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Design, water factors affect service-water piping materials

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The effects of design, water quality, and water composition factors on the performance of alloy and carbon steel nuclear piping are reviewed

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Cement-lined carbon steel piping is a standard material of construction for water distribution systems and the principal material found in most nuclear plant service water piping systems. Cement-lined carbon steel was originally selected, apparently under the assumption that since it was standard for municipal water handling systems it would be the most reasonable material to use for nuclear service water systems.

Although this selection performed reasonably well initially, maintenance increased as the systems aged and the leak rate proved to be greater than could be tolerated for nuclear service water piping systems.

Upgrading to alloy piping systems is underway.

This report identifies some of the principal factors that affect the performance of cooling water piping. Although several factors are interrelated, each is considered separately. This allows the engineer to use this report as an engineering checklist to ensure that none of the major factors have been overlooked. There is considerable data in the published literature on each of the factors discussed but it has not been brought together as in this report.

In developing this report, carbon steel cement-lined piping and other coated steel piping types are assigned the symbol (CS); 304L and 316L stainless steels are represented by (SS); C70600 and C61400 by (CA); and 6% Mo and titanium by (HA). In some sections SS, CA and HA materials are grouped under the heading ALLOY.

The factors that affect their behavior are identified and one of three ratings is given. A "G" rating indicates the piping material has given good performance under the indicated condition. "Y" indicates the material may give good performance depending on site-specific conditions and the interrelationship with other factors. "R" means the material has not performed well under the indicated conditions and special precautions are required if good performance is to be achieved.

Five design factors, three water quality factors, and six water composition factors that have a significant effect on the piping materials are reviewed.

Design factors

Design factors that influence piping performance include (1) size, (2) arrangement, (3) orientation, (4) velocity, and (5) fabrication.

It is difficult to cement-line or coat small-diameter piping. It is even more difficult to repair the lining or coating where it has been damaged by butt welding during pipe fabrication and erection or during incidental maintenance. Alloy piping has an inherent advantage over lined or coated piping in the smaller diameters (see Table 1).

Municipal water distribution systems and utility raw water intake systems where cement-lined piping performs well are of large diameter, generally greater than 24 in., and more frequently 36 to 96 in. where it is possible to repair lining damage from the inside of the pipe. Many expedients have been tried to repair lining damage in piping smaller than 36 in. but none have proved completely successful.

Municipal water distribution systems and utility raw water intake systems are characterized by long straight runs of several hundred feet with 20 feet or more between joints or welds. Shipboard, chemical plant and nuclear service water piping systems are characterized by short runs, frequent bends and numerous valves and fittings.

It is difficult to maintain the integrity of any lining in fabricating and erecting a complex piping system of any diameter. Alloy piping has an inherent technical advantage over lined or coated steel for any complex piping system.

The economics favor alloy piping over carbon steel for complex piping systems (see Table 2), since labor to fabricate and install is 80-90% of the final cost. The high proportion of labor in the overall cost strongly favors use of the best, not the low-priced, material in complex piping systems.

Alloy materials are affected somewhat differently by the position of the piping, Table 3. Horizontal lines that are slightly sloped and open vertical lines are easily flushed out and drained completely. SS has suffered numerous failures when water residues have been left in horizontal runs that could not be completely drained. CA is somewhat more tolerant of such water residues, as is CS. However, both perform best when easily drained. HA is less affected by pipe position.

Design velocities below 3 fps in fresh

Design factors

Table 1. Pipe diameter - in.

	6 in. and <	8 in. - 30 in.	> 30 in.
CS	R	Y/R	G
Alloy	G	G	G

Table 2. Arrangement

	Straight runs	Complex systems
CS	G	R
Alloy	G	G

Table 3. Orientation

	Horizontal		Vertical	
	Level	Sloped	Open	Dead ended
CS	Y	G	G	Y
CA	Y	G	G	Y
SS	Y	G	G	Y/R
HA	G	G	G	G

Table 4. Design velocity - FPS

	No flow	< 3	3-6	6-9	> 9
CS	Y	Y	G	Y	R
C70600*	R	R	G	G	Y
SS	R	R	G	G	G
HA	G	G	G	G	G

*C70600 is used rather than CA in this table as not all copper alloys are as tolerant of the higher velocities.

or saline waters lead to excessive sediment and debris buildup, biofouling and microbiological induced corrosion (MIC) in piping, Table 4. CS is more tolerant of low velocity; however, it fouls readily and sediment buildup can lead to deterioration of the coating. Corrosion failures of SS and under-sediment corrosion of copper alloy have occurred in low- and no-flow piping.

The normal design velocity for piping is about 6 fps and all of these piping materials perform best at 6 fps. Actually, it is the low velocities where sediment can deposit and MIC can occur that must be guarded against. Generally, pipe design velocities are well within the upper velocity limit for these piping materials, although there are reports of cavitation failures where too great a pressure drop has been taken across a single orifice. SS and HA are unaffected by velocities higher than normally found in piping systems.

Procurement practice and fabricability considerations have a major impact on the suitability of each of these candidate piping systems.

In CS piping, the cement lining or coating is easily applied to straight runs prior to pipe fabrication and installation. After installation, the lining or coating is subject to mechanical damage when pumps and valves are removed for repair or replacement and when the system is opened and cleaned. The lining is also subject to damage when, for example, a gusset might be welded on to the outside to brace the piping and reduce vibration.

The fact that so many cement-lined carbon steel piping systems have been installed in nuclear service water piping systems indicates that most of the problems can be overcome. That these apparently properly installed carbon steel piping systems must now be upgraded differentiates the more stringent requirements that nuclear service water piping systems must meet.

In CA systems copper nickel piping is routinely fabricated into the complex piping systems found in the engine rooms of naval and merchant ships. Fabrication is not a limitation for CA provided brazing is limited to 2 in. and smaller diameters.

In SS systems Type 304L piping is purchased to ASTM A 312 and fabricated to user requirements. Fabrication is not a limitation for type 304L in fresh water service. However, other considerations, and the minimal differences in installed cost as compared to type 316L piping, tend to limit the use of type 304L piping.

Type 316L piping is also purchased to ASTM A 312 and fabricated to user requirements. However, welding and post-welding cleanup is critical to success with 316L. Type 316L tends to be used in the more saline waters where 304L would not be considered. Following are some of the key considerations required to obtain the best performance from 316L piping:

1. Procure pipe to ASTM A 312.
2. Fabricate pipe using matching composition filler metal or higher Mo content filler metal for all butt and fillet welds.
3. For butt welds specify smooth root bead with no undercuts, no areas of incomplete penetration and no excessive buildup of weld metal on the I.D.
4. Specify HNO3-HF pickling of fabricated piping before final assembly in the field.
5. Specify end protectors to prevent entry of dirt during shipment and storage after pickling.

A major objective of pickling 316L is to improve the resistance of the welds to microbiological induced corrosion. It is quite possible that the use of a higher Mo content filler metal such as 904L, 625 or C22 would also improve the resistance of welds in 316L to MIC. With a higher alloy filler metal the base metal should tend to protect the weld metal galvanically, reducing the possibility of MIC attack on welds. The evaluations of the resistance to stagnant water conditions and MIC now underway should help clarify the usefulness of such galvanic protection of the weld metal and of HNO3-HF pickling in improving the resistance of type 316L to MIC and stagnant water corrosion.

For HA systems, following are some of the key requirements needed to obtain good performance from 6% Mo piping:

1. Procure pipe to ASTM A 312 (S31254), B 675 (NO8637) or B 673 (NO8925).
2. Fabricate pipe using higher Mo content filler metal, alloy 625 or C22, for all butt and fillet welds.
3. Specify smooth root bead with no undercuts, no areas of incomplete penetration and no excessive buildup of weld metal on the I.D.
4. Specify HN03-HF pickling of fabricated piping before final assembly in the field.
5. Specify end protectors to prevent entry of dirt during shipment and storage after pickling.

For titanium:

1. Procure pipe to ASTM B 337 Grade.
2. Fabricate pipe in a qualified shop using matching composition filler metal for all butt and fillet welds.
3. Specify smooth root bead with no undercuts, no areas of incomplete penetration and no excessive buildup of weld metal on the I.D.
4. Specify end protectors to prevent entry of dirt during shipment and storage after pickling.
5. Prohibit field welds, except in unusual situations when special precautions can be taken to avoid loss of shielding gas caused by outdoor breezes.

Water quality factors

Table 5. Cleanliness of water

	Clean	Sediment Mud	Sediment Sand	Debris sticks and stones	Bifoulers mussels, barnacles
CS	G	Y	Y	Y	R
CA	G	Y	Y	Y	G
SS	G	Y	G	G	R
HA	G	G	G	G	R

Table 6. Startup/standby

	Time left full or in wet standby < 3 days	4-7 days	> week
CS	G	G	Y
CA	G	Y	R
SS	G	Y	R
HA	G	G	G

Table 7. Schedule for mechanical cleaning

	Scheduled cleaning interval monthly/quarterly	Yearly
CS	G	Y
CA	G	R
SS	G	R
HA	G	G

Water quality factors

Water quality factors that affect piping performance are cleanliness of water, start-up/standby, and schedule for mechanical cleaning.

Design engineers tend to assume cooling waters are clean, a condition that exists only occasionally. In a few installations where special care is taken to operate and maintain screens and filters diligently, plants have been able to maintain relatively clean cooling water with considerable benefits in reducing cooling water system maintenance. More often debris, (sticks, stones and shells) and sediment (sand and mud) succeed in bypassing the several screening stations.

Debris and sediment are responsible for many of the problems the nuclear industry has encountered with service water piping. The difference in behavior of piping materials in clean and more typical cooling waters is not fully appreciated and frequently neglected in the piping materials selection process.

All piping materials perform best in the clean waters designers assume will be used (See Table 5). Under-sediment corrosion is a common cause of corrosion of stainless steel and copper alloy piping. The coatings used to protect carbon steel piping also suffer progressive damage from sediment and debris. Debris can be eliminated by improved screens and strainers. Sediment can be reduced by better piping arrangements, especially at the intake. HA is quite resistant to debris and sediment.

Biofouling is the most difficult factor to control. Copper nickel's inherent resist-

Water composition factors

Table 8. Chlorides

	Chlorides in ppm < 200	< 1000	> 1000	Sea water
CS	G	G	G	Y
CA	G	G	G	G
304	G	Y	R	R
316	G	G	Y/R	R
6% Mo	G	G	G	G
Ti	G	G	G	G

Table 9. Dissolved oxygen/sulfides

	> 3-4 ppm O_2	Deaerated	Sulfide pollution
CS	G	G	Y
CA	G	G	R
SS	G	G	G
HA	G	G	G

Table 10. Chlorine residual

	< 2 ppm	2-10 ppm	> 10 ppm
CS	G	Y	Y
CA	G	Y	R
SS	G	Y	R
HA	G	G	?

Table 11. pH

	Normal 6-8	<5	>9
CS	G	R	G
CA	G	R	Y
SS	G	G	G
HA	G	G	G

Table 12. Temperature

	32-45 F	60 F	120 F - 140 F
CS	G	G	Y
CA	Y	G	G
SS	G	G	G
HA	G	G	G

Table 13. Manganese

	Present	Absent
CS	G	G
CA	Y	G
SS	R	G
HA	G	G

ance to biofouling is a major reason for its use in piping on naval and merchant vessels. While the resistance is not complete, it is adequate to permit ship operation for a month or more between flush cleanings in port. None of the other piping materials have any resistance to the growth of the biofouling organisms present in most cooling waters. Flow has been reduced and blocked in some smaller diameter lines by biofouling growth; Asiatic clams, for example. Biofouling must be controlled with biocides such as chlorine in order to maintain flow capability with CS, SS and HA piping.

The extended start-up periods (see Table 6) of modern power plants and the extended outfitting periods of ships have led to failures of copper alloy and stainless steel piping where water has been left in, or incompletely drained from, the piping after initial wetting or during extended outages in later operation. Failures of this type are easily prevented by keeping the water circulating for short shutdowns and by draining for longer shutdowns. Nevertheless, failures still continue to be reported.

Leaving units full, partially drained or simply wet invites stagnant water corrosion. The oxygen in a stagnant system is rapidly depleted by corrosion and by biological oxygen demand, i.e., decay of micro and macro organic matter found in nearly all waters. Organisms die and stagnant waters rapidly become foul. Bacteria thrive, creating local environments that favor microbiological induced corrosion (MIC). Sediments deposit, inviting under-sediment corrosion. The remedy is simply good housekeeping.

If units are to be left full for more than 2-3 days, pumps should be cut on once a day to displace the foul stagnant water with fresh water. If the units are to be down for more than a week, they should be fully drained and blown dry. CS is less affected than the alloy materials, but requires similar attention for best performance. HA is resistant to considerably more abuse but good housekeeping should still be maintained.

Piping systems are frequently flushed out when heat exchangers are opened and mechanically cleaned. As long as these cleanings are done at reasonable intervals little difficulty from sediment and deposits is reported. It is when sediment is allowed to build up over extended periods that under-sediment corrosion becomes a problem in piping (see Table 7).

Both copper alloys and stainless steels perform best in these relatively clean waters where monthly or quarterly mechanical cleanings are sufficient to keep the heat exchangers operating at design levels. CS is somewhat more tolerant of extended cleaning intervals. HA is quite resistant to such abuse, but good housekeeping is still in order.

Water composition factors

Water composition factors that affect piping performance include chlorides, dissolved oxygen/sulfides, residual chlorine, pH, temperature, and manganese.

Chlorides provide a convenient framework for differentiating the individual stainless alloys. See Table 8. Type 304 is resistant to crevice corrosion below about 200 ppm. Crevice corrosion of type 304/304L in fresh waters, which are generally in the range of 20-100 ppm chlorides, is rarely reported. Type 316 is resistant below about 1000 ppm. Performance of CS and CA piping is not significantly affected by chloride ion concentration. HA (6% Mo and titanium) have proven resistant to crevice corrosion and under-sediment corrosion in saline waters and sea water.

Regarding dissolved oxygen/sulfides (see Table 9), copper alloy piping performs best in natural waters with sufficient oxygen for fish to live, about 3-4 ppm. Both copper alloy and stainless steel also perform well in deaerated waters, such as those used in water flooding operations in oilfields and in desalination plants. Copper alloys do not perform well in severely polluted waters where dissolved oxygen has been consumed in the decay processes and sulfides are present. In such waters SS and HA are resistant and preferred. CS is less affected by sulfide pollution than copper alloy.

All classes of piping materials have performed well in waters with up to about 2 ppm residual chlorine (see Table 10), which is the maximum the piping is likely to encounter except in the vicinity of the point of injection and under unusual conditions of over-chlorination. Heat exchanger and condenser tubing of both classes of material have failed in waters that were heavily over-chlorinated. Normal good practice is to aim at about 0.2 to 0.5 ppm residual chlorine at the inlet tube sheet and near zero at the outfall. Higher residuals may occur due to foul waters, poor control of chlorination, or over-chlorination as in some Mideast desalination plants.

Since stainless steels and HA as well as CS are dependent upon chlorination or other biocide treatments for control of biofouling, a number of programs have been instituted to study the effect of residual chlorine on the corrosion behavior of SS and HA. These studies are far from complete, but have shown that the effect of chlorine may be quite complex. Chlorine impacts the nature of the slime layer and of the bacteria colonies, both of which can affect the behavior of stainless steel. Chlorine also has a direct effect on the behavior of stainless steel. The net effect seems to be a considerable increase in sensitivity to crevice corrosion. More information is needed, but normal chlorination practice is not expected to greatly affect the selection of piping materials.

At low pHs, corrosion of carbon steel tends to be rapid where defects in the coating expose the substrate steel. At high pHs the coatings tend to deteriorate and spall. At pHs of less than about 5, copper alloys have difficulty in forming a good protective film in aerated waters and are subject to rather high general corrosion rates and thinning. In deaerated waters of low pH, copper alloys have excellent resistance to corrosion. SS and HA have performed well at pHs less than 5 and greater than 9 (see Table 11).

The protective film forms readily on copper alloys in warm waters, about 10 minutes at 60 F, but takes much longer at the lower temperatures encountered in arctic waters and in temperate waters during the winter months. The film forms almost instantaneously on SS and HA in both arctic and tropical waters. The performance of cement and most coatings used with CS is not significantly affected by temperatures within these ranges (see Table 12).

Type 304 stainless steel tubing has suffered failures in fresh waters with appreciable manganese present (see Table 13). Copper alloy and higher alloyed tubing are less affected, although there are reports of corrosion of copper nickel in some waters with high manganese content.

Summary

Alloy piping, not lined or coated carbon steel, must be rated the material of choice for nuclear service water piping systems of less than 36 in. in diameter. The complexity of most nuclear water piping systems also favors alloy over carbon steel.

Carbon steel cement-lined or coated is most likely to meet nuclear service water piping reliability requirements in long straight runs of 36 in. and larger diameters.

Copper nickel piping, although standard in the complex piping systems characteristic of ships, has met with less success in nuclear service, due primarily to low flow and under-sediment type corrosion. Copper nickel may have to be reevaluated if increasingly stringent regulations ban the use of biocides to control biofouling.

There is so little difference in final installed cost that there appears to be only a limited role for type 304L piping in some fresh water systems.

Type 316L piping has suffered MIC and weld metal corrosion in nuclear service water piping. Pickling in HNO3-HF and the use of more highly alloyed weld metal may increase the resistance of type 316L piping to the point where it will be resistant to MIC and low flow conditions in nuclear service water piping systems. Evaluations now underway should clarify the usefulness of properly fabricated and pickled Type 316L piping.

6% Mo alloy piping is the material most likely to met the nuclear industry's need for highly reliable service water piping.

Titanium also appears to meet the nuclear industry's need for high reliability piping provided field welds can be avoided.

References

1. Tuthill, A.H., "Successful Use of Carbon Steel, Copper Base Alloys, and Stainless Steels in Service Water Systems in Other Industries," *Proceedings EPRI Service Water System Reliability Improvement Seminar,* Charlotte, N.C., October 17-19, 1988.
2. Maurer, J.R. and G.J. Zelinski, "Developing a Six Percent Molybdenum Stainless Alloy for Extended Service Water Piping System Reliability," *Proceedings EPRI Service Water System Reliability Improvement Seminar,* Charlotte, N.C., October 17-19, 1988.
3. Tuthill, A.H., "Installed Cost of Corrosion Resistant Piping," *Chemical Engineering*, March 3, 1986, p. 113.

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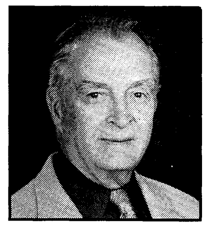

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