Materials for Seawater Pipeline Systems

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Summary

Choice of material for seawater pipeline systems will depend upon the particular environmental situation and the nature of the application. It will be affected by availability, price and political considerations, as well as the life expectancy; previous performance in similar situations will also influence the decision.

Of the materials considered in this paper, 90/10 copper-nickel is the one most widely used and most likely to fulfil the majority of requirements for the future.

711 O/D and 508 mm O/D CuNi10Fe1Mn pipework used on saltwater cooling lines for 'TCP2' compression package - 'Frigg' Field (photo: IMI Dreh)

Introduction

A range of materials is available for the construction of piping systems conveying seawater to machinery and plant installations. The purpose of the present paper is to review the technical and economic advantages and disadvantages of the different types of materials for the various applications concerned.

Applications

The main applications to be considered are seawater intakes and distribution systems for:

- Sea-going and coastal vessels of all types
- Offshore oil and gas platform installations
- Desalination plants producing fresh water from seawater
- Coastal petroleum and petrochemical processing plants
- Coastal electricity generating stations.

Material Requirements

The factors that are relevant in choosing a material for such applications are:

- Resistance to corrosion by seawater over a wide range of operating conditions
- Resistance to corrosion by the external environment
- Resistance to marine biofouling
- Permissible water velocities
- The physical and mechanical properties of the material
- Ability to cut, machine, bend and perform other fabricating operations
- Availability of suitable jointing techniques and of NDT methods to confirm the quality and serviceability of joints
- Availability of comprehensive ranges of components to enable complete systems to be assembled, including compatible pumps, valves, heat exchangers, etc
- Existence of adequate and reliable supplies of pipes and components and free availability of raw materials for their fabrication
- Initial cost of pipe and components and costs of fabricating and installing systems
- Life expectancy and the value of scrap when the system is dismantled
- Demonstrable reliability based on adequate service experience
- Ability to withstand hazards during construction and service, eg. mechanical damage, fire.

In considering behaviour in seawater, account has to be taken of many factors including:

- Rate of general and/or localised corrosion under steady state flow conditions
- Possibility of crevice corrosion and of deposit attack or pitting, particularly under stagnant or slowly moving conditions
- Resistance to stress corrosion cracking
- Effect of variations in composition of seawater including salinity, oxygen content, suspended material, pollutants, etc.
- Effect of chlorination of seawater, if practised

- Velocity limitations
- Effect of variation of temperature, possible spheres of operation being anywhere from arctic to tropical regions. In some applications hot brine has to be handled.
- Possible galvanic effects between different materials.

It must also be borne in mind that in the marine environment external corrosion of piping systems can be a hazard, e.g. occurrence of crevice corrosion due to ingress of chloride beneath sheathings, laggings, brackets, etc. There have been many recorded cases of piping systems failing prematurely from the outside.

Materials

The main types of material to be considered for seawater piping systems are:

- Copper alloys, particularly the copper-nickel series
- Bare carbon steel
- Galvanised steel
- Carbon steel internally coated or lined (e.g. with paint, bitumen, rubber, cement, mortar)
- Stainless steels
- Plastics or reinforced plastics
- Titanium.

A summary of the relevant properties of these materials is given in Table 1. To make a complete economic assessment of the various competitive materials taking into account all the factors enumerated above is a matter of extreme complexity, verging on the impossible. Adequate data on service conditions may not be available and even if the initial conditions can be specified fairly precisely, they may subsequently change in an unpredictable manner. Estimates of the probability of satisfactory behaviour for the various materials will have to be made. First costs must be balanced against subsequent costs of maintenance, repair and replacement and loss of revenue due to outage. The calculations need to include assumptions about variations in material costs, labour costs, interest rates, inflation, taxation policies, product prices and so on. In some situations the costs of breakdown are much higher than in others. In offshore installations, loss of production could quickly nullify any savings made in the first cost of the installation and the carrying out of repairs could be a matter of considerable difficulty and expense.

Because of these complexities heavy reliance must be placed on actual or related prior experience. A change from an established material will not be considered unless there is a great enough economic incentive and a sufficient body of evidence of the reliability of the new material. Acceptable evidence could take the form of long and satisfactory service in related applications. A good example is the widespread change from carbon steel to 90/10 copper-nickel alloy for seawater pipelines on offshore platforms, based on the proven satisfactory service behaviour of copper-nickel pipelines in ships and other marine installations. (Figure 1)

Table 1: Comparison of Properties of Various Pipeline Materials

Material	**General Corrosion**	**Deposit Attack**	**Crevice Corrosion**	**Impingement Attack**	**Behaviour in the Presence of Sulphide Pollution**	**Effect of Chlorination**	**Marine Fouling**	**Mechanical Strength**	**Fire Resistance**	**Fabrication and Component Availability**
90/10 Copper-Nickel CuNi10Fe1Mn	2	2	2	1	1	2	2	1	2	2
Carbon Steel	1	1	1	1	1	1	0	2	2	2
Austenitic Stainless Steel	2	0	0	2	1	1	0	2	2	2
Austenitic Stainless Steel *	2	1	1	2	1	1	0	2	2	1
Duplex Stainless Steel *	2	1	1	2	1	1	0	2	2	1
Ferritic Stainless Steel *	2	1	1	2	1	1	0	2	2	1
Plastics	2	2	2	2	2	2	0	1	0	1
Titanium	2	2	2	2	2	2	0	2	2	1

0 – Not resistant

1 – Potential problems, limited life or some design etc reservations

2 – Satisfactory

* High Molybdenum

Figure 1 -. Seawater pipeline systems of CuNi10Fe1Mn on the Texaco TARTAN A platform. (photo: VDM)

90/10 Copper nickel alloy

This material is also known under the name of Kunifer10.

The material that appears most nearly to meet the broad requirements of a wide range of seawater pipeline applications is 90/10 copper-nickel (Figure 2). It has a long history of satisfactory use as material for both heat exchangers and pipelines in marine applications (Figure 3). There is an extensive literature of published information and various comprehensive review papers are available [1, 2, 3]. One major manufacturer recorded [1)] that over the first 20 years of the use of the material for seawater pipelines (during which time large quantities were supplied), only nine cases of premature failure occurred, four of which were associated with material having a lower iron content than that normally added to confer good corrosion resistance. In no case was failure due solely to excessive seawater velocity.

Figure 2 - 711 mm O/D CuNi10Fe1Mn pipework in Frigg. TCP2 compression module at Grinstad Norway (photo: IMI Dreh).

Figure 3 - Seawater pipeline systems for the YANBU seawater-desalination plant in Saudi Arabia.(photo: VDM).

The rate of corrosion of 90/10 copper-nickel in static, quiescent or flowing seawater rapidly decreases and after a short time becomes negligible, due to the formation of a protective film. Current research by Castle (4) has shown that the film has a multi-layer structure and that the low corrosion rates are due to a thin inner film, which displays strong cathodic polarisation. An overlying mechanically strong iron-rich protective layer provides resistance to impingement attack.

90/10 copper-nickel is not susceptible to stress corrosion, crevice corrosion or pitting attack in seawater and chlorination within normal limits has no significant adverse effects. The material has good resistance to marine biofouling and surfaces remain relatively clean indefinitely in contact with untreated seawater. At times, some fouling may become loosely attached, but this usually falls off of its own accord.

90/10 copper-nickel is readily cut, machined, forged, brazed and welded using a variety of techniques (TIG, MIG, submerged arc) (Figure 4). Fabrication procedures and non-destructive testing techniques are well established and personnel with the requisite skills are available at many sites. There are many sources of the material which is made to matching national specifications, ensuring that supplies from all sources are compatible. Comprehensive ranges of components (bends, reducers, tees, weld-neck flanges, etc.) are available, together with suitable pumps and valves and other components. The material is fully accepted by the major classification and insurance bodies and has passed all the test requirements laid down by such bodies. It has had wide-spread and successful use in all the applications listed at the beginning of this paper, including use in ships of many of the world's navies.

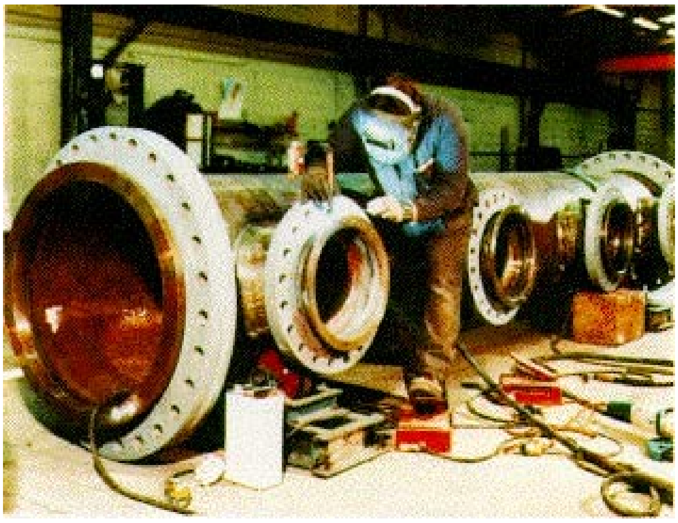

Figure 4 - 90/10 Copper-Nickel inlet/outlet manifolds for Seawater Course filtration unit 813 mm 0/D 17 mm wall and 419 mm 0/D 9 mm wall Branches with weld neck flanges 3001 b ANSI B 16.5.(photo: IMI Dreh).

The material does, of course, have limitations, the main ones being as follows:

a) The mechanical strength is not as great as that of some of the competitive materials. This is of little consequence in low pressure systems and with the smaller size pipes, but in some of the large high pressure systems relatively thick walls have to be used. For these particular applications a stronger copper alloy would be an advantage and development work on modified copper-nickel alloys is in progress in Germany, the UK and USA; alternatively it could be advantageous to make use of aluminium bronze alloys. (Cast or wrought aluminium bronze alloys are widely used and accepted for valves and pumps, flanges and other components for pipeline systems).

b) Copper alloys can suffer rapid corrosion if exposed alternately to sulphide polluted seawater and aerated seawater, sulphide films being non-protective. These alloys may not, therefore, be a good choice in coastal locations where a limited volume of water is known to be regularly and seriously polluted. However, such situations have become relatively rare in recent years as pollution control measures have taken effect. As no significant pollution problems arise in open sea situations, the only precautions needed are to ensure that poor protective films do not form during initial testing and fitting out periods.

c) If the seawater velocity/turbulence in a system is excessive 90/10 copper-nickel will suffer impingement attack (corrosion/erosion). Much has been made of this limitation, but in practice it is rarely a problem as the material will normally handle without difficulty, the velocities at which it is economic to pump the seawater. In a few critical applications the currently accepted velocity limitations may impose increased costs by requiring the use of larger diameter pipes than would be necessary if higher velocities could be used. This is the situation in some parts of some offshore oil and gas platform installations.

Work is currently in hand [5] to define more precisely the acceptable velocity limitations for 90/10 coppernickel and also to investigate the possibility of modifications to the alloy to increase further its resistance to impingement attack. A widely used design guideline BSMA 18 [6] requires that with 90/10 copper-nickel alloy maximum design velocities shall not exceed 3.5 m/sec in pipes of 100 mm diameter and over, with progressively lower maximum velocities for pipes of smaller diameter. The velocity limitations in size up to 100 mm do not impose any great economic penalties as no great savings would accrue from small size reductions in this range. The limitation of 3.5 m/sec in larger pipes is more significant. For many applications there is no desire to use higher velocities than this, and indeed the extra pumping costs would make it uneconomic to do so. In certain offshore applications, however, it could be economic to use higher design velocities. In this context the following points should be made:

(i) If 3.5 m/sec design velocity is acceptable in pipes of 100 mm diameter, progressively higher design velocities should clearly be acceptable as the pipe size increases. For a given velocity, the shear stress values on the pipe wall (which determine whether or not film breakdown will occur) decrease as the pipe size increases. There is a need to revise the velocity rules in BSMA 18 to take account of this and permit 90/10 copper-nickel to be used to its full potential in all applications. As stated above, this aspect is being evaluated.

(ii) In firefighting systems where the pipes are either empty or full of stagnant water, except when there is a fire, no velocity limitations apply. During the short time of use under fire conditions water can be pumped at whatever velocity is required. The size of pipes in fire systems can, therefore, be the same whatever materials are used (Figure 5).

Figure 5 - Seawater suction pipe for the fire extinguishing plant at Jeddah airport in Saudi Arabia.(photo: VDM).

Other materials

Carbon steel

The main advantages of steel pipelines are the low initial cost compared with other materials, the ready availability of pipes and components and the existence of widely used and accepted welding procedures. However, steel corrodes comparatively rapidly in seawater, at reasonably predictable rates (tending to increase as flow rates and oxygen content increase and as the temperature rises). A steel system, though comparatively cheap, will be relatively large and heavy and will have a short life. Failures may occur within a year or two and complete replacement may well be needed within five years. Such a system will be favoured only when first cost heavily outweighs any consideration of repair and replacement costs, when the required life of the system is short, when there is good accessibility for repairs and when loss of revenue incurred when repairs are being carried out is not a major consideration.

Application of coatings to protect the steel (inside and outside) will increase the initial cost by a significant factor depending on the nature of the protective system. Coatings also will introduce complications into the fabrication procedures, such as the need for local removal prior to welding and re-application afterwards.

A widely used protective coating is galvanising. The rate of corrosion of zinc in seawater is somewhat less than that of steel, but galvanised coatings have a limited life and in almost all applications, a galvanised steel piping system would need to be replaced one or more times during the life of the installation. In one of the few published papers giving a detailed economic assessment of the use of alternative materials for seawater piping systems, a report by the British Ship Research Association [7] shows the economic advantages that can be obtained by using copper alloy systems rather than galvanised steel. A paper by Albaugh (8) shows that for offshore oil platforms in the Gulf of Mexico designed for a 20 year life, use of 90/10 copper-nickel seawater piping instead of steel pays for itself within two to nine years (depending on the pipe size chosen).

Use of non-metallic coatings (paint, bitumen, rubber, cement, mortar, etc) appears to have few attractions. Both the material costs and the fabrication costs will be significantly increased (due, for instance, to the welding problems already referred to). However, the main problem is to guarantee 100 % integrity of the coating. At any gap or discontinuity, localised corrosion of the steel will occur at a rate that may well be considerably more than for bare steel. Progress of corrosion will tend to undermine and dislodge the coating, leading to rapid failure. Not only is it virtually impossible to repair or renew internal coatings in situ, but pieces of debris may block valves and pumps and other equipment. Many problems of this type have been experienced in service.

Plastic materials

Material costs for plastics or reinforced plastics may not be unduly high, but in some applications there are serious doubts about the suitability of these materials. These are mainly centred round:

a) Availability of satisfactory jointing and fabrication procedures

b) The long term durability under a range of environmental conditions

c) The vulnerability of the materials in the event of fire

d) The occurrence of marine biofouling

e) Poor shock-resistance.

Because of these considerations plastics are likely to be of restricted importance for seawater systems. They may be of use for some non-critical applications.

Stainless steels

The traditional ferritic and austenitic stainless steels (including types 304 and 316) are unsuitable for use in seawater because they are prone to crevice corrosion and pitting attack, giving rise to a high probability of premature failure. Recent development work has produced materials with improved resistance to these forms of attack in seawater. The materials fall into three categories:

a) Ferritic steels containing 25 to 29 % chromium, 3 to 4 % molybdenum with titanium or niobium for stabilisation and possibily up to 4 % nickel.

b) Austenitic steels containing about 18 to 25 % nickel, 20 % chromium, 6 % molybdenum and 0.1 to 0.2 % nitrogen.

c) Duplex structure steels containing 22 to 25 % chromium, 5 to 7% nickel, 3 % molybdenum and 0.15 to 0.2 % nitrogen.

The main advantages of these materials in the seawater pipeline application are their immunity to impingement attack in high velocity seawater and their good mechanical properties. Pipes can be of smaller diameter and thinner wall compared with competitive materials, the pipe size being governed by considerations of the economics of pumping, noise generation, vibration (number of supports), etc. rather than by material limitations. This assists the economic case for the use of stainless steels, particularly in situations where weight saving is important.

However there are a number of areas of doubt surrounding the use of the stainless steels containing molybdenum and these are mainly centred on the following points:

(i) The resistance of the materials to crevice corrosion and pitting in service has not been fully defined. They are better in this respect than the traditional stainless steels judging by laboratory tests and field trials. However, a much wider range of environmental conditions occur in practice including variations in inorganic and organic composition of seawater and temperature. The behaviour of complex fabricated seawater circulating systems, with a variety of types and forms of materials, in these changeable environments has yet to be demonstrated.

(ii) There is no long term accumulated practical experience in seawater service. The first applications of the materials were in seawater cooled condensers and there have been a small number of such installations in service for a few years. The results have been encouraging, but do not provide entire reassurance about behaviour in the rather different conditions in seawater systems.

(iii) Fabrication, welding and (where applicable) heat treatment procedures have yet to be fully worked out for all the different types of metallurgical structure and thicknesses of material involved so that the metallurgical as well as the mechanical integrity of welds can be guaranteed, avoiding any possibility of preferential attack at welds. The usual NDT procedure of radiography will not provide information about the presence of detrimental phases in the metallurgical structure.

(iv) There may be some doubts about the availability from sufficient reputable suppliers, or requisite quantities of materials, including all the components that go to make up complete systems fabricated from compatible materials.

(v) Assurance is required about the resistance to crevice corrosion and pitting not only in flowing seawater, but also in the external marine environment, e.g. under laggings, sheathing, brackets, etc. Some applications would present particularly severe conditions in this respect, e.g. conveyance of hot brine in desalination plants.

(vi) Stainless steels readily suffer micro and macro biofouling in natural seawater and unless steps are taken to control fouling, systems would readily clog up. If control is exercised by chlorination, the susceptibility of the stainless steels to crevice corrosion and pitting is increased.

(vii)A clear picture of the first cost of the various special stainless steels in relation to competitive materials has yet to emerge, particularly when taking into consideration the costs of components as well as pipes.

In view of these considerations, it would seem that the use of stainless steels for seawater piping systems needs to be approached with caution. The best economic case can be made where the incentive to save weight and space is greatest, e.g. on offshore platforms, but it is here that the financial penalties of unsatisfactory performance are also greatest.

Titanium

This material has excellent resistance to all types of corrosion in seawater and can be considered to be suitable for almost all service conditions. However, there have been some failures by crevice corrosion in hot brine in a desalination plant. The considerations that limit the use of titanium include:

a) Relatively high material and fabrication costs.

b) Limitations on supplies, particularly of components.

c) Stimulation of galvanic corrosion of adjacent components unless effective precautions are taken.

d) Marine fouling in untreated seawater.

e) The possibility of hydrogen embrittlement.

Therefore the use of titanium is likely to be limited to special situations where the need for its high resistance to corrosion outweighs other factors.

Cost Considerations

Reference has already been made to two papers [7, 8] demonstrating the economic advantages of 90/10 copper-nickel compared with carbon steel. Eriksen [9] has estimated savings of as much as 35 % in installed pipe cost by using an austenitic stainless steel in place of 90/10 copper-nickel for offshore platform systems. However, these estimates are open to doubt on several counts including the materials costs used and the respective diameters for some parts of thesystem (see comments under ‘Stainless Steels’).

A recent calculation by the semifabricating industry of the materials costs for a particular seawater system, involving pipes and components up to 14 in diameter, showed that the overall total for an austenitic stainless steel was almost double that for 90/10 copper-nickel, despite making allowance for the smaller diameter (with consequent higher water velocities) permissible with the stainless steel.

M. Roche [10] has given comparative cost data, including supply and installation, for most of the materials referred to in the present paper. A range of cost was obtained for each material and if the lowest values for each are taken, the approximate ratios (taking the installed cost of carbon steel as unity) are as given in Table 2. Other information on costs has been published [11].

Table 2 - Comparison of costs of various pipeline materials

	Material Alone	Installed Cost
Carbon Steel	0.14	1.0
Galvanised Steel	0.20	1.05
Epoxy Coated Steel	0.31	1.07
Neoprene Coated Steel	0.45	1.33
Stainless Steel 316L	0.48	1.55
High Alloy Stainless Steel (Avesta 254 SMO)	1.62	3.67
Duplex Stainless Steel	0.95	2.17
90/10 Copper-Nickel CuNi10Fe1Mn	0.77	1.86
Epoxy GRP	0.52	1.17

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