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Memo

Hydrogen evolution in galvanized pipes

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1 Background

A pressure increase was seen in some galvanized steel fire extinguishing sprinkler systems in Norway. To investigate the reason for this an inspection of a system (wet) in Trondheim was done on the 03.12.2014. Further, piping from another system with similar specification was analysed in the laboratory at SINTEF. White zinc corrosion products were found, see Figure 1 below. By the formation of these corrosion products, hydrogen gas evolved causing a pressure increase in the system [1].

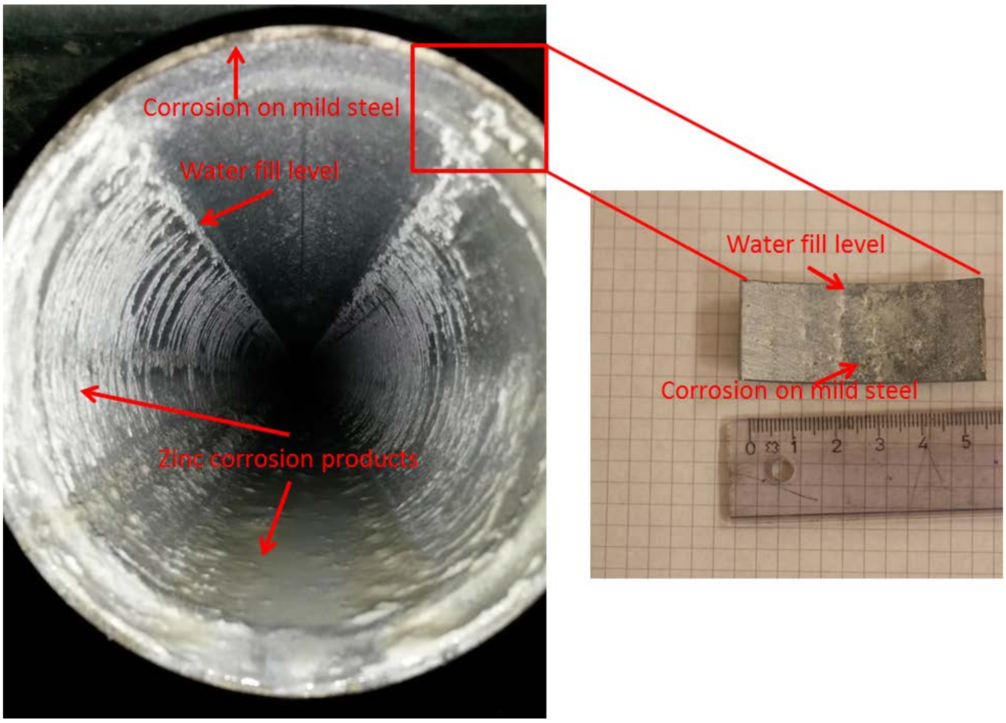

Figure 1. View of the joining area of a galvanized steel pipe with white corrosion products

2 Questions from the Task Force coordinated by Lars Eliassen

2.1 How does the oxygen concentration in the sprinkler system affect the corrosion rate of Zn?

The thermodynamical driving force for the zinc dissolution and the formation of hydrogen gas is also strong without O_2 (dead water) dissolved in it, see Figure 2.

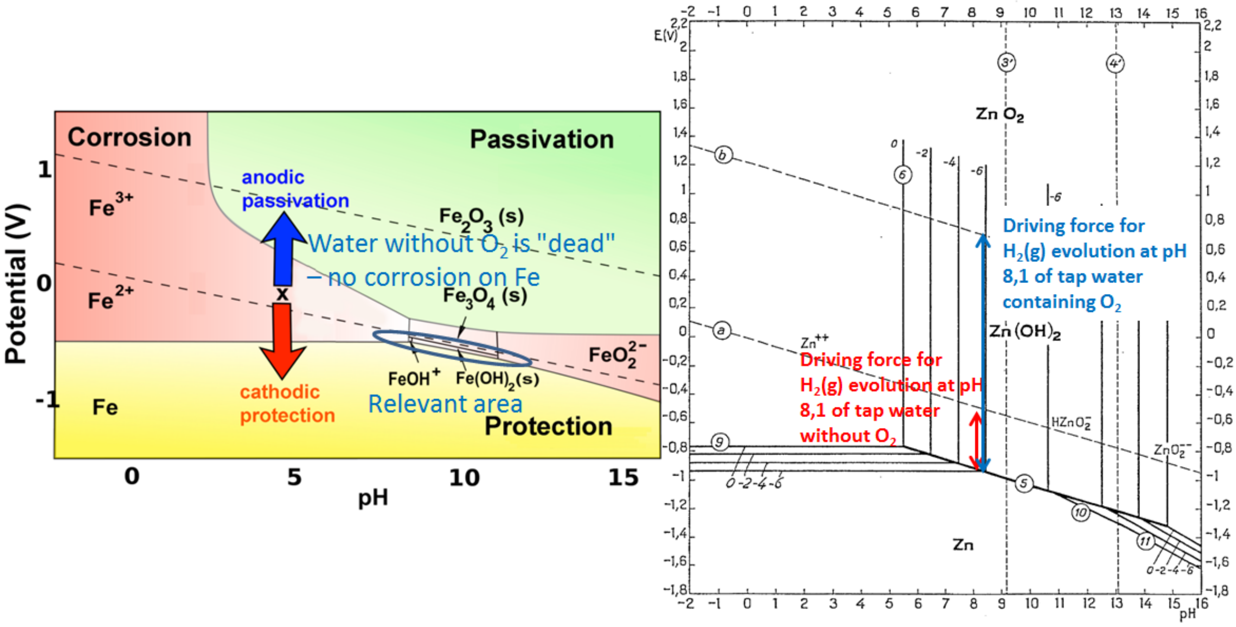

Figure 2. Stability diagrams (Pourbaix) of the iron and zinc chemistry. The thermodynamical driving forces for the hydrogen evolution are seen in the figure [2].

Independent of whether O_2 is present in the water or above the water or not, the red arrow in the Zn-diagram to the right will proceed forming hydrogen gas.

2.2 How does the pressure affect the corrosion rate of Zn? Is there a maximum pressure for the process to proceed?

The chemical reaction for the zinc dissolution is:

(1) $Zn \rightarrow Zn^{2+} + 2e^-$

The counter reaction being:

(2) $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

The dissolved oxygen in the water is then consumed. This process causes uniform corrosion, but can be inhibited by limiting one of the reactants, such as oxygen[3].

Corrosion can also occur under hydrogen evolution from water:

(3) $2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-$

The hydrogen evolution will cause the pressure to increase, as observed. The theoretical maximal pressure is by far higher than the system can handle. The pressure will escape at the weakest point (at a joint, valve, thread etc.) long before.

2.3 Will the formed $H_2(g)$ dissolve in water?

No, not all of it. The maximal solubility in water is 0,0016g H_2 / kg H_2O at 20°C, 1atm, see the diagram below.

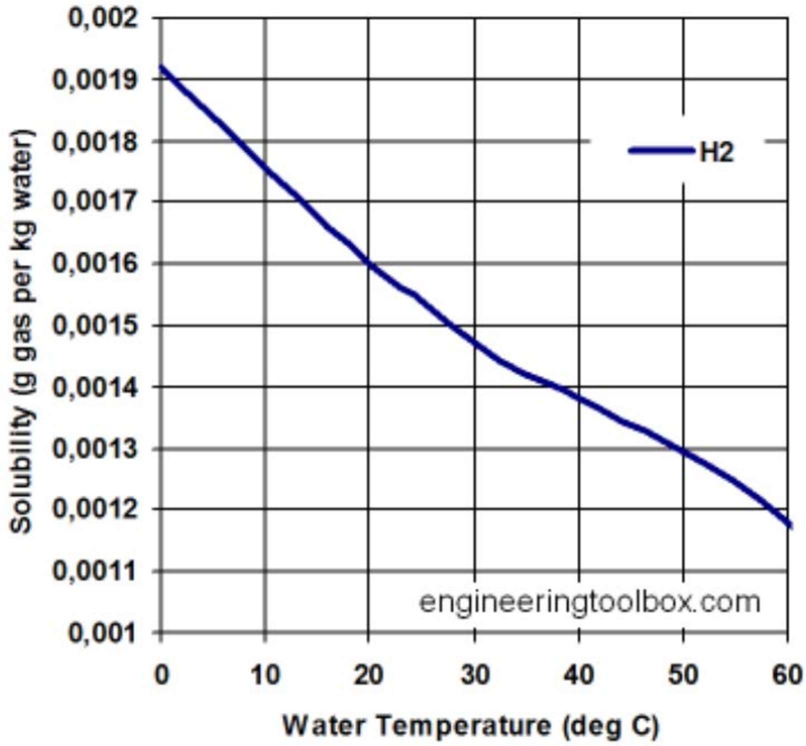

Figure 3. Solubility of H_2 in H_2O g gas H_2 / kg H_2O [4]

This corresponds to about 2,2L $H_2(g)$. 1m pipe (r=0,036m) can form about 19L $H_2(g)$ at 1atm per year (31µm corrosion / year):

area (cm^2) of 1m pipe	Thickness (cm corrosion/year)	volume Zn (cm^3)	density Zn (g/cm^3)	weight Zn (g / 100cm^2)	Amount (moles) Zn / m^2	Amount (moles) H_2	volume (m^3) of $H_2(g)$	Volume (L) H_2/year
2260	0,0031	7,006	7,133	49,97	0,76	0,76	0,01869	18,7

Hence, about 17L $H_2(g)$ remains in the gas phase above the water helping to increase the internal pressure in the system.

2.4 What happens if the system is to 100% filled with water? Will the pressure in the system immediately become very high when hydrogen gas is formed?

The pressure will only get as high as the weakest point in the system can handle, i.e. joints, valves, threads etc. To solve the problem, escape valves should be installed at the highest points.

2.5 Will the process start directly after water is introduces?

Yes, see (1), (2)and (3).

2.6 Is there an effect of grounding the system?

Grounding the system does not have any effect on the reactions (1), (2) and (3). If the system is polarized there may be a bigger electrical problem at hand.

3 References

1. Bengtsson Blücher, D. and O.Ø. Knudsen, *Sintef report F26631*. 2015.
2. Pourbaix, M., *Atlas of electrochemical equilibria in aqueous solutions.* 1966.
3. Zhang, X.G., *Corrosion and electrochemistry of zinc*. 1996: Springer Science & Business Media.
4. http://www.engineeringtoolbox.com/gases-solubility-water-d_1148.html.