REDOX CONDITIONS EFFECT ON FLOW ACCELERATED CORROSION: INFLUENCE OF HYDRAZINE AND OXYGEN

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ABSTRACT

Flow Accelerated Corrosion (FAC) of carbon steels has been studied world-wide for more than twenty years and is now fairly well understood. The influence of several parameters like water chemistry (i.e. pH and oxygen content), temperature, hydrodynamic or mass transfer conditions (i.e. flow velocity, geometry, steam quality...) and steel composition on the corrosion kinetics has been demonstrated both theoretically and experimentally. However, the effect of a reducing environment and variable redox conditions have not yet been fully explored.

It’s well known that a reducing environment is effective in increasing the resistance of steam generator tubing to intergranular attack / stress corrosion cracking (IGA/SCC) and pitting. In that way, secondary water chemistry specifications have been modified from low hydrazine to high hydrazine chemistry in the steam-water circuit. Nevertheless, increasing hydrazine levels up to 200 µg/kg could have a detrimental effect by potentially enhancing the FAC process. Moreover, in order to have a complete understanding of the possible impact of the water chemistry environment it is also important to consider the impact of redox conditions during shutdowns (cold and/or hot shutdowns) and start up periods when aerated water injections are made to maintain a constant water level in the Steam Generators from the auxiliary feedwater circuit. Therefore, a common EDF and EPRI R&D effort has been recently carried out to study the effects of hydrazine and oxygen on FAC. The results are presented as follows.

First, temperature (i.e., 180°C versus 235°C), is shown to be an important parameter leading to a significantly different effect of hydrazine on the FAC rate of carbon steels as exhibited in the CIROCO loop in strictly controlled water chemistry and mass transfer conditions (water velocity of 5 or 10 m/s).

Next, in mixed conditions, the FAC process is stopped as soon as the oxygen concentration is locally greater than 1 µg/kg (180°C). According to the electrochemical potential measurements, this result is in relation to the formation of hematite in the pores of the original magnetite layer. The ratio between hydrazine and oxygen necessary to stop the FAC process (i.e., to obtain enough oxygen) is determined. It is different according to the temperature because the kinetics of the reaction between oxygen and hydrazine is also different depending on temperature.

Finally, recent field experience has been examined with respect to these results in order to evaluate the possible impact of high hydrazine chemistry on FAC for PWR steam generators and feedwater piping systems. These results could allow secondary water chemistry specifications to be optimised in terms of hydrazine and redox conditions.

1. INTRODUCTION

Flow Accelerated Corrosion (FAC) of carbon steels has been studied world-wide for twenty years and is now fairly well understood. This phenomenon which occurs in high temperature (100-250°C), deaerated and alkalised flowing water can lead to severe component degradations and even failure of piping in nuclear power plants. The influence of several parameters like water chemistry (i.e. pH and oxygen content), temperature, hydrodynamic or mass transfer conditions (i.e. flow velocity, geometry, steam quality...) and steel composition on
the corrosion kinetics has been clearly demonstrated both theoretically and experimentally. However, the effect of a reducing environment and variable redox conditions have not yet been fully explored.

It's well known that a reducing environment is effective in increasing the resistance of steam generator tubing to intergranular attack / stress corrosion cracking (IGASCC) and pitting. In that way, secondary water chemistry specifications have been modified from low hydrazine to high hydrazine chemistry in the steam-water circuit. Nevertheless, increasing hydrazine levels up to 200 µg/kg could have a detrimental effect by potentially enhancing the FAC process. Moreover, in order to have a complete understanding of the possible impact of the water chemistry environment it is also important to consider the impact of redox conditions during shutdowns (cold and/or hot shutdowns) and start up periods when aerated water injections are made to maintain a constant water level in the Steam Generators from the auxiliary feedwater circuit.

Therefore, a common EDF and EPRI R&D effort has been recently carried out at 180°C whereby several tests in the CIROCO loop have been performed to examine the FAC rate dependence with hydrazine concentration and in mixed conditions (presence of hydrazine and oxygen). In situ electrochemical potential measurements were made to define the precise redox conditions in all the tests. The data reported here include two temperatures: 180°C and 235°C, representative, respectively, of piping located upstream of the last high pressure feedwater heater and potentially blowdown piping systems, and piping located downstream of the last high pressure feedwater heater. The effect of hydrazine on FAC rate at 235°C has already been reported in a previous conference4.

2. EXPERIMENTAL

Tests were performed on carbon steel specimens with a chemical composition (C: 0.109, S: 0.015, P: 0.013, Si: 0.24, Mn: 0.72, Ni: 0.06, Cr: 0.009, Mo: 0.01, Cu: 0.02 weight %) close to those found in various carbon steel components of nuclear power plants. Specimens are straight tubes (8 mm internal diameter).

The FAC tests were carried out on the CIROCO loop using the following conditions:
- single-phase flow with water velocity for tubular specimens: 5 m/s or 10 m/s,
- temperature: 180°C or 235°C, pressure: 40 bar,
- water chemistry: conditioned water at pH25°C = 9.0 by addition of ammonia and hydrazine (hydrazine concentrations from 0 to 300 µg/kg). The corresponding pH value changes between 6.2 and 6.3 at 180°C and between 5.9 and 6.0 at 235°C (calculated with MultieQ code2),
- deaerated water ([O2] < 0.5 µg/kg) or oxygen concentration between 5 µg/kg and 40 µg/kg in the feedwater tank,
- test duration: 24 h to 100 h (until the steady-state FAC process is reached).

Monitoring of temperature, flow rate, pH, conductivity, oxygen and hydrazine is performed in situ. Oxygen and hydrazine are measured in the feedwater tank and in the test cell section. Water chemistry pH is controlled and adjusted by the conductivity value inside the feedwater tank.

The tubular specimen thickness loss rates were measured using the Thin Layer Activation (TLA) method with 56Co as a radionuclide surface marker. The principle is to bombard the sample with an ion beam, in order to activate it over a well-defined area and a limited depth. The loss of material due to the studied phenomenon can be related to the decrease of the material residual volumetric activity (accounting for the natural decrease of 56Co activity) which is measured on-line3,4.

FAC rate is calculated with the slope of the thickness loss when the steady-state FAC process is reached. In order to compare different run tests, results are expressed in terms of relative FAC rate with the ratio between the FAC rate in the investigated environment to the mean value of the FAC rate in the reference environment (without hydrazine and oxygen) in the same run-test.

The electrochemical potentials of platinum (redox potential) and carbon steel were measured in high temperature using an Ag/AgCl (KCl 10⁻² M) reference electrode provided by Studsvik. Measured potentials were converted to the standard hydrogen electrode scale (+0.18 V/SHE at 180°C and +0.11 V/SHE at 235°C) considering liquid junction potentials5. The accuracy of these values is not better than ±25 to 50 mV6.
3. RESULTS

3.1. Influence of hydrazine on FAC rate without oxygen

3.1.1. FAC results

First, two different effects of hydrazine on FAC rate of carbon steels has been exhibited on the CIROCO loop in strictly controlled water chemistry (deaerated : \( \text{O}_2 < 1 \mu\text{g/kg} \)) and mass transfer conditions (water velocity : 5 or 10 m/s). Figure 1 shows how the corrosion rate for a given hydrazine concentration changes relative to the corrosion rate obtained without hydrazine.

These results show two different trends with respect to temperature:

- at 180°C, hydrazine had no measurable effect on FAC rates other than the effect it has on high temperature \( \text{pH} \) (6.2 to 6.3);
- at 235°C, as reported previously\(^1\), an increase of the relative FAC rate for hydrazine concentrations from 0 to 150 \( \mu\text{g/kg} \) was observed. In this range, the maximum FAC rate increased by a factor of 2.5 with an average increase of a factor of 2. Then, a subsequent decrease of the FAC rate was observed for concentrations beyond 150 \( \mu\text{g/kg} \).

![Graph showing FAC rate versus hydrazine concentration](image)

\( \text{Figure 1: Relative FAC rate (ratio to FAC rate without hydrazine) versus hydrazine concentration for tubular carbon steel specimens exposed to a single-phase flow at 180°C and 235°C using ammonia (\( \text{pH}25°C = 9.0 \)).} \)

Considering firstly the corrosion test temperature (mass transfer through the boundary layer is the rate-controlling step) and secondly the observed low magnetite layer thickness, the FAC model carried out by \( \text{EDF}^7,8 \) provides a simplified expression of the FAC rate given by:

\[
\text{FAC rate} = 2 \ k \ \Box \ \text{Ceq}
\]

(1)

where \( k \) is the mass transfer coefficient, \( \Box \) the oxide porosity and \( \text{Ceq} \) the soluble ferrous iron concentration at the equilibrium with the magnetite. The value of \( \text{Ceq} \) depends on the \( \text{pH} \) of the water, hydrogen pressure and temperature.

In a previous study at 235°C\(^1\), surface analyses on specimen coming from FAC tests in the CIROCO loop have shown that the oxide layer consists of magnetite and that hydrazine has no effect on the surface oxide thickness. Moreover, hydrazine affects the sample surface by changing the aspect of the oxide grains and very likely the oxide porosity (affecting \( \text{Ceq} \) and \( \Box \) in reaction (1)).

The different behaviour between 180°C and 235°C could possibly be explained if this hydrazine effect is due to the hydrogen resulting from hydrazine thermal decomposition (2 \( N_2H_4 \rightarrow 2 \text{NH}_3 + H_2 + N_2 \)) which is very low at 180°C and becomes more important for \( T > 200°C \)^\(^{4,10} \). This hypothesis is examined below.
3.1.2. **Electrochemical results**

Measurements of electrochemical potential (ECP) on Platinum and Carbon steel have been performed in situ. Figure 2 exhibits these potentials versus the hydrazine concentration. The potential range indicates the reducing character of the studied environment.

The increase of hydrazine from 0 to 200 µg/kg causes a potential variation of about 30 mV at 180°C and 235°C. The measured redox potentials have an evolution in the range of the equilibrium potential of the hydrogen electrode. By only taking into account the hydrogen evolution and according to the Nernst and Henry's law\(^9\), this potential difference corresponds to a factor of 3 or 4 on hydrogen concentration in the environment:

- At 180°C : \( E(H^+/H_2) = -0.090 \text{ pH} - 0.045 \log P_{H_2} \)
  Without hydrazine, \( E_{Pt} = -0.38 \text{ V/SHE} \) corresponding to \( [H_2] = 0.3 \mu g/kg \). A factor of 3 leads to 0.9 µg/kg with 200 µg/kg of hydrazine. This increase of hydrogen concentration (0.6 µg/kg) could possibly be explained by the thermal decomposition of a part of hydrazine (20 µg/kg = 10%).

- At 235°C : \( E(H^+/H_2) = -0.101 \text{ pH} - 0.050 \log P_{H_2} \)
  Without hydrazine, \( E_{Pt} = -0.48 \text{ V/SHE} \) corresponding to \([H_2] = 12 \mu g/kg\). A factor of 4 leads to 48 µg/kg with 200 µg/kg of hydrazine. These values of hydrogen concentration are not considered possible.

The absolute values of ECP (i.e., the values versus the standard hydrogen electrode) have to be reconsidered taking into account the accuracy of the reference electrode (see § 2). Even if all 200 µg/kg of hydrazine decomposed, that would lead to only 6 µg/kg of hydrogen generated. In this case, a factor of 3 or 4 would correspond to an initial hydrogen concentration of 2 or 3 µg/kg (\( E_{Pt} = -0.44 \text{ V/SHE} \)).

It should be noted that for the flow rates and temperatures in the CIROCO loop, the calculated amount of hydrogen generation based on hydrazine decomposition data reported by Dickinson\(^9\) (i.e., 0% hydrazine decomposition at 180°C and approximately 20% hydrazine decomposition at 235°C) is 0 µg/kg hydrogen at 180°C and 1.2 µg/kg hydrogen at 235°C. However, unique loop characteristics, such as catalysis effects, may produce different results in the CIROCO loop which might not be inconsistent with the results presented above.

![Figure 2: Measured electrochemical potentials on carbon steel and platinum during the FAC tests in a single-phase flow at 180°C and 235°C using ammonia (pH_{25°C} = 9.0). 2 run tests at 180°C (black and grey)](image)

The Carbon steel ECP is not as reproducible as the Platinum electrode (i.e., one test run with ECP around -0.55 V/SHE and another test run with ECP around -0.6 V/SHE ; Figure 2, 180°C). The Carbon steel ECP is approximately 200 mV lower than that of Platinum.

The oxidation of the Carbon steel leads to the reduction of proton to hydrogen when oxidation on Platinum does not exist. So, ECP which is fixed by the cathodic reaction \((H^+/H_2)\) and consequently by the local activity (or partial pressure) of hydrogen, is lower on Carbon steel than on Platinum.
3.2. Influence of hydrazine and oxygen

3.2.1. Test results

In order to have a complete understanding of the possible impact of the water chemistry environment it is also important to consider the impact of redox conditions. So, some tests in the presence of oxygen and hydrazine have been carried out in the CIROCO loop.

Results in Figure 3a show that at temperature of 180°C and 235°C, the FAC process is stopped as soon as the oxygen concentration at the test cell is greater than 1 μg/kg. Electrochemical potential on Platinum and Carbon steel measured during the same tests have been summarised in Figure 3b versus the oxygen concentration in the test cell. ECP increases very quickly with oxygen concentration and reaches high values for oxygen concentration higher than 1.1 μg/kg (180°C) and 1.4 μg/kg (235°C). Another study shows that the oxygen concentration corresponding to the potential change depends on the water flow velocity: around 15 μg/kg oxygen for 0.3 m/s and less than that for 1 m/s at 280°C in the ammonia environment. It is consistent with our results which are just higher than 1 μg/kg for or 10 m/s at 180°C and 235°C.

It is only necessary to obtain more than 1 μg/kg oxygen to obtain oxidising conditions and potential higher than -0.5 V/SHE at 180°C and higher than -0.6 V/SHE at 235°C. According to the potential-pH diagram for iron at high temperature, the transition between magnetite and hematite is situated between -0.35 V/SHE and -0.45 V/SHE. The comparison between ECP measurement and calculated potential-pH diagram is not so direct for at least two main reasons:
- measured ECP are mixed potentials which are dependant on the local partial pressure of hydrogen and potential-pH diagrams are calculated for an hydrogen activity of 1.
- accuracy of reference electrode potential versus the hydrogen scale is not better than 25 to 50 mV.

In this case, it is possible to consider that the magnetite inside the pores of the original oxide layer could be progressively removed by hematite and consequently stop the FAC process.

Figure 4 shows the results in term of relative FAC rate versus the ratio between hydrazine and oxygen in the feedwater tank (Figure 4a) and in the test cell (Figure 4b).

- At 180°C: the FAC process started when \([\text{N}_2\text{H}_4]/[\text{O}_2]\) in the feedwater tank is higher than 8 and \([\text{N}_2\text{H}_4]/[\text{O}_2]\) in the test cell is higher than 80. This threshold ratio represents the amount of hydrazine for which the oxygen concentration in the test cell is lower than 1 μg/kg. (Figure 3a). It is important to note that in every experiment in which the test cell oxygen concentration was less than 1 μg/kg a measurable FAC rate was observed. Conversely, in every experiment in which the test cell oxygen concentration was greater than 1 μg/kg a measurable FAC rate was not observed.

* For the shortest test run duration (24 h), ECP values are not always totally stabilised and an arrow is added on the figures.
At 235°C, considering the lack of data, it is quite difficult to determine the limit value of \([N_2H_4]/[O_2]\) for which the FAC process was initiated. Nevertheless, this threshold should be lower than at 180°C because the kinetics of the reaction between oxygen and hydrazine is faster at the higher temperature. So, the amount of hydrazine necessary to consume the oxygen and obtain less than 1 µg/kg in the test cell must be lower.

![Figure 4: Relative FAC rate (ratio to FAC rate without hydrazine and oxygen) measured in a single-phase flow at 180°C and 235°C using ammonia (pH25°C = 9) with different amount of hydrazine and oxygen. (a) hydrazine/oxygen ratio in the feedwater tank (b) hydrazine/oxygen ratio in the test cell.](image)

Hydrazine consumption is due to two main reactions:
- thermal decomposition of hydrazine (important for T > 200°C) \(2 N_2H_4 \rightarrow 2 NH_3 + H_2 + N_2\)
- oxygen reduction by hydrazine: \(N_2H_4 + O_2 \rightarrow N_2 + 2 H_2O\)

The remaining hydrazine available to reduce oxygen depends on the transit time of hydrazine at high temperature. So, the threshold ratio \((N_2H_4)/[O_2]_{fw}\) measured in the feedwater tank is characteristic of the CIROCO loop. With the test conditions and the design of the loop, the transit time at high temperature is not very long: around 18 s for a local water velocity in the test sample of 10 m/s and 36 s for 5 m/s. Moreover, there is no accumulation or recycle phenomenon.

In all cases, this threshold ratio \((N_2H_4)/[O_2]\), i.e., the amount of hydrazine for which the oxygen concentration in the test cell is lower than 1 µg/kg, must be lower at the feedwater location than locally.

For a short time of residence at high temperature (conditions in the CIROCO loop):
- at 180°C: \([N_2H_4]/[O_2]_{fw} = 8\),
- at 235°C: \(5 < [N_2H_4]/[O_2]_{fw} < 8\).

### 3.2.2. Correlation between FAC and electrochemical results

Figure 5 summarises the results at 180°C in terms of FAC rate and electrochemical potential values versus the ratio \((N_2H_4)/[O_2]\) cell (local conditions):
- in presence of hydrazine and oxygen, the FAC process started for the same ratio \((N_2H_4)/[O_2] = 80\) from which electrochemical potential decreased drastically, down to -0.6 V/SHE;
- without hydrazine and oxygen (open symbols: \([N_2H_4]/[O_2] = 0\), the reducing character of the environment (low ECP) is always correlated with the FAC phenomenon though the ratio is lower than the threshold (80).

The good correlation between FAC rate and low potential is confirmed by the situation at the threshold \((N_2H_4)/[O_2] = 80\) where there are two situations: a point with high potential (> -0.4 V/SHE) without FAC (dark grey and black points) and another one with low potential (< -0.6 V/SHE) and quite high FAC rate (relative FAC rate = 0.8, light grey points).

It is quite difficult to perform the same analysis at 235°C since there is not enough data with accurate measurements of hydrazine and oxygen.

* For the shortest test run duration (24 h), ECP values are not always totally stabilised and an arrow is added on the figure.
Figure 5: Electrochemical potential of Carbon steel and relative FAC rate (ratio to FAC rate without hydrazine and oxygen) measured in a single-phase flow at 180°C using ammonia ($pH_{25°C} = 9.0$) with different amount of hydrazine and oxygen. Hydrazine and oxygen concentrations measured in the test cell.

The good correlation between FAC and electrochemical potential can be illustrated with the Figure 6 at 180°C and 235°C. This representation allows determination of the electrochemical potential value for which the FAC process can start:
- at 180°C: transition around -0.45 / -0.5 V/SHE,
- at 235°C: transition around -0.65 V/SHE.

Figure 6: Relative FAC rate (ratio to FAC rate without hydrazine and oxygen) measured in a single-phase flow at 180°C and 235°C using ammonia ($pH_{25°C} = 9.0$) with different amount of hydrazine and oxygen.

According to the potential-pH diagram for iron at high temperature, the transition between magnetite and hematite is situated around -0.4 V/SHE (10 to 20 mV higher at 180°C and lower at 235°C). Measured ECP at 180°C show that the FAC phenomenon is stopped as soon as magnetite located at the bottom of the pores of the oxide layer is oxidised in hematite (ECP > -0.45 V/SHE). At 235°C, suppression of the FAC phenomenon occurs for lower ECP values than the theoretical one of transformation between magnetite/hematite. But at this temperature, hydrogen inside the pores can be much higher for two reasons:
- thermal decomposition of hydrazine to hydrogen and nitrogen,
- hydrogen generation by general corrosion.
On the other hand, there is no quantitative correlation between the FAC rate and the ECP value for values lower than the determined transition (Figure 6). It is only an indication of the FAC process existence or not.

4. IMPACT FOR PWR PLANTS

The present tendency for PWR units is to increase the hydrazine concentration to approximately 100-200 μg/kg, to minimise secondary side corrosion of steam generator tubing. However, several trends highlighting the effect of high hydrazine water chemistry on FAC damage of components within the secondary cycle based on the results obtained in the CIROCO loop:

- For low hydrazine water chemistry (i.e., when hydrazine is not in excess of oxygen), when the redox potential is not clearly fixed by a large excess of hydrazine, the residual oxygen or oxygen ingress in water could stop or reduce largely the FAC damage in component made of carbon steel.

- For high hydrazine water chemistry (i.e., when hydrazine is in excess versus residual oxygen), the results obtained on the CIROCO loop show two trends:
  - At 180°C, excess hydrazine imposes a reductive redox potential and FAC is not effected by hydrazine except for the effect of hydrazine on the at-temperature pH (an increase of the hydrazine concentration increases the at-temperature pH, thus decreasing the FAC rates).
  - At 235°C, FAC rates are effected by the hydrazine concentration, with a peak in the FAC rates at approximately 150 μg/kg hydrazine. It should be noted that the increase in the FAC rate is expected to be dependant on several variables: the residence time at high temperature if the thermal decomposition of hydrazine is involved, mass transfer of hydrazine from the bulk water to the component wall...

In a PWR unit, the components potentially affected by the increase in FAC rates under high hydrazine water chemistry are mainly (Figure 7):

- Piping located downstream the last High Pressure Feedwater Heater, including piping in the containment,
- High Pressure turbine drain lines,
- Drains from the Moisture Separator-Reheaters,
- Steam Generators Internals made of Carbon steel (Tube support plates, Dryers and Separators, Wrappers ...),
- and potentially Blowdown piping systems.

Several damages were reported in France in the final feedwater piping system just downstream of the check valve in Gravelines 1 to 4 where hydrazine concentrations in the range of 35 to 100 μg/kg were used\(^{14}\). FAC damages has also been observed in the carbon steel internals of the steam generators of Gravelines 2 to 4 in 1995\(^{15}\).

The impact of high hydrazine water chemistry on FAC damage in the final feedwater piping system were also reported recently in several US PWR plants (Diablo Canyon, Salem 2, Wolfe Creek, Palo Verde and Callaway)\(^{16}\).

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\(^{16}\) The impact of high hydrazine water chemistry on FAC damage in the final feedwater piping system were also reported recently in several US PWR plants (Diablo Canyon, Salem 2, Wolfe Creek, Palo Verde and Callaway).
It should be noted that an increase in degradations caused by the use of high hydrazine water chemistry is not easily observed in power plants, because of the large uncertainty in the nominal thickness of the line and the uncertainty of thickness measurement. For a thickness loss of about 0.1 mm/year (value not to be unexpected in the final feedwater when high pH chemistries are used), a period greater than 5 years is needed before observing any effect (if the uncertainty of the thickness measurement is on the order ± 0.25 mm). So, the problem in using high hydrazine water chemistry with respect to FAC is mainly related to the problem associated with plant maintenance (i.e., inspections and replacements) compounded by the balance between trying to mitigate IGSCC in steam generators and FAC in components and piping systems. Plant personnel need to be aware that high hydrazine water chemistry could potentially increase FAC in the single phase portions of the high pressure feedwater system, including piping in the containment and possibly the steam generators internals.

5. CONCLUSION

A common EDF and EPRI R&D effort has been recently carried out to study the effects of hydrazine and oxygen on FAC. The results of the tests performed in the CIROCO loop are presented as follows.

First, temperature (i.e., 180°C versus 235°C), is shown to be an important parameter leading to a significantly different effect of hydrazine on the FAC rate of carbon steels as exhibited in the CIROCO loop in strictly controlled water chemistry and mass transfer conditions:
- at 180°C, hydrazine had no measurable effect on FAC rates other than the effect it has on high temperature pH;
- at 235°C, hydrazine could enhance the FAC process for hydrazine concentration in the range 0-150 µg/kg with an average increase of a factor of 2; then, a subsequent decrease of the FAC rate was observed for concentrations beyond 150 µg/kg.

Next, in mixed conditions, the FAC process is stopped as soon as the oxygen concentration is locally greater than 1 µg/kg (180°C). According to the electrochemical potential measurements, this result is in relation with the formation of hematite in the pores of the original magnetite layer.

The ratio between hydrazine and oxygen necessary to stop the FAC process (i.e., to obtain enough oxygen) is determined. At 180°C, in the CIROCO loop conditions, the ratio must be at least 8 at the feedwater location and 80 in the local conditions. At 235°C, this ratio must be lower, taking into account the kinetics of the reaction between oxygen and hydrazine.

Finally, recent field experience has been examined with respect to these results in order to evaluate the possible impact of high hydrazine chemistry on FAC for PWR steam generators and feedwater piping systems. These results could allow secondary water chemistry specifications to be optimised in terms of hydrazine and redox conditions. Plant personnel need to be aware that high hydrazine water chemistry could potentially increase FAC in the single phase portions of the high pressure feedwater system, including piping in the containment and possibly the steam generators internals.

Moreover, additional studies are in progress to re-evaluate the phenomena at 235°C and to take into account others parameters such as pH, temperature, transit time, etc. The results of these studies on FAC of carbon steels can be considered in conjunction with the significant concerns of IGA/SCC of Alloy 600 SG tubing and tube fouling to optimise secondary-side PWR chemistry.
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