Pipe Joint Integrity: Cementitious and Metallic Pressure Pipes

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ABSTRACT

The ability of a municipal pressure pipeline to prevent leakage at joints is an indicator of the efficiency of that piping system. Cement-based and metallic pipe materials used in pressurized municipal water distribution and transmission systems include high head concrete pressure pipe (CCP), gasket-sealed-joint and welded-joint welded steel pipe (WSP), and ductile iron pipe (DIP). For these materials, hydrostatic pressure testing is typically performed twice, once at the pipe manufacturing plant to confirm structural integrity and proper manufacture, and again after the pipeline has been installed and backfilled to confirm that the pipe, joints, and thrust restraint systems have been properly constructed. For field hydrostatic leakage testing, most pipe materials have an associated "allowable makeup water" or "allowable leakage" to accommodate the unique characteristics of the material as well as other irregularities during testing such as air in the line, temperature variations, and even instrument inaccuracies. Test methods and formulas for calculating makeup water usually vary based on the pipe material-specific standards. The wide discrepancies that exist for makeup water between different pipe materials do not place them on a level playing field for a given application. This paper is a review of both in-plant and in-field hydrostatic pressure testing and the topic of makeup water as outlined in AWWA and ASTM standards for the above-named pipe materials. Quality control and qualification tests for joints of each pipe material standard are also reviewed. Recommendations are made for consideration by the Specification Engineering community for future revisions of standards pertaining to the field testing of pipelines.

INTRODUCTION

Various cementitious and metallic pipe materials used for the distribution and transmission of potable and raw water under pressure include high head concrete pressure pipe (CPP), gasket-sealed-joint and welded-joint welded steel pipe (WSP), and ductile iron pipe (DIP). Since low-head concrete pressure pipes such as ASTM C361 (ASTM, 2008) and AWWA C302 (AWWA, 2004a) are not often used in pressurized municipal water service, they will not be covered in this paper. Hydrostatic pressure testing of CCP, WSP and DIP is typically performed twice, once at the pipe manufacturing plant to confirm structural integrity and proper manufacture, and again after the pipeline has been installed and backfilled to confirm that the pipe, joints, and thrust restraint systems have been properly constructed. Pipe joints are usually qualified through testing to prove that their unique designs can provide a zero-leakage sealing mechanism.

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While the topic of "allowable leakage" was discussed in a previous publication (Beieler, 2001), the intent of this paper is to revisit the topic almost a decade later, specifically for cementitious and metallic pipe materials, in light of any changes that may have taken place in the revision of standards and design manuals. Since Beieler (2001) provides a discussion of methods and equipment for field hydrostatic testing as well as problems encountered during field testing, these topics are not discussed herein. In-plant hydrostatic testing, field hydrostatic testing and joint performance qualifications are systematically surveyed for each of the pipe materials named above. It is hoped that recommendations made by the authors will be considered by the Specification Engineering community for future revisions of standards pertaining to the field testing of pipelines.

Allowable Makeup Water: For field hydrostatic leakage testing, "makeup water" or an "allowable leakage" is permitted by most pipe installation standards to accommodate not only the uniqueness of each material but also initial irregularities in the piping system that may require the addition of more water to maintain the specified field hydrostatic test pressures. Unique properties of materials may include things such as the initial absorption of water by cement-based pipe materials or cement-mortar lined steel pipes. Anomalies within a test section that may require additional water to maintain test pressures include entrapped air, faulty connections between the pipe and other appurtenances such as valves, hydrants, fittings and service connections, proper seating of gaskets in pipe and appurtenance, shifting of fittings before joint restraint systems engage, temperature variations, or even instrumentation inaccuracies. The term "allowable leakage" is misleading if interpreted as an allowance for actual pipe joints to leak. Leakage of pipe joints is not permitted as a general practice. Most standards now use the term "makeup water" or "test allowance" in lieu of "allowable leakage" for clarification.

HIGH-HEAD CONCRETE PRESSURE PIPE

High-head concrete pipe is defined as a pipe with a steel cylinder as covered by the AWWA C300 reinforced concrete cylinder pipe (AWWA, 2004b), C301 prestressed concrete cylinder pipe (AWWA, 2007a), and C303 concrete bar-wrapped cylinder pipe (AWWA, 2008) standards.

In-Plant Hydrostatic Testing: The requirements for in-plant hydrostatic testing vary depending on the type of pipe being manufactured. The C300 standard and the C303 standard require that hydrostatic shop tests for leakage be conducted on each steel cylinder, with the joint ring welded on the steel cylinder. The test pressure must be such that the stress in the steel cylinder will be 0.75 times the specified minimum yield point of the steel used. The pressure must be held for sufficient time to observe the weld seams. No leaks are allowed. Any leaks in the welded seams must be repaired, after which the pipe section must be retested. The C301 standard requires that each steel cylinder, with joint rings welded to its ends, be subjected to a hydrostatic test such that the steel stress is at least 20,000 psi, but no more than 25,000 psi.

For fabricated fittings, no further testing is required on welds that have been previously hydrostatically tested. The weld seams that have not been hydrostatically tested must be tested by the dye-penetrant method for butt-joint welds and single fillet welds. The air-

soap method, using air at a pressure of 5 psi or the dye-penetrant method applied from one side, must be used for double-fillet welds.

Field Hydrostatic Test: The AWWA Manual M9 (AWWA, 2008b) recommends hydrostatic testing to 120 percent of the working pressure for which the line is designed, measured at the lowest point in each test section. The test pressure should be applied for a minimum of 2 hours. Suggested criterion for allowable leakage is 10 gallons per inch of diameter per mile per 24 hours (gal/in-dia/mile/day).

Joints: Typical joints for high-head concrete pipe are the gasket-sealed, push-on type. AWWA M9 shows cross sectional diagrams of joints for both high head and low head concrete pressure pipes. All AWWA concrete pressure pipe standards require that manufacturers submit drawings showing full details of joint dimensions for all projects. There is no formal AWWA standard for joint qualification; hydrotesting of steel cylinders is performed w/joint rings welded on, and this verifies that the welds between the cylinder and rings are leak free.

WELDED STEEL PIPE (WSP)

Welded steel pipe (WSP) is typically manufactured by spiral welding steel coils or butt welding rolled steel plates. WSP can have both gasket-sealed joints as well as welded joints. Manufacturing and testing of WSP is covered in the AWWA C200 standard (AWWA, 2005a), and currently undergoing revision at the AWWA Committee-level. The 4th edition of the M11 manual (AWWA, 2004c) and the steel pipe installation standard AWWA C604 (AWWA, 2006a) are also undergoing revision. Unless otherwise stated, information presented herein is based on the current versions of C200, C604 and M11. Since WSP is generally an engineered product and is custom-fabricated, no upper limit on size or pressure is stated. WSP made by the largest manufacturers in the US typically range in diameters of 20-inch through 156-inch, though diameters as small as 6-inch, as stated in the title of C200, can be produced if needed. Specified or nominal diameters of WSP refer to their inside diameter, unless otherwise stated, and pipes are not automatically manufactured to a standard diameter regimen such as IPS or DIPS.

In-Plant Hydrostatic Testing: Per AWWA C200, every piece of steel pipe manufactured must go through a hydrostatic pressure test, determined by Equation (1) below, unless a purchaser agrees to substitute the each-piece hydrostatic test with other non-destructive tests (NDT). For the hydrostatic test, the steel is stressed to 75% of the specified minimum yield strength of the steel. Pressure is held for sufficient time to observe the weld seams and ensure no visible leakage.

$$P = \frac{2St}{D} \qquad (1)$$

Where: P = min. hydrostatic test pressure, psi
S = stress in pipe wall – 75% of min. yield strength of steel, psi
t = wall thickness, in
D = outside diameter, in

Note that this testing requirement may result in very high thrust forces for large pipe with heavy walls. For example, if 72-inch diameter pipe is to be supported on piers and a wall thickness of ¾ inch is necessary to resist bending forces, the test pressure would be 562 psi (based on a yield stress of 36,000 psi), and the end forces on the testing machine would be in the range of 2.3 million pounds. Heavy duty testing machines are required to resist forces of this magnitude.

Testing of steel fittings and specials per AWWA C200 can include several NDT methods, including visual inspection, dye penetrant, magnetic particle, ultrasonic, or radiographic, depending on the preference of the purchaser. Specials manufactured from hydrostatically tested steel pipe only need to have NDT performed on those weld seams that weren't tested in the original pipe. Personnel performing NDT are required to have various levels of certification from the American Society of Nondestructive Testing. There is an option to replace the NDT for fittings and specials with hydrostatic testing in a machine. If a machine can not be utilized, temporary test heads or blind flanges can be welded on the fitting or special, but this process is very expensive. Test pressures are not recommended for this alternative. The pressure must be maintained long enough to permit visual inspection of all seams. Any seam showing leakage must be repaired and retested.

Field Hydrostatic Testing: For both gasket-sealed-joint and welded-joint pipe, AWWA M11 recommends that the test section be filled with water for 24 hours prior to the actual test to enable the lining, if it is a cementitious material, to absorb as much water as possible. The pipeline is then visually inspected for leakage. After this, a test pressure that is not more than 125% of the "actual (or design) operating pressure or pipe class, whichever is the greater" is applied for a 2 hour period.

For steel pipe with gasket-sealed joints, M11 recommends a test allowance of 10 gal/in-dia/mile/day. If the pipe has welded joints or mechanical couplings, M11 recommends allowing "no significant leakage." Because the term "no significant leakage" could be interpreted differently by contractors than by project owners, the next revision of AWWA C604 (currently being reviewed at the committee level) will recommend a test allowance of 10 gal/in-dia/mile/day for pipe with gasket-sealed joints, welded joints, or mechanical couplings.

It should be noted that in the on-going revisions of AWWA C200, C604 and the M11 manual, the section on "allowable leakage" is being removed in its entirety from M11 and addressed in greater detail in AWWA C604. The term "allowable leakage" is being replaced by "allowable makeup water" to be consistent with other pipe material standards and prevent confusion.

Joints: AWWA C200 allows for steel pipe to incorporate either gasket-sealed or welded joints. The M11 manual displays a number of different types of gasket-sealed joints. In all cases, the gaskets are seated on the spigot rather than inside the pipe bell. The section on gasket joints in AWWA C200 is also being revised with added quality control measures to ensure that the best quality elastomers are utilized. When gasket-joint pipes are supplied on a project, AWWA C200 requires that manufacturers submit details of the joint, with

dimensions and tolerances, along with performance data showing that similar joints have successfully been utilized under the same conditions. If this is unavailable, then manufacturers are required to submit results of a successful testing program for approval. This process serves as the qualification of gasket joints for WSP.

Welded joints for steel pipes, also addressed in M11, range from single lap-welded to butt-welded joints. Lap joints are frequently welded only on the inside or only on the outside, and in special cases where the pipe may experience elevated longitudinal stresses such as in seismic zones or in areas with high thrust forces, both the inside and outside of the joint is welded. Butt-welding is typically required for special applications or very high stress applications where high internal pressures or thrust forces are of concern. Other types of joints include flanges, couplings and expansion joints.

DUCTILE IRON PIPE (DIP)

The manufacture of ductile iron pipe is covered in the AWWA C151 standard (AWWA, 2009). The standard includes pipe in sizes of 3-inch through 64-inch. 4-inch to 12-inch DIP is only available in pressure class 350 psi, while multiple pressure classes of up to 350 psi are available for larger sizes. Pipes may be either 18-ft or 20-ft long sections. Ductile iron fittings are addressed in AWWA C153 (AWWA, 2006b) and C110 (AWWA, 2008c).

In-Plant Hydrostatic Testing: Per AWWA C151, each piece of DIP is required to undergo a hydrostatic test of not less that 500 psi, applied for 5 seconds. While AWWA C153 mentions that it is not customary for specials and fittings to undergo hydrostatic testing at the foundry, fittings must be capable of withstanding pressures of up to 3 times their rated working pressure. If hydrostatic proof testing is required by a purchaser, test pressures of 150% of the rated working pressure of the fittings are used.

Field Hydrostatic Test: The AWWA C600 standard (AWWA, 2005b) for installation of ductile iron pipe recommends a field hydrostatic test for a 2-hour period at a pressure of at least 1.25 times the working pressure at the highest point and at least 1.5 times the working pressure at the lowest elevation along the test section. Equation (2) below, from AWWA C600 for testing allowance, is used for the hydrostatic field testing of DIP:

$$L = \frac{SD\sqrt{P}}{148{,}000} \qquad (2)$$

Where: L = testing allowance (makeup water), gal/hr
S = length of pipe tested, ft
D = nominal diameter of pipe, in
P = average test pressure during hydrostatic, psi (gauge)

To pass the test, the water supplied to keep the system within ± 5 psi of the specified hydrostatic test pressure should not be greater than the amount calculated using Equation (2). The equation is based on a test allowance of 10.49 gal/in-dia/mile/day, at a pressure of 150 psi. Using Equation (2), the testing allowance will vary based on the test pressure; higher pressures will yield higher testing allowances. It should be noted that AWWA M41

(AWWA, 2003), which was last revised two years before the last revision of AWWA C600 in 2005, states that the test allowance for DIP should be 11.65 gal/in-dia/miles/day.

Joints: Typical DIP joints are mostly of the gasket-sealed push-on type. Two main types of dual-durometer gasket designs are in use in North America (Rahman, 2007). Other joint types include mechanical, flanged, and restrained joints. Performance requirements for push-on type joints are outlined in AWWA C111 (AWWA, 2007b) and also include information on gasket properties. C111 requires that both push-on and mechanical joints should be pressure rated at 350 psi for diameters under 20-inch, 300 psi for 20-inch diameter pipe, 250 psi for 24-inch pipe, and 200 psi for 30-inch through 64-inch diameters. For joint designs less than ten years old, the joints must be qualified and records maintained for ten years. For push-on joints, two qualification tests are applied to each diameter size as follows:

1) the joint is angularly deflected to the maximum allowable angle within the bell
2) the joint is not deflected but offset laterally within the bell to the maximum allowable by design

At the above configurations, the joints are hydrostatically tested for 10 seconds without leakage at a pressure that is twice the minimum working pressure, or twice the rated pressure of the joint (350 psi for diameters less than 20-inch, 300 psi for 20-inch diameter, 250 psi for 24-inch diameter, and 200 psi for 30-inch through 64-inch). Again, this procedure is intended to serve as a qualification of performance characteristics of a particular joint design and is not a routine quality control measure.

DISCUSSION OF HYDROSTATIC TESTS

In-plant hydrostatic testing of all pipe materials has been summarized in Table 1. The following points should be noted:

a) Between the various standards, there are differences in both the required test pressure and the duration of the test. Some standards require a test at a pressure slightly above working pressure for several minutes; others require a very high pressure for a few seconds.
b) Some standards require testing only a particular component of the pipe instead of the final product.
c) All standards require each-piece hydrostatic proof test, but not necessarily on the final end-product.

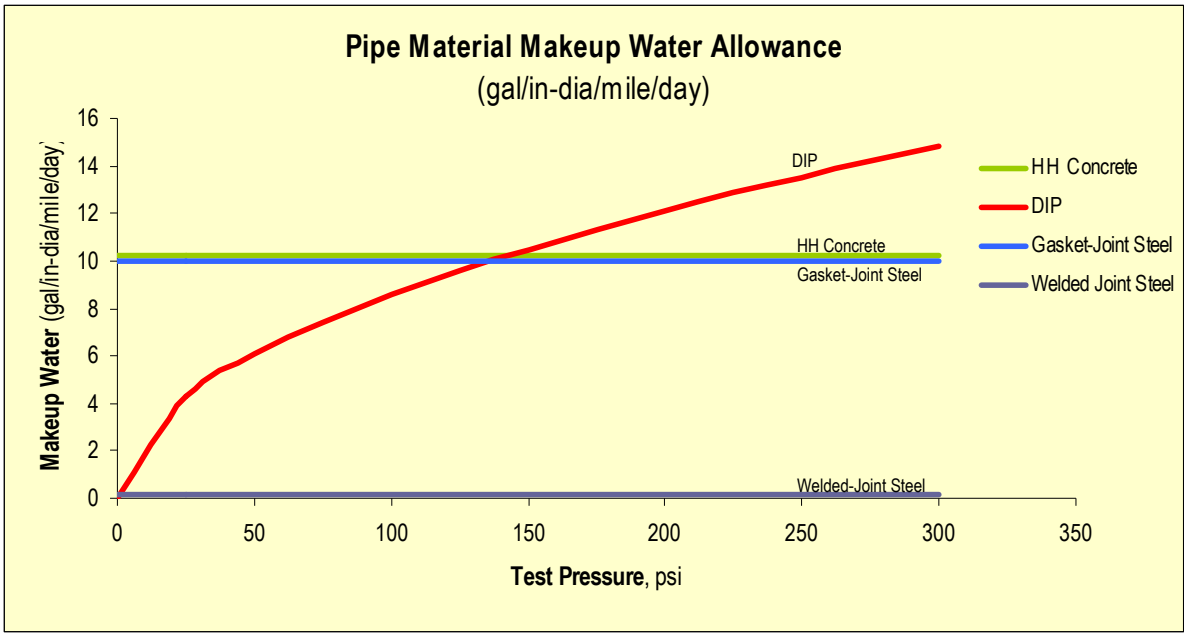
Table 2 summarizes field hydrostatic testing of pipe materials. The following points should be noted:

a) One of the standards provides an equation for the calculation of allowable makeup water. This equation incorporates the test pressure. In this case, higher test pressures allow for higher makeup water. Other material standards do not provide an equation incorporating the test pressure parameter. Their makeup water allowances must remain the same regardless of test pressures.
b) It is the opinion of the authors that for formulas with pressure as a variable, an "average test pressure" should be utilized by taking pressure readings at several locations between the highest and lowest points of a pipeline. A vertical rise of 100-

ft results in an increase of 43 psi of head pressure added to the line pressure as measured at the lowest point.

c) Hydrostatic test pressures for field testing should be brought to at least the maximum working pressure of the pipeline. Cement-based and metallic pipe material installation standards recommend test pressures in the range of 120 % to 150% of operating pressure or working pressure of a pipeline. This allowance over the maximum working pressure should be carefully considered because an excessively high allowance can increase the cost of a system by increasing the pressure rating of all other system components including appurtenances such as valves and flanges, number of restrained joints, size of thrust blocks, etc.

d) It is of interest to compare the recommended allowable makeup water for field hydrostatic testing of various materials. As shown in Figure 1, there are differences in the computed amounts.



Note: Since the term "no significant leakage" for welded-joint steel pipe could be interpreted differently by contractors than by project owners, the next revision of AWWA C604 (currently being reviewed at the Committee level) will recommend a test allowance of 10 gal/in-dia/mile/day for steel pipe with welded joints, gasket-sealed joints, or mechanical couplings.

Figure 1: Allowable Makeup Water Comparisons

RECOMMENADATIONS

- The term "allowable leakage" should not be interpreted as an allowance for gasket-joint pipes to leak when installed. Joint qualification tests exist primarily to prove that a joint design and configuration is capable of being leak-free or bottle tight when exposed to various pressures at various angular deflections. All pipe material installation standards should use terms such as "allowable makeup water" or "test allowance" in lieu of "allowable leakage" to prevent confusion.

- Users should be aware of the testing requirements in the standards, and confirm that they are suitable for a project. If additional testing is appropriate, the additional requirements should be added to the project specification.
- If more than one pipe material is allowed on a project, owners, specifiers, and designers should develop testing requirements that are fair and uniform based on the pipe materials and joints that have been selected or at least recognize the different leakage allowances between pipe joints and materials when selecting or evaluating joints or materials that should be used.
- The allowable makeup water during field testing should be calculated as part of the design process, and evaluated by the owner and design team. The quantity of allowable makeup water for long, large diameter pipelines can be quite significant. The owner and design team should agree that if all the makeup water was leaking from one, poorly assembled, joint, that the quantity of makeup water is acceptable. If it is not acceptable, the length of the pipe segment being tested should be reduced.
- Identifying a defective joint during the installation phase of a project, rather than the hydrostatic test phase, can avoid significant effort to locate a problem after the trench is backfilled. If a relatively simple field test of assembled joints can be performed, this test should be required in the specifications.
- In the absence of a formal joint qualification standard for a pipe material, an in-plant test, representative of the anticipated field conditions, or proven success of the joint on previous projects under the same conditions should be required to confirm the joint performs properly.

CONCLUSION

The advancement of technology now enables pipe manufacturers to provide leak-free or bottle-tight joints for pressurized municipal systems, whether by gasket-sealed joints or welded joints. Pipe materials are typically tested once in the plant to confirm structural integrity and proper manufacture, then a second time after the pipeline has been installed and backfilled to confirm that the pipe, joints, and thrust restraint systems have been properly constructed. While pipes with all types of joints provide leak free joints, an “allowable makeup water” or “test allowance” or “allowable leakage” is permitted by most pipe installation standards to account for initial anomalies that may exist in a line which may require the addition of extra water to maintain system test pressure for the duration of the test. Test durations, test pressures, and other parameters currently differ depending on pipe material. It is important to have equal performance requirements for all materials specified on a given project or recognize the performance differences between different pipe joints and materials when evaluating the type of pipe joint or material to be used. The term “allowable leakage” should be eliminated altogether from installation standards and replaced with “allowable makeup water” or “test allowance” to prevent misinterpretation of the former terminology. “Allowable leakage” is not an allowance for pipe joints to leak when installed.

Table 1: Pipe Material In-Plant Hydrostatic Test Comparisons

Pipe Material Type / Standard	Test Required	Every Piece	Pressure / Duration	Other Details
High Head Concrete / AWWA C300	NOT END PRODUCT/ Only Steel Cylinder	NOT END PRODUCT/ YES -Only Steel Cylinder	Test steel cylinder only – 75% of min. yield of steel, long enough to observe weld seams	Tested with Joint Rings welded to the pipe
High Head Concrete / AWWA C301	NOT END PRODUCT/ Only Steel Cylinder	NOT END PRODUCT/ YES -Only Steel Cylinder	Test steel cylinder only – steel should be *stressed* to at least 20,000 psi, but not more than 25,000 psi	Tested with Joint Rings welded to the pipe
High Head Concrete / AWWA C303	NOT END PRODUCT/ Only Steel Cylinder	NOT END PRODUCT/ YES -Only Steel Cylinder	Test steel cylinder only – 75% of min. yield of steel, long enough to observe weld seams	Tested with Joint Rings welded to the pipe. If diameter and wall thickness of steel cylinder are such that the capacity of the testing equipment is exceeded by these requirements, test pressures may be reduced or substituted w/ NDTs, in agreement with Purchaser.
Steel / AWWA C200	YES	YES	75% of min. yield of steel, long enough to observe weld seams	When applicable, if Joint Rings are not welded to the pipe prior to hydrostatic testing, "means must be provided to prove the soundness of the welds used for that attachment."
Ductile Iron / AWWA C151	YES	YES	500 psi min., for 5 seconds	

Table 2: Pipe Material Field Hydrostatic Leakage Test

Pipe Material Type / Standard	Test Pressure	Duration	Location of Test Pressure Reading	Makeup Water / Allowable Leakage	Comments
High Head Concrete / AWWA C300, C301, C303, per AWWA M9	120% of working pressure	2 to 4 hours	Lowest point in each test section	10 gal/in-dia/mile/day	NO FORMULA. Term used in Standards: "MAKEUP WATER ALLOWANCE." Line should be left pressurized at the pressure of the filling source for 48 hrs prior to testing
Steel / AWWA C200 – WELDED JOINT, per AWWA C604 and AWWA M11	125% of actual (or design) operating pressure or pipe class, whichever is greater	2 hours	Lowest point in each test section	"No significant leakage"	NO FORMULA. Term used in Standards: "ALLOWABLE LEAKAGE." Line should be filled and allowed to stand for 24 hrs prior to testing if lining is cement-mortar. Additional Valve leakage allowance of 0.0078 gal/in-dia/mile/day is mentioned.
Steel / AWWA C200 – GASKET JOINT, per AWWA C604 and AWWA M11	125% of actual (or design) operating pressure or pipe class, whichever is greater	2 hours	Lowest point in each test section	10 gal/in-dia/mile/day	NO FORMULA. Term used in Standards: "ALLOWABLE LEAKAGE." Line should be filled and allowed to stand for 24 hrs prior to testing if lining is cement-mortar. Additional Valve leakage allowance of 0.0078 gal/in-dia/mile/day is mentioned.
Ductile Iron / AWWA C151, per AWWA C600 and AWWA M41	1.25 times to 1.5 times of working pressure, depending on elevation	2 hours	at the highest point, 1.25 times working pressure, at lowest point, 1.5 times working pressure	Formula based on 10.49 gal/in-dia/mile/day @ 150psi. Will vary by Test Pressure	FORMULA PROVIDED. Term used in Standards: "TEST ALLOWANCE." Additional testing allowance of 0.0078 gal/in-dia/mile/day when testing against closed valve

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