Operational Plant Lifetime Assessment - UK National Nuclear Laboratory Experience – 15366

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ABSTRACT

Inspection and monitoring of the condition of key plant assets at the Sellafield Site is an important task in helping to enable the continued operation of the reprocessing and waste management facilities. This takes place within a range of environments, from non-active areas to highly active black cells where no man-access is possible. NNL staff work closely with the plant operators and other contractors in carrying out inspection and monitoring tasks, and have a particular expertise in the black cell environments where increased challenges exist. As plants age more work is required in order to underpin ongoing operations and understand the operational lifetime of key assets in order to achieve maximum throughput and utilisation. This paper discusses how expertise in a variety of different technical disciplines is combined in order to both understand and extend the operational life of the Highly Active (HA) evaporators at Sellafield, and a small number of further similar examples are also discussed.

INTRODUCTION

The UK National Nuclear Laboratory (NNL) is a Government owned organization that helps support primarily UK nuclear operations and carries out research and development work on behalf of UK and international customers. NNL was formed as part of the transformation of the UK nuclear industry over the last decade, and has its roots as the Research and Technology division within the now obsolete British Nuclear Fuels plc (BNFL). In its various guises, NNL has been involved in plant lifetime assessment work for 20+ years, and continues to provide new and innovative solutions to deal with present day challenges.

NNL work in the area of plant lifetime assessment is complementary to the service that the organisation provides in the area of plant inspection and assessment, including deployment into black cell areas of plant, via both integrated inspection ports and unforeseen routes that have required pre-existing containment to be broken and modified.

Plant lifetime assessment is a complicated task, particularly in the nuclear industry where plant access is often an issue, and specialist knowledge in a number of technical disciplines is usually required. NNL experts in the areas of plant inspection, statistics, corrosion and a variety of modelling disciplines work together to provide regular lifetime updates pertaining to key vessels in reprocessing and waste treatment plants on the UK Sellafield Site. Examples of this are discussed below, including how effective programme management and unique partnering arrangements have helped deliver complicated portfolios of work.

Computational Fluid Dynamics (CFD), thermal, process and structural modelling have been used in order to predict plant conditions and assess future operational limitations. Complimentary corrosion assessments have also been carried out, in order to understand the corrosion mechanisms and provide advice as to how plant operations can be modified in order to increase the remaining operational lifetime. This has often required unique operational conditions to be replicated under experimental conditions in both laboratory and rig hall environments, particularly with regards to nitric acid based liquors and cooling water systems.

The provision of bespoke, one of a kind experimental test rigs is a key part of the plant lifetime assessment jig-saw, as this allows plant conditions to be replicated, theories to be investigated, and solutions to be trialled and/or tested prior to deployment or application. Test rigs have been designed, built and operated by NNL to physically replicate operational plant and the use of such rigs is discussed below.

DESCRIPTION

HA Evaporator

The HA evaporators on the Sellafield Site are primarily used to concentrate raffinate (waste) liquors from the Magnox and Thorp reprocessing plants. These evaporators play an important role in the volume reduction of this waste, so that it can be stored in Highly Active Storage Tanks (HASTs) prior to encapsulation in the Waste Vitrification Plant (WVP) in preparation for long term storage. Thus the HA evaporators play a key role in support of HA waste treatment operations in the UK. Much of the recent attention has focused on evaporator C, which is currently the newest operational HA evaporator, prior to the commissioning of evaporator D, which is nearing completion of construction. Figure 1 below shows evaporator C stored horizontally prior to final installation in a vertical orientation.

Fig. 1. HA Evaporator C

The evaporator vessels are steam heated using a jacket and array of coils, all of which are also used as cooling components to prevent boil off of the HA liquor (HAL) at the end of each batch. Figure 2 is a schematic of part of an HA evaporator, showing a single heating/cooling coil. The raffinates fed into the evaporators are nitric acid based solutions containing relatively low concentrations of dissolved metal nitrate salts and very small quantities of un-dissolved solids. As the raffinate is concentrated to produce HAL significant quantities of solids are formed and the effect of these is taken into account within the assessment. In addition to the lifetime assessment itself the technologies applied and data produced are used to assess ways of extending the operational lifetime of the evaporator by varying the operational parameters. Ideas identified are technically assessed/confirmed and then discussed with plant operators in order to determine if and how they can be implemented.

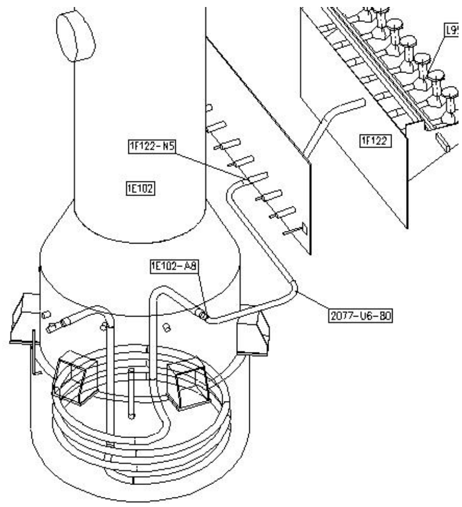

Fig. 2. Highly Active Evaporator Showing Coil

Modelling

A variety of modelling disciplines are used throughout the HA evaporator lifetime assessment process:

Structural modelling is used early in the process in order to understand the operational limitations of the vessels, including how thin various components may become before any potential failures may take place. Sufficient excess safety margin is included and clear minimum thickness limits are then set. As discussed later in this paper thickness measurement of key components within the evaporator is regularly carried out, and this data is then applied to the structural model to provide a more up to date representation of the vessel and to re-assess/confirm the limits previously set.

Thermal modelling plays an important role in the lifetime assessment as it provides a means of calculating the surface temperatures throughout the evaporator vessel. This allows corrosion rates to be determined when considered alongside thickness measurements, historic operational data, a detailed knowledge of the chemistry of the waste processed and careful consideration and understanding of the corrosion mechanisms that occur. Calculation of these corrosion rates then allows the future operational lifetime of the evaporator to be calculated based on an understanding of the liquors to be processed and at what rate the components will continue to corrode as they become thinner and surface temperatures change as a result.

Computational Fluid Dynamics (CFD) fluid flow modelling is used in order to assess how liquors/solids move around within the evaporator vessel during operations. The flow velocities of the liquor and location of the solids have an effect on the surface temperatures and therefore corrosion rates of the components. Experimental rigs, some of which are scaled replicas of the full scale evaporator, have been built in order to help understand the behaviour of HAL. CFD models are being developed to replicate the results of experimental rig trials with the intention of applying the findings to full scale active plant operations.

Process modelling is used to assess and improve the throughput of the evaporator vessel, by providing an understanding of the performance of the evaporator components and highlighting bottlenecks that exist. This can lead to operational improvements being made in order to alleviate throughput restrictions. In a similar fashion, process modelling is used to assess the effect of operational changes suggested to increase the operational lifetime of the HA evaporator, such as changing the operating pressure of the vessel. This provides assurance that the suggested change does not significantly impact on throughput or reduce the volume of HAL that can be processed during the lifetime of the evaporator.

Inspection Devices

Over the last decade a number of different inspection devices have been developed by the NNL Inspection team for deployment in the HA evaporators, with the majority of these having subsequently been deployed as part of lifetime assessment and extension projects. Such devices include the coil thickness inspection device, annulus device and base thickness inspection device. The coil thickness inspection device comprises a camera, lighting, centralizing units and an array of ultrasonic probes that allow the thickness of the coils to be measured along virtually their full length. This device has undergone various design changes and improvements as new challenges emerged and deployment experience increased. A recent version of this device is shown in Figure 3 below, and Figure 4 shows a typical thickness measurement plot obtained using the coil thickness inspection device shown.

Fig. 3. Coil Thickness Inspection Device

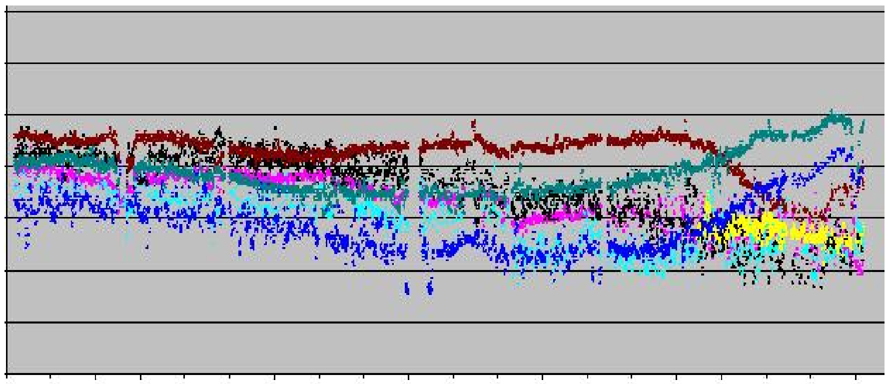

Fig. 4. Ultrasonic Thickness Measurements

Figure 5 below shows the HA evaporator base thickness inspection device which was designed for use via deployment into the annulus of the evaporator heating/cooling jacket. This device comprises a camera, lighting and a single ultrasonic probe which can be orientated and tilted in such a way as to ensure that the thickness of the base can be measured when it is deployed. This device has been fully tested using a non-active mock-up of HA evaporator C but has never been deployed on the active plant as advances made in the lifetime assessment methodology have prevented this being necessary. As a result the risk of deployment has so far been avoided.

Fig. 5. Base Thickness Inspection Device

During the design phase full scale evaporator coil/jacket replica rigs are used in order to carry out prototype testing, investigate potential design enhancements and test the accuracy of the devices developed. These rigs are also used to carry out a series of test deployments of the completed devices, including stakeholder witnessing, prior to the deployment in the operational plant. The use of these rigs leads to accelerated device development and improved stakeholder confidence throughout the inspection and lifetime assessment process.

Corrosion

A key component of the HA evaporator lifetime assessment is the understanding of the corrosion mechanisms that take place within the evaporator vessel. The evaporators are known to corrode as a result of ongoing operations and over the last decade a great deal of work has been carried out to understand the extent of this corrosion and the impact on future operational capacity. The nitric acid based raffinates processed through the evaporators have different corrosive properties, dependent on the fuel from which they have resulted. Therefore a detailed knowledge of the chemistry of HAL and identification of the key corrosion accelerators within this complex liquor is vitally important. In addition to process-side corrosion, water-side corrosion within the cooling water system also contributes towards the operational lifetime of the evaporator and hence must be considered within the assessment.

A great deal of small scale laboratory experimental work has been carried out over the last decade in order to understand the contribution that elements such as cerium, neptunium, technetium and iron make towards the nitric acid based process-side corrosion within the evaporators. Early lifetime assessment work showed that the actual plant corrosion measured via the coil inspections was larger than that predicted from corrosion experiments and this presented a significant challenge in explaining why this occurred. It became apparent that cerium speciation in nitric acid liquors held the key to explaining the differences seen, but not before significant work had been carried out to rule out other alternative explanations. Recent work using the Thermosiphon Test Rig (TTR) has resulted in experimental corrosion rates similar to those measured via coil inspection. As a result more accurate forward prediction of future corrosion is now possible, and more informed suggestion of operational changes to extend the lifetime of the evaporator is possible.

Construction of the TTR was necessary as the complex chemistry that occurs within the process-side of the HA evaporator could not be replicated in small scale laboratory tests. The full liquor height within the evaporator is replicated using the TTR and this has led to confirmation of the cerium corrosion mechanism postulated. Figure 6 shows the main features of the TTR. Corrosion and HA chemistry experts within the NNL Waste Behaviour and Materials (WB&M) team have worked together closely in this area and have been responsible for the recent advances in understanding. Complex non-active simulants have been developed and are used within the TTR to replicate the process-side conditions.

Fig. 6. Thermosiphon Test Rig (TTR)

As mentioned previously a base inspection device has been designed, built and tested, but has not yet been deployed in any of the HA evaporators. This is due to the fact that the lifetime assessment methodology has been developed to extrapolate the corrosion rates calculated for the heating and cooling coils onto the base of the vessel. This has been carried out by considering the results of the corrosion assessments alongside thermal modelling, statistical assessments and the use of another experimental rig known as the "Boling Rig" shown in Figure 7.

The Boiling Rig replicates closely the conditions at the base on the process-side of the HA evaporator. This is done by using steam to heat an 18/13/1 grade stainless steel plate made from the same batch that was used when HA evaporator C was constructed. A variety of non-active HAL simulants in contact with the heated plate have been used to replicate different liquors at different stages of operation, including solids present that are expected to have an insulating effect on the base of the evaporator. Surface temperatures and internal plate temperatures have been measured, allowing heat flux through the 18/13/1 plate to be calculated. As a result evaporator surface temperatures can also be calculated and the coil corrosion rates than extrapolated to apply to the base of the vessel.

Fig. 7. Experimental Boiling Rig

Statistics

Forward prediction of the remaining lifetime of the evaporator is carried out by taking into account the outputs from the inspection, modelling and corrosion work, and considering different options with regards to the source of the HAL to be processed in future, i.e. Magnox, Oxide or a blend of the two. Statistics play an important role in this calculation as a large amount of data is considered, which increases each time a new inspection is carried out, and the extrapolation of the measured coil corrosion rates to the base of the evaporator results in associated calculation errors. Statistical tools such as bootstrapping are used to improve the accuracy of the calculation, thus reducing the errors involved and resulting in a reduced minimum base thickness within the required 95% certainty parameter.

Reporting

The output from the evaporator lifetime assessment is updated on a regular basis each time new coil thickness measurements are taken using the coil inspection device. Inspections take place in line with an agreement between Sellafield Ltd and the UK Office of Nuclear Regulation (ONR), enabling evaporator operations to continue provided that agreed thickness limitations and operational constraints are not exceeded.

The updated evaporator lifetime report published each time is used to facilitate and underpin business and operational planning within Sellafield Ltd while providing the re-assurance that the Sellafield Site will be able to continue to provide the required level of support to the UK nuclear industry.

Programme Management

Over the last 10-12 years the UK nuclear industry has undergone significant change. BNFL plc was disbanded and a number of new organizations were formed as a result, including Sellafield Ltd and NNL. The Nuclear Decommissioning Agency (NDA) was formed, with the primary aim of accelerating the decommissioning of UK nuclear facilities, while driving efficiencies and reducing costs in the process.

These changes have resulted in different contracting arrangements between Sellafield Ltd and NNL, in contrast to the historic arrangements where both organisations were part of a single company, BNFL. Despite these changes significant efforts have been made over the last decade to sustain a strong partnership between Sellafield Ltd and NNL, while maintaining the formal contractual arrangements now required. This has been particularly successful within the Highly Active Liquor Evaporation and Storage plant (HALES) portfolio, within which the HA evaporator lifetime assessment work is included.

Successful features within this partnership include the existence of programme manager and technical programme manager roles within NNL. The incumbents of these roles have overall responsibility for project delivery and technical co-ordination of work respectively, giving single points of contact against clear accountabilities. Complimentary features have included 1:1 matching of Sellafield staff with project managers within NNL, and the facilitation of joint workshops to discuss recent results and agree future work programmes. The process used to scope and endorse individual projects and overall programmes of work has been streamlined, and various secondments and exchanges of technical staff have occurred, leading to increased understanding of operational constraints and day to day challenges across the two organisations.

Thorp Salt Free Evaporator Assessments

The Thorp Salt Free Evaporator (SFE) is a two stage thermosiphon used to concentrate various waste streams arising primarily from Thorp operations. During the lifetime of the Thorp reprocessing plant SFE has experienced some operating challenges, including the required replacement of one of the associated vessels due to process-side corrosion. NNL have been involved in the lifetime assessment of the SFE system, and continue to carry out periodic inspection of the key vessels to monitor their condition as operations continue. While not as complicated as the HA evaporator assessment, support to SFE has involved a variety of experts from within NNL, primarily in the areas of plant inspection, corrosion and HA chemistry.

Cooling Water Systems

The HALES plant at Sellafield requires a high capacity cooling water system to maintain the required operating conditions to ensure ongoing storage of HAL prior to vitrification in WVP. A number of the older plants on the Sellafield Site also have similar cooling water systems. As the plants age more robust lifetime assessment is required to support continued operations and ensure availability of the plants to complete the Sellafield mission.

Over the course of a number of years a large programme of waterside corrosion work was carried out in support of the HALES plant, in order to understand the operational constraints and identify best practice for future operations. This included the completion of medium to long term corrosion experiments and attempts to identify a suitable inhibitor for addition to the cooling water system. A more robust understanding of the HALES cooling water system resulted from this work, and the knowledge gained has since been used to support the continued operation of other cooling water systems on the Sellafield site, primarily via lifetime assessment activities.

Once again an array of technical expertise is required to carry out such lifetime assessments, including structural and thermal modelling, plant inspection, corrosion and radiation chemistry expertise.

CONCLUSIONS

NNL staff work alongside Sellafield Ltd and other contractors to provide a variety of robust lifetime assessments that help to underpin the continued operation of key assets on the Sellafield nuclear reprocessing and waste management site in the UK. These assessments, such as that for the HA evaporators, often require complicated programmes of work requiring input from a number of different technical disciplines. Focus on the technical programme management of such complicated programmes has led to improved efficiency and cost-effective delivery of the associated business benefits.

It is important to maintain a significant level of expertise to support lifetime assessment requirements, particularly where unexpected challenges are likely to occur, and where the required operational lifetime of facilities becomes longer than the expected design lifetime of the plant. Expertise acquired through plant lifetime assessments is often transferrable to other similar or related facilities, nuclear or otherwise.

REFERENCES

N/A.

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