INTRODUCTION

Steam reformers are the heart of the operation for hydrogen, ammonia and methanol producers. Within the steam reformer, catalyst tubes are one of the most critical and expensive components. With the price of nickel at an all-time high, the cost of installing a single reformer tube can be upwards of $30,000 USD and require a purchase lead time of 17 weeks or more. Even more important in today’s highly competitive markets, the effect of unplanned downtime in reducing the on-stream factor is far greater than the installation cost of a single reformer tube.

Individuals at the plant level responsible for day-to-day monitoring and operation of these assets commonly rely on external experts to conduct specialized reformer tube inspections and remaining life assessments. The quality of such data can positively or adversely affect the operational decisions made by plant engineers. Therefore, a solid inspection and remaining life assessment program with a proven track record is essential.

Globally for more than a decade, hundreds of plants have relied on the quality inspection data produced by the Laser-Optic Tube Inspection System (LOTIS®) technology. Further complimenting LOTIS is the external tube crawler technology, now branded as MANTIS™. A combined internal and external tube crawler inspection approach has provided clients with the ability to inspect steam reformer tubes, regardless of whether catalyst was present.

Over the last few years, MANTIS has undergone a major enhancement redesign. To further complement the precise creep strain data already being collected, an innovative technique called permeability cross-canceling eddy current was added, providing crack detection capabilities. For years, conventional eddy current has been applied to inspect reformer tubes with limited success. The challenge associated with conventional eddy current is that permeability variations within the reformer tube material will often produce erroneous inspection results. This can result in premature retirement of expensive tubes which were in good condition, or worse, leaving tubes in the steam reformer which are at the end of their useful life.

For decades the nuclear industry has dealt with permeability variations when inspecting critical high alloy tubes. Due to the enormous risk associated with component failure in nuclear power plants, the industry developed a unique eddy current approach which eliminates the effects caused by this phenomenon. In addition, the need to place high powered saturation magnets near the eddy current sensors is also eliminated. MANTIS leverages this unique approach, and, for the first time, applies it within the hydrogen, ammonia and methanol industries. Even with this new approach, it is important to note that eddy current will only detect creep strain damage when cracking is present, or when close to 80% of the tube life is consumed (see Figure 1).

FIGURE 1
Creep Strain detection verses Eddy Current Detection Overlay comparison
The eddy current functionality added to MANTIS was developed specifically to provide crack detection capability. The prime method of detecting normal service creep damage remains measurement of diametrical expansion. However, the presence of cracks is not the only factor that may influence the eddy current signal and the data may be interpreted to identify these influences. These include:

- Cracking - the principal reason for employing eddy current technology
- Minor effects caused by creep void formation prior to crack formation
- Material changes caused by the extended exposure to service temperatures (aging)
- Manufacturing defects such as inclusions, porosity and cold-shuts

MANTIS allows confident interpretation of cracking. The other influences however, may be more difficult to identify and are referred to as metallurgy changes in this paper. While positive identification of these eddy current effects may be difficult in isolation, in combination with the diametrical expansion data the risk associated with these readings can be assessed.

INSPECTION TEST RESULTS

Detecting and quantifying creep strain in its early stages allows plant engineers to proactively make operational or physical design changes to the reformer to extend tube life. Three-dimensional modeling of creep strain damage in both individual tubes as well as the full population of tubes provide powerful visual aids in understanding the root cause of the damage (see Figure 3). Both LOTIS and MANTIS technologies provide full 3D modeling of inspection data within minutes of collection.

REMAINING LIFE ASSESSMENT

The precise inspection data captured by LOTIS and MANTIS feed directly into Quest Integrity’s proprietary LifeQuest™ Reformer software, thereby providing remaining life assessment for each inspected tube, following the guidelines developed by API 579 and ASME FFS-1/2007. Finite Element Analysis using Quest Integrity’s proprietary materials database assesses through-wall creep damage gradient and includes longitudinal and through-thickness stress gradients to accurately model current condition, historical stresses and predicted stresses (see Figure 4).

This database includes creep properties in as-cast and aged conditions of HP alloys and microalloys, and represents years of empirical data. Additional creep testing on both uniaxial and tube samples is ongoing, thereby continually expanding the database.

A proprietary creep model has been developed that captures the unique behavior of HP alloys. The model incorporates the various stages of creep damage, as well as material aging, formation and growth of microcavities proven by extensive laboratory research and field testing programs. The tertiary creep stage, where creep rate accelerates prior to rupture, is captured with a continuum damage model where void fraction increases with strain accumulation.

This solution monitors tube life over the entire life cycle, while other techniques that rely on creep cracking damage are typically only useful at or very near end of tube life (when greater than 80%
damage has occurred). This is often too late for remnant life prediction or effective tube replacement management.

The LifeQuest Reformer life assessment approach requires the following four significant pieces of information:

- LOTIS or MANTIS tube diameter (strain) inspection data
- Total service time of the tube(s)
- Operating history (e.g., shutdowns and significant trip events)
- Future expected and planned operating conditions

While the above is required for engineering assessment, additional information such as internal or external temperature history, catalyst performance and past inspection data will also be incorporated into the engineering analysis, subject to availability.

The model effectively calculates a strain-rate or creep curve similar to that shown in Figure 1. This curve is adjusted by the LifeQuest Reformer model to account for the effects of cyclic operation, such as shutdown cycles and significant trip events. Of the infinite number of possible creep curves dependent on temperature, pressure and location along the axial length of the tube, only one will pass through the unique value of strain and time as defined by each LOTIS or MANTIS data point. The definition of such a strain-rate curve allows the failure of the tube to be predicted and hence, the remaining life to be estimated.

The remaining life of each tube is clearly a principal of such an exercise and is reported in a typical LifeQuest Reformer report in tabulated form. These data can be analyzed in a variety of ways, and an example customized to work with future shutdown schedules is illustrated in Figure 5. Such data allows refinement of tube procurement scheduling.

CONCLUSION

Inspections conducted by LOTIS or MANTIS technologies are key to an accurate and comprehensive data collection process. Critical steam reformer tube inspections can be completed quickly, thereby minimizing furnace downtime. Preliminary results can be available within minutes data download from either inspection technology, enabling engineers to make real-time decisions concerning the return of the steam reformer to service.

The major benefit of applying a comprehensive inspection and remaining life assessment program is increased confidence in actual tube condition coupled with the knowledge of how long it will continue to operate without failure.

REFERENCES

1. API, RP-573 (2003) Inspection of Fired Heaters and Boilers, Washington DC USA


