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DOMESTIC WATER HEATERS

INTRODUCTION

Domestic water heaters have traditionally been manufactured in enamelled carbon steel, copper lined carbon steel or ferritic stainless steels. The demanded properties are, as for all hot water tanks, resistance to pitting and stress corrosion cracking, and a sufficient strength.

The corrosion resistance in the carbon steel tanks is achieved by enamelling or copper cladding. The copper cladding gives a protection of the steel. Decreasing pH-levels affect the durability of the copper cladding. The copper leakage to the water has often been discussed out of health aspects. Green coloured hair has for some people been the result of too much copper in the water. The enamel protects the steel, but since the enamel is gradually decomposed by the hot water, and since there are often some pores in the enamel layer(s), a sacrificial anode is needed. The sacrificial anode is consumed and needs to be checked/replaced regularly. What is meant by "regularly" varies. Sometimes it's twice a year, and sometimes every fifth year is said to be enough. How fast the anode is consumed depends on the quality of the enamel and the water. The dissolution rate of the enamel has shown to be doubled by an increase of the operating temperature by 15°C (~70 → 85°C).

The advantage by using a stainless steel cylinder is that neither, coating or pressure supporting material is needed, nor any sacrificial anodes. If the right grade of stainless steel is chosen, both sufficient corrosion resistance and strength are achieved.

STAINLESS STEELS

Ferritic Stainless Steel

The in domestic water heater most commonly used stainless steel has so far been the ferritic grade EN 1.4521 (AISI 444), a steel with18%-chromium and 2%-molybdenum. When it was procured within the Avesta Group it was called Eli-T 18-2. However, the resistance to pitting corrosion of this grade has shown to be insufficient in many types of water, especially in the weld area.

Due to the general decrease in water quality, with an increasing chloride content, the number of failures on ferritic stainless steel cylinders have increased rapidly. The main problem is pitting corrosion at welds and at the water line.

Austenitic Stainless Steels

In some areas the problems with type 18-2 have led to the use of more pitting resistant materials, molybdenum alloyed austenitic stainless steels like 17-11-2/L/Ti (EN 1.4401/1.4404/1.4571). These austenitic steels have in general a rather low resistance to stress corrosion cracking (SCC). The combination of hot water and normal chloride contents can cause SCC on the vessels.

Duplex Stainless Steels - SAF 2304 and 2205

Both the duplex grades SAF 2304 (EN 1.4362) and 2205 (EN1.4462) have a sufficient resistance to pitting corrosion and stress corrosion cracking. They have also a desirable high mechanical strength that can be utilised in this type of pressure vessel.

Table 1, *Typical chemical compositions of steels appearing in the present text.*

Grade	EN	C	Cr	Ni	Mo	N	Other
Eli-T 18-2[1)]	1.4521	0.01	18	-	2.2	-	-
17-11-2	1.4401	0.04	17	11	2.2	-	-
17-11-2L	1.4404	0.02	17	11.5	2.2	-	-
17-11-2Ti	1.4571	0.04	17	11	2.2	-	Ti
SAF 2304	1.4362	0.02	23	4.5	0.3	0.10	-
2205	1.4462	0.02	22	5.5	3.0	0.17	-

[1)] Was produced by Avesta until 1990

CORROSION RESISTANCE

Pitting Corrosion

Pitting corrosion can occur on stainless steel as deep pits. The risk of pitting arises with increasing chloride levels and temperature. The pits can very quickly penetrate the steel sheet. The resistance to pitting corrosion increases with higher contents of chromium, molybdenum and nitrogen. Crevice corrosion occurs under the same conditions as pitting corrosion, although the critical temperatures for crevice corrosion are lower than for pitting corrosion.

By calculating the pitting resistance equivalents (PRE-values) the relevant steel grades a comparison of the pitting resistance can be made. Several different PRE formulas can be used, here the one by Truman using the factor 16 for nitrogen has been used.

$$PRE = \% Cr + 3.3 \times \% Mo + 16 \times \% N$$

According to these calculations, see table 2, SAF 2304 is slightly better than 18-2 and 17-11-2. This is the same result as has been achieved in different practical tests. The higher alloyed duplex grade 2205 has even better pitting resistance.

The Avesta pitting cell is an electrochemical test method to evaluate the critical pitting temperature (CPT) in a 1M sodium chloride solution. The CPT is just a tool to compare different steel grades with each other. The CPT cannot be used to relate to a certain application or environment. The CPT values in table 2 indicate that SAF 2304 and 17-11-2/L/Ti have about the same resistance to this kind of corrosion. 18-2 is less and 2205 is more resistant.

Table 2 *PRE and CPT values for some relevant steel grades*

Grade	EN	PRE	CPT
Eli-T 18-2	1.4521	25	< 0
17-11-2/L/Ti	1.4401/4404/4571	24	15
SAF 2304	1.4362	26	15
2205	1.4462	35	48

Stress Corrosion Cracking

Stress corrosion cracking (SCC) appears as narrow cracks, which under certain circumstances very quickly can penetrate the steel.

This kind of corrosion occurs in chloride containing media at somewhat elevated temperatures (50-60°C is enough). Furthermore, tensile stresses have to be present. Residual stresses from the manufacturing can be enough. Austenitic grades of type 18-8 and 17-11-2 can be very susceptible to stress corrosion cracking under such conditions. Duplex stainless steel has due to the dual phase structure a superior resistance to stress corrosion cracking when compared with austenitic stainless steel. Also ferritic stainless steel has a high resistance to SCC.

One method to evaluate the resistance to SCC is to run a laboratory corrosion test, e.g. the drop evaporation test (DET). In this test, a uni-axially stressed specimen is electrically heated to 200°C and then exposed to a dripping dilute sodium chloride solution, where the dripping rate is adjusted to let one drop evaporate before the sample is hit by the next drop. The specimen temperature is around 100°C due to the cooling effect from the sodium chloride solution. The time to failure at a stress level related to the yield strength is measured. The threshold value, as the applied stress in percent of the yield strength that leads to failure after 500 hours, is determined, see figure below.

The resistance of the duplex grades is far better then that of the austenitics.

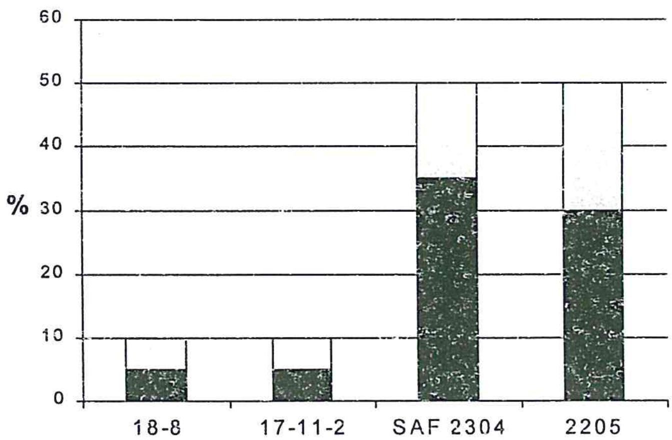

Figure 1 Relative stress level that leads to failure after 500 hours of testing. (Stress / $R_{p0.2}$ at 200°C in per cent)
The shadowed parts of the bars indicate the normal spread. Arrows show indications of higher and lower values respectively.

WALL THICKNESS OF STAINLESS STEEL DOMESTIC WATER HEATERS

Duplex stainless steels, Avesta Sheffield SAF 2304 and Avesta Sheffield 2205, have about twice the strength of austenitic stainless steels, 17-11-2 type. As an example of how this strength can be utilised in pressurised domestic water heaters, calculations have been made according to the Swedish building code. The smallest allowable thickness of the shell and head are:

$$t(shell) = \frac{P * d}{20 * \lambda * (\frac{\sigma}{1.5})}$$

$$t(head) = \frac{1.3 * P * D}{20 * \lambda * (\frac{\sigma}{1.1})}$$

Where

d	=	Inner diameter of the vessel		= 500 mm
D	=	Outer diameter of the vessel	Approx.	= 500 mm
P	=	Design pressure		= 10 bar
λ	=	Weld factor		= 0.7 for the shell
				= 1.0 for the head
σ	=	Minimum proof stress at calculation temperature		

Table 3. *The smallest allowable thickness for some combinations of steel grades at a design temperature of100°C.*

Grade	EN	Yield strength σ, MPa	Wall thickness mm		Weight[1)] kg
			Shell	Head	
17-11-2L	1.4404	166	3.23	2.15	25.3
17-11-2Ti	1.4571	185	2.89	1.93	23.0
Eli-T 18-2	1.4521	250	2.14	1.43	16.3
SAF 2304	1.4362	330	1.62	1.08	12.7
2205	1.4462	360	1.49	0.99	11.2

1) Calculated weight for a 100-litre vessel, Calculated with one decimal wall thickness rounded to thicker material

As a rule of thumb: the thickness of SAF 2304 is half that of 17-11-2L and 80% of that of the ferritic 18-2 grade. By the use of 2205 even smaller wall thickness can be used.

CONCLUSIONS

Stainless steel is the most suitable material for domestic water heaters. The choice of a stainless steel inner tank ensures a maintenance free water heater.

Cylinders in stainless steel are easier to produce since they are single skinned, than are the double skinned copper clad or enamelled carbon steel cylinders.

Stainless steel cylinders are healthier than those are where the cladding or sacrificial anode is dissolved into the hot water.

Duplex grades are better grade for water heaters than standard molybdenum alloyed austenitic grades due to the better stress corrosion cracking resistance and better than ferritic grades due to the better weldability and the better pitting and crevice corrosion resistance.

Higher water temperatures can be allowed in duplex cylinders than in austenitic ones, due to the better stress corrosion resistance.

SAF 2304 is with its combination of the pitting resistance of the 17-11-2 type and the stress corrosion cracking resistance of the ferritics representing new possibilities of material selection for hot water equipment, including pressure vessels, storage tanks and pipes. SAF 2304 in coil produced products is approved as a pressure vessel material according to vdTÜV WB 496.

The duplex grade 2205 is a good alternative in situations where the conditions are severe; e.g. the chloride content in the water is extra high.