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The Influence of System Design, Station Operations and Cycle Chemistry on Corrosion Product Generation and Flow-Accelerated Corrosion (FAC) at Coryton Combined Cycle Gas Turbine (CCGT) Power Station

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ABSTRACT

A systematic study of the influence of system design, station operations and cycle chemistry on corrosion product generation and flow-accelerated corrosion (FAC) was carried out at Intergen's Coryton CCGT in Essex, UK. Coryton is a modern 779 MW two-by-one combined-cycle natural gas plant equipped with an air-cooled condenser (ACC). The plant was designed and constructed for operational flexibility and functional efficiency in a merchant power environment, which in practice means a cycling operation with occasional two-shifting. The study was instigated by the frequent occurrence of FAC in combined cycle power plants and the retrospective nature of non-destructive testing (NDT). The station wanted to invest in advanced monitoring techniques with the objective of reducing corrosion in the air-cooled condenser and the potential for FAC in the heat recovery steam generator (HRSG) during normal and cycling operations, and to determine the impact of cycling operation on unit life expectancy and reliability. Of special interest was the evaluation of the use of all-volatile treatment oxidising (AVT-O) versus all-volatile treatment reducing (AVT-R) chemistry control in the all-steel system as a means to reduce FAC in the HRSG and iron pick-up in the air-cooled condenser. On-line "at-temperature" Oxidation-Reduction Potential and Particle Monitor instruments were applied to supplement the standard array of chemistry and operational monitoring. The study should allow Coryton Power to identify the best cycle chemistry control specifications to minimise FAC and ACC corrosion, leading to more reliable, efficient and lower cost generation for the life of the plant.

INTRODUCTION

The practical measurement of oxidation-reduction potential (ORP) of condensate and feedwater at operating temperature and pressure can provide visibility to unfavorable conditions or events. These conditions or events impact plant reliability, thermal efficiency and plant emissions, and require both identification and development of strategies to prevent damage. It is usual to monitor and control pH, dissolved oxygen, acid conductivity and, when used, reducing agent residual, and to consider these parameters as an indirect measure of the corrosion potential of the water. Corrosion products are released every time there is a thermal, chemical, or hydraulic shock to the system. Intermittent corrosion product monitoring often leads to questions on the validity and interpretation of the data produced. Grab sampling only provides a snapshot, but if the full extent of the events could be made visible, responses can be developed to minimise corrosion and iron transport. The results from particle monitoring can be related to particulate iron levels with sensitivity in the ppb range. Moreover, the results from particle monitoring can be correlated to the ORP at operating temperature and pressure.

FLOW-ACCELERATED CORROSION

Consensus has formed about the causes of Flow-Accelerated Corrosion (FAC): these include materials of construction and geometry, low pH, low oxygen concentration, rapid or turbulent flow, and temperatures of ca. 150°C ± 50°C. The economizer outlet (typically single-phase) and the LP evaporator section (two-phase) are particularly susceptible to FAC, especially the upper bends and the upper header of the evaporator tubes. The metal

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wastage mechanism is accelerated by flow hydrodynamics, but the basic process is the dissolution of magnetite, which is directly related to the oxidation-reduction potential at system temperature and pressure. If the rate of dissolution of magnetite exceeds magnetite formation, then the metal surface becomes less protective resulting in tube thinning, which impacts station reliability and integrity.

The Electric Power Research Institute (EPRI) suggests that iron measurements can be used as an indicator for FAC. As the dissolution of magnetite results in the formation of iron hydroxide, the species of iron present can also be relevant. Particles of iron oxide may be dislodged when the passive film is disrupted by magnetite dissolution, contributing to the particulate levels and iron balance. EPRI suggests that high iron levels, under severe FAC conditions, always consist of over 95% particulate iron[1]. All of the above considerations contribute to make the measurement of the oxidation-reduction potential at operating temperature and pressure and particle monitoring a vital part of a FAC monitoring programme.

Specific mechanical and operational factors cannot be changed in most existing systems. The question of using reducing agents for metal surface passivation complicates matters. Long considered a best practice, institutes like EPRI now recommend against the use of reducing agents in all-steel systems, citing evidence that they increase FAC by increasing the dissolution rate of magnetite in the more reducing environment. However, when station operations, such as cycling or two-shifting, results in high variability in the at-temperature ORP environment, then the composition and properties of the passivation layer will also be in constant flux and under stress. Variable at-temperature ORP values lead to variable oxides with variable density and protective properties. Additionally, there are many systems where mechanical oxygen removal in the condenser is so effective that the feedwater system runs in a reduced state even with no reducing agent present. The opposite can also be observed in stations that experience highly variable oxygen levels, in excess of 10 ppb, during cycling and two-shifting.

Although EPRI has recommended against the use of a reducing agent in all-steel systems, they suggest using ORP measured in-situ as a means of controlling feedwater chemistry[2]. For all- steel systems they suggest a room temperature ORP value between 0 and +100 mV ($Ag/AgCl_2$, saturated KCl reference electrode). Research by Nalco has demonstrated that oxidation-reduction potential should be measured at operating temperatures and pressures (AT ORP®)[3]. Using the Nalco AT ORP technologies[4] for high-temperature and pressure evaluation of corrosion stress, as compared to room temperature oxidation-reduction potential (RT ORP), provides a much better technical solution. AT ORP is a more sensitive and realistic indicator of the actual condition at the system's metal surfaces. Research by Nalco on AT ORP measurement and control resulted in the development of a reliable, sensitive, high-temperature probe and control strategy that allow power stations to operate at a constant AT ORP value that facilitates the formation of protective metal surfaces[5,6].

The ideal monitoring programme would correlate the interplay of the oxidising environment with all of the relevant variables contributing to system corrosion and FAC across the AT ORP "space" and relate that to corrosion product generation and transport (Figure 1). The diagnostic and preventative value of this approach will be discussed in a case history format that describes the initial outcome of a study which is currently in progress. This study was prompted by the frequent occurrence of FAC in combined cycle power plants, the retrospective nature of non-destructive testing (NDT), the need for advanced diagnostic information, and the evaluation of cycle chemistry improvements.

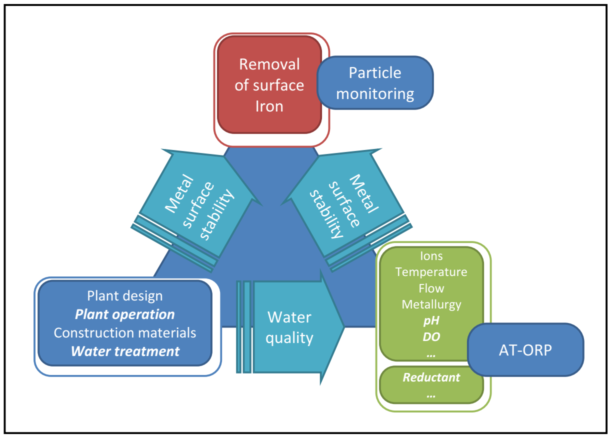
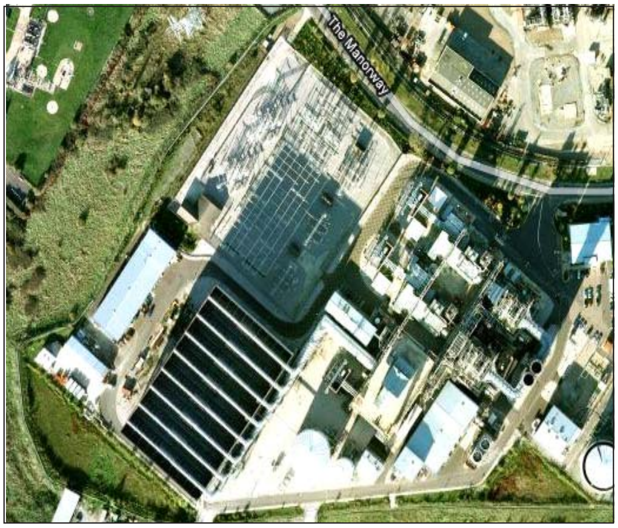


Figure 1 — *Holistic representation of how design, operating conditions and cycle chemistry influence the metal surface stability.*

CASE STUDY – CORYTON POWER STATION

Coryton Power is a modern 779 MW two-by-one combined-cycle natural gas power station equipped with an air-cooled condenser (ACC) and a pre-coat filter for particulate matter removal from the steam condensate. The plant was designed and constructed for operational flexibility and functional efficiency in a merchant power environment, which in practice means a cycling operation with occasional two-shifting.



Picture 1 – Coryton Energy Company Ltd (Source: Google Maps).

For the Coryton Power Station case study, we will examine the impact of station design, operation and chemistry on AT ORP and corrosion product generation from the air-cooled condenser and the low pressure (LP) section of the heat recovery steam generator. The LP section is part of the feedwater system and is currently operated in an AVT-R cycle chemistry environment (pH 9.4-9.6, 10-30 ppb reductant). The station operates at dissolved oxygen levels in the range of 30-70 ppb, peaking to levels above 100 ppb during low load conditions when cycling. For corrosion control in the air-cooled condenser, the water chemistry parameters, most noticeably dissolved oxygen and pH, are of primary importance in the absence of a volatile reductant. For the LP Section three scenarios will be discussed. The first scenario covers the collection of baseline data at 'normal' reductant dosage. In the second scenario, the reductant feed was changed. Finally, it is the intention to stop the feed of reductant and operate in an oxidising (AVT-O) mode, which is recommended by EPRI. Two AT ORP probes measured feedwater corrosivity. One probe was installed in the condensate system after reductant addition and after filtration (T= 45-50°C), and the second sensor on the LP evaporator (drum sample) (T= 120-130°C, p= 3.5 bar).

The particle monitor provides what the manufacturer describes as a "relative number". Higher numbers indicate more particles and lower numbers indicate fewer particles. Particle counts can be correlated to an exact number and then used to monitor metal transport. This correlation has been established for the Coryton Power Station (Figure 2).

AIR-COOLED CONDENSER

Iron pick-up and transport from the air-cooled condenser can be established via iron measurements on grab samples. These data can be augmented with online AT ORP measurements, particle monitoring, online pH and online dissolved oxygen measurements. The latter two are located after the condensate pump discharge.

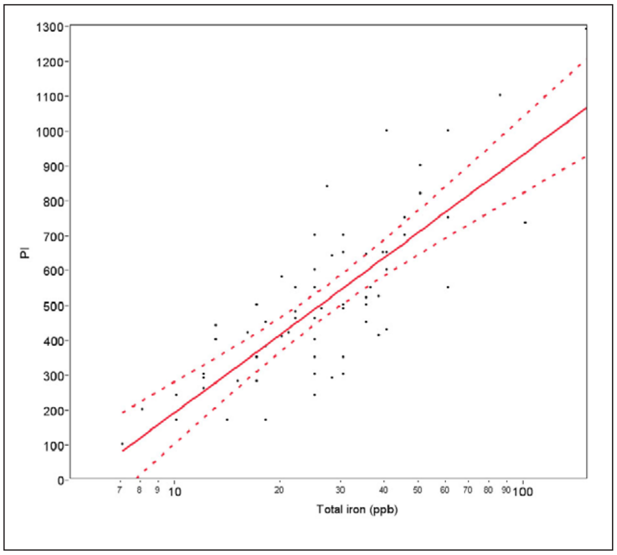


Figure 2 – ***Correlation between particle index and total iron with 99% confidence interval for the Coryton station.***

Oxygen ingress at the seals of the condensate pump was discovered during the trial, which hindered the establishment of a direct correlation between the on-line pH and oxygen measurements and corrosion of the air-cooled condenser (Figure 3).

Daily variability of ca. 100 mV of the feedwater AT ORP was observed which correlates well with dissolved oxygen (Figure 4). This variability can, in part, be attributed to the intervals at which demineralised water is added to the condenser hotwell.

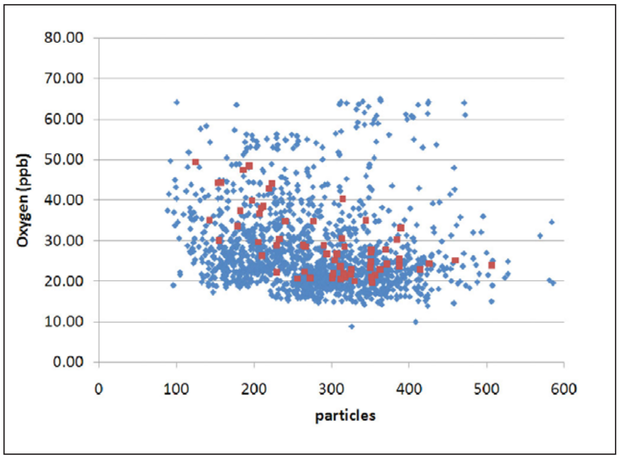


Figure 3 – ***Condensate discharge pump particle index versus dissolved oxygen (red squares without reductant feed).***

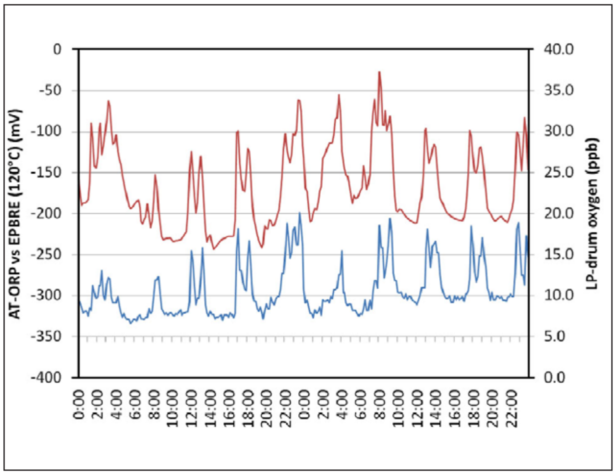


Figure 4 – ***The variability of feedwater AT ORP*** *(dissolved oxygen in red and AT OPR in blue).*

Variation in the AT ORP of the feedwater of this magnitude is likely to impact metal surface stability and should be minimised.

LOW PRESSURE SECTION OF THE HRSG

The test protocol included the evaluation of AVT-O versus AVT-R chemistry control specifications in the all-steel system as a means to reduce FAC in the Heat Recovery Steam Generator. The response of the system to a change in the level of reductant was virtually immediately (Figure 5).

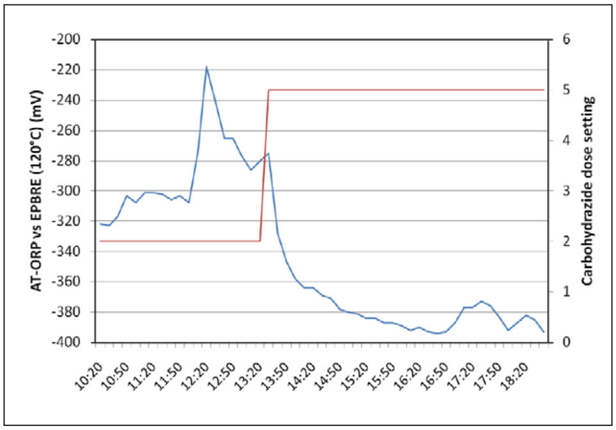


Figure 5 – ***Response time of to a 2.5 times increase in reductant feed.***

Moreover, it was demonstrated that there was a good response of AT ORP to different levels of reductant (Figure 6). It was not considered appropriate to stop the feed of reductant because that would bring the AT ORP value, in the presence of >100 ppb of dissolved oxygen, within the range typical for corrosion to take place. The VGB considers a dissolved oxygen level of 2-100 ppb as a reason for root cause analysis, but not to initiate an alarm condition[7]. Values above 100 ppb require corrective action. Once the oxygen ingress at the condensate discharge pump has been adequately addressed, a period of operating the plant without reductant feed could then be considered.

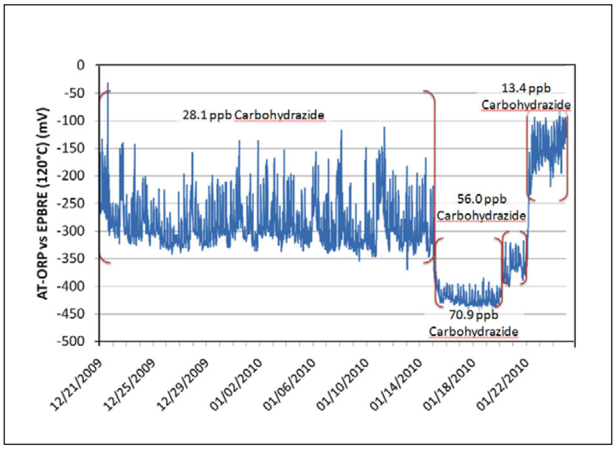


Figure 6 – ***Response in AT ORP to change in reductant concentration.***

The responsiveness of the AT ORP signal to different levels of reductant suggests that feedback control can be applied to allow the station to operate at a constant AT ORP.

One of the questions posed, based on earlier experiences with AT ORP technology, concerned the reduction in variability in AT ORP, and its impact upon reducing the number of iron oxide particles moving through the system. A good linear correlation between the variability in AT ORP and the average particle index was established (Figure 7). A logical next question is which AT ORP results in the lowest corrosivity and iron wastage in the LP section of the Heat Recovery Steam Generator, thus minimising FAC?

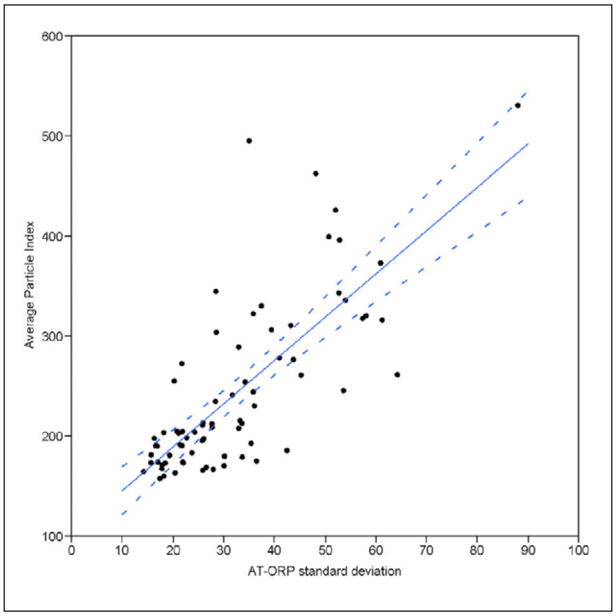


Figure 7 – ***Correlation between the variability in AT ORP and average particle index with 95% confidence interval.***

A statistical test (one-way ANOVA) was performed to determine the effect of different levels of reductant feed on iron transport (Figure 8). This test of variance determines if the arithmetic means of several groups are significantly different. The data set was restricted to data at high generating load to minimize the effect of other variables, such as the effect of cycling and associated particle bursts. Changes in plant load temporarily increases particle transport in the boiler system after which the particle count levels-off at a more elevated level. The Welch ANOVA test on this subset of high generating load particle count data rejects the hypothesis that all are equal, and identifies a significant difference between the groups of data obtained at different AT ORP values.

Tukey-Kramer is a single-step multiple comparison procedure and statistical test that can be used together with an ANOVA to determine which means are significantly different. Despite the unequal variances in the data, the Tukey-Kramer provides insight into trends and suggests that there is an AT ORP level around -300 mV that produces the lowest particle index.

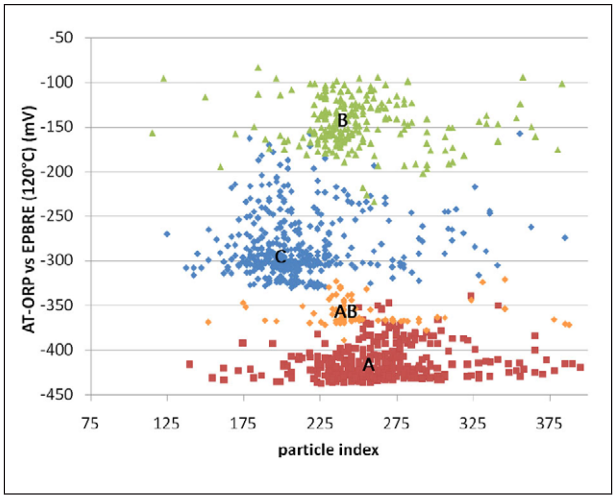


Figure 8 – ***LP drum particle index vs. LP drum AT ORP levels at high plant load (>240 MW GTB)*** *(B = 1/2 reductant dose, C = normal reductant dose, AB = double reductant dose, A = 2.5 times reductant dose).*

As shown in Figure 8, the feed of reductant can be used to lower the AT ORP levels into a bandwidth where iron pick-up and transport, thus metal surface wastage, is minimal. Above this level, the oxidative corrosion process becomes more prevalent. In addition, lower values should be avoided to minimise conditions favourable to FAC in the system. The effect of reducing conditions on metal surface wastage became especially evident at high plant loads and higher flow conditions.

The impact of flow has also been analysed for low load periods during the night. The effect of different levels of reductant under these conditions is less profound, which emphasises the impact of flow on metal wastage. This observation implies that special care should be taken with CCGTs that are equipped with, and frequently use, duct-burners to temporarily increase steam flow and generating output.

CONCLUSION

The first results of study of the influence of system design, station operations and cycle chemistry on corrosion product generation and flow-accelerated corrosion at Intergen's Coryton CCGT has been discussed in this paper. Although not all encompassing, the results demonstrate that AT ORP and particle monitoring techniques augment our knowledge of corrosion and FAC in modern CCGTs. The trial demonstrates that an optimum AT ORP of about –300 mV produces the lowest metal wastage. This value can be controlled via a feedback control loop to the reductant feed pump. Moreover, reduced variability in AT ORP results in a more stable oxide layer on the metal surface. Coryton Power and Nalco plan to extend the study to control the AT ORP of the LP section of the HRSG around the -300 mV value, and minimise variation in AT OPR through feedback control of the reducing agent. The goal of the longer term test is to reduce the corrosivity of the condensate, feedwater and LP boiler water, resulting in the lowest metal wastage and FAC. We expect the effect of different AT ORP levels to be more pronounced when longer periods of stable AT ORP conditions are evaluated.

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