

Stainless steels and drinking water around the world

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(The opportunity has been taken to add a number of pictures to the text from November 2003, in agreement with the author.)

1. Why stainless steels are used in drinking water applications

Stainless steels have been used in the treatment, storage and distribution of drinking water for over thirty years. Today that use is increasing and there are opportunities worldwide for further increase. The benefits to society and to industry are better water quality and reduced environmental impact at lower cost.



Tapping sleeve on distribution pipe



Stainless steel plumbing

The excellent corrosion resistance of stainless steels when they are applied correctly underlies these benefits. There is no general corrosion so there is no need for a corrosion allowance, or any protective coating, or any control of water chemistry (except normal biocide treatment), or any corrosion protection system. Correct grade selection and good practice will minimise the risk of any localised corrosion. Therefore there is practically no contamination of water in contact with stainless steel and equipment will last a long time.

1.1. Water purity

That stainless steels maintain the purity of water has been demonstrated in rig tests which were part of a European pre-normative research project¹. The latter showed that leaching values for chromium and nickel were less than 5% of the maxima permitted by the European Drinking Water Directive² (50 and 20 µg/l respectively). This has been supported by 24-hour stagnation tests carried out by the UK Drinking Water Inspectorate (DWI) on 54.5 mm bore

pipes in three waters which produced leaching levels of $<1.0 \mu\text{g/l Cr}$ and $<2.0 \mu\text{g/l Ni}^3$ ⁴. The relevant DWI Committee concluded that “... the use of products made from the specified stainless steel grades in contact with water for public supply would be unobjectionable on public health grounds”⁵.



Granular activated carbon tanks

The decline in leaching levels with time was shown in a study in a Scottish hospital⁶. The data in Table 1 are for samples drawn from the cold and hot water systems up to three and a half years after commissioning.

Days in use	Metal content of water, $\mu\text{g/l}$					
	Cold water				Hot water	
	304		316		304+316	
	Ni	Cr	Ni	Cr	Ni	Cr
0	1.7	0.2	0.6	<0.1	3.8	0.2
1	1.1	0.2	1.9	0.4	4.5	<0.1
2	1.3	0.2	1.9	<0.1	4.3	0.3
3	1.4	<0.1	1.3	<0.1	5.5	0.4
4	1.7	0.3	1.6	0.4	5.7	0.9
11	1.5	<0.1	6.1	0.2	9.3	0.9
18	<0.5	<0.1	1.1	0.5	11.1	0.3
25	1.0	0.3	0.7	<0.1	15.4	<0.1
32	1.1	<0.1	2.1	<0.1	14.0	<0.1
180	1.0	<2.0	<0.5	<2.0	2.8	<2.0
1250	0.6	<0.5	<0.5	<0.5	1.2	<0.5

Table 1. Ni and Cr content of water drawn from stainless steel water systems in a Scottish hospital.

Many countries insist that materials have to be approved before they can be used in contact with drinking water. (Note that in some jurisdictions, “drinking water” or “water intended for human consumption” is taken to include the water from the point of extraction, before any treatment.) The DWI tests referred to above were part of an approval in

the UK but there have also been approvals elsewhere: for example, in the USA stainless steels are the only materials approved for use in the public water supply without restriction⁷ and they have also been approved there for use in both residential⁸ and institutional⁹ buildings. A European Acceptance Scheme (EAS) for Construction Products in Contact with Drinking Water is currently being developed¹⁰ and it is expected that stainless steels will be well placed to satisfy its requirements.

It is also necessary to consider the fate of any metals which leach into the water, since they may pass into the waste water stream. After treatment, they will then be concentrated in the sewage sludge. There are already some parts of Europe where the metal content of the sewage sludge may restrict its use as an agricultural fertiliser. The low leaching levels from the use of stainless steel in the drinking water distribution system could provide an environmental benefit in this situation.

1.2. Durability

The corrosion resistance of stainless steels means that not only will they last a long time in drinking water applications without replacement but also they will require little maintenance, so reducing operating costs. However, the benefits do not stop there because when the installation is no longer needed stainless steels still have residual value and so are likely to be fully recycled.

Since there is no general corrosion, there are no corrosion products to deposit on internal surfaces which would reduce both the bore and smoothness of the pipe. In turn, this means that the initial flow characteristics of the system will not be impaired, so no extra flow or pumping capacity will be needed during the lifetime of the application - unless there are deposits for other reasons.

There are many old distribution systems in traditional materials which are now suffering through major leakage. The consumers then suffer because they may have supply shortages, they have to pay unnecessarily for the treatment of the wasted water and they may have to pay for extra treatment capacity to be provided. The durability of stainless steels means that their use in distribution networks can reduce the leakage virtually to zero, benefiting consumer, industry and environment alike.

Trenchless relining of water main



1.3. Lightweight installations

The good ductility, strength, weldability, resistance to high water flow rates and corrosion resistance of stainless steels combine to enable lightweight structures to be used. For example, only thin-walled tubes may be needed which can be joined by welding, or by flaring and using loose flanges. In turn, this leads to easier transport to site, greater capability for offsite shop fabrication (better control and cheaper) and easier installation without heavy lifting equipment onto lightweight supporting structures. In some cases, complete package treatment units may be viable¹¹.



Pulled tee in thin-wall pipe



Loose backing flanges



Lightweight pipe for drinking water main in sports stadium, Detroit, USA

The net effect may be an installed cost which is less than the cost of an equivalent system in a more traditional material, in spite of the higher cost per kilogram of stainless steel. Some applications may also achieve lightweight by utilising the higher strength of the duplex grades of stainless steel, for example large diameter buried pipelines or spanning wide gaps.



Bridge to carry drinking water across river, Tokyo, Japan

Installation of complete water softening reactor



1.4. Life cycle cost (LCC) benefits

The true cost of a material selection decision has to be looked at over the whole life of the installation. Thus it covers initial, operating, maintenance, replacement and disposal costs - with the latter containing a credit for residual value. These can be compared properly for different material choices by using a standard Life Cycle Cost (LCC) analysis to reduce all the costs to present day values. (Software is available to make this easy, e.g. from Euro Inox.) Apart from the benefits of lightweight - which impact directly on reducing initial costs - the reduction in the other costs, as discussed above, can often make stainless steel the most cost-effective choice.

There are signs that some authorities are now requiring such long-term financial justification of projects, for example, the impact of GASB 34 in the USA¹².

2. Good practice in the selection and use of stainless steels

In common with all other materials, the best performance of stainless steels will only be obtained if the grade has been selected correctly for the application, design is correct, fabrication has been carried out properly and the appropriate maintenance regime is in operation.

2.1. Grade selection

Only a small number of grades of stainless steel are in common use with drinking water. Practical experience and tests have shown that the chloride content of the water is the most important parameter in grade selection because

of its influence on localised corrosion - crevice corrosion in particular. This has led to the guidelines in Table 2 for ambient temperatures, although other grades with equivalent corrosion resistance may also be suitable.

Chloride level	Suitable grades
<200 ppm	1.4301 (304), 1.4307 (304L), 1.4404 (316L)
200 - 1000 ppm	1.4404 (316L), (duplex 2205)
1000 - 3600 ppm	1.4462 (duplex 2205), 6% Mo superaustenitic, superduplex
>3600 ppm and seawater	6% Mo superaustenitic, superduplex

Table 2. Chloride level guidelines for waters at ambient temperatures.

When it is necessary to handle hot water or when more conservative guidelines are necessary, then upper chloride limits of 50 ppm for 1.4307 (304L) and 250 ppm for 1.4404 (316L) may be appropriate.

2.2. Design and fabrication

After grade selection, the most important aspect of design is to minimise the opportunities for crevice corrosion at joints by use of welded connections or good detailing¹³.

Galvanic corrosion of other materials in contact with stainless steel must be considered but does not seem to be a practical problem if copper-based fittings are used with stainless steel pipes in a plumbing system^{14 15}. However, electrical insulation between the different metals may be necessary if cast iron, carbon steel or galvanised steel is used in conjunction with stainless steel.

Equipment design also extends to ensuring that treatment chemicals are injected and mixed properly, since in concentrated form they can be aggressive to stainless steels. For example, chlorine injection should be into the middle of the water stream to ensure good mixing, rather than adjacent to the wall of a pipe where mixing may be poor leading to high local concentrations.

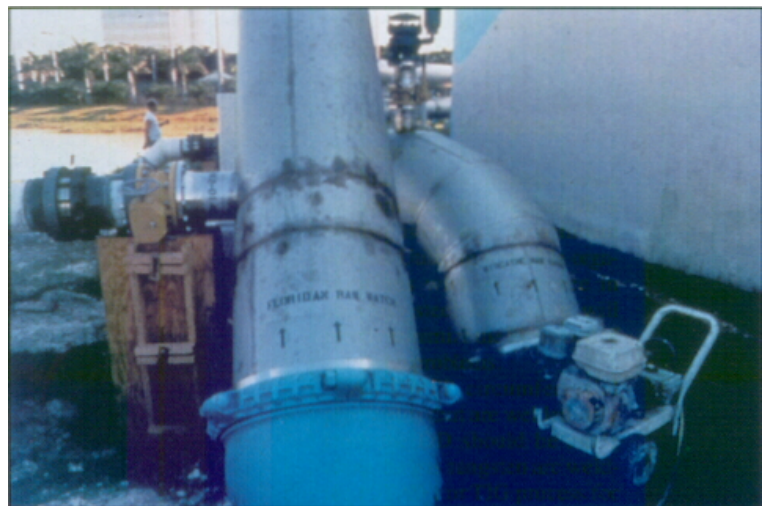


Ozone chlorine mixer, USA

There is plenty of guidance available on welding of stainless steels, and housekeeping during material storage and fabrication¹⁶. Attention must be given to making full-penetration welds and eliminating (or at least minimising) heat tint if the best corrosion performance is to be obtained¹⁷. This has been a critical topic in presentations on stainless steels targeted at the water industry around the world over at least the last ten years - and remains just as important today.



*Good fabrication practice-
Heat tint removed*



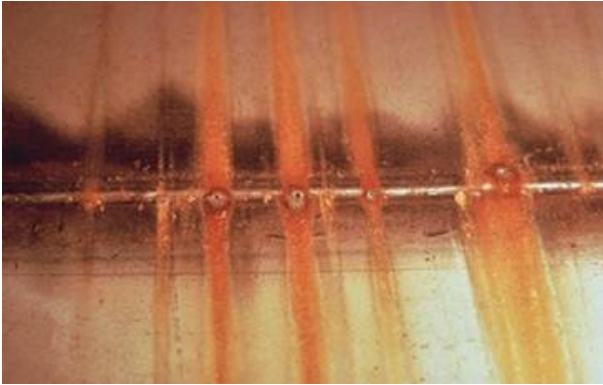
Iron contamination when cleaning weld has caused rust staining

Iron contamination may only cause cosmetic rust staining on plant but experience around the world is that clients see it as something unexpected and wrong with the stainless steel. It is easily prevented or removed - and should be.

2.3. Guidelines for good practice

It is important that good practice is followed so that the best performance of stainless steels is obtained. Otherwise equipment may fail prematurely, water be contaminated and the image of stainless steel will be tarnished. Not only does this apply to the design and fabrication aspects discussed above but also to commissioning and operating practice. There have been a few instances of hydrostatic pressure tests being carried out using untreated water which is then left in the equipment before it is put into operation. Sometimes this has led to microbiologically influenced corrosion (MIC) failures, particularly if weld heat tint has not been removed. The recommendations are:

- always remove heat tint;
- use drinking water (or better) for hydrostatic pressure testing;
- drain and dry, promptly and thoroughly, after hydrostatic pressure testing if the equipment will not be put into operation immediately¹⁸.



Weld heat tint and stagnant hydrotest water led to MIC

As with all equipment, care must be taken during operation that the conditions remain inside the envelope on which the design was based - for example, chlorination or other disinfection practice.

All these aspects have been recognised with documents such as the Information and Guidance Note published by WRc in the UK in association with the water and stainless steel industries, by specific inclusion of stainless steels in the AWWA standards¹⁹ and others in the USA, and by standards in Germany²⁰. It has also been recognised with the Operating Guidelines and (mandatory) Code of Practice²¹ demanded by the DWI in the UK as a necessary part of its approval of stainless steel products. Providing similar industry-accepted guidelines, covering design and fabrication, around the world would contribute to increased and correct use of stainless steels.

3. Illustrative applications

The examples described here reflect the reasons discussed above for choosing stainless steel and some innovative applications. Many more will be given in this seminar or have been published elsewhere.

3.1. Handling raw water

It is important that water intended for human consumption should not be contaminated by screens, pipes etc, right from the point of extraction. However, in this first use of a stainless steel pipe to handle raw water in India, the prime reason for selection was a lifecycle cost analysis in comparison with cast iron²²:

- 50-year life compared with less than 20 years for cast iron;
- reduced maintenance;
- lower weight meant lower transport and installation costs;
- pumping efficiency would be maintained.



Raw water handling, India

3.2. Water treatment



Stainless steels are used throughout water treatment, e.g. screens, settlement tank equipment, pipework, ozone generators, chemical reactors, equipment covers and other mechanical equipment. This pipework in Germany illustrates lightweight construction and a high fabrication standard using a variety of techniques.

Water treatment pipework, Germany

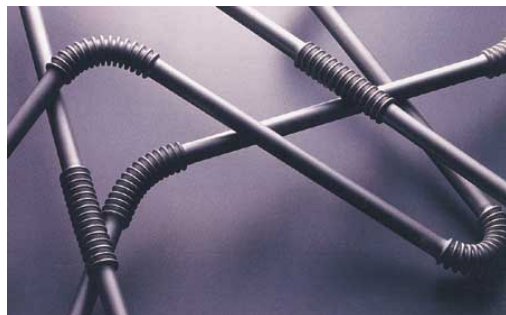
3.3. Water storage and distribution



Many stainless steel tanks are now in use in Japan for storing treated drinking water. This example uses grade 304 for the lower part and all external fittings; grade 316 is used for the middle part of the wall; duplex grade is used for the roof where its greater corrosion resistance can handle the vapours above the water in which aggressive chlorine-containing chemical species have been shown to accumulate.

Water Storage Tank, Japan

Leaks in the service pipes which connect the water main in the street to the building were a problem in Tokyo. A replacement programme was started using stainless steel pipes. Recently a novel corrugated pipe was introduced which can be bent easily and reduces installation cost²³. The programme has been so successful that it has avoided the alternative solution of building another reservoir.



Easy-to-bend pipe, Japan



Stainless steels have been used in water treatment (and municipal waste water treatment) for over 30 years. However, it is only recently that their use in the distribution network and public buildings has been increasing. This example is from a sports stadium in the USA where the principal 350 mm diameter line was selected in stainless steel, primarily because its lightweight meant that lengths could be installed by two people and simple lifting equipment²⁴.

Water distribution piping, USA

3.4. Plumbing systems



One of the first countries to make widespread use of stainless steel for plumbing systems was Germany, where it now has an estimated 15% of the market. Although both press-fitting and compression systems are available in other countries, penetration is slower - partly because of the perceived expense of stainless steel. However, this perception may be ignoring the considerable time-saving during installation which is possible with some systems and the more favourable comparative costs at larger pipe sizes²⁵.

The illustration is from China where entire prestigious new high office buildings are being plumbed in stainless steel.

Office building plumbing, China

There have also been developments in composite piping systems which are intended to improve on the characteristics of both components and so extend the opportunities for stainless steel: stainless steel inside and plastic outside; vice versa; stainless steel inside and galvanised steel outside.

4. Promotional activities and sources of further information

Drinking water has been recognised as a market where there are clear opportunities to increase the use of stainless steels to the benefit of society and the environment. As a result, many stainless steel development associations - for example in Australia, China, France, Germany, India, Italy, Thailand, UK and USA - are working closely with local partners to increase awareness of the possibilities of using stainless steel and ensuring that the necessary knowledge of good practice is available so that stainless steels will be used correctly. Further information may be obtained from them and from www.stainlesswater.org, the “Water Portal” on the Nickel Institute’s website.

5. Acknowledgements

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¹ Co-normative Research on Test Methods for Materials in Contact with Drinking water, MAT1-CT94-0058, Centre de Recherche et de Contrôle des Eaux, Paris, 1999.

² Drinking Water Directive, 98/83/EC.

³ UK Drinking Water Inspectorate, private communication.

⁴ Lewus M.O. et al, Review of Metal Release from Ferritic, Austenitic and Duplex Stainless Steel Grades, Exposed to Potable Water and Related Environments, 4th Stainless Steel and Market Congress, Paris, 2002.

⁵ UK Drinking Water Inspectorate Regulation 25 Letter 7/2001.

⁶ Powell C.A. and Strassburg W., Stainless Steel for Potable Water Service, 2nd European Stainless Steel Congress, Düsseldorf, VDEh, 1996; also this seminar.

⁷ ANSI/NSF 61: Drinking water system components - health effects

⁸ US International Residential Code.

⁹ US International Building Code.

¹⁰ See paper by J. Baron in this seminar

¹¹ Steel Package Water and Waste Water Treatment Units, Steel Construction Institute, 2000.

¹² Basic Financial Statements - and Management Discussion and Analysis - for State and Local Governments, Statement #34 of the Government Accounting Standards Board (USA), June 1999.

¹³ Applications for Stainless Steel in the Water Industry, IGN 4-25-02, 1999, WRc.

¹⁴ Stainless steel plumbing - an introduction, NiDI technical series number 11019

¹⁵ Data from industry cooperative study, to be published.

¹⁶ See publications from stainless steel manufacturers, development associations and NiDI.

- ¹⁷ The corrosion performance of heat tinted stainless steel weldments, L. Boulton and R. E. Avery, to be presented at Austarlian Corrosion Association conference, Melbourne, November 2003.
- ¹⁸ Microbiologically Influenced Corrosion of Stainless Steel by Water used for Cooling and Hydrostatic testing, NiDI Technical Series No 10085, 1998.
- ¹⁹ American Water Works Association: various standards on stainless steel in pipes, couplings, tapping sleeves, flanges and fittings.
- ²⁰ DIN 50930 Corrosion of metals; corrosion of metallic materials under corrosion load by water inside of tubes, tanks and apparatus;
Part 4 - evaluation of the corrosion likelihood of stainless steels
Part 6 - influence of the composition of drinking water
- ²¹ Operational Guidelines and Code of Practice for Stainless Steel Products in Drinking Water Supply, British Stainless Steel Association, 2002.
- ²² Stainless India Vol. 7, No. 2, p. 5.
- ²³ Nickel, p.12, Vol.15, No.2, Dec. 1999.
- ²⁴ Nickel, p.8-9, Vol 16, No 4, June 2001.
- ²⁵ The suitability and use of stainless steel for plumbing applications, Special British Stainless Steel Association Report, February 2003.