Flow Assisted Corrosion: The Different Ways to Avoid Damage

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INTRODUCTION

The Erosion-corrosion phenomena, better named Flow Assisted Corrosion (F.A.C.) concern every equipment of carbon steel working with a degassed water or steam-water mixture in a temperature range between 120°C and 250°C. These conditions are found in the secondary circuits system of pressurized water reactor, in fossil units but in boiling water reactor in two phase flow, where the oxygen solubility is low.

F.A.C is a continuous phenomena without threshold. There is in fact a life-time problem for components and only a detailed analysis can conclude on the sensitivity of each component to this phenomena.

For the last two years, both Specialists and Operators developed the conviction that erosion-corrosion damages could be mastered. EPRI has carried out important work resulting in the CHEC and CHECMATE code (1); KWU also propose the WATHEC(2) analytical method, as well as such procedures existing at EDF(3) and in a different form at CEGB (4). University or private laboratory researchers also propose other methods (5), (6).

We developed in this presentation the model used by EDF to explain the influence of every parameter. From this approach, a better understanding is possible to avoid or to master potential damage.

EDF MODEL

Theoretical developments concerning chemical equilibriums present, and the soluble product removal conditions gives a very simple form of erosion-corrosion mechanism (7) :

$$TL = k * Céq$$

where TL is the thinning kinetic, k the mass transfer coefficient and Céq the soluble ferrous iron concentration, when the reduction reaction of the magnetite is in equilibrium. In order to obtain the absolute kinetic, the effect of the steels actual chemical composition must be added to these two parameters:

$$TLA = TL * f\ (\ (Cr),\ (Mo),\ (Cu)).$$

This last function was shown by DUCREUX (8) and has been verified even for very low concentrations: $f((Cr), (Mo), (Co)) = A /(Cr)^{0.89} * (Mo)^{0,2} * (Co)^{0.25}$.
'A' being defined by : $f((0.025), (0.04), (0.02)) = 1$

All parameters which govern the phenomena, intervene through the mass transfer coefficient and the ferrous iron concentration at equilibrium, because the mechanism which limits material removal is the convective transport mechanism which has a slower kinetic than those chemical reactions.

For this reason it is essential to understand the mass transfer mechanism in order to explain the erosion-corrosion process.

POULSON(6) first recalled that a thermohydraulic mechanism must involve adimensional numbers. However, up until now, none of the proposed models have been subjected to an adimensional examination, which is the only way to avoid scale effects or choice of measuring unit.

The characteristic mass transfer number is SHERWOODS number which is written :

$$Sh = k*d / D$$

where "d" is the tube diameter and 'D' the ferrous ions diffusion coefficient in water. A second adimensional number can be formed, which characterizes the thinning kinetic. Let us call it "W" for "Wall thinning kinetic number" :

$$W = TL*d/(Céq*D)$$

We use both adimensionnal number to compare laboratory results and in situ measurement.

Influence of mass transfer

To have an idea of the real dependence between mass transfer and thinning, it is necessary to see this variation over a wide range of REYNOLDS' number. Tests are carried out with REYNOLDS number lower than 2.10^5 on the EDF loops and up to $1.5.10^6$ on the KWU loop (2). The feedwater piping system of the PWR power stations correspond to REYNOLDS up to 2.10^7.

Thus, in figure 1 the evolution of the wall thinning kinetic characteristic number W with the SHERWOOD number is compared, under situations corresponding to REYNOLDS numbers between 3.10^4 and $1.5.10^7$. For the lowest values, the points concern loop test from EDF, KWU or CEGB. For the large REYNOLDS numbers, wear values are coming from in situ measurements. All this values deal with straight tubes. Providing that no change in the flow regime appears in this REYNOLDS number range, it can be concluded that there is effectively a simple proportionality between mass transfer and thinning by corrosion. The results presented by CEGB diverge from this linearity, but flow downstream of a orifice, is more complex: several flow regimes can occur, giving different mass transfer conditions. The use of dimensional models such as those proposed in the analysis which then involve various mass transfer coefficient exponents can only be justified in so far as they necessarily integrate scale factor and that they are used in a restricted REYNOLDS number range.

The linear dependence between mass transfer and F.A.C thinning is clearly proved by the fact that the corrosion mechanism is used in laboratory tests to estimate the mass transfer coefficient. We use the same way to deduce the mass transfer coefficient from the in-situ measurement in the aim to form a data base for each type of singularity. That is the most easy mean to obtain mass transfer data for piping working in two phase flow.

fig.1- F.A.C in tube adimensionnal representation

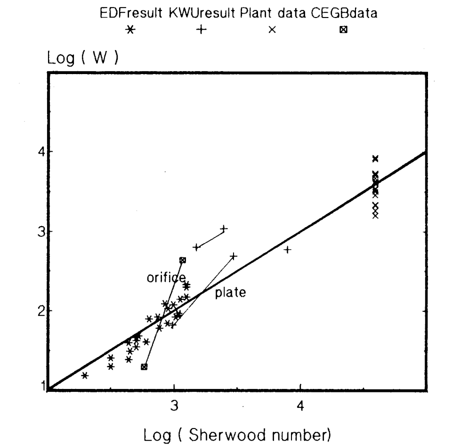
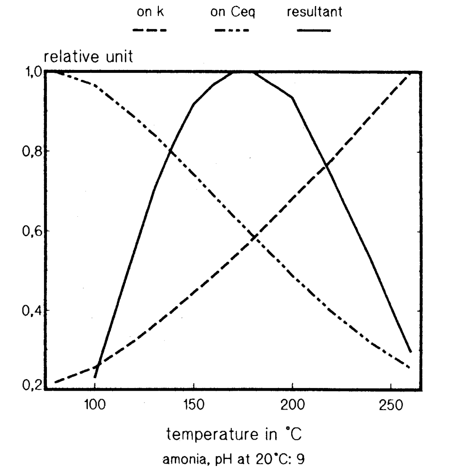


Fig.2- Calculated Temperature effect



The influence of the temperature

Temperature s an other key parameter. Its influence is double: on one hand, when the temperature is increasing, the ferrous iron concentration decrease ; that signifies that at low at low temperature the capacity of water to remove ferrous iron is maximum (figure2, curve 1). But on the other hand the temperature effect is very important on the flow viscosity and on the ferrous iron diffusivity which govern the mass transfer coefficient (Figure 2 curve 2). The resultant dependence is shown on the curve3: it is the curve very often published, but the position of the maximum depends clearly upon the test conditions. It is the same that can be observed on the power plant: If the flow conditions correspond to a very high mass transfer , even with low temperature, the thinning kinetic is large: there is the case when large flashing occurs, for example, on the drain.

The pH influence

Deduced from the pH, the used amine and the hydrogen concentration, the ferrous iron concentration is calculated with the SWEETON and BAES relation. In fact, test results shown that in both one or two phase flow, the effect of a pH increasing appear when the pH value is higher than 8.6. The neutral water meet on BWR is equivalent, what concerns the pH, to a bad PWR water treatment (figure 3).

Fig.3- the pH influence

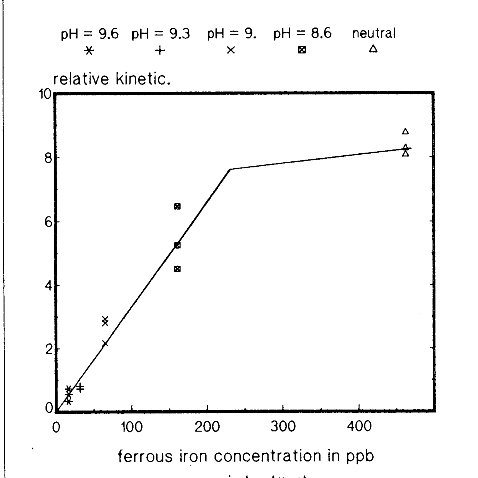
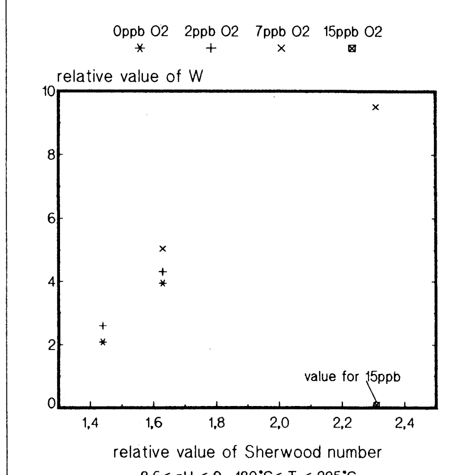


Fig.4- oxygen effect



Oxygen content influence

The influence of oxygen on F.A.C in one phase flow has been observed even with a low temperature (9). Experiment have shown that the oxygen effect have a mass transfer dependence (9)(10): The F.A.C is inhibited when the oxygen level is higher than 15ppb. On EDF loop where we can monitored the oxygen level between 0 and 15 ppb, we shown that the sensitivity to the oxygen content is very low between 0 and 7 ppb which are the normally feedwater rate on PWR (figure 4) and for a temperature range between 180 and 250°C.

We can conclude from this that BWR one phase flow piping is excluded from the F.A.C area, due to the large oxygen content, but for the two phase flow equipment, B and PWR are the same behavior because the solubility of the oxygen is very low in steam-water mixture.

THE MASTERY OF THE EROSION-CORROSION

Where does F.A.C occur

The historical listing of F.A.C cases give a good idea of the sensitivity on every equipment. The first problem occurred on PWR units on the feedwater pump casing and at the same time on MSR separator. In a second time, it was necessary to change J-tubes from carbon steel to inconel and the HP turbin to MSR line with stainless steel or inconel. We can observe that during this period F.A.C concerns both one phase and two phase flow equipment. After 30,000 hrs of operating time, F.A.C occurs on extract steam line, heaters, flashing drain piping, and vent pipe. For EDF, the piping replacement, the wet steam drying upstream of the heaters and the modification of the water treatment make this problem disappear. The new water treatment with high pH and by using morpholine, allows us to avoid damage on feedwater piping. Nevertheless some thinning is still found on the S.G. feedwater ring and on the vent pipe. This experience and the knowledge of the F.A.C mechanism allow us to classify the equipment and deduce what it is possible to do to avoid damage or to master this problem. We present on the next table how to limit the damage ; on this table we distinguish if the plant possess full flowrate polishing (yes or no) and copper alloy tube bundle(yes or no). In a first time we list what is remaining when the water treatment is optimized and in a second time, what it is again necessary. In all cases, the predictive analysis allow to limit the expenses because it can limit the inspection and differ a replacement.

What we can do?

Type of plant				
Polishing? Copper alloys?	Yes Yes	Yes No	No No	No Yes
Feedwater chemistry cure				
.To increase pH .To use morpholine	impossible (NH3 corrosion) impossible with polishing	Yes impossible	Yes Yes	Impossible Yes

After water treatment optimization, what is the remaining problem?				
One phase flow				
• Feedwater pump casing J-tubes	Large F.A.C kinetic in all cases (more than 1 mm per cycle)			
• Feedwater piping Feedwater ring drain upstream regulating valve	Large kinetic largest risk for LP piping.	Small F.A.C kinetic (less than 1mm per cycle)	the maximum sensitivity is removed to the high T°C.	
• Zero flowrate p.	F.A.C can occurs if the valves are not leaktight			
Two phase flow				
• HPturbine to MSR piping MSR	Very large wear	The effect of a pH increasing is lower with ammonia for two phase flow		mass transfer is too large to prevent F.A.C
• Extract steam p.	" " "		If the mass transfer is weak, the kinetic can be limited	
HP Heaters	" " "	F.A.C wear depends on internal arrangements		
• drain downstream regulating valves . normal	" " "	The kinetic is around 1mm per cycle		
• . emergency	Normally those circuits don't be used a longtime. In the opposite case these behavior is more bad than the normal line due to a larger flashing.			
• Vent pipe	Very large wear	We cannot avoid wear kinetic avoid to provoke leakage after 50,000hrs.		

After, What it is necessary to do?				
One phase flow				
• Pump casing J-tubes	replacement*	replacement*	replacement*	replacement*
Feedwater piping Feedwater ring	inspection	inspection	inspection	inspection
Zero flowrate p.	Verify that the valves don't leak			
• Drain upstream regulating valve	no problem	no problem	no problem	no problem
two phase flow				
• HPturbine to MSR	replacement*	replacement or wall protection		
• MSR	To install a preseparator allow to protect MSR internal and shell and to increase the plant electrical output			
• Extract steam p. HP heaters	The drying of the wet bled steam can allow to avoid the piping and heater replacement.			

Drain downstream regulating valve	
.normal	It is necessary to replace* pipe downstream the valves. The time when replacement occurs depends on the water treatment
.emergency	Don't use normally this line avoid large F.A.C: verify the normal level control
Vent pipe	Limit the vent flowrate and change the place the orifice downstream to avoid large mass transfer. If no, replace* fittings
*: replace signify "change with a more than 1% chromium steel"	

CONCLUSION

The erosion-corrosion phenomena causes damage the consequences of which can present danger to people and large maintenance casts. The use of analysis method allows the management of this problem in the aim a increasing the operation reliability and decreasing the expenses.

If it is possible, the first action to limit the wear kinetic is to improve the water chemistry. The inspection can then be limited to a prediction confirmation and it is easy to avoid mechanical consequences. There is the way followed by EDF for the French units. But when we appreciate a wear large enough to conclude that problem occur at mean time, the analysis allows to optimize inspection, replacement or modification.

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