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TECHNICAL UPDATE - TU-1005

SUBJECT: **Stainless Steel Grades for High Temperature Applications**

Scope:
This technical update covers the use of austenitic stainless steel tubing in Dekoron Unitherm preinsulated bundles operating at temperatures from 800°F (371°C) to 1100°F (593°C).

Background:
Cogeneration units have generated the need to provide stainless steel instrument tubing bundles for much higher temperatures than is normally seen in other applications. This is a small part of the total application, but one that requires further research to determine the proper tube materials and constructions.

Discussion:
We will examine the material requirements from four viewpoints: Code Requirements; Pressure Requirements; Corrosion Resistance; and Material Availability. Our recommendations will follow the discussion.

Code Requirements:
The governing Code may depend upon the area where the unit is installed. Power generation applications may fall under the Power Piping Code, while units installed in chemical plants or refineries may be covered by the Process Piping Code. Each Code has design and material requirements for high temperature applications. Most requirements are the same in both Codes, but there are exceptions. Of note, tubing manufactured to ASTM Standard A-213 is accepted by the Power Piping Code but not the Process Piping Code. The reverse is true for tubing manufactured to ASTM Standard A-269. This is not necessarily a problem as most tubing materials are available under both specifications. Also, the Code allows for materials not specifically recognized by the Code to be used as long as they are qualified for the application.

Instrument tubing sizes and standards are not specifically listed in the Piping Code. Tubing is required, however, to meet the same design criteria as pipe for the specific application.
The Code sets the pressure and temperature limits for tubing materials by tabulating the allowable stresses at temperature. The designer uses these stresses to determine the size and thickness of tubing used. The allowable stresses are based on continuous operation at the temperature listed. But, the Code allows higher allowable stresses in applications that have high temperature or pressure excursions from an otherwise normal operating condition. This could include areas that have high temperature blowdown. There are a number of criteria that must be met to allow this variation. They are found in the Design section of the Code.

Pressure Requirements:

The designer must select tubing materials and sizes based partly on their ability to withstand pressure at a given temperature. But, to properly design the application, the designer should consider the design pressure at design operating temperature, and the upset pressure at upset temperature. For example, a process tube may be operating normally at 1000 psig and 400°F, but be subjected to a blowdown of 100 psig and 1000°F. These values are part of the process design package.

Austenitic (300 Series) stainless steels are generally chosen for operation at temperatures above 1000°F because of their combination of strength and oxidation resistance. Methods to increase strength from cold working, martensite formation and precipitation hardening become ineffective as operating temperatures increase.

The most common steels used are TP 316 (UNS S31600) and TP 316L (UNS S31603). These provide a good combination of high temperature strength and corrosion resistance. The low carbon grade provides added corrosion protection as noted later in this report.

Allowable stresses for these materials drop off as the temperature increases. The drop becomes sharp as the temperature climbs past 1000°F. The table below shows the drop in allowable stress in tension for metals, as shown in ASME B31.3, Table A-1.

Material	800°F	900°F	1000°F	1100°F	Notes
TP 316, A-269	15,900 psi	15,500 psi	15,300 psi	12,400 psi	(14)(26)(28)(31)(36)
TP 316L, A-269	12,400 psi	11,800 psi	11,200 psi	10,200 psi	(14)(36)

Notes: From ASME B31.3 "Notes for Appendix A Tables"
(14) For use in Code piping at the stated stress values, the required minimum tensile and yield properties must be verified by tensile test. If such tests are not required by the materials specifications, they shall be specified in the purchase order.
(26) This unstabilized grade of stainless steel increasingly tends to precipitate intergranular carbides as the carbon content increases above 0.03%. See also para F323.4(c)(2).
(28) For temperatures above 538°C (1000°F) these stress values apply only when the carbon content is 0.04% or higher.
(31) For temperatures above 538°C (1000°F) these stress values may be used only if the material has been heat treated by heating to a minimum temperature of 1038°C (1900°F) and quenching in water or rapidly cooling by other means.
(36) The specification permits this material to be furnished without solution heat treatment or with other than a solution heat treatment. With no solution heat treatment, minimum temperature is -29°C (-20°F) unless impact tested.

Put in terms that are more relevant to the designer, the internal design gage pressure for 1/2" OD x 0.049" wall stainless steel tubing based on the above design stresses are as follows:

Material	800°F	900°F	1000°F	1100°F
TP 316, A-269	3125 psi	3050 psi	2990 psi	2450 psi
TP 316L, A-269	2450 psi	2300 psi	2200 psi	1990 psi

Per ASME B31.3; 304.1.2, the lesser of equation 3a or 3b

The allowable stress value for TP 316 stainless steel at 1100°F is valid only for heats where the carbon content is above 0.04% per Note 28, above. However, the design gage pressure can also be determined by other methods. One method is to calculate the pressure using 67% of the average stress for rupture at the end of 100,000 hours at the designated temperature. (B31.3, 302.3.2(d)(5)) Using this stress value gives a design gage pressure of 2725 psi. As this is higher than the values listed in the table, the table would be used. There are other several other methods listed in the Code that must be checked. The design gauge pressure would be the lowest value calculated.

The allowable stress value for TP 316L stainless steel at 1100°F does not carry the note regarding modification, so it is used as the basis for internal design gage pressure.

A recent addition to the list of materials is the high carbon or "H" grades. Boiler and superheater tubes manufactured under ASTM Standard A-213 using TP 316H (UNS 31609) are listed as approved materials in the Power Piping Code. This material has proven long-term service life when used in pipe. It would also meet the minimum carbon content required in the stress table. There may be some problems, however, when this material is used in preinsulated tubing applications.

The ASTM A-213 tubing standard was developed for straight, cut lengths of tubing used in boilers, heat exchangers, and superheaters. The design yield strength is based on a manufacturing process including tube straightening. If the tubing is purchased unstraightened (as in coils), the design yield strength at room temperature must be reduced 5,000 psi. This puts TP 316H at the same level at TP 316L. If this follows throughout the temperature range, then the internal design gage pressure would be the same as that shown for TP 316L, above.

The higher carbon content in the "H" grade stainless steel will also increase the rate of work hardening. This can be a special problem for bundles that require multiple layers of insulation. Each pass through the insulating equipment could increase work hardening. The question may be compounded by the requirement that "H" grade steels be supplied to the application in the solution annealed condition. This requirement may preclude any processing on coiled tubing.

If the tubing is supplied in straight lengths to take advantage of all the properties of the "H" grade stainless steel, then it must be joined in the field. Many design specifications require socket weld fittings for tubing used at high temperatures. At this point, the designer must be concerned with the effects of welding on the high carbon steel. It is generally known that heating stainless steel tubing to welding temperature will sensitize the steel resulting in loss of corrosion resistance. Improper attention to welding the high carbon material may also lead to localized stresses that could reduce service life.
Corrosion Resistance:

As noted above, intergranular attack and intergranular stress corrosion cracking can be significant problems with stainless steel tubes operating at temperatures above 850°F. The problem occurs when carbides precipitate to the austenite grain boundaries. These areas then become susceptible to corrosive attack.

If the system is constructed of straight lengths of tubing joined with socket welds, then the most likely area for corrosive attack is the area least protected.

Two methods readily available to increase corrosion resistance are lowering the carbon content of the tubing material and reducing the instances of unprotected tubing.

Material Availability:

The recent flurry of high temperature applications has caused designers to look at a number of material and construction options. Some of these options are to migrate materials and processes used in pipe applications to relatively thin walled, smaller diameter tubing.

A problem occurs when the tubing manufacturers are called on to fill these requests. The new material may not process on the existing equipment. A case in point is the request for TP 316H tubing.

The high carbon content in TP 316H causes the material to work harden rapidly. This reduces the amount of draw and the number of draws allowed before the tubing must be annealed. It also increases the chance of tube fractures during the drawing process. This increases both the lead times and the cost of the tubing.

At the time of this report one major seamless tubing supplier has determined that they are unable to efficiently produce the tubing sizes and wall thicknesses required for cogeneration applications, and have declined to bid on any requests for TP 316H tubing.

Dekoron/Unitherm Recommendation

After discussions with suppliers and customers, and review of the Codes, Standards, and information available to us, Dekoron/Unitherm feels that the high temperature bundles for cogeneration applications can be best provided using seamless type TP 316L austenitic stainless steel tubing in coils. This material and construction can provide a bundle that meets the pressure and temperature requirements of the application and is well respected in the industry.

References:

1. ASME B31.3-1999 Process Piping Code", The American Society of Mechanical Engineers, New York, 1999
2, M. L. Nayyar (ed), "Piping Handbook", 7th Edition, McGraw-Hill, New York, 2000
3. W. H. McAdams, "Heat Transmission", McGraw-Hill, New York, 1942
4. J. H. Hoke, "Mechanical Properties of Stainless Steels at Elevated Temperatures", Metals Handbook, The American Society of Mechanical Engineers, New York