for renewed mains:** A pump with the capacity to raise and control the test pressure for a period of at least 10 min.

Note: An estimate of the volume of water to pressurise pipelines of different materials can be calculated using the guidance in Appendix A.

3.5.3 Measurement and recording equipment

- **Pressure gauge:** A digital pressure gauge with a 0.01 bar resolution or better. For rigid or semi-rigid pipes, a calibrated conventional circular pressure gauge, minimum 200 mm diameter.
- **Flow Meter:** A calibrated flow meter, ideally with a resolution of 1 litre or better, to measure the volume of water added during the pressure rise phase.
- **Data Logger System:** a pressure transducer with an accuracy of 0.25% of full scale connected to a logger that can record data at fixed time intervals or at fixed pressure decay intervals. Time intervals of 20 sec. are normally suitable unless the test is unusually long or short. Pressure decay intervals of a minimum of 0.1 bar are recommended. It is recommended that the data logger has GPS capabilities to allow the test location and pipeline to be easily identified.
- **Volume container (Water Loss test):** A calibrated container, suitable for the expected volume loss (e.g. a 200 ml measuring cylinder would be suitable for small volumes). This will allow the draw off to be accurately measured.

3.5.4 Test apparatus layout

Figure 1 shows a general layout for testing equipment.

The data logger and pressure gauge should be mounted at the point of lowest elevation of the pipeline; any deviation from this should be noted in the test report (see also 3.5.5).

Any air vents should be located as close to the top of the pipeline as possible.

3.5.5 Differences in pipeline elevation

If the test gauge and data logger are higher than the lowest point on the pipeline, the STP should be adjusted by subtracting the additional pressure caused by static head between the lowest point and the point at which the pressure reading is being taken. Without this adjustment, there will be a significant effect on STP and air content calculation.

The gauge pressure after filling the main should only reflect that part of the natural static head lying above the gauge level. The height of the gauge above the lowest point of the main, when added to the gauge pressure, should equate to the total static head.

Figure 2 shows the correction for static head where the test point is above lowest point of main.

Example calculation – correction for static head where test point is above the lowest point of main

Pressure gauge reading = 1.2 bar. Vertical distance between pressure gauge and lowest point = 7 m. STP = 10 bar.

Additional static head pressure = 7/10 = 0.7 bar (where 10 m static head = 1 bar of pressure)

Corrected STP = 10 bar – 0.7 bar = 9.3bar

Corrected gauge pressure (for the purpose of air percentage calculation) = 1.2 bar + 0.7 bar = 1.9 bar

It is not necessary to make any adjustment to the pressure gauge readings to establish the raised pressure for the purpose of calculating the pressurised air content. It is assumed that the test gauge and data logger will be at the same height and therefore detecting the same pressure.

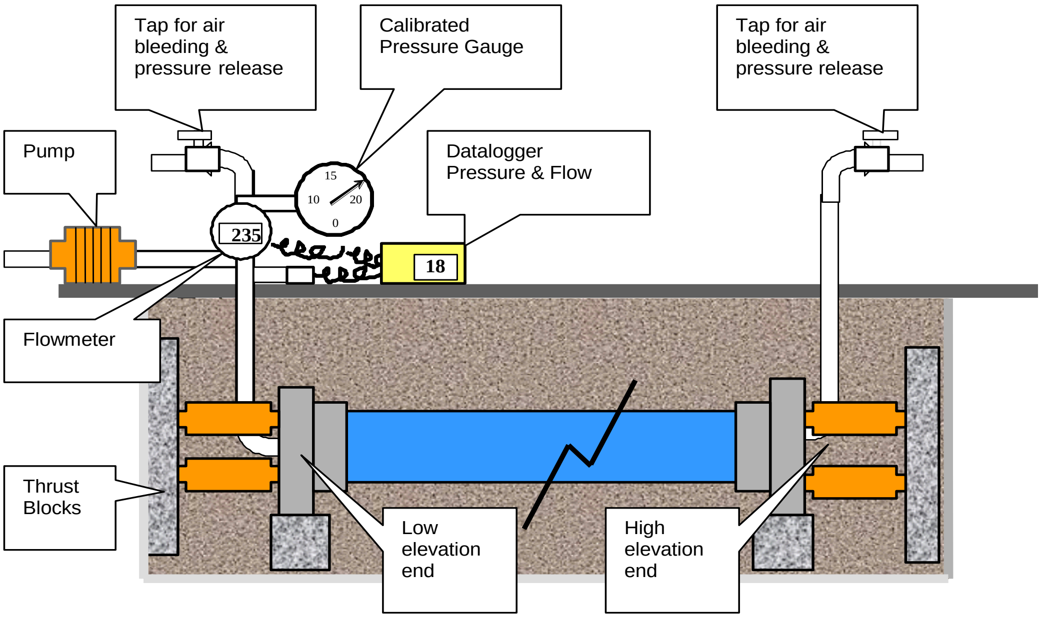


Figure 1: General layout for testing equipment

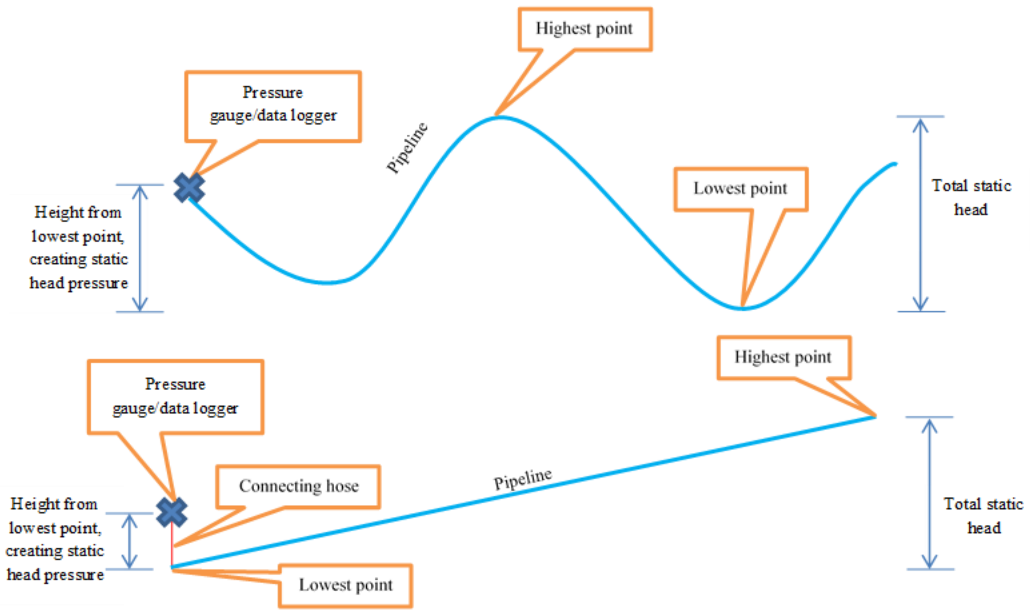


Figure 2: Diagram showing correction for static head where test point is above the lowest point of main

4 Test Report (all tests)

For every test, a formal report containing complete details should be prepared.

The report should contain:

- The name, company and contact details of the person carrying out the test.
- All details of the materials, dimensions, length and PN ratings of the pipeline.
- The System Test Pressure (STP).
- Details of the date and start / end time of the test and its location, including GPS co-ordinates.
- The differences in elevation.
- A description of the type of pressure and flow meter, together with details of their maximum range, precision and calibration history.
- The pump volume flow rate at rated speed, or the logged data from the flow meter.
- All the recorded measurements of the pressure and water flow during the pressure rise phase.
- The pressure decay data.
- Details of any analysis carried out in accordance with the methods described in this IGN.

5 Test for new PE and PVC pipelines (Type II test)

5.1 Filling of the main

Water for the testing of potable water mains should be taken from the existing supply.

An adjacent main may be used to fill the main, but for PE and PVC pipelines every effort should be made to ensure the pressure in the pipeline at the lowest point does not exceed the static head generated by elevation changes. If the pressure is raised above this value then water should be bled from the main to reduce the pressure prior to the test commencing.

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

After filling the main and bleeding air from the system, the valve at the point of highest elevation should remain open to ensure there is no residual head at that point.

<u>Any attempt to shorten the pumping phase by increasing the initial pressure to local mains pressure (pre-pressurisation) using an adjacent main is not allowed and will result in the test being classed as invalid.</u>

The following points should be noted:

- It will be obvious from input volumes and elevations that pre-pressurisation has occurred.
- The time for which the pipeline has been pre-pressurisation will distort the effective loading time. The time correction factor will be in error. The error in correcting time will result in a larger slope change of the pressure decay characteristics.
- There is a greater likelihood of the test failing the specified criteria.

5.2 Removal of air

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

- Ensure that all air valves are functioning properly.
- It is recommended that a foam swab ahead of the water column is used to assist the removal of air.
- It is recommended that swabbing is carried out as one continuous operation and at sufficient velocity to prevent the swab stalling and consequently getting trapped within the pipeline.
- All non-self-sealing air vents should be closed prior to testing.

<u>There is an upper limit of 4% air in any main for a valid test.</u>

The presence of air in a main will have a number of effects:

- Air will markedly increase the pressure rise time and period over which pressure decay readings are taken.
- Air will distort the interpretation of pressure decay results.

Air content greater than 4% complicates the interpretation of the test data. Whilst every effort should be made to remove air, it is acknowledged that this will not always be possible. In such cases, guidance is given in Appendix B of this IGN.

An estimate of the required water volume should be calculated prior to pressurisation, with an assumed air content of no more than 4%: see A.2 in Appendix A of this IGN.

Once the air has been removed from the test section, the data logger should be connected and all information logged.

5.3 Test procedure

5.3.1 Preliminary conditioning of main

For PVC pipelines with socket and spigot joints, the pressure should be raised to the STP and allowed to settle for 15 min.

There should be no preliminary conditioning of PE pipelines; any such conditioning will result in the test being classed as invalid and a retest will be required.

5.3.2 Raising pressure

The pressure should be raised to the test level (STP) by pumping in a controlled manner. The pressure changes and the added volume of water should be continuously logged.

A more accurate estimate of air volume can be calculated by comparing the actual water input volume required to bring the pipeline up to STP (obtained from the flow meter) with the estimated water volume calculated prior to pressurisation (see 5.2).

If the actual input volume is significantly more than predicted, this suggests that the air volume is also greater than predicted, and the test should either be extended or abandoned and restarted once the air content has been reduced. The guidance in Appendix B should be followed.

5.3.3 Pressure decay phase

After the test pressure (STP) has been reached, the system should be isolated, the pump shut off and the pressure decay logged for the minimum test decay time, t_3, given in Table 1.

Table 1 - Minimum test decay times by air content and pipe material

Pipe Material	Air Content (%)	Suggested t_3 time
PE	≤ 4%	$20*t_P$
PVC	≤ 4%	5 hr.
(1) t_P is time taken to reach STP (2) When t_P is less than 3 minutes, the minimum test decay time t_3 is 1 hr.		

The minimum test decay time, t_3, is dependent on the percentage air content and for PE, the time (t_P) taken to reach the System Test Pressure at the start of the test. Where air content exceeds 4%, the pressure decay time would need to be extended to counteract the effect of air in slowing the pressure decay and to accurately determine whether the pipe is leaking. The guidance in Appendix B should be followed.

As the pressure decays, an analysis may be carried out to check whether there is reason to believe that the main is leaking. This may be done whilst the test is in progress.

It is recommended that the test apparatus attached to the main is not de-commissioned or the main put into service until there is strong reason to believe that the pipeline meets the acceptance criteria (see 5.4.4) and is deemed to be free from leakage.

5.4 Data analysis

5.4.1 General

PE and PVC materials creep under stress and therefore the analysis of the test data is a little more complicated than for the other materials. The calculation steps below can be used to obtain two ‘n’ values which are used to indicate a pass or fail.

5.4.2 Correcting for creep during pressurisation time

For PE pipes only, a correction to the decay time is needed to account for the amount of creep occurring during the time spent in raising the pressure. This is achieved by adding 0.4 * pressurisation time (t_P) to the recorded decay time. The calculated time is the ‘corrected decay time’ (t_c).

Corrected Decay Time (t_c) = (0.4 * t_P) + (Time since pump shut off t_1, t_2, t_3 etc.) (1)

where:

t_P is the time to reach System Test Pressure

5.4.3 Calculating rates of decay

Two rates of decay should be calculated using the pressure change or Raised Pressure (P_A) data between the times t_1 and t_2 (slope n_1) and between t_2 and t_3 (slope n_2) as follows:

$$n_1 = \frac{[\log(P_A at\ t_1) - \log(P_A at\ t_2)]}{[\log(t_{c2}) - \log(t_{c1})]} \qquad (2)$$

$$n_2 = \frac{[\log(P_A at\ t_2) - \log(P_A at\ t_3)]}{[\log(t_{c3}) - \log(t_{c2})]} \qquad (3)$$

Where:

P_A is Raised Pressure = (Actual Pressure at time t_1, t_2 etc.) – P_0

P_0 is static head at lowest point due to elevation changes in the pipeline.

<u>For PE</u>
Times: $t_{c1} = t_P + 0.4t_P$, $t_{c2} = 8t_P + 0.4t_P$, $t_{c3} = 20t_P + 0.4t_P$
Pressure readings: P_A at $t_1 = P_A$ at t_P, P_A at $t_2 = P_A$ at $8t_P$, P_A at $t_3 = P_A$ at $20t_P$

<u>For PVC</u>
Times: t_1 = 1 hr, t_2 = 3 hr, t_3 = 5 hr.

Figure 3 shows a typical pressure v time graph for PE with times at which pressure values are analysed to determine the 'n' values.

5.4.4 Pass / Fail Criteria

If $\frac{n2}{n1} \leq 1.25$, then the test is a pass.

Note: If the ratio is slightly greater than 1.25, the data may be analysed graphically and the "n" values obtained by a trend line analysis to reduce single point errors. The graphical "n" values should then be used to establish if the test passes. Further guidance on the use of graphical values can be found in Appendix D of this IGN or a specialist may be contacted to offer advice.

If pipelines fail to meet the acceptance criteria, the test should be stopped and the excess water bled carefully from the system. A search for potential leaks should be initiated. After leaks are found and repaired, the test should be repeated, but only after a time greater than four times the total original test time has elapsed to allow for complete creep deformation recovery.

5.5 Post-test procedure

When a main has been positively accepted as being free from leaks, the water should be released slowly from the pipeline with all valves opened.

The water should be discharged safely to a pre-planned site.

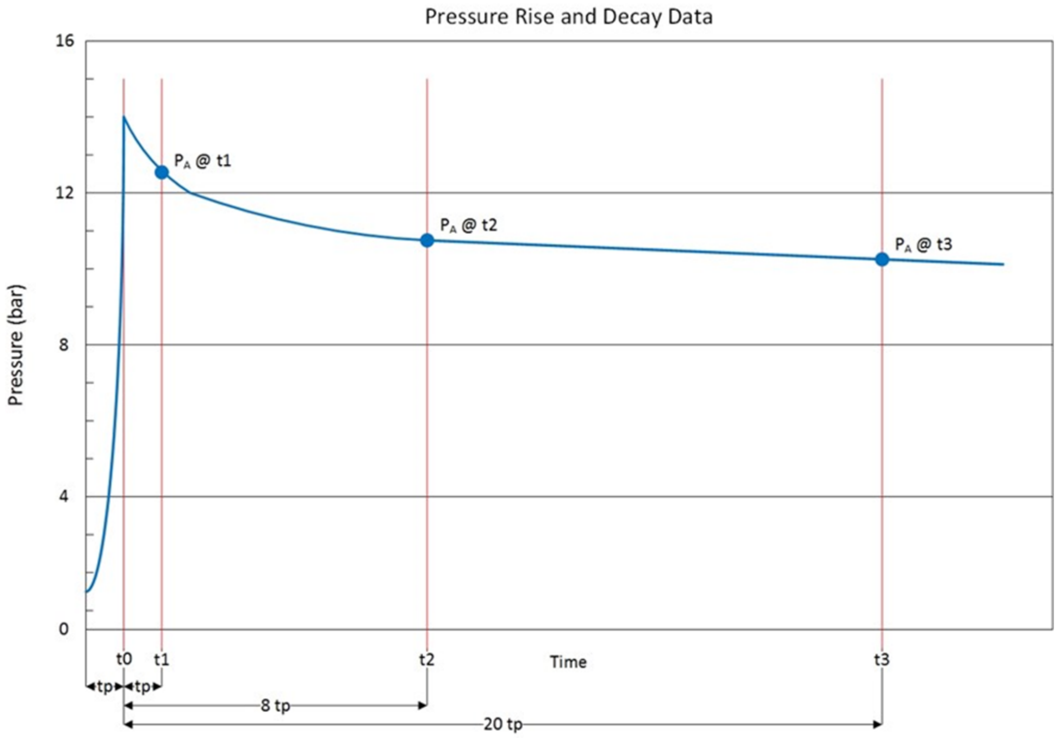


Figure 3: Response of pressure v time for a PE pipe showing the times at which pressure values are analysed to determine the "n" values

6 Test for new ductile iron, steel and GRP pipelines

6.1 Filling of the main

Water for the testing of potable water mains should be taken from the existing supply.

The main should be charged from the lower end, with all air valves open and an open valve at the point of highest elevation. After filling the main and bleeding air from the system the valve at the point of highest elevation should remain open to ensure there is no residual head at that point.

Once the main has been charged (prior to pressurisation), the data logger should be connected and all information logged.

6.2 Removal of air

Where possible, efforts should be made to remove as much air from the pipeline as possible to keep the test time to a minimum. <u>There is an upper limit of 4% air in any main for a valid test.</u>

Note: For the Volume of Water Lost/Added methods (see 6.6.3a and 6.3.3b), it is not necessary to remove the air from the system as this will not affect the results. It is advisable, however, to remove the majority of the air to minimise health and safety risks.

For the Pressure Decay method, air content greater than 4% complicates the interpretation of the test data. Whilst every effort should be made to remove air, it is acknowledged that this will not always be possible. In such cases, guidance is given in Appendix B of this IGN.

An estimate of the required water volume should be calculated prior to pressurisation, with an assumed air content of no more than 4%: see A.2 in Appendix A.

The air volume can then be estimated by comparing the actual water input volume required to bring the pipeline up to STP (obtained from the flow meter) with this estimated water volume. If the actual input volume is significantly more than predicted, this suggests that the air volume is also greater than predicted, and the test should be abandoned and restarted once the air content has been reduced.

Attempts should be made to purge air from the main during/after filling with water and before the start of the pressure test:

- Ensure that all air valves are functioning properly.
- It is recommended that a foam swab ahead of the water column is used to assist the removal of air.
- It is recommended that swabbing is carried out as one continuous operation and at sufficient velocity to prevent the swab stalling and consequently getting trapped within the pipeline.
- All non-self-sealing air vents should be closed prior to testing.

6.3 Test procedure

6.3.1 Raising pressure

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

A more accurate estimate of the air content percentage can be calculated from the actual water input volume (obtained from the flow meter) and other known data, see A.4 in Appendix A.

If the inputted volume indicated an air volume greater than 4%, the test should be abandoned and actions taken (as detailed in 6.2) to remove the air from the system prior to retest.

6.3.2 Preliminary conditioning of main

For ductile iron or steel pipes with epoxy linings or GRP pipes with socket and spigot joints, the pressure should be raised to the STP and allowed to settle for 15 min. For ductile iron or steel pipes with cement linings, the main should be allowed to settle overnight.

6.3.3 Test phase

After the preliminary conditioning, the pressure should be raised to the STP. Once the STP has been achieved, use either of the following procedures for measuring the amount of water required to maintain pressure.

a) Volume of Water Added

Maintain STP for a period of one hour by additional pumping as necessary, accurately measure the volume of water added and record with a resolution of 5 ml or better.

b) Volume of Water Lost

Maintain STP for a period of one hour by additional pumping as necessary. Isolate the main by disconnecting the pump and closing all valves. Allow pressure to decay for a period of one hour. The pressure should then be raised and returned in a controlled manner to STP. Water is then drained back to the decay level pressure and captured in to a calibrated volume container.

6.4 Data analysis

If the drawn off or added volume is less than the allowable volume given in Table 2, then the test is a pass, if it is above the test is a fail. If the pressure decay rate is close to the allowed rate, the test may be repeated immediately.

Table 2 – Standard allowable leak rates (litres/km/hour) as a function of diameter

Nominal Pipe Diameter (mm)	Leakage Rate (litres/km/h)
100	0.18
150	0.41
200	0.72
250	1.13
300	1.62
350	2.21
400	2.88
450	3.65
500	4.50
600	6.48
700	8.82
800	11.52
900	14.58
1000	18.00

Note 1: Further information on the derivation of the values in Table 2 is provided in Appendix C of this IGN.

If pipelines fail to meet the acceptance criteria, the test should be stopped and the excess water bled carefully from the system until only static head remains. A search for potential leaks should be initiated. After leaks are found and repaired, the test should be repeated.

Note 2: These are small volumes and as such the pressure gauge used to monitor the STP and the decayed pressure needs to have a resolution of 0.01 bar or less. Small errors in the pressure may lead to relatively large differences in the drawn off volume and therefore lead to secure pipelines apparently failing the test.

Where the calculated volume loss is very small, i.e. less than 0.025 litres (25 ml), a pressure loss test of 0.2 bar/hr. may be acceptable over the one hour test period.

6.5 Post-test procedure

When a main has been positively accepted as being free from leaks, the water should be released slowly from the pipeline with all valves opened.

The water should be discharged safely to a pre-planned site.

7 Test for renewed mains (10 minute test)

7.1 Introduction

The rehabilitation of mains is often conducted under severe time constraints to ensure disruption to customers' supplies is kept to a minimum.

The test for renewed mains does not provide the same level of robustness (especially with regards to data interpretation and therefore identification of a small leak) as the longer Type II or Water Loss test but can provide an element of confidence in the system being installed, especially if there are few joints (e.g. the testing of two 100 m coils with an electrofusion coupler joining them). It can identify leaks at joints or, if a straight coil is being tested, it can identify damage such as that caused during slip lining.

This test is a constant pressure test rather than a constant volume test. Modifications can be made to the testing setup as follows:

- The test may be conducted against valves and 'squeeze off' seals.
- There is no necessity to remove the air from the system as this will not affect the result. It is advisable, however, to remove the majority of the air to minimise health and safety risks.

Note: 'Squeeze off' units are not specifically designed for use in pressure testing. Care should be taken when undertaking the test.

7.2 Filling of the test section

Water for testing of potable water mains should be taken from the existing supply.

An adjacent main may be used to charge and initially pressure the test length.

Once the main has been charged (prior to pressurisation), the data logger should be connected and all information logged.

7.3 Test procedure

The pressure should be raised to the STP by pumping in a controlled manner. For this test, the STP should be 1.5 * PN of the lowest rated component in the length under test, up to a maximum of 15 bar. Once the STP has been reached, the pump should be left running to maintain the STP for a minimum of 10 min. A visual inspection of all possible sources of leakage (e.g. a 'squeeze off', valve or joint) should be made by walking along the length of the pipeline under test. If these possible sources are present, a note should be made on the results sheet.

7.4 Data analysis

The data is analysed by inspecting the graphs of pressure against time and flow against time. A typical graph is shown in Figure 4.

A successful test will have a high flow as the main is being pressurised; this will reduce significantly when the STP is reached. To keep the pressure constant, more water will need to be added as PE creeps. The amount of water needed should reduce with time and, depending on the diameter and length of main being tested, should be small in magnitude. A slightly increased level of flow can be attributed to a slight leak on a squeeze off or valve but this should have been identified by the contractor when they conducted a visual inspection of the test length. Although not ideal, the use of 'squeeze offs' and testing against valves is needed to ensure this test is quick to conduct.

A successful test is one where the pressure does not fluctuate significantly and there are low, reducing flow rates. If the volume inputted over three equal periods in the duration of the test is analysed, there should be steady volume or reduction in the volume inputted to maintain the pressure. Allowable volumes cannot be given as there is no control of air volume and pre-pressurisation is allowed.

An unsuccessful test is one where the pressure fluctuates significantly and a significant amount of water, which does not reduce, is required to maintain pressure. An example graph is shown in Figure 5.

Once a contractor has become familiar with the test it should be possible to identify if the test will be a pass or fail by monitoring the flow meter – both the magnitude (depending on the diameter and length) and how the flow rate varies with time.

If the test indicates there is a leak, this should be identified and the test repeated until a satisfactory result is obtained.

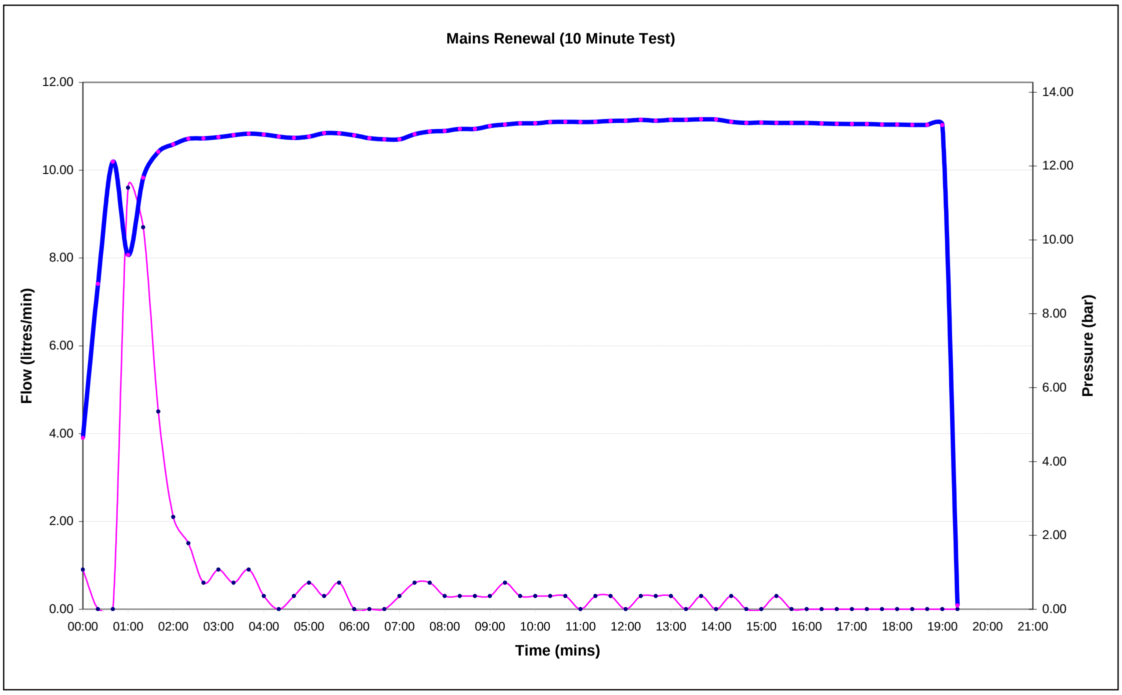


Figure 4: Typical graph for acceptable renewed mains test showing pressure increasing with high flows, reducing as the test pressure is reached and decreasing as the rate of creep slows.

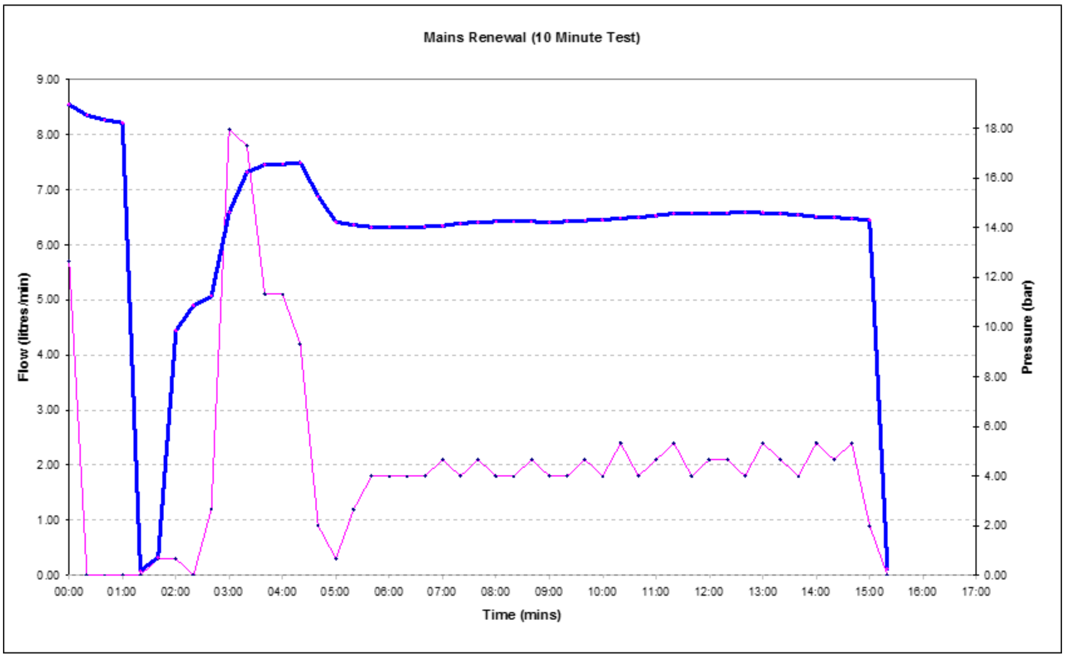


Figure 5: Example graph for unacceptable renewed mains test indicating a leak - pressure fluctuates from the test pressure, flow rate is high and does not reduce over the duration of the test.

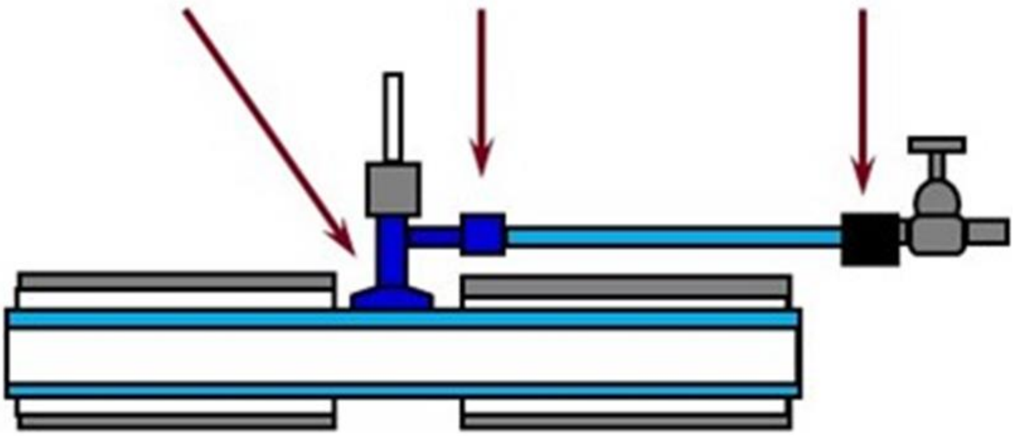


Figure 6: Joints which could be assessed using the test for service connections

8 Test for service connections

8.1 Introduction

Service connections are often overlooked and are a potential source of leakage. To ensure a leak free system, all joints and connections should be tested. Figure 6 shows three joints which could be assessed using this service connection test.

As there can be a large number of services on a main, this test has been designed to be quick and easy to conduct. It is essentially a visual test and there is no data logging to support the reported result. Neither the equipment detailed in 3.5 nor the reporting in Section 4 is required for this test.

8.2 Equipment

A hand pump capable of raising and maintaining a pressure in the test length at 18 bar.

8.3 Test procedure and reporting

8.3.1 Choice of System Test Pressure (STP)

The test pressure is 18 bar.

Note: This value is specific to SDR 11 PE80 service pipes with a maximum operating pressure of 12.5 bar. This may seem high but the service will not suffer any damage from this pressure if it is only applied for a short period of time.

8.3.2 Preparation and procedure

The service should not be tapped prior to this test being conducted.

Fill the section to be tested. Raise the pressure to 18 bar and maintain the pressure for 2 min.

Inspect the service visually during the test. Release the pressure.

If a leak has been identified then the service should be replaced. If no leak has been identified then the test is a pass.

8.3.3 Reporting

The observations should be recorded together with:

- The start time and date of the test.
- All details of the location of the service pipe.
- Details of the contractor who conducted the test.

9 References

BS EN 805: Water supply. Requirements for systems and components outside buildings.

BS EN 1610: Construction and testing of drains and sewers.

BS EN 545: Ductile iron pipes, fittings, accessories and their joints for water pipelines. Requirements and test methods.

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

APPENDIX A: ESTIMATED WATER INPUT VOLUMES FOR DIFFERENT PIPE MATERIALS AND DIAMETERS

A.1 Introduction

To assist contractors in the choice of pumps to raise pressure in mains, the estimated water input volumes have been calculated for different pipe materials.

Tables A1 to A5 (column 3) show the volume of water required to raise the pressure to STP with no air present in the main.

The calculations assume **100 m** length of main and give the estimated volume inputs for a **10 bar** gauge pressure rise. Values for other lengths/pressures should be scaled *pro rata* in accordance with equation (A1) below.

The volume of water required to raise pressure to STP with no air:

E_x = estimated volume to add for pipe pressurisation (from column 3 of Tables A1 – A5) * P_A/10 * L/100 (litres) (A1)

Where:

P_A is raised pressure (bar) = (Actual pressure at time t_0 – Static Head P_0)
L is tested pipeline section length (m)

If air is present, a larger volume of water will be required to compress the entrained air and scaled *pro rata* in accordance with equation (A2).

Water required to raise pressure to STP (litres) with v% air:

$V_w = E_x + A_v$ (A2)

Where:
E_x is given by equation (A1)
A_v is estimated volume to compress initial air content of v% (from columns 4, 5, 6, 7 of Tables A1 – A5 as appropriate) * L/100
L is tested pipeline section length (m)

Values of unpressurised pipe volumes are also given in the tables (column 2). The tables given here are for guidance only:

- Precise values will alter for different types / grades of PE and PVC.

- Values for all plastics will be affected by temperature as plastics become stiffer as temperature is reduced.

  An increase in the temperature of the pipe material by 1°C would cause the material modulus to reduce slightly and, if the pipeline is free to change in length, would cause the pipe to expand. This leads to a slight increase in the pipeline dimensions, so to compensate for this change there would need to be an adjustment in the pressurisation water volumes. Similarly a decrease in temperature of the pipe material by 1°C would cause the material modulus to increase slightly.

  Volumes should be decreased by approximately 1.35% per degree for temperatures below 10˚C and increased by approximately 1.35% per degree for higher temperatures.

- Values for all materials will be affected by the volume of air in the pipeline.

A.2 Estimated water volumes for different pipe materials and diameters

NOTES TO TABLE A1 TO TABLE A5:
- 10 bar has been selected as the reference pressure for tables A1 to A3 as the error margin is small, around ±5%, for a range of test pressures from 6 bar to 24 bar. The use of 10 bar as the reference pressure also renders the pro-rata calculations for other air content and/or pipe SDR values simpler.
- 10°C has been selected as the reference temperature as this is a typical value for buried water supply pipelines. Variation from this figure is not significant except in the cases of above ground pipelines or wastewater pipelines carrying high temperature effluent. In these instances, the pressure rating (PN) of the pipeline should be de-rated in accordance with the guidance set out in IGN 4-32-18 which may reduce the allowable system test pressure.
- Provided the pipe wall temperature remains reasonably constant, temperature would have no effect on the test results. For above ground pipelines where the pipe wall temperature may vary during the course of the test period, there would be an effect on the test results and this may result in an apparent test failure. It is recommended that a visual inspection of the full length of pipeline under test is carried out in such cases.

NOTE TO TABLE A4:
- The data assumes Class 40 cement lined pipe to BS EN 545: 2010 is used. The actual pipe volumes vary with manufacturing tolerances as these can increase or decrease the actual internal diameter. Other pressure classes are available and would also have different water volumes.

Table A1: PE100 pipes (SDR 11), 10 bar pressure increment for 100m of pipe at 10°C

Diameter DN / OD (mm)	Unpressurised pipe volume (litres)	Volume to add for pipe pressurisation no air (litres)	Volume to add for air compression, no pipe pressurisation (litres)			
			1% air	2% air	3% air	4% air
63	207	2	2	4	6	8
75	296	3	3	5	8	11
90	425	5	4	8	12	15
110	636	7	6	12	17	23
125	820	9	7	15	22	30
140	1031	11	9	19	28	37
160	1344	15	12	24	37	49
180	1702	19	15	31	46	62
200	2102	23	19	38	57	76
225	2659	29	24	48	72	97
250	3288	36	30	60	90	119
280	4126	45	37	75	112	150
315	5220	57	47	95	142	190
355	6633	73	60	120	181	241
400	8419	92	76	153	229	306
450	10648	116	97	193	290	387
500	13151	144	119	239	358	478
560	16504	181	150	300	450	599
630	20879	229	290	379	569	758
710	26512	290	241	481	722	963
800	33675	369	306	612	917	1223
900	42614	467	387	774	1161	1548
1000	52604	576	478	955	1433	1911

Table A2: PE 100 pipes (SDR 17), 10 bar pressure increment for 100m of pipe at 10°C

Diameter DN / OD (mm)	Unpressurised pipe volume (litres)	Volume to add for pipe pressurisation no air (litres)	Volume to add for air compression, no pipe pressurisation (litres)			
			1% air	2% air	3% air	4% air
63	241	4	2	4	7	9
75	342	6	3	6	9	12
90	493	9	4	9	13	18
110	736	13	7	13	20	27
125	954	17	9	17	26	35
140	1196	22	11	22	33	43
160	1561	28	14	28	43	57
180	1976	36	18	36	54	72
200	2438	44	22	44	66	89
225	3085	55	28	56	84	112
250	3815	69	35	69	104	139
280	4784	86	43	87	130	174
315	6052	109	55	110	165	220
355	7685	138	70	140	209	279
400	9765	176	89	177	266	355
450	12354	223	112	224	337	449
500	15247	275	138	277	415	554
560	19136	345	174	347	521	695
630	24210	436	220	440	659	879
710	30758	555	279	559	838	1117
800	39058	706	355	709	1064	1419
900	49440	894	449	898	1347	1796
1000	61015	1101	554	1108	1662	2216
1200	87881	1588	798	1596	2394	3192

Table A3: PE 100 (SDR 21), 10 bar pressure increment for 100m of pipe at 10°C

Diameter DN / OD (mm)	Unpressurised pipe volume (litres)	Volume to add for pipe pressurisation no air (litres)	Volume to add for air compression, no pipe pressurisation (litres)			
			1% air	2% air	3% air	4% air
63	255	6	2	5	7	9
75	361	8	3	7	10	13
90	520	12	5	9	14	19
110	776	18	7	14	21	28
125	1003	23	9	18	27	36
140	1259	29	11	23	34	46
160	1642	37	15	30	45	60
180	2082	48	19	38	57	76
200	2567	59	23	47	70	93
225	3249	74	30	59	89	118
250	4019	93	36	73	109	146
280	5035	116	46	91	137	183
315	6379	147	58	116	174	232
355	8103	187	74	147	221	294
400	10281	236	93	187	280	373
450	13010	299	118	236	354	473
500	16060	369	146	292	437	583
560	20157	464	183	366	549	732
630	25518	589	232	463	695	927
710	32391	745	294	588	882	1176
800	41146	949	374	747	1121	1494
900	52066	1200	473	946	1418	1891
1000	64269	1480	584	1167	1751	2334
1200	92561	2133	840	1681	2521	3362

Table A4: Ductile iron, 10 bar pressure increment for 100m of cement mortar lined Class 40 D.I. pipe to BS EN 545: 2010

Diameter DN / OD (mm)	Unpressurised pipe volume (litres)	Volume to add for pipe pressurisation no air (litres)	Volume to add for air compression, no pipe pressurisation (litres)
			1% air
100	850	0	8
125	1327	1	12
150	1911	1	17
200	3391	2	31
250	5236	3	48
300	7489	5	68
350	10032	7	91
400	13010	10	118
450	16360	13	149
500	20189	16	184
600	28957	24	263
700	39058	34	355
800	51048	45	464
900	64525	59	587
1000	79548	73	723

Table A5: PVC (SDR 26, PVC-A PN12.5 / PVC-U PN8), 10 bar pressure increment for 100m of pipe at 10°C

Diameter DN / OD (mm)	Unpressurised pipe volume (litres)	Volume to add for pipe pressurisation no air (litres)	Volume to add for air compression, no pipe pressurisation (litres)			
			1% air	2% air	3% air	4% air
90	542	7	5	10	15	20
110	810	11	7	14	22	29
160	1713	22	16	32	47	63
200	2677	35	24	49	73	97
250	4183	55	38	76	114	152
315	6640	87	60	121	181	242
400	10707	140	98	195	292	390
450	13552	178	123	246	369	493
500	16730	219	153	305	457	609
630	26561	348	242	483	725	966

A.3 Example - calculation showing volume of water to raise pressure to STP with air content above zero

Pipe specification: Diameter 180mm; Material PE100 SDR17; length 250m; STP 15bar; static head 1bar. Estimate based on maximum 4% air content.

P_A = STP – Static Head = 15 bar – 1 bar = 14 bar

Using equation (A2), water required $V_w = E_x + A_v$

E_x = Estimated volume to add for pipe pressurisation (from column 3 of Table A2) * P_A/10 * L/100 (litres)
= 36 *(14/10) * (250/100) = 126 litres

A_v = Estimated volume to compress initial air content of 4% (from column 7 of Table A2) * L/100 (litres) = 72 * (250/100) = 180 litres

V_w = 126 litres + 180 litres = 306 litres

Note: The values derived presume that pressure is being raised from zero to STP, above any static head due to elevation changes.

A.4 Pressurised air percentage calculator

It is always advantageous to have less air in the system as leak detection sensitivity is increased at shorter times. Air has an effect on the pressure decay, so it is essential to have a quantitative measure of the air contained in a pipeline under test.

It is possible to calculate the volume percentage of air present from the actual volume of water pumped into a pipeline when the pressure is raised to its test pressure (STP) using equation (A3).

Initial air content (%) = $(V_w – E_x) / A_{v1}$ (A3)

Where:

V_w is actual input volume (litres)
E_x is estimated volume to add for pipe pressurisation (from column 3 of Tables A1 – A5) * PA/10 * L/100 (litres)
P_A is raised pressure (bar)
L is tested pipeline section length (m)
A_{v1} is required volume to compress 1% initial air volume (from column 4 of Tables A1 – A5)

If initial air content is greater than 4%, the guidance in 5.2 should be followed. If the air content cannot be reduced to 4% or less, the test would need to be either extended or abandoned. The guidance in Appendix B should be followed.

APPENDIX B: ANALYSIS TO DETERMINE INITIAL VOLUMES OF AIR IN A PIPELINE

B.1 Introduction

The purpose of this appendix is to provide additional background information on the effect of entrained air on the pressure test to support the guidance given in Sections 5 and 6.

B.2 Modelling the effects of different air volumes

Large volumes of air contained in a pipeline can be dangerous if a pipe failure occurs. There will be a massive sudden release of stored energy.

All testing standards acknowledge that contained air will totally confuse ‘added volume’ measurements in constant pressure tests and will have some effect on pressure decay characteristics.

Having large initial air volumes will always increase pressure-rise times:

- High air content will slow down the rate of pressure rise. This is shown graphically in Figure B1.
- Air may mask signs of leaks since air expansion will delay the time before leakage affects the degree to which the pressure decays.

Thus, having high air content always leads to increased test times and the possibility of reduced test sensitivity.

B.3 Effects of different air volumes on pressure decay for PE pipes

An analysis has been made of the effects of air on pressure decay data in PE pipe systems. The results (Figure B2) show how air produces a delay before leakage becomes apparent via a slope change in the logarithmic decay data.

The results of modelling different pressure drops below the expected creep power law stress relaxation profile are shown in Figure B3. The presence of air will tend to mask the pressure decay due to a leak. In pipelines with higher air contents, it will take longer to detect any given percentage drop in pressure caused by a leak. This is shown in Figure B3 where the time to detect two different pressure drops below expected rates is shown vs air content. The time is shown as a multiple of the loading time.

For a pipeline with no air, the pressure will have dropped by 2% more than expected at 6 * the pressurisation time. With 4% air, the pressure will have dropped by 2% more than expected at 9 * the pressurisation time. When the pressure has decayed by 5% more than expected, the power law slope 'n' will have doubled. It is always advantageous to have less air in the system as leak detection sensitivity is increased at shorter times.

Air has an effect on the pressure decay, so it is essential to have a quantitative measure of the air contained in a pipeline under test. Methods of calculating volume of air are given in B.4 below.

B.4 Estimating the volume of air in a pipeline

B.4.1 Calculating air volume percentage from data

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

If the air content so calculated is up to the acceptable limit of 4% of the total pipe volume, the test time should be 20 times the pressurisation time t_P plus 0.4 * t_P.

Where the calculated air content is greater than 4% but less than 8%, the test may proceed with caution. The pressure decay time needs to be extended to counteract the effect of air in slowing the pressure decay and accurately determine whether the pipe is leaking. The test time should be extended as indicated in Table B1 plus 0.4 * t_P.

Table B1 Extended test period for air content greater than 4%

Pipe Material	Air Content (%)	Suggested t_4 time (min.)
PE	4% < 6%	30* t_P
	6% < 8%	45* t_P
PVC	4% < 6%	8 hr.
	6% < 8%	10 hr.

(3) t_P is time taken to reach STP
(4) Where the suggested t_4 time is less than 60 min., the t_4 time is taken as 60 min. The minimum t_3 time of 1 hour no longer applies when a fourth reading is being taken at t_4.

By taking this additional pressure reading (P_A at t_4), a further n value (n_3) can be calculated using the following formula:

$$n_3 = \frac{[\log(P_A at\ t_3) - \log(P_A at\ t_4)]}{[\log(t_{c4}) - \log(t_{c3})]} \qquad \text{(B1)}$$

If $\frac{n3}{n1} \leq 1.25$, then the test is a pass.

If the air volume estimate is greater than 8% or if the test period cannot be lengthened as set out in Table B1, the test should be abandoned as such large air volumes would confuse data analysis. The pressure should be reduced to zero 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.4.2 Calculating air volume from pressurisation characteristics

The shape of the Raised Pressure (P_A) vs Volume of water added (V_w) characteristic is a good measure of whether significant air is present. When there is negligible air, the pressure will rise quickly as water is pumped into the main. Eventually, the pressure rise rate will slow down slightly, as the plastic pipe becomes less stiff due to time dependent creep effects. This is shown as curve (1) in Figure B4.

If the pressure rises slowly in the initial phase and then more rapidly at higher pressures (curve (2) in Figure B4), this is a sign that there is significant air present. However, where the pipeline has already been pre-pressurised, the air content will already have been compressed which allows a normal pressure rise time, hence masking the effect of the excess air.

It is possible to calculate the volume percentage of air present from the actual volume of water pumped into the pipeline to raise the pressure to STP using equation (A3), see A.4.

However, if the pipeline is pre-pressurised, equation (A3) needs to be modified to take into account an air compression factor (F_c) derived from the raised test pressure and the initial pressure.

Initial air content (%) = ((V_w-E_x)*F_c) / (V/100) (B2)

Where:

V_w is actual input volume (litres)
E_x is estimated volume to add for pipe pressurisation (from column 3 of Tables A1 – A5) * PA/10 * L/100 (litres)
P_A is raised pressure (bar)
L is tested pipeline section length (m)
F_c is air compression factor derived from raised test pressure (P_A) and initial pressure (i.e. pre-pressurisation)

V is the unpressurised pipe volume = pipe volume (from column 2 of Tables A1 to A5) * L/100 (litres)

B.4.3 The impact of pre-pressurisation on air content

Any pressure in a pipeline over and above the static head due to elevation changes just prior to testing has a dramatic effect on the initial air content.

Table B2 shows the air compression factors which would be required for calculating initial air content (see A.4, equation A3) if the pipeline had not been pre-pressurised and (see B4.2 equation B2) when pre-pressurised to 1 bar and 2 bar.

Using the example in A3, where there is an initial air content of 4% and no pre-pressurisation, the initial air content calculated using equation B2 and table B2 would be 9% and 15.5% at 1 bar and 2 bar pre-pressurisation respectively. These higher values are the result of the same actual input volume (V_w) in each case.

Table B2 Air compression factor where pre-pressurisation has been applied

Raised Test Pressure P_A (bar)	Air compression factor Fc (for given initial pressure at lowest point above static head)		
	0 bar	**1 bar**	**2 bar**
10	1.10	2.40	3.90
Note: These values have been calculated using Boyle's Law.			

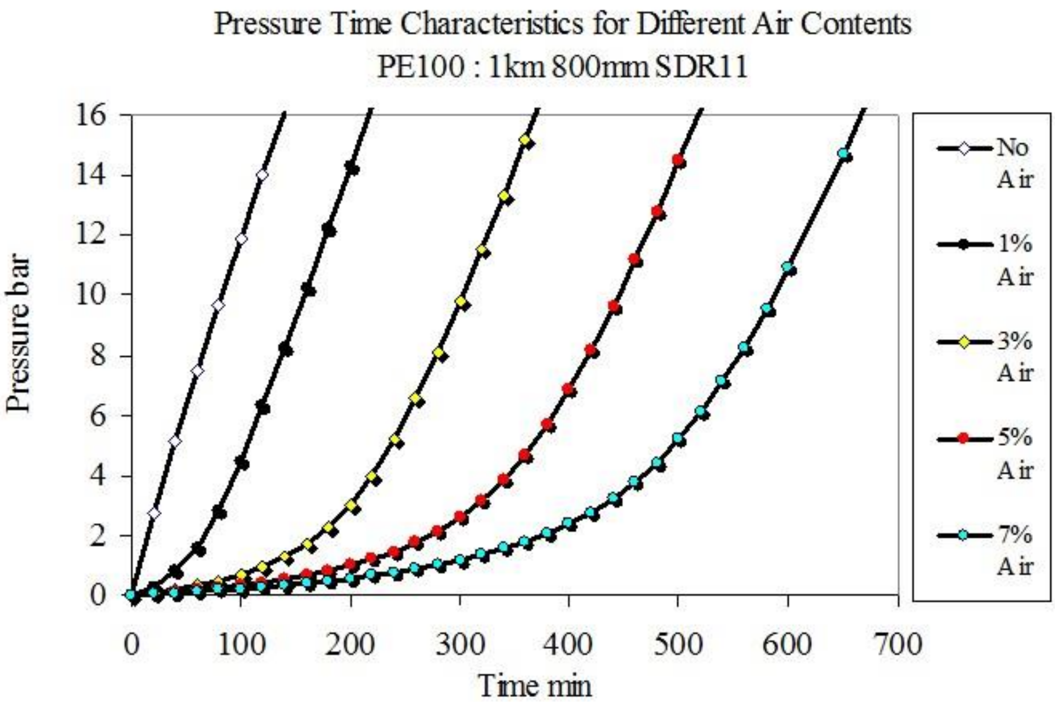


Figure B1: Pressure rise characteristics for 1 km of 800mm SDR 11 PE 100 Pipe

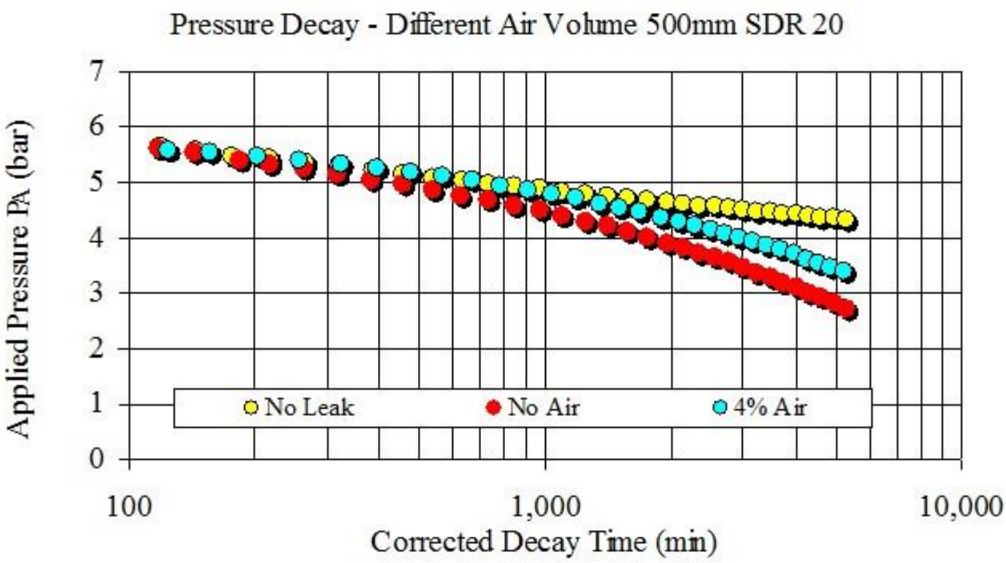


Figure B2: Effect of air on pressure decay in a PE Main with (a) No Leak and with (b) Leakage at 4 * Allowable Rate

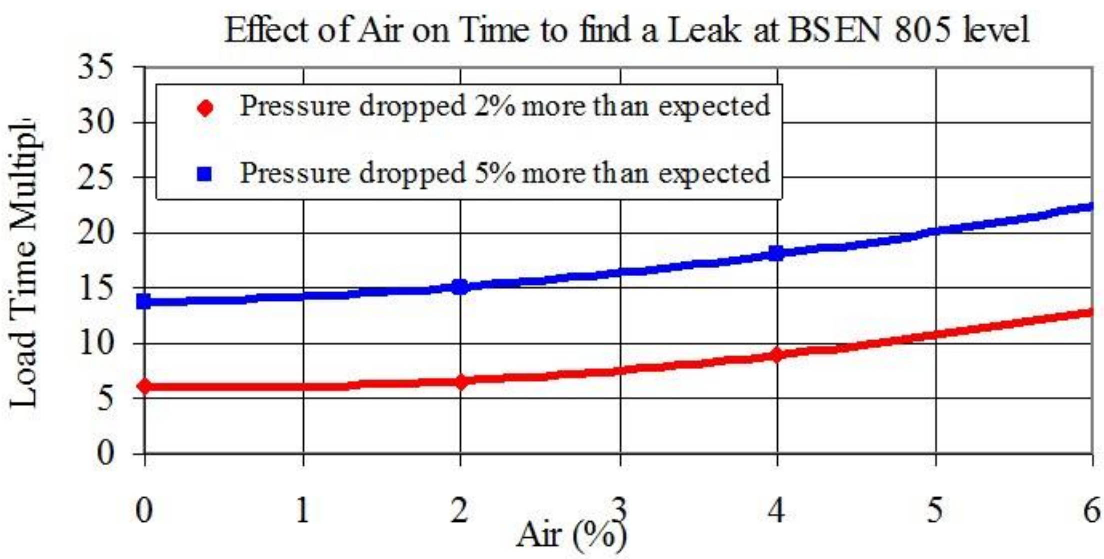


Figure B3: Effect of air on time (multiple of loading time) to detect a leak at BS EN 805 level

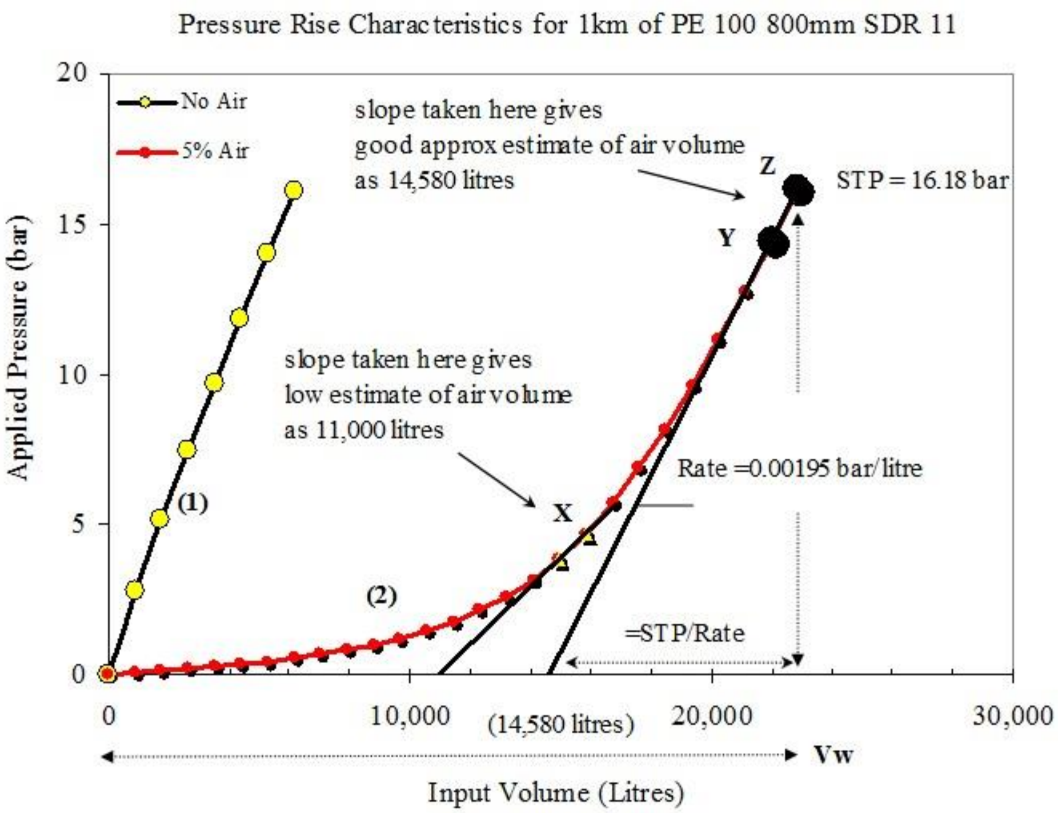


Figure B4: Pressure v Vol for (a) No Air and (b) 5% Air - 1km: 800mm SDR 11 Pipe

APPENDIX C: BS EN 805

C.1 Introduction

The purpose of this appendix is to describe the range of tests available in BS EN 805 and the background to the selection of certain tests by the UK water industry.

C.2 Rate of leakage – general issues

Historically, the pressure testing of pipe systems in the U.K. has been governed by codes of practice and specifications that have followed procedures developed by clients and suppliers over a long time period.

For ductile iron (DI) and PVC pipes, there was specified a maximum rate of volume loss of 0.02 litres per day per mm diameter per km per bar pressure applied.

This criterion was a sensible model of a leakage rate in that it is implicit that the rate of leakage will be directly proportional to the pipe diameter and the Raised Pressure (P_A).

For PE systems where creep relaxation effects can make the discernment of leakage problematical, the procedure was to compare and contrast the actual decay in pressure with that which was to be expected because of stress relaxation due to creep.

BS EN 805 (issued in 2000) specifies that a pipe under pressure should not suffer a pressure loss of greater than 0.2 bar/hr. due to water loss. BS EN 805 requires that this pressure decay be translated into an acceptable water volume loss by calculating the change in volume caused by the pressure drop, using the pipe stiffness to calculate the diameter change.

The standard gives a criterion for acceptance which is described in terms of an allowable pressure loss per hour.

The formula in BS EN 805 is:

$$\Delta V_{\max} = 1.2 \cdot V \cdot \Delta p \cdot \left(\frac{1}{E_{\mathrm{w}}} + \frac{D}{e \cdot E_{\mathrm{R}}}\right) \qquad \text{(C1)}$$

$\Delta V_{\max}$ is the allowable water loss in litres;
V is the volume of the tested pipeline section in litres;
Δp is the allowable pressure loss as stated in kilopascals (20kPa);
E_{w} is the bulk modulus of water in kilopascals;
D is the internal pipe diameter in metres;
e is the wall thickness of the pipe in metres;
E_{R} is the modulus of elasticity of the pipe wall in the circumferential direction in kilopascals;
1.2 is an allowance factor (e.g. for air content) during the main pressure test.

For allowable pressure loss Δp in bar (0.2 bar) and with terms 'D' and 'e' in mm, equation (C1) is modified to:

$$\Delta V_{\max} = 1.2 \cdot V \cdot \Delta p \cdot 100 \cdot \left(\frac{1}{E_{\mathrm{w}}} + \frac{D}{e \cdot E_{\mathrm{R}}}\right) \qquad \text{(C2)}$$

It is noted that this formula has nothing whatsoever to do with leakage rates per se. The formula is a simple stress – strain relationship, where ΔV /V is the strain and the Δp * SDR component is the stress in the pipe wall. It should also be noted that the pass/fail criteria is independent of test pressure, unlike criteria historically used.

The formula allows for calculation of the pipe contraction (or expansion) if water is lost (or added) because of a pressure change, Δp. 'Allowable water loss' is that water loss which causes a drop in pressure of Δp. The formula works in terms of pipe volumes, so any allowable water loss rate is automatically proportional to ΔD^2. This may/may not be the real case.

In practice, many leaks around flanges or socket and spigot joints are likely to vary as a linear function of diameter. They are controlled by changes in the pipe circumference rather than the pipe volume. In other cases (such as with leaks at tapping tee connections), there may be no pipe diameter sensitivity since the hole for the tapping does not vary significantly.

For materials which do not have stiffness properties that vary with time and temperature (e.g. ductile iron, steel), it is simple to calculate the allowable water loss using known material properties. For plastics materials, which are inherently more flexible and have modulus (stiffness) properties that change very significantly with temperature and time under load, there are major problems.

The lack of commonly agreed values of material modulus values for plastics makes it impossible to define universally agreeable water loss rates. There is also a strong implication, whether intended or not, that the lower modulus materials (e.g. plastics) have a higher "allowable water loss". Obviously, this cannot be tolerated.

The U.K. water industry wishes to standardize on a common rate of water volume loss as the assessment criterion. Therefore, the water volume changes caused by the 0.2 bar/hr. decay rate stated in BS EN 805 have been adopted as standard, using ductile iron pipe as the yardstick.

C.3 BS EN 805 – water loss calculation

In BS EN 805, the allowable pressure loss is 0.2 bar in any test where the main is raised to the test pressure and then sealed. This drop in pressure is specified to be common to ductile iron, steel, concrete and 'plastic' pipes.

There is a major problem in adopting this universal criterion for both metal and plastic pipes. Because plastics are much less stiff the volume change caused by a decrease in pressure of 0.2 bar will be some 10 - 20 times larger than for ductile iron where the volume change is small.

For example, consider the volume of water loss that would cause a pressure drop of 0.2 bar in 1 km of a 250mm pipeline:

- For a rigid / semi-rigid pipe such as ductile iron, 1.13 litres would need to be lost.
- For a flexible pipe such as PE100, some 16 litres would be lost.

The specification of one simple pressure loss rate in BS EN 805 leads to the acceptance of totally different water volume losses for pipes of different wall thicknesses and made from different materials.

Since water engineers are driven to maintain leakage at very low uniform rates – independent of the pipe material, it is recommended here that the water loss rates calculated from equation (C1) of this IGN for BS EN 545: 2010 Class 40 ductile iron pipes be taken as the acceptable measure of water loss. These rates should then apply for all materials, based on nominal pipe diameters.

The allowable water loss rates for BS EN 545: 2010 Class 40 Ductile Iron are shown in Table 2 of Section 6 and Figure C1. However, it should be noted that actual pipe volumes will vary with manufacturing tolerances, as these can increase or decrease the actual internal diameter. Other pressure classes are available and will also have different water volumes.

For an exact calculation, the following equation may be used where D is the nominal diameter in mm

Allowable water loss (litre/hr/km)
$= 0.000018*(ID)^2$ (C3)

C.4 Acceptable pressure loss rates

A value of pressure loss may be an easier parameter to measure in any test, so it is necessary to calculate acceptable loss rates for different pipe materials and stiffness.

Having accepted that the BS EN 805 allowable pressure loss rate of 0.2 bar/hr. shall apply for ductile iron pipes, the resulting acceptable pressure loss rates for pipes made in different stiffness categories for all other materials have then been calculated.

The criterion is that the acceptable water losses are those given in Figure C1. Equation (C1) has then been used to calculate Δp, given ΔV as an input for pipes of different SDRs and with different modulus values Ep.

The values of acceptable pressure decay rates (APDR) are given in Table D2 in Appendix D of this IGN.

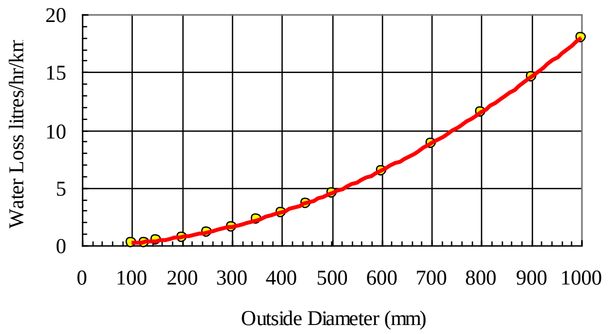


Figure C1 Allowable Leak Rates for ductile iron with a Pressure Loss of 0.2 bar/hr.

C.5 Pressure test methods

C.5.1 BS EN 805 tests

BS EN 805 does not directly specify any given test method for pipes. In Section 11 and in Appendices A26 and A27 of BS EN 805: 2000, the details for mains testing and data analysis are given. It is always left to the discretion of the 'designer' to choose the test method, and for PE pipes the method described is a recommendation rather than a requirement. The tests described are described in C.5.2 to C.5.4 below.

C.5.2 Limited Pressure Decay - Pressure Loss Method (BS EN 805 11.3.3.4.3)

Following raising of pressure to STP, the main is closed and it is stated that any changes in pressure are monitored over a one hour period (or longer if specified by the designer).

BS EN 805 states that the rate at which the pressure is lost should not exceed the specified limit of 0.2 bar/hr. for ductile iron, steel or 'plastic' pipes.

This test is appropriate for the assessment of ductile iron and steel pipes (see 6.3 of this IGN) but the simple analysis recommended is inappropriate for plastic pipes which suffer from creep stress relaxation.

It is likely that a result which can be accepted with confidence will only be obtained after at least 10 hr. of pressure decay for PVC and some 36 hr. for PE pipes. It is only at these times that the pressure drop from creep stress relaxation has decayed to the same level as the 'allowable water loss'. Further information is given in Appendix D of this IGN.

C.5.3 Limited Pressure Decay – Water Loss Method (BS EN 805 11.3.3.4.2 a)

In this procedure (long used for ductile iron evaluation in the UK), the pressure is raised to STP, maintained for one hour, and is then allowed to decay over a 1 hr. - 2 hr. period to a pressure P1. The pressure is then returned to STP. Immediately, water is drained from the system to return the pressure to P1. The volume drained in this final process is deemed to be the amount lost due to leakage in the decay phase. There are two fundamental problems with this test when applied to short lengths of small diameter pipe:

- The BS EN 805: 2000 allowable water loss rates are so small for small diameter pipes that if the pressure is not returned to STP and subsequently drained to P1 with great precision, then the result will be meaningless. Very small errors in pressure control (e.g. of the order +/- 0.05 bar) cause significant variations in the water volumes lost.
- If even small volumes of air are present, the water volume measurements will be meaningless as a true measure of leakage, if pressures are not controlled with great precision.

The new demands for a more sensitive measure of leakage means that water loss assessment is likely to lead to confusing results and **this test is not recommended**. Instead the Pressure Loss Method (C.5.2) is preferred for short lengths of small diameter pipe.

C.5.4 Constant Pressure Test – Water Added Method (BS EN 805 11.3.3.4.2 b)

In this procedure, it is required to hold the pressure at STP and then measure any water needed to be added to hold pressure. There are two items to note with this method:

- The control equipment to hold the pressure absolutely constant needs to be sophisticated. Again, small pressure fluctuations can cause large errors in assigning water leakage rates.
- The water losses allowed can be so small that it is simply not feasible to measure the flow rates of any water added to maintain pressure. Instead, the equipment should be capable of measuring accurately the volume of water added to maintain the STP.

C.6 Use of BS EN 805 Test Methods for Plastic Pipes

The wording in BS EN 805 is very confusing with respect to different materials under test. The standard does not mention PVC or GRP pipes specifically at all, but recommends that "plastics pipes" be treated the same as ductile iron.

There is only mention of PE and PP pipes as being special cases of materials with viscoelastic properties and thereby in need of different assessment. This is quite wrong. PVC will suffer from creep stress relaxation – although not to the same degree as with PE and PP.

The pressure in PVC pipes will naturally decay without leakage and the effects are significant for times up to 10 hours. Thus pressure decay test data (or water volume measurements) on PVC and GRP are difficult to analyse in the first 10 hours since stress relaxation effects could be confused with leakage.

BS EN 805 does recognise that all PE (and PP) pipes will suffer from the problem that the pressure will still decay in a main without any leakage because of stress relaxation. This will totally confuse the assessment of leakage with any test method relying on a simple pressure decay rate or the measurement of water added or removed.

A special test is described in Section A27 of Annex A of BS EN 805: 2000. This was long specified by WRc in their MDPE manuals (Type I test) in the 1980s, but was seldom used in the UK for the reasons outlined below.

BS EN 805 outlines a primitive method of opening a valve to allow the pressure to drop swiftly after STP is achieved. The valve is closed and if the pressure then increases as the pipe diameter contracts, this is taken to be a sign that the main is secure.

There are many problems with this test – primarily:

- There is no possible method of relating any of the pressure measurements to an absolute leakage rate. It is thus a highly empirical analysis procedure.
- Tests have shown that mains with leaks greater than those outlined in Table 2 will still show pressure rebound after valve closure.

This test is not recommended.

APPENDIX D SUPPLEMENTARY INFORMATION ON PRESSURE TESTING OF UK PIPELINES

D.1 Introduction

The purpose of this appendix is to provide additional background information on the testing methods and their applications for all new water and sewerage pressure pipelines laid in the U.K.

Section D.5 provides the mathematical background to the Type 2 test used in Section 5.

D.2 Choice of System Test Pressure (STP)

[Supplementary to 3.3 of this IGN]

Historically, different Water Companies have used an *ad hoc* range of test pressures. These have usually resulted from the whim of individuals. Some engineers have used the mains working pressure as the basis for the test pressure; some have used the pipe rating.

It is now strongly recommended that all companies universally follow the guidelines specified in BS EN 805 and establish common levels for the System Test Pressure (STP). This has the benefit of greatly simplifying data analysis and increasing the ability to detect leakage which is sensitive to pressure.

D.3 End Loads

[Supplementary to 3.4 of this IGN]

Where socket and spigot joints have been used (e.g. for PVC, ductile iron and GRP mains) sufficient thrust blocks or other anchorages should be in position and any concrete used should have been adequately cured.

The ends of the pipeline should be securely anchored and any temporary strutting should be properly designed.

It is the responsibility of the site engineer to ensure that all end fittings can safely withstand the end forces generated by high test pressures.

These forces can be very high and examples of the end loads on PE pipes raised to a test pressure of 15 bar are given in Table D1 below. The forces given should be multiplied *pro rata* for other pressures.

It is essential that the end fittings themselves are watertight.

End fittings or struts installed to resist pressure forces should not be removed until all pressure applied during testing has been removed from the main.

Table D1: Examples of end forces generated by 15 bar pressure on PE pipes to illustrate the level of danger

External Diameter (mm)	End Force (tonnes)
80	0.8
180	3.9
250	7.5
315	11.9
400	19.2
500	30
610	44.7
720	62.3
800	76.9
1000	120.2

D.3 Allowable Pressure Drop Rates

[Supplementary to 5.4 and 6.4 of this IGN]

D.3.1 Allowable Pressure Drop Rates for Single Materials

The corresponding ‘allowable pressure decay rates’ which would cause the allowable volume changes for pipes made from PE, GRP and PVC materials are given in Table D2. Values of moduli used are those measured at 23˚C.

Small pressure changes applied to the less stiff pipes cause considerable volume changes, so the allowable pressure drop rates are always lower for the lower stiffness systems.

For plastics, creep stress relaxation alone will cause higher pressure drop rates than those given in Table D2, for up to 10 hours with PVC and for at least 36 hours with PE pipes. This obscures leakage assessment in simple pressure drop tests and so the analysis for plastics needs to differ from elastic materials such as ductile iron – see Section D.4.

Table D2: Allowable Pressure Decay Rates (APDR) for different pipe materials arising from the “allowable” leakage given in Table 2 (Section 6)

Material	Allowable Pressure Loss (bar/hour)
Ductile Iron	0.200
PE 100 SDR 11	0.030
PE 100 SDR 17	0.016
PE 100 SDR 21	0.012
PVC SDR 17	0.024
PVC SDR 26	0.023
GRP	0.023

Note 1: The values in Table D2 have been corrected from Issue 1 to align with BS EN 805.

Note 2: The values for allowable pressure loss for additional SDR have been calculated using equation (C1) and maintaining the same value for $\Delta V_{\max}$, the allowable water loss in litres, for all SDRs.

D.3.2 Allowable Pressure Drop Rates for Pipelines with Multiple Materials

Sometimes, pipes of different types may be accommodated within a system under test. If there are pipelines with sections of different materials (A and B), a law of mixtures may be used to obtain the allowable pressure loss rate (in bar/hr) for the whole system. The formula for allowable pressure drop (Δp) is:

$$\Delta p = L_{fA} * (APDR)_A + L_{fB} *(APDR)_B \qquad (D1)$$

Where L_{fA} and L_{fB} are the respective length fractions of materials A and B.

It would be most unusual to find more than two materials or a large multiplicity of SDR ratings in a test length, but if this is the case, the Law of Mixtures principle expounded in equation D1 may be extended as necessary. However, it is recommended that this only be done where the ratio of the two different pipe materials is not greater than 3:1.

For small lengths of relatively stiff (metal) pipe mixed with pipe made from viscoelastic (plastic pipe) material, it is necessary to check the metal pipe locally for leaks that are likely to be masked by the viscoelastic nature of the plastic pipe.

D.4 Data Analysis for PVC and PE pipelines
[Supplementary to 5.4 of this IGN]

D.4.1 Correction for creep during pressurization time

The rate of linear decay of pressure with time caused by creep stress relaxation will give rates of pressure drop that greatly exceed the BS EN 805 allowed rate for times up to 10 hours for PVC pipes and 36 hours for PE pipes.

To check whether there is evidence that the rate of decay is predicted to be unacceptably high, it is necessary to analyse the logarithmic decay of pressure with time and compare this with known material creep relaxation behaviour.

Equation (1) in section 5.4 provides a method of calculating a correction to the decay time which is needed to account for the time spent in raising the pressure.

D.4.2 Analysis of Pressure Above Static Head

Where there is a significant static head on the pipeline, analysis can be affected. This head is always present and cannot decay. Therefore, all pressure data should be analysed using the pressure applied by pumping above the static head.

Raised Pressure (P_A) = (Actual Pressure at time t_1, t_2 etc – Static Head P_0) (D2)

D.4.3 Data to be Used for Analysis - Filtering Short Term Decay Pressures

There are frequently odd pressure variations in the time immediately after closing the pipeline via the isolating valve, so no data for either PVC or PE should be analysed until a time period equal to the rise time has passed.

With PVC, the initial decay data will not settle to a constant logarithmic decay rate for at least 1 hour. No data at times less than one hour should be used for PVC pipes.

Data may be analysed by a graphical method (see D.4.4) and also by calculation (see 5.4).

D.4.4 Trendline Analysis

A graph of the Raised Pressure (P_A) value vs the corrected decay time should be plotted on logarithmic axes.

For PE pipes, it is expected that for corrected times greater than the rise time, the Raised Pressure decay results should lie on a straight line with a slope between -0.07 and -0.09.

If pressure decay results are plotted using a spreadsheet program, power law trendlines can be applied to all the data in two separate time intervals. Note: the interval times are approximate – take nearest readings to those recommended.

The time intervals for PE pipes: (t_1 to t_2) between t_L and 8 t_L and (t_2 to t_3) between 8t_L and 20 t_L, dependent on the volume of air present. See Table 1 in section 5. The equivalent pressure readings should be taken at times (t_1 to t_2) between t_P and 8 t_P and (t_2 to t_3) between 8t_P and 20 t_P,

Where t_P = time taken to achieve test pressure (also known as "rise time") and t_L is the corrected decay time for creep.

For PVC pipe, the intervals are: (t_1 to t_2) between 1 hr. and 3 hr. and (t_2 to t_3) between 3 hr. and 10 hr., dependent on volume of air present.

The resulting equations will be of the form:

P_A = (pressure measured at Decay Time (t_1, t_2, t_3 etc.))^n (D3)

The negative slopes between the two time intervals should be determined as the power law exponent (n). The absolute value of n is dependent on numerous factors and cannot be used to determine leak-tightness – this can only be done through change of slope (see 5.4). However, the values are given below as a guide.
PE pipes: The expected slope (n) for most PE materials is between -0.07 and -0.09.

Note 1: Special 'barrier layer' PE pipes with polypropylene or aluminium layers, will have lower slopes. Reference should be made to the pipe supplier for the expected creep relaxation exponents.

Note 2: Values of n may occasionally range between -0.06 and -0.1, depending to some degree on compaction and also the air content. (A slope below -0.06 may be indicative of excessive pre-pressurisation).

PVC pipes: The expected slope (n) for most PVC materials is between -0.03 and -0.07.

Note 3: When pipelines utilise different materials, equation (D1), seeD.3.2 above, may be modified to calculate expected power law pressure decay exponents for lines with multiple materials (A and B) by replacing APDR with values of 'n'.

The formula for allowable value of n is:

$$n = L_{fA}*(n)_A + L_{fB}*(n)_B \quad \text{(D4)}$$

where L_{fA} and L_{fB} are the respective length fractions of materials A and B. It is recommended that this only be done where the ratio of the two different pipe materials is not greater than 3:1.

D.4.5 Pass/Fail Criteria for PE and PVC Pipes

For either PE or PVC pipes, no great significance should be placed on the absolute value of n within the ranges quoted.

It is important to note that for a secure pipeline, the pressure will decay with a constant power law slope and it is any **increase in slope** that is important in assessing whether a main is suffering leakage. Any slope change is directly proportional to the leakage rate and computer analysis has shown that assuming up to 4% air content, a 25% increase in slope corresponds to the allowable BS EN 805 leakage rate shown in Table 2.

Small slope changes or occasional decreases in value at longer decay times are not an issue of concern. It is where there is a consistent increase in slope that leakage is indicated.

The assessment criteria are:

- For both PE and PVC pipes, the value for the longer time period should not increase above the short term value by more than 25%.
- For PE pipes: if the longer term slope exceeds -0.13, the rate of pressure decay is unacceptably high.
- For PVC pipes: if the longer term slope exceeds -0.08, the rate of pressure decay is unacceptable high.

It is to be noted that the simple analysis in Section 5.4 relies heavily on single point data and if there is an indication that the slope has increased by more than 10%, results should be plotted and a computer trendline determined (as in Section D.4.4) using all data in the specified time ranges.

If pipelines fail to meet the acceptance criteria, the test should be stopped and the excess water bled carefully from the system. A search for potential leaks should be initiated.

After leaks are found and repaired, the test should be repeated – but only after a time greater than four times the total original test time has elapsed to allow for complete creep deformation recovery.

Example – steadily increasing pressure decay

An example of a set of pressure decay data is shown in graph below for a PE pipe with a leak generating a pressure loss (in excess of that expected for creep alone) which is just at the BS EN 805 limit given in Table 2.

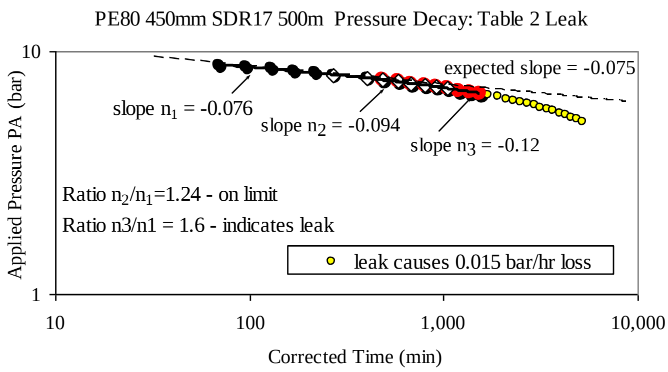


Figure D1: Example

D.4.6 Checking Absolute Rate of Pressure Decay for PVC and PE Pipes

As a final confirmation that the rate of pressure decay is in excess of the allowed limits, it is possible to calculate the current pressure decay rate at the end of the test period. This is only valid if the test has been running for more than 36 hours since creep stress relaxation effects will confuse results at shorter times.

The decay rate should be calculated by use of the time interval over which the pressure decayed by more than 0.05 bar in the last phase of the test.

If the pressure decay rate is in excess of 2*APDR (see Table D2), the pipeline has unacceptable leakage.

Note: The factor 2 allows for the residual creep stress relaxation which will still occur at 36 hours.

D.4.7 Estimating the Rate of Leakage

Finally, when a pipeline has been shown to have an unacceptable pressure decay rate, it is frequently of use to the installation contractor to know the extent of the actual leakage. Knowing the leak rate may indicate whether, for example, a single joint is leaking or whether there are multiple leak paths in various places.

To estimate the leak rate, it is necessary to know the current pressure decay rate in the test. This can be calculated by taking the pressure decay over the last time increment and dividing by the time interval - let this be $\Delta P/\Delta t$.

Note: if the logger is setup to log the time for a defined pressure drop, or if the logger is setup to log at specific time intervals, the time taken for the pressure to decay by the last 0.05 bar should be used as the last time increment.

The pressure drop due to leakage can be converted to a water volume loss (litres/hr/km) using equation (D8) in D.5.4.

D.5 Pressure Decay (Type 2) test

D.5.1 Advantages of pressure decay test

- The test method itself is extremely simple. The pipeline is raised to pressure with a pump and when the test pressure (STP) is achieved, the pump is switched off, a valve is closed and the pressure is monitored.
- The equipment needed to raise the pressure is unsophisticated.
- The pressure measurements may be made using either pressure gauges or transducers. There is no need for highly sophisticated or highly sensitive monitoring equipment.
- Data may be recorded by simple loggers so that constant monitoring by staff is not necessary. There is also a permanent record for QA purposes.
- The test gives more accurate results the longer the pressure is allowed to decay. However, leaks of the order specified in Table 2 in Section 6 can first be detected in relatively short timescales.
- The basic test method may be used for all pipe materials.
- The test actually measures the rate of pressure decay, which is the main criterion specified by BS EN 805.
- The analysis of results for thermoplastics varies depending on the material, but in all cases there are relatively simple procedures that can be performed quickly to give answers that can be directly interpreted as water volume losses, using the principles specified by BS EN 805.

D.5.2 Modified U.K. pressure decay (Type 2) test for metal pipes

The analysis for metal pipes is simple:

- The results of pressure decay with time can be plotted to derive a rate of pressure loss; or
- The rate of pressure loss with time can be calculated after any initial pressure fluctuations have settled.

With metal pipes, there should be no loss in pressure if there has been a pre-test to allow for joint settlement and saturation of any cement mortar lining (see 6.3.2) and so any continuous decay is a sign of leakage. The measured rate of decay can be compared with the BS EN 805 level of 0.2 bar/hr. If it is above this level, the pipeline has an unacceptable leakage level. However, the accuracy of pressure drop measurement required is exacting and can be affected by temperature change.

D.5.3 Modified U.K. pressure decay (Type 2) test for PVC and GRP pipes

With PVC, pressure will decay naturally without leakage for at least 10 hours after achievement of STP. Thereafter the pressure drop caused by stress relaxation alone becomes of less and less significance.

Thus, where there are leaks in PVC pipelines, the sign of a leak can be discerned by plotting a linear graph of the Pressure vs Decay Time. Two typical tests on PVC-A pipes, one known to be leaking, the other secure, are shown in Figure D2.

For the case with the leaking pipe, the pressure was approximately 10 times in excess of the allowable rate (Table 2 in Section 6) and was detectable after less than 2 hours on test. This was caused by a single leaking socket and spigot joint.

After 4 hours there was a constant rate of pressure drop with time when the creep stress relaxation rate became a small fraction of the rate of loss caused by the leakage.

For much smaller leaks, the pressure decay rate caused by the leak becomes dominant in comparison to the creep stress relaxation rate after 7 hr. - 10 hr. Thus tests on PVC materials need to be continued for 8 hours to be certain that the pipeline is secure.

D.5.4 Modified U.K. pressure decay (Type 2) test for PE pipes

Background

Historically, the U.K. Water Industry has used a pressure decay test to assess PE pipes for leakage. This is in accord with BS EN 805. The test procedure itself is in full accord with that outlined simply in Clause 11.3.3.4.3 of BS EN 805: 2000.

Use of Change in Pressure for Analysis

It is now known that the use of an absolute value of pressure led to confusion in the rates of creep stress relaxation when high initial static head existed. The BS EN 805 analysis is actually calculated in terms of the change in pressure (e.g. equation (D5)) and so the new requirement also requires measurement of a pressure change above the initial static level. Examination of some hundreds of historic tests has shown that this greatly enhances the consistency of data expected for creep deformation in tests which showed no signs of leakage.

The basis of the decay data analysis is as follows:

- Pressure will fall continuously with time because of creep stress relaxation.
- The decay is linear on logarithmic axes, because creep stress relaxation follows a power law, i.e.

  $P_A = P_1 * (\text{Corrected Decay Time})^{-n}$ (D5)

  Where:

  P_A is the pressure applied above static head, see equation (D2) in D.4.2

  Corrected Decay Time is given by equation (1) in 5.4.

  P_1 is the value of P_A when time = 1

  n = creep stress relaxation exponent

- Leakage is a linear decay of pressure with time and thus any leak will cause the pressure to deviate continuously from the log-log power law.
- A steady increase in the negative slope of the logarithmic plot of $P_A\Delta$ vs corrected time is a sure sign of leakage.

As an example, Figure D3 shows that on a 7.7 km length of 500mm PE pipe, the leak generated a pressure decay rate that was some four times in excess of the allowable water loss rate given in Table 2 of Section 6. It was obvious from the slope changes that there were serious leakage problems after approximately 12 hours – this was at about twice the pressure rise time.

The change in slope of the log-log plot of pressure change with time is a very sensitive measure of leakage.

Historically, the absolute value of gauge pressure was required to be plotted as a function of time.

A ‘correction’ of 0.4*time taken to reach STP was required to be added to all the decay times – to account for the creep deformation that had accumulated during the pressure rise phase.

Derivation of the Pressure Loss Rate due to Leakage

If equation (D5) is differentiated, we have:

$dP_A/dt = -n*\Delta P_1 * (\text{Corrected Time})^{-(1+n)}$ (D6)

This rate can be predicted from known creep stress relaxation data.

If there is a leak which causes a pressure change $(dP_A/dt)_{leak}$, the total rate of negative pressure change will be:

Measured Rate of Pressure Drop = $-(n*\Delta P_1 * \text{Time}^{-(1+n)}) + (dP_A/dt)_{leak}$, (D7)

The leak rate is the only unknown and can thus be derived.

This relationship can be plotted on logarithmic axes (where the creep relaxation component will follow a linear power law) and the leak component will be a constant.

As an example, a PE pipe leaking at the ‘allowable’ rate would be as shown in Figure D4.

The test data shown were calculated by simply taking the incremental changes in pressure ΔP over logged time intervals Δt as the test continued.

Note: If transducers are set at too sensitive levels, the pressures will oscillate. Therefore, it is recommended that the minimum pressure change ΔP should be at least 0.05 bar - 0.1 bar to prevent *flutter* of logged pressures being too significant.
It can be seen that in this example after 30 hours on test (800 mm diameter, 3.8 km long pipe giving long test time), there is a significant deviation from the expected linear decay due to creep stress relaxation and the leak rate falls to a constant value after approximately 72 hours. This is beyond the time when creep stress relaxation causes any major pressure change and can thus be considered to be the rate of pressure loss caused by a leak.

If this value is in excess of the values given in Table 2 in Section 6, then the pipeline has failed to pass the required criteria.

It is to be noted that sometimes leaks are quite sensitive to the pressure level, in which case the final pressure decay rate may not settle at a constant value. The rate will still be well in excess of the ever decreasing creep rate but in this case it would be necessary to introduce a pressure factor to calculate a leakage rate.

This type of analysis requires that the PE pressure test be continued for at least 36 hours, to be certain that the pressure drop caused by the water leakage rate is in excess of the pressure drop due to creep. However, the early signs that there is a problem can be discerned when the test data deviate from the power law line. The analysis of the slope changes given in D.4.4 give a much more sensitive early warning that there are unusual pressure changes occurring and this analysis is preferred as the first stage in test data interpretation.

The pressure change with time analysis here is to be used when an absolute value of the pressure change due to leakage is required.

Conversion of Pressure Decay Rate to Volume Loss

The derived pressure drop due to leakage can be converted to a water volume loss (litres/hr/km) by the following calculation involving scaling via equation (C2):

$$\text{Water loss} = (\text{Measured Pressure Decay Rate}/\ \text{APDR}) * 0.000018 * (ID)^2 \qquad (D8)$$

Values of the Allowable Pressure Decay Rates (APDR) are given in Table D2.

If the absolute level of leakage is known, it can be of great assistance to the installation contractor in finding and repairing the source of the leak.

D.6 Visual Inspection for Leakage

With most pipes, there is seldom any leakage through the pipe wall. All pressure pipes in use in the UK will have been tested at the factory to much higher pressure levels than STP.

With PE pipes, 25 years of testing have rarely detected a failure of a butt fusion weld with systems welded with modern equipment.

Leaks will occur generally at mechanical joints or electrofusion welded pipes/fittings in PE systems.

It is recommended that the pipeline be raised in pressure back to STP and that the contractor carry out a visual inspection of all joints that are visible.

If there are no signs of visible water loss, a leak-noise correlator may be used and the ground inspected for damp patches.

If there is no success, the pipeline should be divided into shorter sections and further pressure tests conducted.

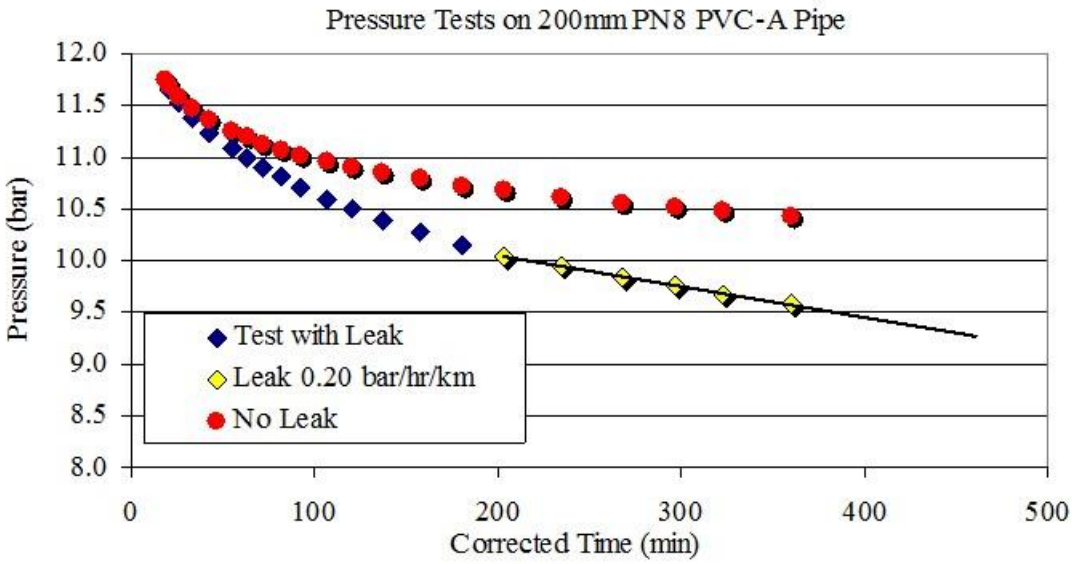


Figure D2: Pressure Decay Curves for PVC-A Pipe: with and without leaks

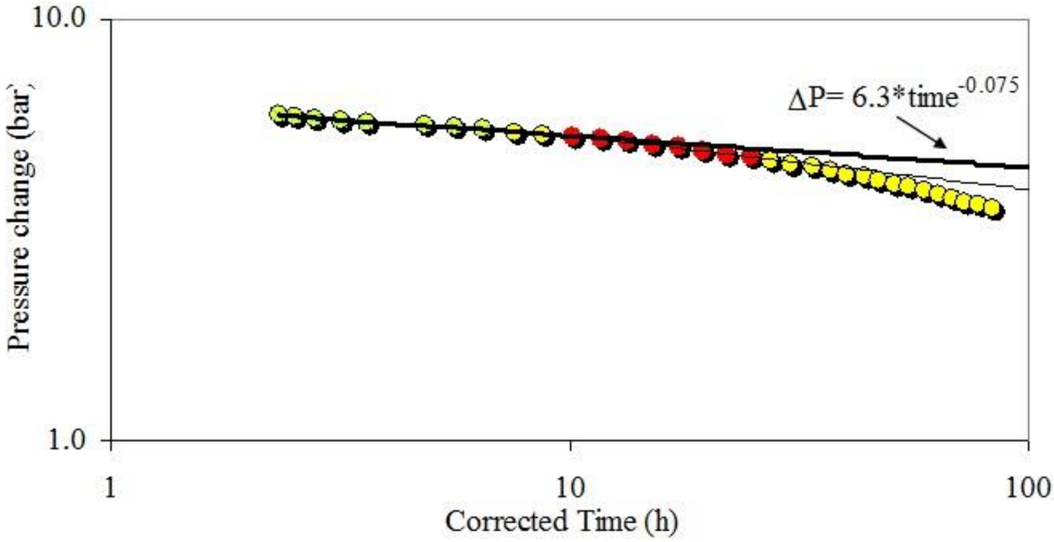
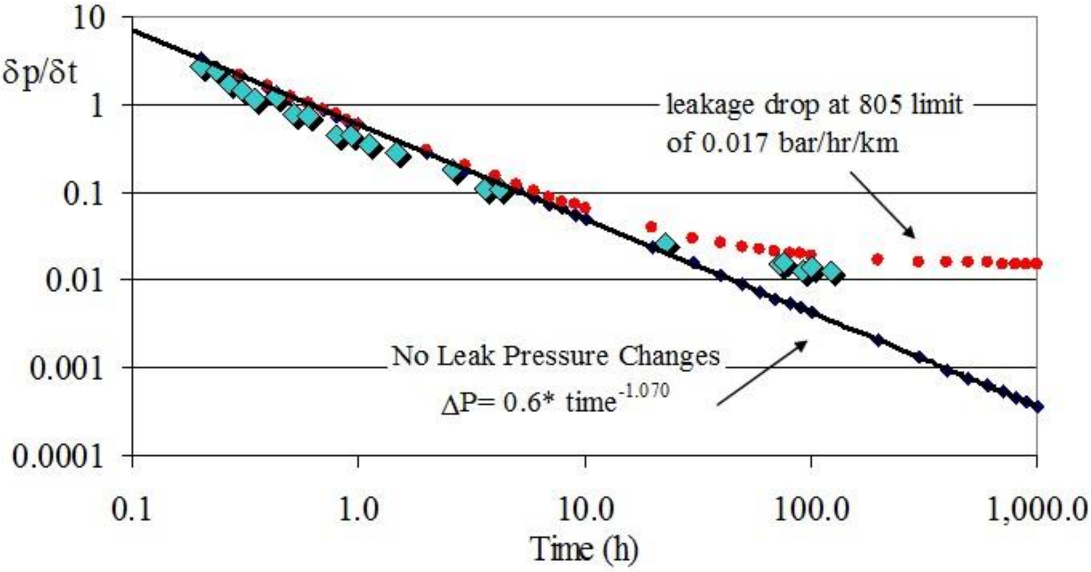


Figure D3: Raised Pressure (P_A) v Corrected Time (on logarithmic axes) for a PE Pressure Test



D4: Rate of Pressure Decay as a function of Time for a PE Pipe (log axes)