Plastics Industry Pipe Association of Australia Limited ACN 086 511 686

Industry Guidelines

Polyethylene Drinking Water Pipes in Contact with Chlorine and Chloramine Disinfectants

Issue 1.0

Ref: POP018
29 June 2018

Pipelines Integrity For a Cleaner Environment

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In formulating this guideline PIPA has relied upon the advice of its members and, where appropriate, independent testing.

Notwithstanding, users of the guidelines are advised to seek their own independent advice and, where appropriate, to conduct their own testing and assessment of matters contained in the guidelines, and to not rely solely on the guidelines in relation to any matter that may risk loss or damage.

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Introduction

The Plastics Industry Pipe Association of Australia (PIPA) Industry Guideline POP018 “Polyethylene Drinking Water Pipes in Contact with Chlorine and Chloramine Disinfectants” has been published as part of PIPA’s ongoing commitment to provide guidance, technical information, correct application and installation of safe and environmentally responsible plastics pipe systems across Australia.

Polyethylene (PE) pipe has been successfully used throughout the world for more than 50 years for the transmission and reticulation of drinking water. The benefits of PE’s material properties; including its corrosion resistance, high strength, toughness and flexibility, makes this material a popular choice of water authorities worldwide.

Although PE’s reputation for durability has been justifiably earned, there are limits to every material’s operating envelope and on the rare occasions when detrimental environmental conditions and operational parameters converge, the expected service life of PE pipe may be reduced. This situation similarly occurs with pipe produced from copper, iron, stainless steel and alternate polymer materials – in fact limits apply to all pipe materials.

The operational service life of PE pipelines is dependent upon a number of factors that include: raw material quality, processing conditions, installation, the aggressiveness of the fluid transported, operating pressure and temperature.

In the case of PE pipe conveying drinking water, it has been recently recognised in Europe, the USA and in some discrete geographical locations in Australia, the type and concentration of the disinfectant residual, in conjunction with the aforementioned operating factors, can in a small number of instances potentially reduce expected service life.

The available reference documents and research make no specific mention of fittings, and hence neither does this guideline. Experience indicates fittings have not been affected in the same manner as pipe. There could be several explanations for this including significantly reduced stress in fittings compared to pipe.

This document describes the atypical service conditions under which compromised performance may occur in PE drinking water pipes and nominates options to improve their performance. The geographic regions of Australia where most PE drinking water pipelines are installed with proven satisfactory service are also described.

Background

To ensure it is suitable for drinking, water is disinfected by water agencies through the use of disinfecting chemicals. A disinfectant residual is also maintained so that the water remains free of pathogens to the point of consumption.

A variety of methods are used to provide a disinfectant residual in drinking water, chloramines and chlorine are frequently used around the world and in Australia.

Although chlorine and chloramine disinfectants are oxidising agents, under typical operating conditions where pH ranges from 6.5 to 8.5 and residual chlorine levels are maintained ≤0.6 mg/L, PE resin compounds contain stabilising additives that provide resistance against the oxidative effects of these chemicals.

Under these operating conditions very long service lives, often in excess of 100 years, in disinfected drinking water pipe systems can be expected.

In Europe and to a far lesser extent in the USA, chlorine dioxide (ClO_2) is also used. ClO_2 is known to be significantly more aggressive towards polyolefins such as polyethylene than other water treatment chemicals at service temperatures above 20°C. [1] The effect of ClO_2 on PE pipe was recognised in 2010 and subsequently PIPA technical note TN008 'Chlorine Dioxide Disinfectant for Drinking Water – Effect on pipe and seal materials' was published. [2]

At that time of publication, the information available to PIPA indicated chlorine dioxide was not used in this country as a disinfection chemical by water agencies and that the average residual disinfection levels for major urban water reticulation networks were below the aesthetic threshold nominated in the Australian Drinking Water Guidelines (ADWG). [3]

Whilst both of the above conditions still hold true today, PIPA has become aware that in a very small number of discrete geographical regions in Australia, the combination of water chemistry and operating conditions may reduce the expected service life of PE pipe.

In the last few years considerable research has been carried out in the USA, Canada and Europe into the impact of drinking water disinfectant residuals on PE pipe.

Notable research that includes actual drinking water supply network case studies includes that of Jana Laboratories, Ontario Canada [4] and Suez Environment [5] in France.

In both the North American and European case studies it was found that characteristics of drinking water in distribution systems vary considerably, namely in terms of residual chlorine levels and pH; thus, resulting in significant differences in the overall oxidative aggressiveness of the water.

Oxidative aggressiveness is defined in terms of Oxidation-Reduction Potential (ORP), measured in millivolts (mV). The higher the ORP value, the higher is the water's oxidative aggressiveness and therefore, the greater the possibility that the expected operational service life of PE pipe may be compromised.

This general trend has been confirmed in several laboratory studies using various accelerated testing methodologies and different type of residual disinfectant e.g. ClO_2 and hypochlorite systems.

Overseas Guidance and Standards

The following overview provides details of North American and European testing, guidance and standards relating to the oxidative resistance of PE pipe materials to disinfected water.

North America

PE pipe materials are assessed for their oxidation resistance to chlorinated water by means of a test method defined in ASTM F2263:2014. [6] This procedure involves the accelerated testing of small diameter pipe subjected to pressurised chlorinated water flows at elevated temperatures. Free chlorine concentration and pH is maintained in the test water to achieve a minimum ORP of 825 mV.

The results of this test, when assessed against the criteria set-out in ASTM D3350:2014, [7] allows pipe resin to be categorised into a four level Chlorine Classification (CC) index, ranging from CC0 to CC3. CC0 is used to identify unclassified materials, CC1 denotes the lowest demonstrated chlorine resistance performance and CC3, the highest.

The Plastic Pipe Institute Inc., (PPI) has published three technical notes that provide guidance on the selection of pipes for long-term resistance to potable water disinfectants. TN43 [8] outlines requirements for the material classification system. TN44 [9] and TN49 [10] provide models for projecting the long-term performance of PE pipes in chlorinated water systems for pipe sizes 4" and larger and for small diameter service connections, respectively.

Europe

In Europe, and in particular France, PE piping systems are certified according to AFNOR Certification NF114:2017. [11] It should be noted that in France, for operational reasons ClO_2, a far stronger oxidising agent than chlorine or chloramine, is the preferred water disinfectant.

PE pipe materials which claim enhanced resistance to chlorine-based disinfectants are assessed using the test method defined in AFNOR XP T 54-986:2013, [12] also known as the "NOL Ring Test".

PE pipe materials conforming with the criteria set out in NF114 for enhanced chlorine resistance are designated as “PE100 RD”, where "RD" stands for Resistant to Disinfectants.

Both the North American and European methods use elevated temperature and high concentrations of chlorinated disinfectants to test materials under accelerated conditions. Similarly, both methodologies can be used to measure the relative performance of different PE materials and distinguish those with improved resistance to disinfectants.

However, while the North American test methods use chlorinated water as the test medium, the European testing has focussed on using ClO_2. Since ClO_2 is used in parts of Europe for disinfection and it is also known to be more aggressive than chlorine, the rationale is that improved resistance in ClO_2 will also imply improved resistance in other chlorinated disinfectants. Microscopic evaluation of fracture surfaces in different disinfectants show similar characteristics and suggest consistent oxidation and degradation mechanisms. [13]

It is important to note that the two above referenced geographic regions, North America and Europe, vary on how pipe grades are assessed and qualified for their suitability to convey fluids under pressure. The most striking difference is that North America follows ASTM governed specifications, whilst Europe follows EN specifications, which are either identical or closely aligned with ISO. Australia has adopted the ISO convention for PE pipe and resin classification, as reflected in AS/NZS 4131 Polyethylene (PE) compounds for pressure pipes and fittings. [14]

Australian Experience

PIPA has recently become aware of a small number of discrete geographical regions in Australia where the long-life expectancy of PE pipe may be reduced.

For PE100 and PE80 SDR11 pipe networks distributing drinking water at a temperature of 21°C or less and maintained within the Australian Drinking Water Guidelines aesthetic limits for free chlorine and pH, the expected operational life of the pipe is not adversely impacted. This covers the overwhelming majority of installations in Australia.

However, in a very limited number of discrete geographical regions in Australia, where higher water temperatures are coupled with an aggressive oxidative environment, PE pipe performance may be compromised.

Some private and public drinking water network operators have specified the use of higher pressure classes of pipe and/or the use of PE materials with high stress crack or disinfectant resistance, to decrease the risk of shortened expected service life due to their specific operational environments.

Risk Factors

In order to assess the level of risk in a given operating environment, information about the actual long-term operating conditions is required. Performance of PE is determined by the effect of the combination of these factors rather than by individual factors in isolation. The key risk factors are outlined in Table 1 below.

Factor	Lower Risk	Higher Risk
Temperature	Lower temperature	Higher temperature
Water Quality	Chloramine disinfection	Chlorine disinfection
	High pH	Low pH
	Low ORP	High ORP
Operating Conditions	Low system pressure	High system pressure
Installation Condition	Deep installation	Shallow installation
	No overlying pavement	Beneath pavement
	Sand pipe-embedment	Stony pipe-embedment
Pipe Selection	Larger pipe size	Smaller pipe size
	Thicker pipe wall	Thinner pipe wall

Table 1 – Key Risk Factors

Temperature

The temperature to consider is the annual average water temperature, which is the weighted average of the daily water temperature and not the maximum temperature experienced by the system. Where water temperature data is not available, annual average soil temperature at typical pipe burial depths can provide an estimation of the likely range until actual service conditions are determined.

Note: Urban installation locations can have an effect on the operating temperature. PPI TN-49 states that service lines buried just beneath the pavement may require a higher water temperature value. Additionally, a published soil temperature study, [15] has demonstrated that the presence of pavement can significantly increase the average temperature of the soil below and that temperature varies with depth. This may result in increased water temperature in pipes buried underneath pavements.

Below is a map (Figure 1) of the estimated Annual Average Soil Temperature in Australia, provided by the Bureau of Meteorology (BOM), which may be used as a guide to possible soil temperature. PIPA does not invite users to rely on this information and strongly recommends users confirm, through actual in-field measurements, the applicability of this information to their specific location and installation conditions.

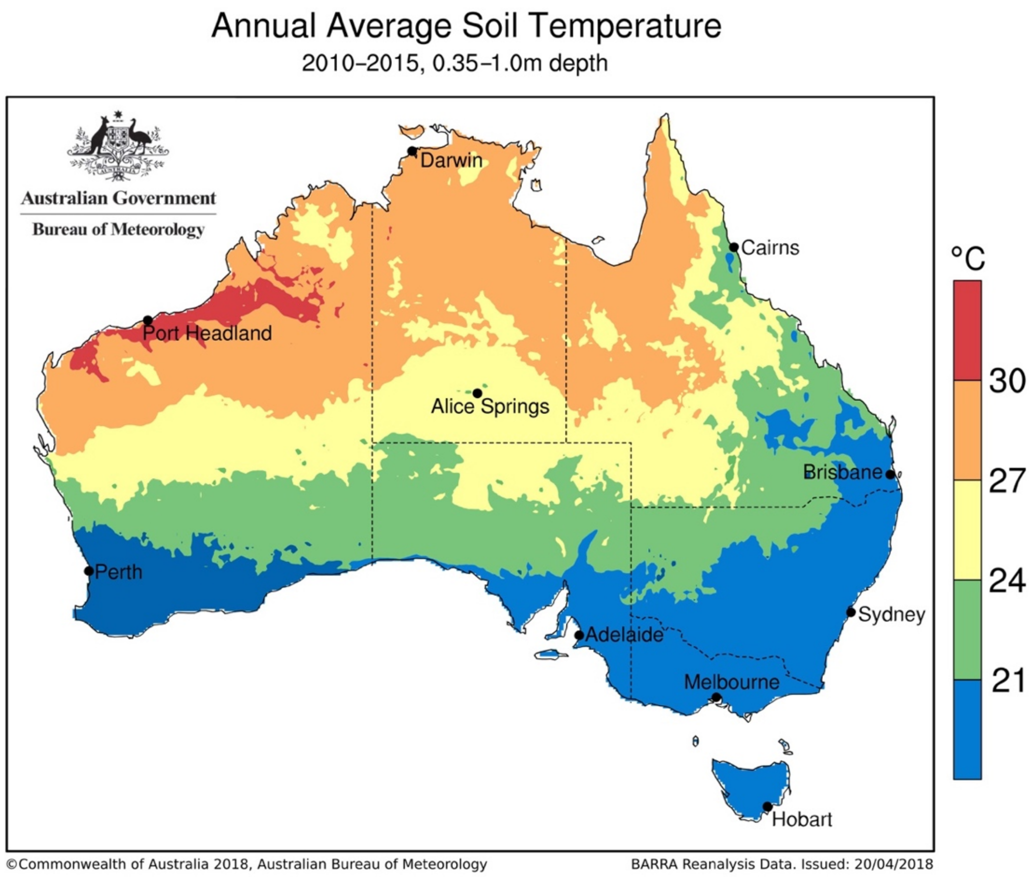

Figure 1 – Annual Average Soil Temperature

Water Quality

The National Health and Medical Research Council's published ADWG, specify health and aesthetic limits for chlorine, chloramine and pH. The ADWG aesthetic limit for free chlorine is set at 0.6 mg/L and the health limit is 5 mg/L. In the case of pH, the nominated aesthetic range is from 6.5 to 8.5. The nominated maximum level of chloramine is 3 mg/L. The Water Services Association of Australia has confirmed that the majority of urban water utilities aim to maintain chlorine levels in the reticulation network and at the property boundary to within the aesthetic limit nominated by the ADWG.

The ADWG also notes the need for water agencies to be cognisant of the potential impact their product may have on all types of plumbing systems and customer appliances. The ADWG mentions the effect water chemistry has on the corrosion of copper pipes citing cupro-solvency and "blue" water as examples and the impact of increased corrosion on the life and performance of water heaters as examples of the unintended consequences created by certain water chemistries.

Water quality for chlorine disinfected systems, in the context of this document, is defined by the ORP of the disinfected water.

As previously stated, ORP increases as free chlorine levels increase and as pH decreases. Drinking water is adequately disinfected at an ORP of 650 mV, whilst in swimming pools an ORP of 700 to 720 mV will ensure quick disinfection. The maximum ORP considered in this guideline is 825 mV. This is the ORP at which testing to ASTM F2263 is conducted and covers 98.2% of USA water utilities surveyed. Appendix 1 of the guideline illustrates the relationship between free (residual) chlorine, pH and ORP in deionised water.

It has been observed that under combined high ORP, stress and temperature, PE pipes will age at an accelerated rate and in a very small number of extreme cases this may result in embrittlement, possibly leading to premature failure.

Research conducted by Jana Laboratories Inc., on behalf of PPI USA [16] into the comparative effect of chlorine and chloramine disinfectants on cross-linked PE piping has demonstrated that chloramine is significantly less aggressive than chlorine. This finding has in-turn been built into the PPI TN44 and TN49 models used to determine anticipated service life of pipe PE service pipes conveying chloramine disinfected water in the USA.

Operating Pressure (Stress)

Systems with high operating pressure have a higher risk than those at low operating pressure. This is due to the hoop stress in the pipe wall which results from internal pressure in the pipe. Another potential source of stress is poor installation where a lack of, or inadequate support and/or rock impingement may result in bending stresses in the pipe. These are additive to the hoop stress.

Stress provides the energy to drive slow crack growth, should conditions be conducive to its initiation. At low stress (energy) levels, crack initiation is unlikely, or if it does occur, crack propagation will be retarded.

Table 2.3 of the WSAA Water Supply Code of Australia, Version 3.1, [17] specifies a Maximum Allowable Service Pressure Limit of 600 kPa for residential and industrial / commercial drinking water single supply pipelines.

This pressure limit has been applied in the guidance outlined in this document. For applications with higher operating pressure, PIPA recommends contacting the pipe manufacturer for specific guidance.

Pipe Size

Small diameter (<DN110) service connection pipes are far more susceptible than larger transmission and trunk water pipelines. PIPA has taken this into consideration and developed guidance for three ranges of PE pipe size.

Pipe Material

The guidance in Tables 2, 3, 4 and 5 of the document pertains only to pipes manufactured to AS/NZS 4130 [18] from PE100 grades conforming with AS/NZS 4131 and listed in the document referred to as PIPA Guideline POP004. Pipes manufactured from PE grades not listed in POP004 are excluded and alternate advice should be sought from the pipe manufacturer.

PE pipe manufactured from materials with enhanced resistance to disinfectants are expected to have an expanded operational envelope in aggressive disinfected environments. PIPA recommends users seek guidance from pipe manufacturers where these materials are considered for applications beyond the limits specified in Tables 2, 3, 4 and 5.

Materials with an Enhanced Resistance to Disinfectants

Over the past few years, a new generation of PE pipe materials with increased resistance to water disinfectants have been developed in the USA and Europe, where research and material testing is ongoing.

Methods for assessing the resistance of PE resin to disinfectants are developing. Presently two unique methods that have achieved national “standard" status are specified in North American and European National Codes for potable water distribution networks. Namely the ASTM and AFNOR Standards described earlier.

Pipe produced from PE100 resin possessing enhanced disinfectant resistance is an option to mitigate where the risk level associated with water quality, local environmental conditions and operational factors is considered unacceptably high. (i.e. Applications denoted “N.R.” in Tables 2, 3, 4 and 5 or where ORP is higher than the nominated maximum.)

PIPA recommends that under these circumstances, water suppliers and pipeline asset owners seek the expert advice and guidance of their pipe manufacturer.

Recommendations

PIPA has reviewed European and USA experience and associated guidance documents. At this point the USA’s approach appears to represent best practice and hence we have elected to base current Australian guidance documentation on the PPI Technical Notes TN44 and TN49.

There are however significant differences between Australian / European and ASTM and USA pipe standards including dimensions, materials classifications and design requirements which mean the USA’s guidance cannot be directly applied to Australian conditions. PIPA has therefore needed to adapt these USA documents to local conditions and PE grades.

It is expected that in the overwhelming majority of cases, PE pipe can be specified as usual. However, where higher risk is indicated, water utilities and pipeline owners will be able to use this information to adjust operational parameters including water ORP, disinfection type and concentration, improve installation parameters such as wall thickness and cover depth, or to select higher category PE materials, to ensure optimal pipe performance for the specific application.

The recommendations contained in this document are based on the best currently available information. In developing the guidance tables, PIPA has assumed the performance of the existing PE100 materials listed in POP004 and conforming with AS/NZS 4131 align with the “base” material classification in the PPI Technical Notes.

Specialised PE materials with enhanced resistance to disinfectants will offer improved performance and may be considered as a mitigation option in higher risk installations.

Steps to Determine PE Pipe’s Application Suitability

Step 1
Determine the annual average water temperature. As noted above, an approximation of the average annual soil temperature is presented in the BOM map of Australia, Figure 1, but other factors may also influence the operating temperature. For ease of use, the tables have been coloured to match the average soil temperature zones. However, if the operating temperature is altered for any other reason, select the correct colour zone based on the actual temperature, irrespective of the geographical location of the installation.

Step 2
If ORP is unknown, determine the average residual disinfectant level and the average pH, then refer to Appendix 1 to determine the ORP of the water. Alternatively, use averaged measured ORP.

Step 3
Determine the pipe size (DN) and SDR.

Step 4 (For chlorine disinfected systems)
Refer to size Table 2, 3 or 4 as appropriate, to determine the maximum ORP for standard PE pipes. If the ORP in the pipeline system is greater than the value in the table for a given SDR, there is higher risk that PE pipe performance may be compromised and standard PE100 pipe is not recommended (“N.R.”).

Alternate Step 4 (For chloramine disinfected systems)
Consult Table 5 for the SDR limitations placed on PE pipes in the size range of DN25 to DN50, under the operating conditions nominated. At the specified operating conditions, no additional limitations are placed on larger diameter pipes (i.e. >DN50) in chloraminated drinking water.

Maximum Water ORP x SDR Pipe Sizes DN25 to DN50 System Pressure ≤600kPa			
Zone	**SDR13.6**	**SDR11**	**SDR9**
Blue	775mV	825mV	
Green	740mV	780mV	825mV
Yellow	720mV	760mV	825mV
Orange	700mV	730mV	825mV
Red	N.R.	700mV	800mV
* Pipe conforming with AS/NZS 4130 produced from PE100 resin listed in PIPA POP004.			

Table 2 Sizes DN25 to DN50 (Chlorine disinfection)

Maximum Water ORP x SDR Pipe Sizes DN63 to DN90 System Pressure ≤600kPa			
Zone	**SDR13.6**	**SDR11**	**SDR9**
Blue	800mV	825mV	
Green	780mV	825mV	
Yellow	770mV	800mV	825mV
Orange	755mV	780mV	825mV
Red	725mV	760mV	825mV
* Pipe conforming with AS/NZS 4130 produced from PE100 resin listed in PIPA POP004.			

Table 3 Sizes DN63 to DN90 (Chlorine disinfection)

Maximum Water ORP x SDR Pipe Sizes ≥DN110 System Pressure ≤600kPa			
Zone	**SDR13.6**	**SDR11**	**SDR9**
Blue	825mV		
Green	825mV		
Yellow	825mV		
Orange	800mV	825mV	
Red	775mV	800mV	825mV
* Pipe conforming with AS/NZS 4130 produced from PE100 resin listed in PIPA POP004.			

Table 4 Sizes ≥DN110 (Chlorine disinfection)

Chloramine Disinfected Water Pipe Sizes DN25 to DN50 System Pressure ≤600kPa			
Zone	**SDR13.6**	**SDR11**	**SDR9**
Blue	OK		
Green	OK		
Yellow	OK		
Orange	N.R.	OK	
Red	N.R.	OK	
* Pipe conforming with AS/NZS 4130 produced from PE100 resin listed in PIPA POP004.			

Table 5 Sizes DN25 to DN50 (Chloramine disinfection)

* Installation of pipelines shall be in accordance with the relevant standards or codes (such as the WSAA National Water Code, AS/NZS 2033 [19] or AS/NZS 3500.1 [20]) and the pipes manufactured to conform with AS/NZS 4130.

Risk Mitigation

Where drinking water for a specific application exceeds the maximum allowable ORP nominated in Tables 2, 3 or 4 at the measured operating temperature or where the applicable table indicates PE100 is not recommended for the application ("N.R."), mitigating action should be considered.

These actions can take several forms with the main options being:

- Adjusting water chemistry to achieve a more favourable ORP value;
- Taking steps to reduce the temperature of the pipe, for example, increased installation depth;
- Increasing the size (DN) of the PE pipe;
- Reducing the stress in the pipe wall by lowering system pressure or increasing the thickness of the pipe wall (i.e. Lower SDR); and/or
- Selecting pipe manufactured from PE resin with an enhanced resistance to chlorine disinfectants.

Worked Examples

Example 1

Average Annual Water Temperature	33ºC (Red Zone)
Pipeline location	750 mm grass/soil cover
Pipe Size / SDR (PN)	DN125 / SDR11 (PN16)
Residual Chlorine	0.7 mg/L (>ADWG aesthetic limit)
pH	7.5
ORP	770 mV
System pressure	55 m = 550 kPa

Result: Satisfactory. Table 4 Red Zone for standard PE100 SDR11 pipe indicates the application is below the maximum allowable ORP of 800 mV.

Example 2

Average Annual Water Temperature	21ºC (Blue Zone)
Pipeline location	600 mm grass/soil cover
Pipe Size / SDR (PN)	DN25 / SDR13.6 (PN12.5)
Residual Chlorine	0.5 mg/L
pH	7.0
ORP	780 mV
System pressure	45 m = 450 kPa

Result: Unsatisfactory. Table 2 Blue Zone for standard PE100 SDR 13.6 pipe indicates the application is above the maximum allowable ORP of 775 mV. Risk mitigation should be considered. Increasing pipe wall thickness to SDR 11 (PN16) which allows a maximum ORP of 825 mV is an available option.

Example 3

Average Annual Water Temperature	29ºC (The geographical location is in the Yellow Zone, but the measured annual average water temperature is 29ºC, possibly due to the pipeline being located beneath pavement. Use Orange Zone.)
Pipeline location	450 mm below concrete pavement
Pipe Size / SDR (PN)	DN25 / SDR11(PN16)
Residual Chlorine	0.5 mg/L
pH	7.0
ORP	780 mV
System pressure	60 m = 600 kPa

Result: Unsatisfactory. Table 2 Orange Zone for standard PE100 SDR 11 pipe indicates the application is above the maximum allowable ORP of 730 mV. Risk mitigation should be considered. Increasing pipe wall thickness to SDR 9 (PN20) which allows a maximum ORP of 825 mV is an available option. Alternately, consult the pipe manufacturer for guidance as to the suitability of materials with enhanced resistance to disinfectants.

Example 4

Average Annual Water Temperature	20ºC
Pipeline location	600 mm grass/soil cover
Pipe Size / SDR (PN)	DN25 / SDR13.6 (PN12.5)
Residual Chloramine	0.2 mg/L
pH	7.8
System pressure	57 m = 570 kPa

Result: Satisfactory. Table 5 Blue Zone for standard PE100 SDR 13.6 pipe, (OK).

Conclusion

All pipe materials have design limits subject to end use operational and environmental parameters.

In the case of PE pipe, PIPA has become aware that in a very small number of discrete geographical regions in Australia, aggressive water chemistry, operational and environmental conditions may potentially reduce the expected service life of PE pipe conveying disinfected drinking water.

A model developed in the USA by the Plastic Pipe Institute Inc., has been identified and adapted to Australian conditions, which will assist pipeline operators to assess risk based on water temperature and water chemistry as described by ORP.

Water utilities and pipeline owners will be able to use PIPA Guideline POP018 to adjust operational parameters including aspects such as ORP, disinfection type and concentration, adjust installation conditions such as pipe size, wall thickness and cover depth, or seek the advice of the pipe manufacturer to select PE materials with enhanced resistance to disinfectants, to ensure optimal performance for their specific application.

Installation of pipelines shall be in accordance with the relevant standards or codes (such as the WSAA National Water Code, AS/NZS 2033 or AS/NZS 3500) and the pipes manufactured to conform with AS/NZS 4130 from PE resin listed in PIPA POP004.

PIPA will continue to work collaboratively with industry and other stakeholders to ensure the best outcome based on informed discussion in the broader public interest.

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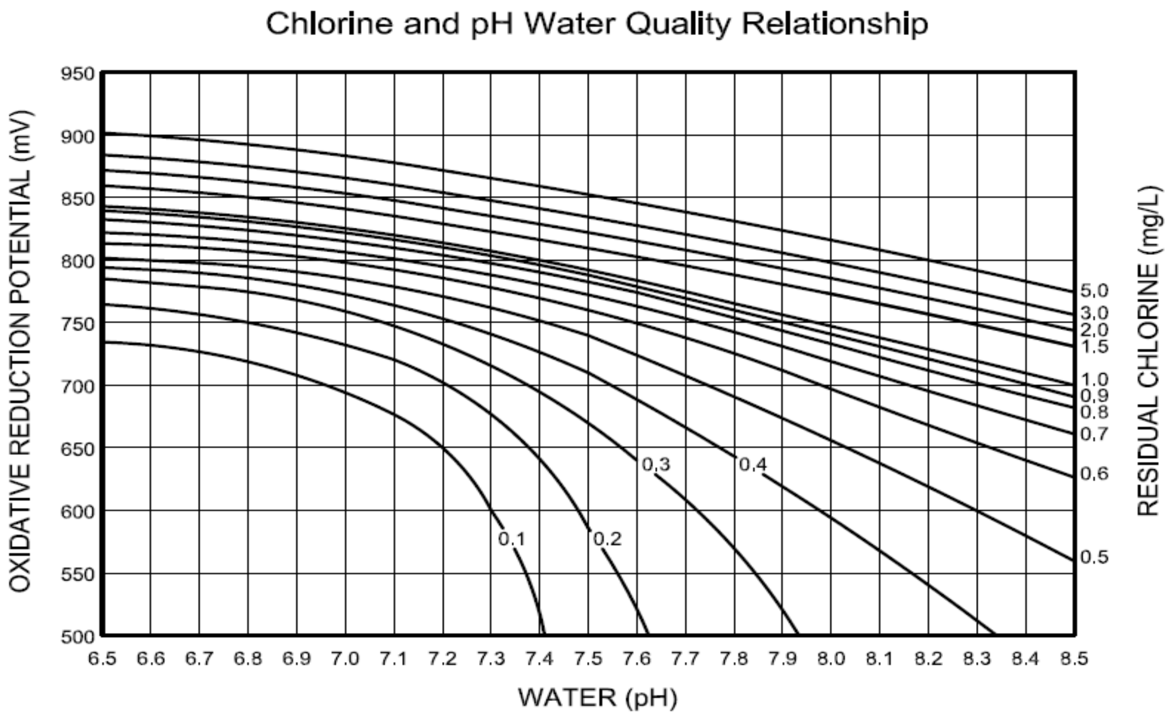
Appendix 1



Source: ASTM Standard F2263:2014 [6]

Notes:

1. Free (or residual) chlorine is defined as both the hypochlorous acid and hypochlorite ions that form equilibrium in solution and is pH dependent.
2. The graph above illustrates the relationship between pH/free-chlorine and ORP in a deionised (DI) water solution. The specific pH/free-chlorine/ORP relationship is dependent on specific water quality.
3. It has been demonstrated that due to the presence of various salts and other elements, the ORP illustrated above is about 4% higher than in tap water.