THE DESIGN AND INSTALLATION OF 90/10 COPPER-NICKEL SEAWATER PIPING SYSTEMS

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

Nº 1107

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Originally, this handbook was published in 1973 by INCO, The International Nickel Company Inc. Today this company is part of Vale S.A.
The Nickel Institute republished the handbook in 2022. Despite the age of this publication the information herein is considered to be generally valid.

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Copper-nickel sea water cooling systems properly designed and properly installed have enabled both naval and commercial vessels to operate for periods up to 30 years with minimal maintenance and without dry-docking for replacement of leaking piping.[1] Modern high performance commercial vessels increasingly rely on copper-nickel sea water piping to reduce maintenance and vessel out of service time.[3]

Inevitably, however, with the rapid increase in number of domestic, European and Japanese shipyards installing copper-nickel piping systems for the first time, some problems have been encountered, usually with the smaller (4" and less) diameter lines. The problems brought to our attention fall into three general categories: Overheating of 90-10 copper-nickel pipe during brazing and rebrazing; turbulence downstream of branch connections, short radius fittings, pipe reducers and mitered fittings; and severe corrosion of galvanically incompatible components such as exposed steel flanges and thermowells, as well as brass tubes, tube sheets, valve and pump components.

The full sea water cooling system includes valves, pumps, pipe, fittings, waterbox, orifices, thermowells, pressure gages, strainers, as well as condensers and coolers. Careful attention must be given to the design, fabrication and material selections, especially the galvanic interaction of all these components, as a failure in any one of these can cause the entire system to be shut down.

Design, procurement, fabrication and installation guidelines for dependable, economic sea water piping systems have been developed from field experience and fundamental principles, and are set forth in the following paragraphs.

DESIGN

Critical points in sea water cooling system design include the materials selection for all components, the pressure drop and friction loss, velocity and turbulence effects and the fabrication and installation methods.

TABLE I – SEA WATER PIPING SYSTEMS

Minimum First Cost System	**Component**	**High Reliability Fouling Resistant System**
Galvanized Steel	**Pipe**	90-10 Cu-Ni
Steel	**Flanges**	Steel backup rings with 90-10 Cu-Ni stub ends or Van Stone Alternate: weld overlayed steel or bronze fixed flanges (see Table XIII)
Cast Iron or Cast Iron coated and protected with sacrificial anodes	**Waterbox**	90-10 Cu-Ni Sheet Rubber or 90-10 Cu-Ni lined steel
Naval Brass Muntz Metal Aluminum Bronze	**Tubesheet**	90-10 Cu-Ni clad steel
Aluminum Brass	**Tubes**	90-10 Cu-Ni 70-30 Cu-Ni
Cast Iron Brass or Bronze trim	**Pumps**	Ni-Resist – Stainless trim Ni-Aluminum-Bronze – Stainless type trim
Steel	**Body Bolts**	Ni-Cu Alloy 400
Cast Iron Brass or Bronze trim	**Valves**	**Butterfly** – Rubber lined – Ni-Aluminum Bronze disc, Ni-Cu Alloy 400 Stem **Gate & Globe** – Ni-Resist or Ni-Al-Bronze body with stainless type trim
Steel	**Bonnet Bolts**	Ni-Cu Alloy 400
Galvanized Steel	**Pipe Fittings – Welded**	90-10 Cu-Ni
Red Brass with Preplaced Brazing Insert	**Pipe Fittings – Brazed**	90-10 Cu-Ni Socket Type Precision Machined

MATERIALS SELECTION

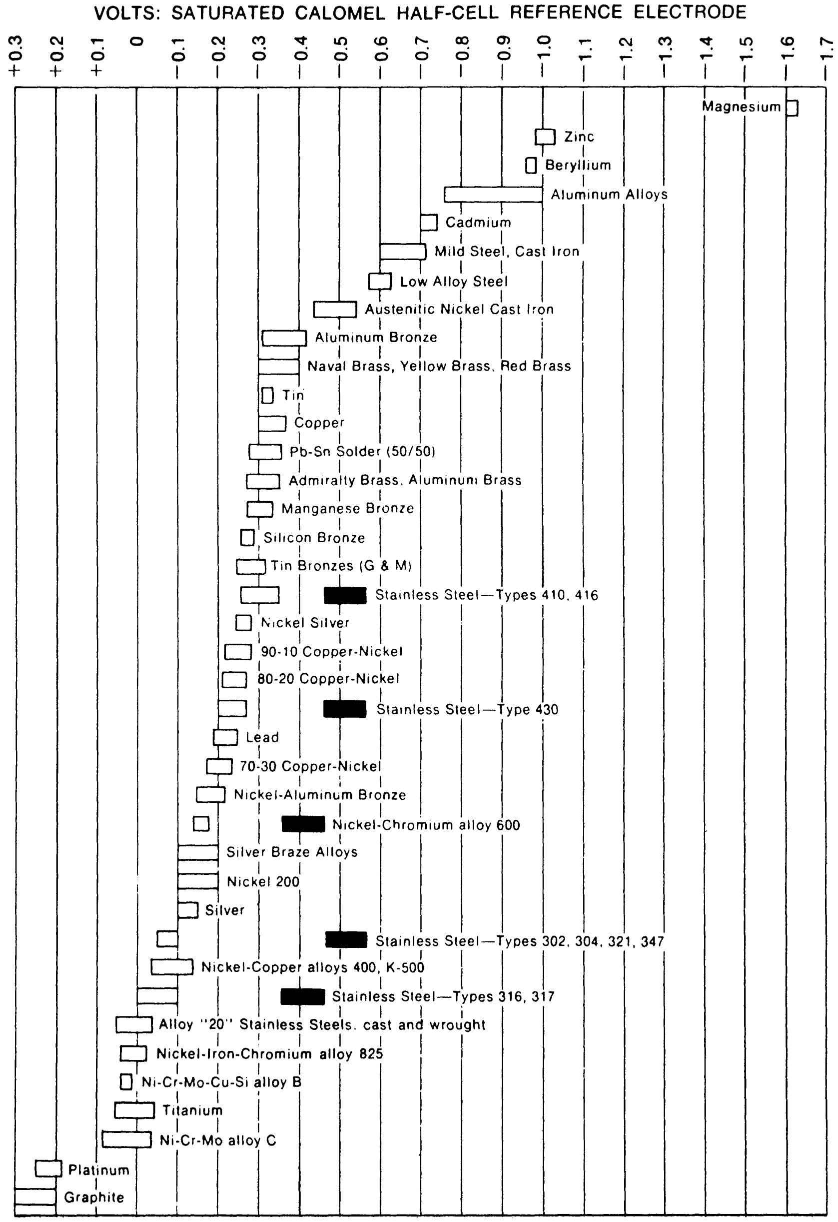
There are two basic types of sea water piping systems: a low first cost, high maintenance, renewable system based on galvanized steel, copper, and brass alloy components and a high reliability, low maintenance fouling resistant system based on 90-10 copper-nickel with galvanically compatible components. Table I shows a typical bill of materials for each system.

Copper-nickel's inherent compatibility with the sea water, its resistance to the growth of hard shelled fouling organisms and the ease with which it can be fabricated have made it the natural and leading material for high reliability, low maintenance sea water cooling systems.

The position of carbon steel and 90-10 copper-nickel in the galvanic series influences the materials that can be used satisfactorily in the valves, pumps, strainers, thermowells, flanges, tube sheets, tubes and other components of each system. Table II shows the complete galvanic series. Tables III, IV and V split this galvanic series into three parts: metals that corrode sacrificially to carbon steel; brass and stainless alloys that for the most part depend upon the sacrificial corrosion of carbon steel for their performance; and metals more noble than 90-10 copper-nickel.

TABLE II – CORROSION-POTENTIALS IN FLOWING SEA WATER (8 TO 13 FT./SEC.) TEMP. RANGE 50°-80°F

VOLTS: SATURATED CALOMEL HALF-CELL REFERENCE ELECTRODE



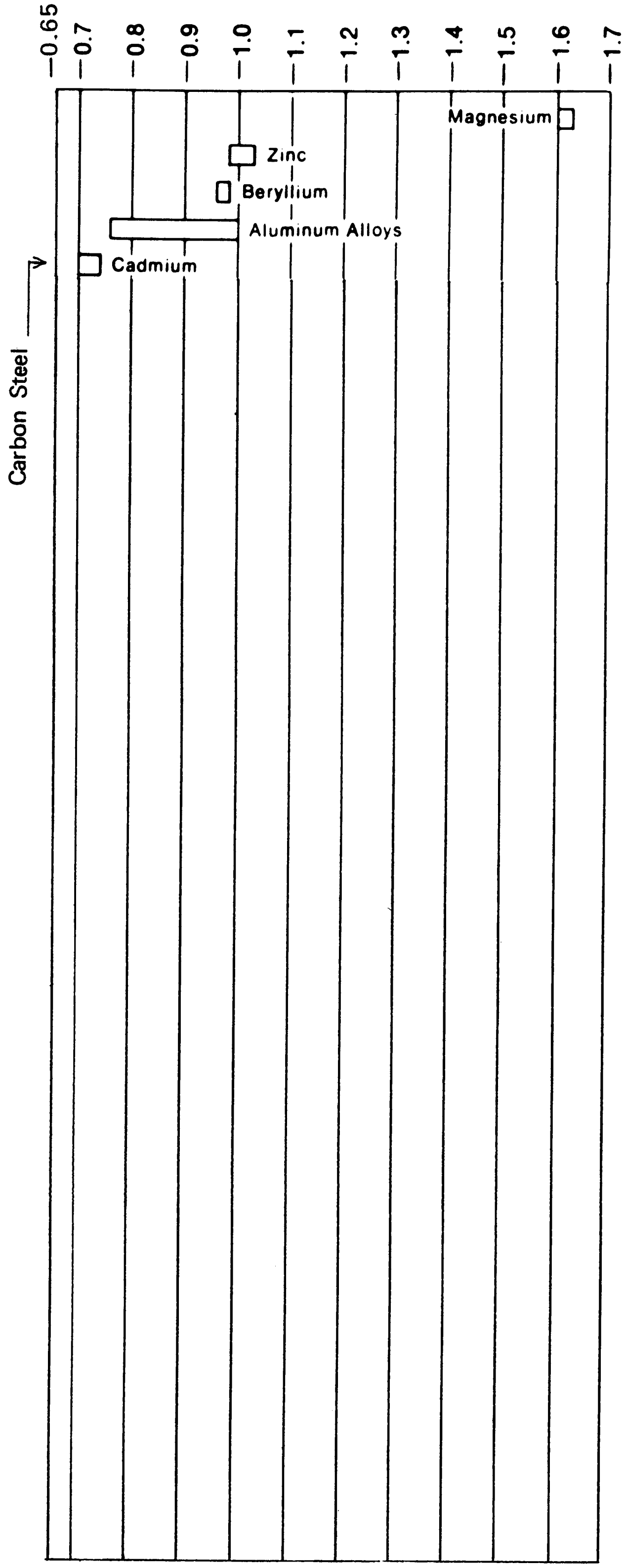
Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol: ■ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near –0.5 volts.

USING THE GALVANIC SERIES

TABLE III THE SACRIFICIAL ANODE GROUP

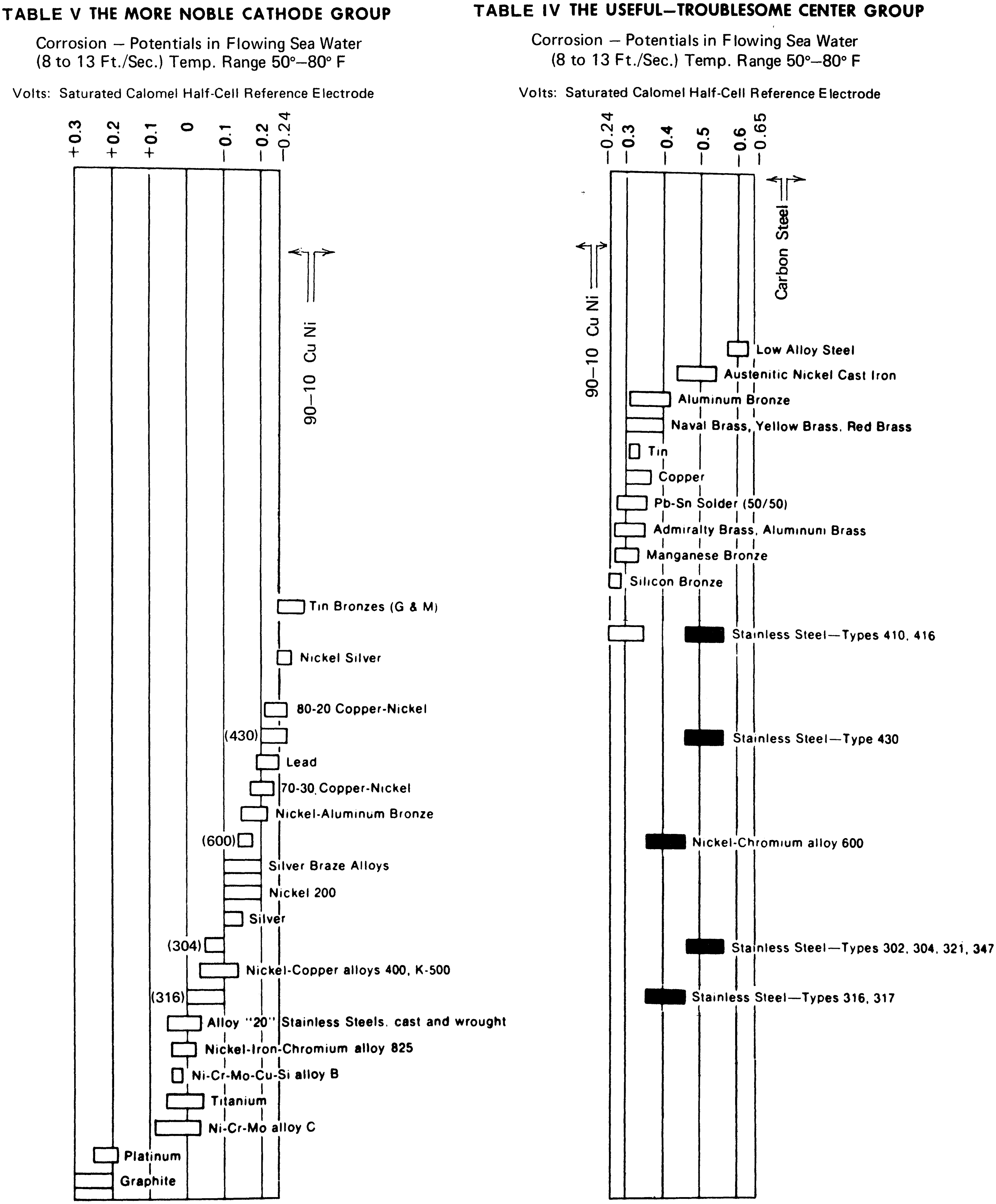
Corrosion – Potentials in Flowing Sea Water
(8 to 13 Ft./Sec.) Temp. Range 50°–80° F

Volts: Saturated Calomel Half-Cell Reference Electrode



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol: ■ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near -0.5 volts.

USING THE GALVANIC SERIES



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol: ▬ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near −0.5 volts.

Returning to Table I, note that common brass alloys such as naval brass and Muntz metal, aluminum brass, red brass, silicon bronze and manganese bronze are properly used only in galvanized steel and cast iron piping systems. These high zinc brasses and silicon or aluminum bronzes exhibit poor to marginal performance in sea water when unassisted by sacrificial corrosion of less noble materials such as steel or zinc. They are useful in freely corroding steel and iron systems where they receive cathodic protection from the sacrificial corrosion of steel and iron. In 90-10 copper-nickel systems, they require special protective measures when used as components of valves, pumps, tube sheets or heat exchanger tubes if high reliability, low maintenance and infrequent replacement is desired.

The stainless alloys which occupy two positions in the galvanic series are found in both the more noble and the useful-troublesome center group metals. This duality of stainless is the source of many conflicting reports on its performance in sea water and places certain constraints on the use of these stainless alloys. Once the normal passivity of these stainless alloys is breached, as can happen in a crevice or under a deposit, they exhibit more active potentials and tend to corrode in the pits even in the presence of the seemingly less noble copper and copper alloys. Consequently, these stainless alloys find their principal usefulness in pump and valve trim and as strainers where turbulence tends to keep the surfaces passivated. The higher alloyed stainless steels of the Alloy 20 type are so much more resistant to crevice corrosion that only their higher cost limits their further application in sea water systems.

Table VI from Fielding's excellent paper[4] brings out the fact that valve cost is more than 50% of the total materials cost of shipboard piping systems. This being so suggests that the designer should review carefully the real need and usefulness of each valve shown on the piping schematic. In many cases, the sea chest valves might be used to block out the water while pumps, condensers and coolers are being replaced, thus eliminating the need for valves on either side of each item of equipment. Butterfly valves of more durable materials can often be used to replace cast iron type gate valves, increasing the durability of the system with a concurrent savings in first cost. Monies thus saved can be invested in more noble cathode group materials for the globe and check valves – see Table V. The all too common sight of spare valves tied to line valves in the engine room is hardly compatible with the concept of high performance and low maintenance so essential to the continued earning power of today's multi-million dollar cargo on tanker vessels.[6]

Special care must be used in selecting gate and check valve and pump body materials. Tin bronzes (G&M), cast 70-30 copper-nickel and nickel-aluminum-bronze are close enough to 90-10 copper-nickel's potential so that adverse galvanic effects on either the thin wall piping or the heavier walled valve body are minimal. Cast MONEL* nickel-copper alloy valve and pump bodies cause the 90-10 copper-nickel pipe to corrode sacrifically. Heavy wall waster spools 1½ diameters long are necessary to avoid premature failure of the piping if nickel-copper valve or pump bodies are to be used. Cast Alloy 20 (CN7M) type valve and pump bodies have been used in 90-10 copper-nickel piping systems without adverse effect on the piping, apparently because this highly alloyed stainless steel polarizes so much more readily than the nickel-copper alloys.

PRESSURE DROP, VELOCITY AND TURBULENCE EFFECTS

Table VII from the Piping Handbook[5] illustrates the importance of streamlined design in reducing friction loss and power required to force water through a piping system. This table is included because the rules for reducing friction loss are identical with the rules for avoiding localized turbulence and attaining the maximum performance from copper-nickel sea water piping systems.

Copper-nickels are outstanding among copper base alloys in their resistance to velocity and turbulence effects, but there are turbulence limits beyond which these alloys will lose their natural protective film and corrode at the higher,

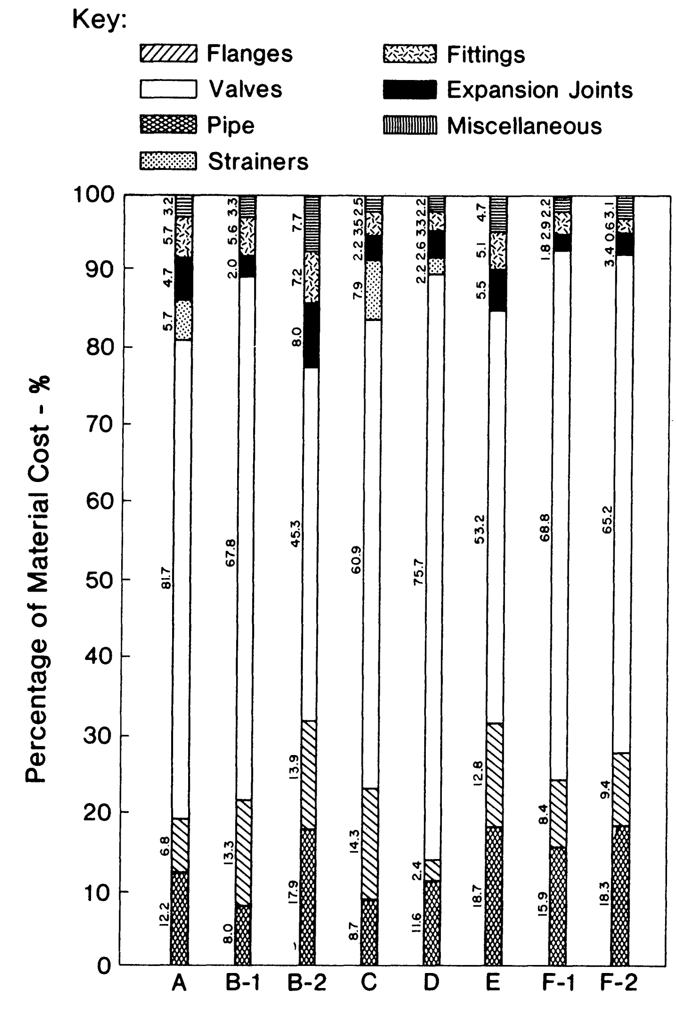


Table VI. Circulating system cost analysis. Relative cost of main and auxiliary circulating piping systems based on bids for recent ship designs

*Trademark of the Inco family of companies initial, bare metal corrosion rate. Gilbert[2] illustrates the relative performance of the common copper base heat exchanger tubing alloys in Table VIII. He also illustrates the important but dual role of small amounts of iron in these copper-nickel alloys – Table IX.

Close examination of these data, together with many studies of velocity effects at the Francis L. LaQue Corrosion Laboratory at Wrightsville Beach, North Carolina, and of actual domestic and European design practice, has resulted in the conclusions combined in Table X – Suggested Guidelines for Velocity in Sea Water Cooling Systems.

The key to good design is streamlining to minimize pressure drop and the power required to pump. Specific suggestions follow:

1. Run all piping as directly as possible with the minimum possible number of bends, fittings, valves and branches.
2. Prefer bends to fittings. Bend radii of 5 diameters is preferred, 3 diameters is minimum. Make all bends cold. However, if heat is used in bending, make certain to remove any oil or carbonaceous deposits from inside of pipe before the pipe is heated. Carbon deposits from oil or grease decomposed by heat and left on the surface can lead to deep pitting in a matter of days in sea water.
3. Use long radius, full formed fittings. Four section mitered fittings have given good service in 24" to 36" diameter lines. Field installed branch connections are a common source of turbulence and should be minimized.
4. Prefer square stub end type flanged joints with gasket cut flush with inside diameter of pipe. Second choice is Van stone rolled over type flanged joint. Reduce velocity 1 to 2 feet per second to allow for the turbulence producing recess on the inside diameter of Van stone joints.
5. Provide positive and continuous means of venting non-condensables from high points in the system.
6. Design so as to control the flow with minimum use of valves. This will permit use of gate or butterfly valves in full open or full closed position and reduce the need for the more expensive globe valves necessary for throttling service.
7. Where reducers, globe valves, orifices, or other turbulence promoters must be used, provide as large a diameter of pipe as possible downstream in a straight run for at least 6 diameters without bends.
8. Locate throttling valve downstream of condenser or coolers.

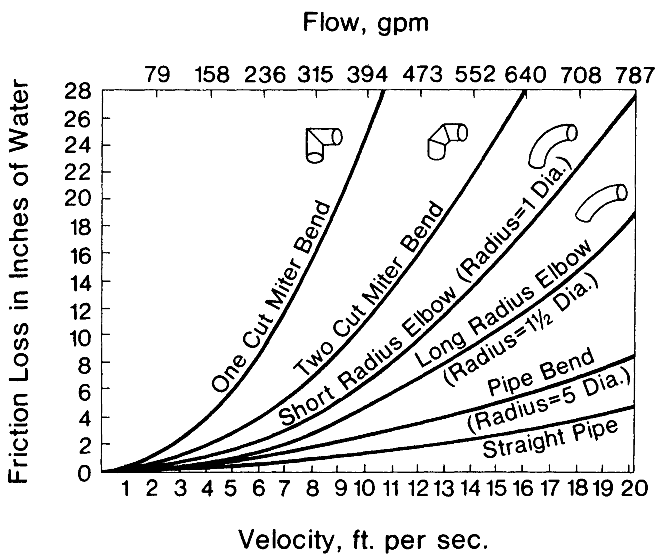


Table VII. Comparative friction losses in 4-in. Schedule 40 pipe and fittings (after G. T. Caspary).

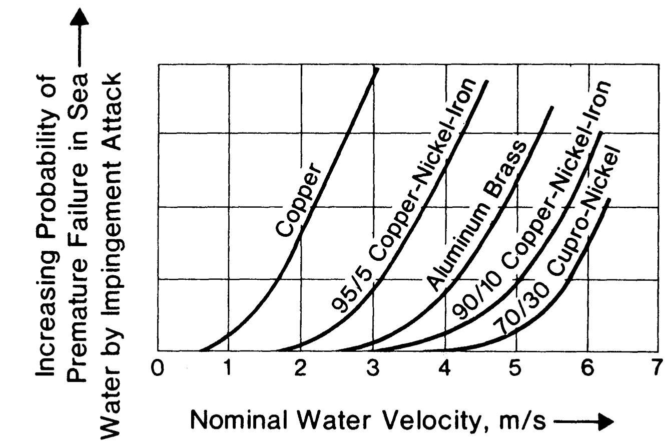


Table VIII. Probability of occurrence of impingement attack in sea water

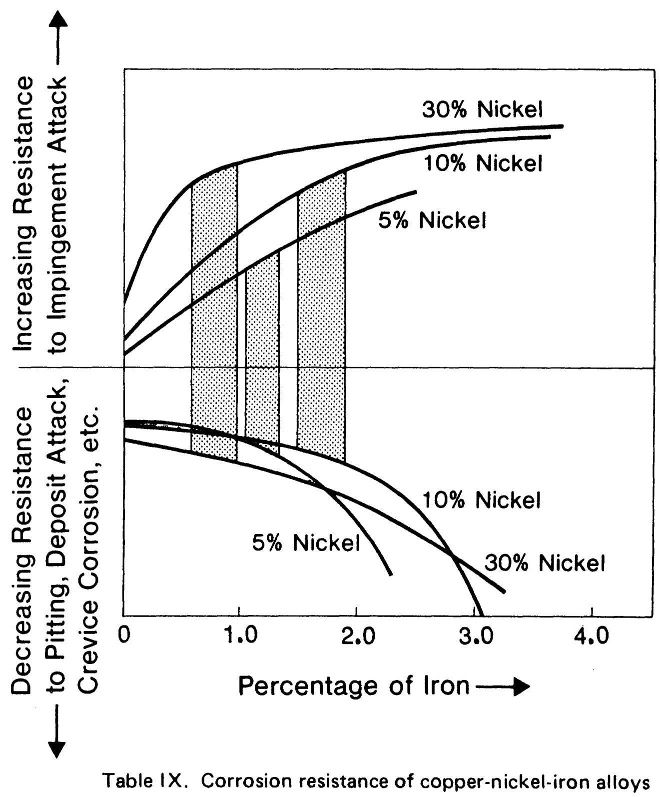


Table IX. Corrosion resistance of copper-nickel-iron alloys

PROCUREMENT, FABRICATION AND INSTALLATION OF PIPING

Wall Thickness

There are several "standards" to which thin wall copper-nickel pipe is commonly produced and procured up to 24" in diameter – Table XI. Domestically, welded pipe to Mil. Spec. 16420 predominates. In Europe, seamless pipe to the producer's schedules predominates. Above 24", standards have not yet evolved although 36" is a common size for main condenser piping and 48" is common in modern desalination plants. There has been some use of 1/16" 90-10 copper-nickel sheet lined waterboxes and large diameter pipe in desalination plants.

The wall thickness schedule in Mil. Spec. 16420 includes an 0.050" constant factor apparently as a safety factor against excessive turbulence. This is five times the normal corrosion allowance one would include for a 20 year service life for copper-nickel in sea water. May-Weldon[9] give the normal corrosion rate for 90-10 and 70-30 copper-nickel in sea water as 0.1 to 0.5 mils per year. The large extra thickness provided in Mil. Spec. 16420 does not appear to be necessary in a reasonably designed and fabricated commercial installation. The European producers have established a schedule of wall thicknesses similar to but somewhat less than those in Mil. Spec. 16420. The European schedules base the extra wall thickness above that required for the internal pressure not on a constant 0.050" corrosion allowance but on the amount they have found desirable to facilitate smooth bends on the pipe bending equipment in use in European shipyards.

It is expected that commercial standards for 50 psi, 75 psi and 125 psi pressure ratings will be developed by the desalination, shipbuilding and coastal power industries as the need for the larger diameter sea water piping increases. Economics weigh against using any greater wall thickness of copper-nickel than needed to provide a reasonable safety factor and normal corrosion allowance. Economic considerations also indicate that such commercial standards, when developed, might well include copper-nickel lined steel pipe for 30" and larger diameters.

TABLE X—SUGGESTED GUIDELINES FOR VELOCITY IN SEA WATER COOLING SYSTEMS

(90-10 Cu-Ni; 70-30 Cu-Ni; Aluminum Brass)

	For 90-10 Cu-Ni Maximum Velocity, Feet per Second	
	Continuous	Excursions for Peak Conditions Not to Exceed 15% of Service
Heat Exchanger Tubing:		
Once-Through Main Condenser	7.5	8
Two pass condensers and all auxiliary coolers	6.5	7
Smaller Diameter Piping:		
1/2" to 1"	5	6
1" to 3"	6	6.5
Intermediate Diameter Piping:		
4" to 10"	8	10
Larger Diameter Piping: 12" to 36"	10	12

For:

Aluminum Brass – reduce values by 2 fps for 4" diameter and larger piping. Reduce values by 1 fps for Heat Exchanger Tubing and smaller diameter piping

For:

70-30 Cu-Ni – increase all values by 2 fps

For:

High pressure drop systems, those falling in the short radius elbow range of Table VII – reduce values for 4" and larger diameter piping by 2 fps

Minimum velocity in all flowing systems – 3 fps

Minimum straight run downstream of pumps and throttling valves – 6 diameters

Waterboxes

The waterbox or channel head serves to conduct the cooling water from the pipe and deliver it to the hundreds of tiny (1") tube openings in the tube sheet. The noncondensable dissolved gases (oxygen, CO_2, etc.) tend to flash or bubble out as the pressure drops slightly as the water leaves the pipe and enters the larger volume waterbox. Unless properly vented, these noncondensable gases tend to be released and corrode, or wash, the tube ends. In some cases, particularly with entrained air from certain scoop injection systems, vapor blanketing of the upper rows of tubes has been reported to occur.

Certain waterboxes have been designed with so little volume and so little attention to the internal flow path that the waterbox itself creates severe turbulence, leading to tube end erosion, washing of tube sheets, excessive velocities in some tubes and flow starvation in others. The leading manufacturers have found they can often develop larger volume lower weight waterboxes in thin wall copper-nickel or in copper-nickel lined steel at costs competitive with the older heavy wall cast iron boxes.[7]

The use of coatings on the internal surfaces of cast iron or steel waterboxes leads to another type of problem. Coatings fail first at corners and other points of irregularity, leading to deep pitting and penetration of the underlying steel or cast iron. Zinc anodes are commonly used to correct this condition. Unfortunately, zinc anodes occupy a significant volume and may lead to more, not less, turbulence in the waterbox. By the time the owner has paid for the "cheaper" steel or heavy cast iron box, the not so cheap coating, the anodes and anode renewal, he has often substantially exceeded the cost of a lighter-weight, virtually trouble-free, streamlined 90-10 copper-nickel waterbox. Alloy waterboxes also reduce tube failures associated with plugging of tubes from steel corrosion products and spalled linings.

If, on the other hand, cast iron heads and waterboxes furnished for auxiliary condensers and coolers and even main condensers are left uncoated and unprotected, another series of events tend to follow. Initially, the ferrous layer in which the graphite is embedded corrodes freely and affords a measure of cathodic protection to the tube sheet and tube ends. After a time, often in a year, the embedded graphite is exposed in a semi-continuous layer. As the graphite is exposed, the galvanic relationship reverses and the tube sheet and tube ends corrode at increasing rates to supply the heavy current demands of the more noble graphite.

There follow basic design suggestions that, when followed, eliminate many of the problems all too frequently encountered with condensers and coolers:

1. Streamline the internal flow from the pipe to the hundreds of small diameter tubes to avoid turbulence and insure uniform distribution of flow in all tubes.

2. Provide positive and continuous venting of all noncondensable gases from the top of the waterbox so that these gases go off before entering the tubes. In the case of scoop injection installations that entrain air, it will usually be necessary to provide

TABLE XI

THIN WALL 90-10 COPPER-NICKEL PIPE WALL THICKNESS COMPARISON (INCHES)

Normal Diameter	Actual Outside Diameter	Mil. Spec. T16420 (1) Class 50	Mil. Spec. T16420 (1) Class 200	Yorkshire Imperial Catalog Table 3 – Schedule of Recommended Inch Size Sea Water Pipelines
3"	3.5	–	.095	.072
4"	4.5	–	.109	.092
5"	5.563	–	.125	.092
6"	6.625	–	.134	.104
8"	8.625	–	.148	.104
10"	10.75	.134	.187	.128
12"	12.75	.156	.250	.144
14"	14.0	.165	–	.160
16"	16.0	.165	–	.160
18"	18.0	.180	–	.160
20"	20.0	.180	–	.176
22"	22.0	.180	–	–
24"	24.0	–	–	–
30"	30.0	.250	–	–
36"	36.0	–	–	–
42"	42.0	–	–	–
48"	48.0	–	–	–

(1) This schedule of wall thicknesses also appears as a non-mandatory reference table in ASTM Specification B466-68, Standard Specification for Seamless Copper-Nickel Pipe and Tube, and in B467-68 for Welded.

very large vents and possibly entrainment separators to remove the much larger volumes of air involved. This is necessary to avoid vapor blanketing of the upper tubes, loss of heat transfer surface and associated tube failures.

3. The cross section of the waterbox provided for flow should be significantly greater than the total cross sectional area of the tubes to reduce velocity and turbulence at the inlet end of the tubes. This is particularly desirable in the flow return head of a two pass condenser or cooler and in both heads of all auxiliary air and oil coolers.

4. Redesign waterboxes and heads in thin wall 90-10 copper-nickel with external steel reinforcing or in spot welded 90-10 copper nickel lined steel. A useful spot welding technique was developed by International Nickel Limited laboratories and is detailed in Reference 8.

5. Avoid coatings on the internal surfaces and waster plates or anodes.

Tubesheets

The common tube sheet materials, Muntz metal, naval brass and aluminum bronze, all depend upon freely corroding steel piping, freely corroding steel waterboxes or zinc anodes to overcome their natural tendency to dezincify or dealuminify. In all alloy or even in lined waterbox installations, such brass or bronze tube sheets receive no cathodic protection and deteriorate rapidly by dezincification or dealuminification. Avoid these alloys as tube sheets in high reliability systems.

Copper-nickel or copper-nickel clad tube sheets perform satisfactorily in high reliability systems.

Tubes

Aluminum brass, 90-10 copper-nickel and 70-30 copper-nickel comprise 90% of the shipboard heat exchanger tubing. The beneficial effect of the normal iron content of the two copper-nickel alloys was referred to earlier – see Table IX. The 90-10 copper-nickel alloy requires 1.0% minimum Fe and the 70-30 Cu-Ni alloy requires 0.4% minimum Fe for best performance. Either copper-nickel alloy as tubing is fully compatible with all elements of high reliability sea water piping systems.

In order to use aluminum brass tubes successfully in an all alloy or lined system, large steel waster plates must be installed in the waterbox or continuous ferrous sulphate injection must be provided. Aluminum brass requires substantial quantities of ferrous ion in sea water for good performance. The ferrous ion can come from freely corroding steel upstream of the condenser or from ferrous sulphate injection.

Pipe Fabrication

Brazing and welding appear to be closely competitive in first cost for 1/2" to about 3" diameter piping. Copper-nickel socket type fittings and fillet welds, see Table XII, make welding quite competitive with brazing as an installation method for the smaller diameter lines. Some shipyards prefer to braze these small diameter lines using heavy wall bronze fittings with preplaced brazed inserts or copper-nickel socket fittings and flowed brazing alloy.

Unfortunately, the lower cost brazing alloys (BCuP) are high in phosphorus which leads to cracking of copper-nickel. They will also corrode preferentially to copper-nickel in sea water. The silver braze alloys (BAg) are low in phosphorus and will remain cathodic to copper-nickel in sea water. BAg-1a, a commonly used brazing filler, has a melting range of 1160F-1175F and requires joint clearances of 2-5 mils to ensure capillary feeding of the filler. When torch brazing with these fillers, the metal temperature should be kept below 1300F to avoid incipient grain boundary melting. The use of temperature indicating crayons to achieve this control requires careful consultation with the manufacturer to avoid those containing sulphur which can cause local cracking under the crayon mark during torch heating for brazing.

In order to achieve good brazed joints, annular clearance between the outside diameter of the pipe and inside diameter of the fitting must be a fairly uniform 0.002" to 0.005". This requires a closer tolerance on the outside diameter of pipe ends than normally furnished and careful assembly and jigging for brazing.

Some piping installations have been observed where excessive brazing compound is flowed into and around the socket fittings as though a fillet weld were being made. It is virtually impossible to avoid damage to the base metal by overheating when brazing joints in this fashion. Overheated base metal is so reduced in corrosion resistance that localized corrosion failure of the pipe wall in the vicinity of the joint can and indeed has occurred in a few years. One such installation had to be replaced in its entirety.

For larger diameter piping, the cost of maintaining the 0.002" to 0.005" uniform clearance increases exponentially with pipe size. Shipyards which have studied their man-hours to fabricate brazed piping systems are nearly unanimous in preferring welding for 4" diameter and larger piping for economy in installation.

For 4" to about 6" diameter sizes, socket weld fittings and fillet welds compete technically and economically with butt-welded fittings. In this size range, Van stone joints with carbon steel slip-on flanges compete economically with butt-welded stub ends. Above about 6" diameter, butt-welded fittings and stub ends appear to offer the best economy.

For diameters up to 6" to 8", smooth long radius bends are preferred to fittings to reduce man-hours to fabricate and for lower pressure drop. Both welded and seamless 90-10 copper-nickel pipe is readily bent cold. Heating to bend is unnecessary and introduces unnecessary cleanliness requirements and local overheating problems. Bends are made in conventional steel pipe bending equipment since the outside diameter is the same. However, the shoes or mandrels used on the inside must be enlarged to fit the larger inner bore of copper-nickel pipe if wrinkling is to be avoided in bending.

Shipyards often find it more economical to anneal, or to purchase annealed, only that portion of the pipe they intend to bend. If annealing is done at the shipyard, care must be taken to deoil and degrease the inside of copper-nickel pipe before annealing. Oil and grease on the surface break down to carbon during annealing. Carbon left on the surface leads to severe pitting and wall penetration once sea water is introduced into the piping.

TABLE XII

STANDARD COPPER-NICKEL FITTINGS

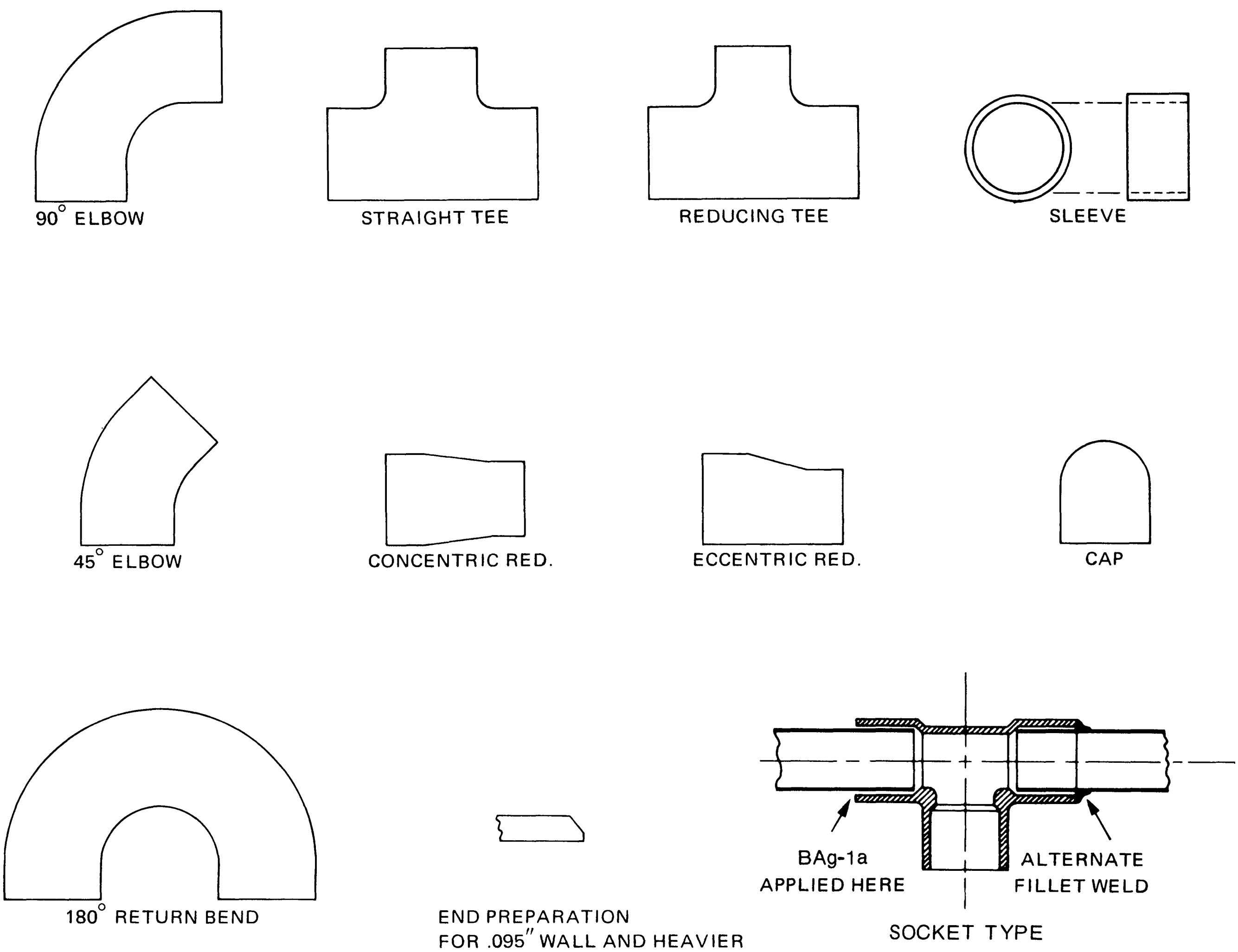
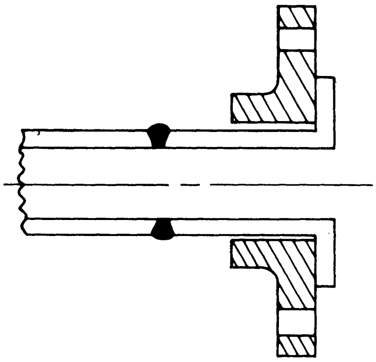
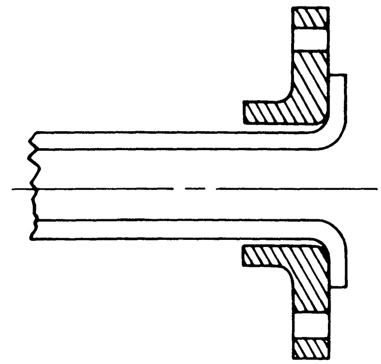


TABLE XIII

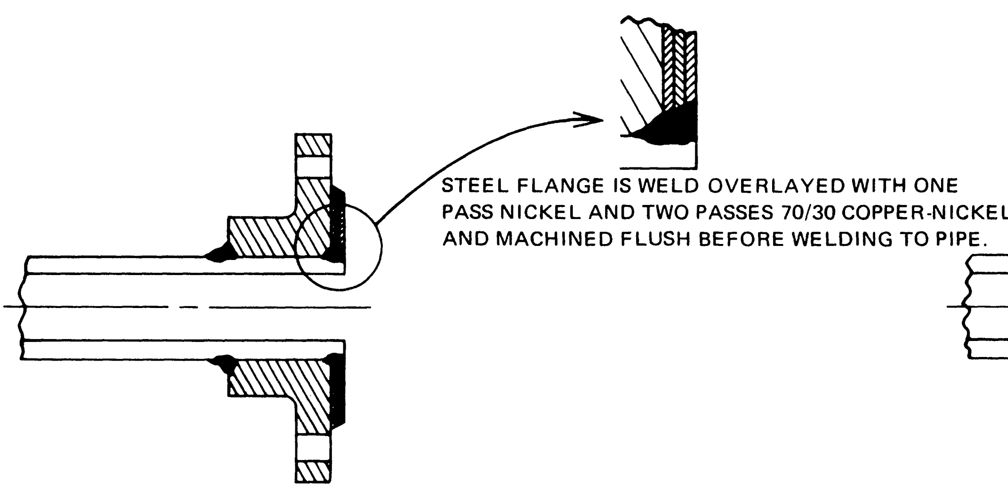
COMMONLY USED FLANGES FOR 90-10 COPPER-NICKEL PIPING



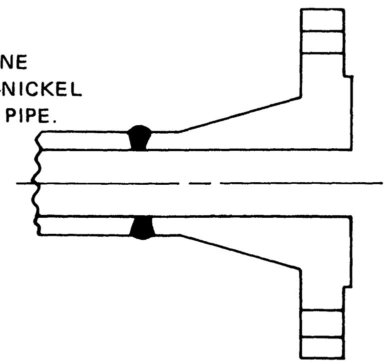
STUB END WITH SLIP-ON STEEL FLANGE



VAN STONE FLANGE



SLIP-ON WELDED STEEL FLANGE



WELD NECK FLANGE

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