A FINE BALANCE

D. J. F. Drabble and C. W. Thomas, Quest Integrity, New Zealand, present a method that provides good information regarding the balance of reliability and production in the primary steam reformer.

The primary steam reformer often ranks highly in plant risk assessments, due to complex damage mechanisms and large consequences of failure. However, the risk associated with the primary reformer is highly dependent on its operation. A balance exists between reliability and production, and in some cases it is necessary to operate close to the limits. This may be either intentional (i.e. in order to maximise production), or simply a consequence of a separate issue (i.e. catalyst deactivation).

In order to do this successfully, it is necessary to understand the effects of operating conditions on reliability.

This article describes an engineering methodology for understanding risk, particularly in catalyst tubes, and how to make decisions regarding operation. A successful case study is described in which the production of a hydrogen-constrained unit was optimised through inspection and engineering.

Introduction

Primary steam reformers represent an integral part of the process chain in ammonia, methanol, and other petrochemical plants. By nature, their design is often aggressive, due to the need for harsh operating conditions and specialty materials. A failure in the primary reformer typically has large financial implications, most often into the millions of dollars, as significant downtime is incurred alongside the costs of tubes, engineering, and catalysts.

The primary damage mechanism in catalyst tubes is creep, which causes diametric expansion and eventually leads to leak failure. Creep is a highly temperature-dependent mechanism, and the service life of a catalyst tube is exponentially affected by tube metal temperature (TMT). The rule of thumb is that 10 – 15°C change (approximately 20 – 30°F) can halve or double the life a tube. As one tube failure most often necessitates a plant shutdown, it is therefore said that

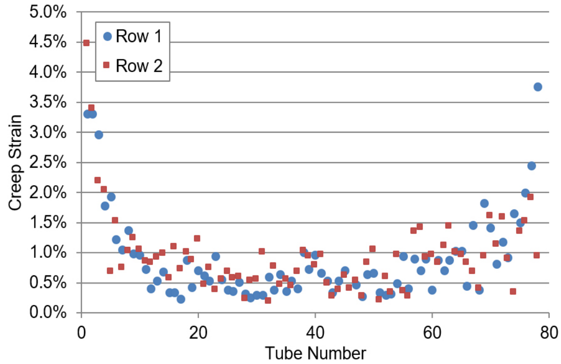

Figure 1. Distribution of creep strain within furnace.

the reliability of a reformer is controlled by the maximum tube metal temperature.

The production (hydrogen output) of a reformer also scales with temperature, driven largely by the endothermic reaction: $CH_4 + H_2O \rightarrow CO + 3H_2$. Increasing the tube operating temperature pushes the reaction towards the right hand side, effectively increasing the 'efficiency' of the reformer. The production of the unit is controlled largely by the average temperature throughout the tube set. Therefore, a balance exists between reliability and production. Operating temperature can only be increased so far before the reliability of the tubes (and potentially other downstream components, such as pigtails and manifolds) is compromised. The cost of unplanned outages is such that the decision is ultimately one of economics and risk management. In some cases, the reformer is operated heavily towards the reliability aspect, as hydrogen production is not a bottleneck. In other cases, extra production from the steam reformer translates directly into increased product (this is often termed 'hydrogen constrained'). It is these cases in particular where competitive advantage can be gained by ensuring the reformer is run at its optimum conditions.

This article describes the methodology for understanding reformer tube condition, and how it is related to the operating conditions of the furnace. A case study is presented in which this methodology was successfully applied to optimise production in a hydrogen-constrained application.

Methods

In order to optimise reformer operation, it is important to have good information on both sides of the equation. Understanding the effects of operating conditions on production is relatively straightforward. Plants are frequently run at varying 'loads' depending on many factors, such as feed gas contracts, feed prices, storage, transportation, and product prices. In the case of hydrogen-constrained plants, the production side of the equation becomes fairly simple; production (and hence temperature in the reformer) should be as high as possible.

Understanding the reliability side of the equation is somewhat more complicated. There are two major obstacles on the engineering side: the difficulties in monitoring temperature and the complexity of the material. Metal temperatures are typically measured using infrared (IR) techniques from the site ports of the reformer. The measurements are affected by several factors, such as the angle of incidence, the measurement distance, and additional reflections from other tubes and furnace interior surfaces.[1] These uncertainties may be on the order of 50°C (90°F) and therefore become highly significant when the aforementioned rule of thumb is considered.

A widely-used method for the determination of remaining life in reformer tubes based on inspection data has been developed, known as LifeQuest Reformer™.[2] This programme is based on over 20 years of research and creep testing of common reformer tube alloys. In particular, it is designed to capture the effect of material aging, which causes significant reduction in creep strength during service, independently from the accumulation of creep damage. The major advantage of this approach is that it is strain-based, as opposed to temperature-based, and therefore is not subject to errors in temperature measurement.

Within the programme, the operating temperature is back-calculated from the strain. This allows the effects of changes in operating conditions to be analysed. In effect, the programme can be used to develop integrity operating windows (IOWs) depending on requirements in the future. These IOWs may be based on corrected IR temperatures in conjunction with specialty temperature correction programmes,[3] or based on relative changes in uncorrected measurements, provided the same tools and measurement techniques are used.

Historically, the programme has been primarily used in order to determine remaining life and fitness-for-service of reformer tubes.[4] Recently however, the programme has been utilised more in engineering decisions regarding the operation of the reformer. These decisions fall into two categories: intended changes in the operation to influence production; or non-intended changes in operation, for example analysing the effect of tube hotspots caused by flame impingement or local catalyst deactivation.

A case study from the first category is described in the following section.

Case study

This case study relates to a steam reformer operating in Southeast Asia, with 156 tubes in two rows of 78. The plant is currently hydrogen-constrained, and so there is significant advantage to be gained in increasing its hydrogen output. The reformer was commissioned in 2009 and first inspected internally in 2016. At that time, significant diametric expansion was found, but the damage was seen to be very localised. In particular, the damage was restricted to only a few tubes at either end of each row. The majority of the tubes showed very little damage. The strain distribution from 2016 is shown in Figure 1.

With reference to the balance described in the introduction, this is not an ideal scenario. The reliability in this case is controlled by the end tubes, which showed

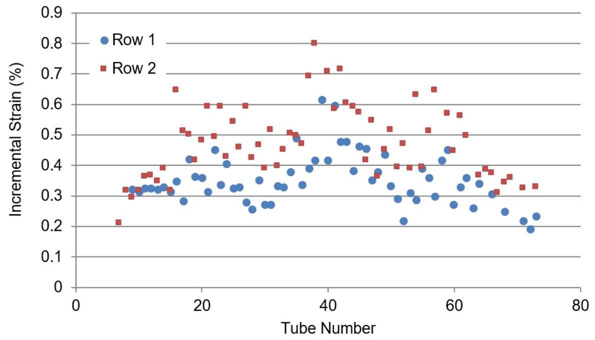

Figure 2. Incremental strain distribution for 2016 – 2018 period.

high damage, whereas the majority of the tubes were working within their limits, thereby limiting production.

The first decision made related to the end tubes. Remaining life assessment performed at the time of inspection showed that there were a few tubes which were not fit for service through the next operating period. These tubes were predicted to exceed 80% calculated life during that time. It was therefore recommended that some tube replacements be made. However, due to turnaround time constraints, this was not possible. It was decided instead to continue to operate these tubes but with reduced operating conditions for the next period, necessitating the calculation of IOWs. As the critical tubes were grouped together at the end of the tube rows, it was decided that this could be achieved through local adjustment of burners (in fact, just the burners at each end).

In order to calculate the allowable operating conditions for these tubes, specialty software was utilised. The simulated operating temperature for the next operating period was varied until it was deemed that no tubes would exceed 80% life before the next major turnaround. The allowable limit corresponded to a reduction of 30°C compared to the previous period. As a consequence, the reformer was returned to service with a reduction of 30°C in the allowable TMT limit on the end tubes only. The allowable TMT for the remainder of the furnace was very slightly increased to maintain production. Note that these changes were reviewed as part of a management of change programme.

Despite the significant damage in 2016, the unit ran without failure for two years until 2018, when it was shut down again for its scheduled turnaround. The internal reformer tube inspection was repeated and this time the incremental strain (i.e. strain between 2016 – 2018) was calculated. The results of this calculation are shown in Figure 2. Note the end tubes had been replaced prior to the inspection.

Three findings are important here:

- No tubes showed significant damage, indicating that the risk of online failure was very low. All tubes subsequently passed a fitness-for-service remaining life assessment for the next two year period.
- The damage profile has been essentially inverted compared to the previous profile (Figure 1). This has ensured that the tubes with lower damage, as of 2016, have been asked to work slightly harder in the following period (and vice versa). This was seen to be an effective method for maximising production with negligible added risk.
- All tubes showed some damage. This may seem a counter-intuitive statement. However, when it is considered that both life consumption and production are tied to temperature, it in fact is an excellent finding. The vast majority of reformer tubes inspected in furnaces globally show zero damage, indicating that they are fully capable of higher production (of course this is not always required). The fact that in this case the entire furnace showed low, but not zero damage, indicated that the operating conditions between the last two inspections were optimised for production at no significant cost to reliability. Ultimately, the furnace was shown to be well balanced and all tubes had contributed equally to hydrogen production.

Following the inspection, another engineering decision was to be made concerning the next operating period (2018 – 2020): continue operation as per the 2016 – 2018 period; or increase the allowable TMT by 18°C.

It was found that continued operation at the 2016 – 2018 limits resulted in four replacements being required in 2020. Increasing the allowable TMT was permissible in terms of fitness-for-service until 2020, but the result was that over 60 tube replacements would be required in 2020. This allowed the plant management to consider the economic impact of each scenario and tailor the operation of the furnace with good information.

Conclusion

A method has been presented in this article which provides good information regarding the balance of reliability and production in the primary steam reformer. This method has been used heavily in remaining life assessment of reformer tubes, but has also been recently applied to higher level engineering decisions. The method has been shown to:

- Provide good information on the reliability limitations of each furnace.
- Determine where each reformer sits on its production versus reliability spectrum.
- Predict the impacts of changes in operation (either intended or non-intended) in order to make decisions regarding production or risk. **WF**

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