know your steam reformer

Diana Tudorache and Marie Basin, France, and Dieter Ulber, Germany, Air Liquide, look at state-of-the-art solutions for optimising reformer performance.

While optimising operations towards minimum production cost at maximum plant availability and reliability, the operators of steam methane reforming (SMR) furnaces typically face a number of challenges, including the following:

- Process analytics and optimisation of operating parameters.
- Catalyst tube monitoring during operation.
- Control of the SMR combustion system and the heat distribution inside of the firebox.

In order to better meet the needs of the customers, more than 30 researchers, reformer operators and engineering teams jointly work within Air Liquide to develop innovative technologies and solutions to continuously improve the efficiency and reliability of the more than 85 SMR units operated by Air Liquide worldwide, producing more than 2 million Nm^3/hr of hydrogen.

The state-of-the-art solutions and tools for plant optimisation developed and first deployed at Air Liquide plants are now available to other SMR operating companies, and will enable them to do the following:

- Perform plant energy audits.
- Implement accurate, reliable and reproducible tube temperature monitoring.
- Resolve heat distribution issues by minimising the temperature spread inside the SMR firebox.

Plant energy audits

Getting reliable plant data is at the heart of the challenge of plant operation and optimisation. Data reconciliation is a powerful technique that has been used for the past two decades to establish accurate plant heat and mass balances. At the same time, it is widely acknowledged that process measurements may not be 100% accurate.

Methodology

Air Liquide developed a methodology using an equation-based commercial software (Belsim Vali®). This tool uses information redundancy, conservation laws and thermodynamic principles to correct raw measurements and convert them into accurate and reliable information. The statistically corrected (reconciled) measurements and estimates are consistent with respect to the mass and energy balances of the considered process.

The first step of the methodology consists of evaluating the plant heat losses, which are relevant for the heat balance and may open ways for savings by adding additional insulation in key areas. The second step is building a dedicated model of the plant including all the sensors from the P&IDs. Finally, the last step before reconciling plant data is to evaluate the sensors' accuracy.

The outcomes of data reconciliation are as follows:

- Reliable and accurate plant balances.
- Key performance indicators computation with their uncertainty.
- Access to non-directly measurable parameters (e.g. PSA yield, catalyst activity, etc.).

This is the basis for further plant optimisation as described hereafter.

Case study: gains achieved on a 130 000 Nm^3/hr plant

A 130 000 Nm^3/hr H_2 plant was the first candidate to deploy data reconciliation a few years ago. The benefits of the study were twofold:

- Achieving an accurate plant performance evaluation.
- Highlighting potential for efficiency improvement.

The key performance indicator for SMR plants within Air Liquide is the thermal efficiency indicator (TEI), which measures the overall energy export over the energy consumption of the plant. Computing this indicator with

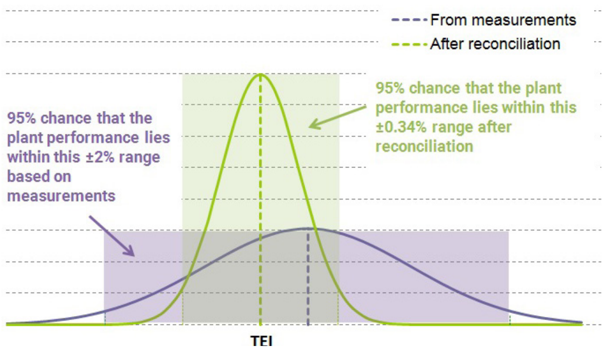

Figure 1. Plant thermal efficiency indicator range before and after data reconciliation.

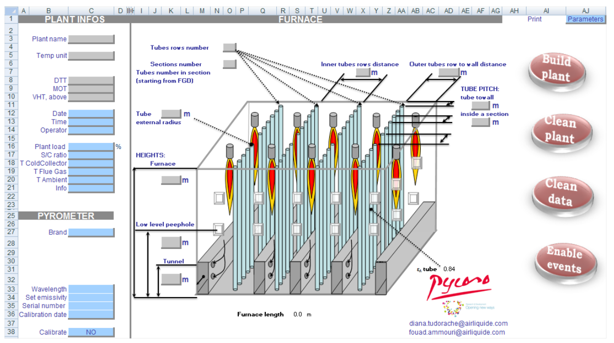

Figure 2. PYCOSO interface.

accuracy is crucial to evaluate plant performance and compare them with expected or design performances. A manual calculation done with process measurements and their accuracy landed a TEI with an accuracy of ±2%. The range of statistically probable values was so wide that it was not possible to conclude if the expected performance was met or not. Data reconciliation helped to improve this accuracy, reaching a high precision of ±0.34%. This is shown in Figure 1.

Based on accurate plant data obtained, the plant operation can be optimised. Data reconciliation computes key data, which allows for cost-saving adjustments without further investment. The findings for this case study were as follows:

- The steam to carbon (S/C) ratio was found slightly higher than its displayed value in the distributed control system (DCS). This provided an opportunity to optimise the performances and manage the risks of a low S/C ratio. A decrease of S/C as low as 0.1 would mean €100 000/yr savings for the plant.
- The flue gas temperature at stack was found higher than measured. More heat could then be recovered for preheating. A change in heat exchangers' operating set points could yield up to €130 000/yr.

This technique has been employed at numerous large SMR plants operated by Air Liquide.

Reliable and reproducible tube temperature monitoring

To get the best performance and highest reliability of steam methane reformers, an accurate, reliable and reproducible measurement of the SMR catalyst tube skin temperature is of major importance in order to detect hot tubes and to avoid excess design temperatures during operation. The availability of such data allows the operator to do the following:

- Operate the SMR unit at the highest possible SMR tube temperature, leading to maximum efficiency.
- Avoid exceeding the design limits of the SMR catalyst tubes, which can lead to major equipment failure in a short period of time.

Another tool, PYCOSO (Pyrometric Correction Software), provides accuracy to pyrometry measurements, which are subject to various uncertainties and complex specific corrections. Pyrometry is based on the measurement of radiation at a specific wavelength range that is converted by a detector into a temperature value.

When pointing out a SMR catalyst tube, the pyrometer receives the radiative flux leaving the tube surface, both emitted by the tube, but also reflected from the surrounding walls.

PYCOSO calculates the correction that must be done to retrieve the actual temperature of the tubes from:

- Tube temperature direct measurements.
- Wall temperature direct measurements.
- The exposition of the measured tube to the nearby walls.

Otherwise, as the walls are hotter than the tubes, the actual tube temperature may be overestimated up to 20°C. A tube facing a high temperature wall will have a higher correction than a tube situated in the middle of the furnace.

PYCOSO is a plant-universal tool with a user-friendly interface shown in Figure 2. It was successfully deployed to numerous Air Liquide SMR plants worldwide.

Implementation and benefits

The tool provides more accurate tube temperature values, leading to maximum operating margins. An example is given in Figure 3, showing the tube temperature distribution in a large SMR plant operated at nominal load. Measurements evidenced several tubes with raw temperature values exceeding the maximum operating temperature. Nevertheless, the more reliable PYCOSO corrected temperatures were all below SMR catalyst tubes' design temperature limit and thus the plant could be operated at nominal load or higher.

Mitigation of tube temperature spread in an SMR plant

For the safe and optimised operation of an SMR plant, the temperature difference between the hottest and the coldest SMR catalyst tubes is critical. This temperature difference is commonly called tube temperature spread, and it has to be reduced in order to operate the SMR furnace more efficiently. For large units, the spread can be up to 90°C. Such high temperature spreads provide significant potential for energy savings to the extent of several hundreds of thousands of euros per year.

Furthermore, high temperature spreads can limit the production capacity of the SMR unit, in case the design temperature of the SMR catalyst tubes is met for individual tubes before reaching full plant capacity.

As a result, finding mitigation strategies is of great interest for companies operating SMR plants.

An intuitive way to process is to adapt the power of each individual burner to homogenise the heat transfer to the reforming tubes. This strategy is called 'burner throttling' and has

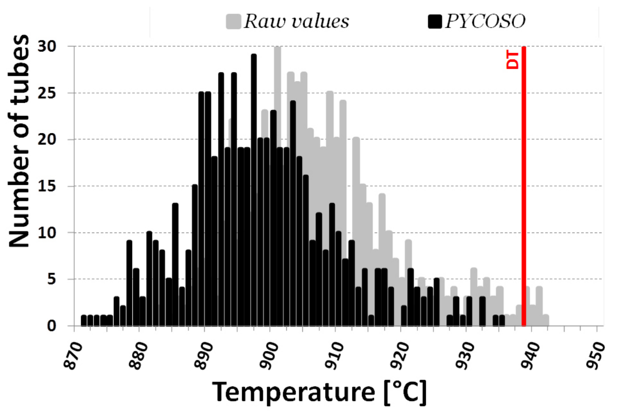

Figure 3. Tube temperature distribution in a large scale SMR plant. Comparison between raw values (in grey) and reflected luminance corrected values with PYCOSO (in black).

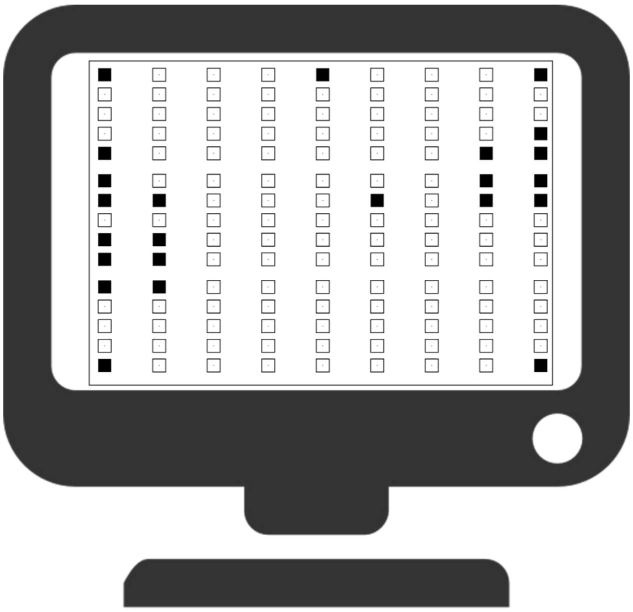

Figure 4. Example of throttled burners map with a single throttling condition (throttled burners are represented with full squares and non-throttled burners with empty squares).

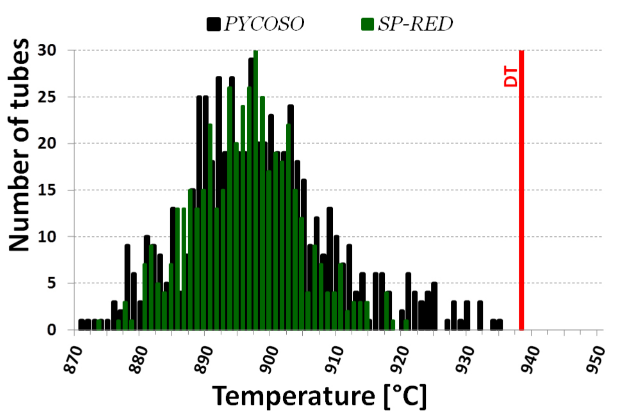

Figure 5. Tube temperature distribution in a large scale SMR plant. Comparison between PYCOSO values (in black) before throttling with SP-RED values after throttling 23 burners (in green).

two main advantages: it does not require a plant shutdown; and no additional device needs to be installed. In short, burner throttling does not imply any specific investment, but brings major savings. It is definitively a cost-effective technique. Though the method is simple in principle, finding the right burners that need to be throttled may be tricky and time consuming in practice, especially for large furnaces with dozens of burners. That is why Air Liquide developed SP-RED (Spread Reduction tool) – a tool based on an in-house mathematical model and optimiser capable of determining the burners that need to be throttled in less than 10 minutes. The method includes the following three steps:

- Firstly, measuring temperatures of the reforming tubes under non-throttled conditions by a pyrometer. It is mandatory to correct the measurements with PYCOSO to accurately capture the tube temperature profile.
- The second step consists of running the SP-RED algorithm with the tube temperatures measured on site as input and thus getting a SMR-specific burner throttling map (Figure 4).
- Finally, throttle the burners on site thanks to the map generated by SP-RED.

Several burners' throttling conditions can be implemented thanks to SP-RED, which means that the burners can have different percentages of power reduction. Figure 4 shows an example of a burner throttling map with burners throttled by the same power rate of 40%. To mitigate the tube temperature spread, SP-RED estimates that the power of the 23 burners highlighted by black squares must be reduced by 40% with respect to the baseline burners shown in empty squares.

Benefits of implementation: an example

SP-RED methodology was implemented in a 135-burner furnace. The tube temperatures of this furnace under non-throttling conditions are shown in Figure 5, as well as the temperature profile after throttling 23 burners identified by SP-RED optimiser, pointing out a significant spread reduction. In addition, once implemented, SP-RED will allow the plant debottlenecking as the hottest tube backs away from the design temperature limit.

The SP-RED methodology was further implemented in other furnaces with successful spread reductions of approximately 25°C.

Conclusions

Modelling and numerical tools are essential to improve the efficiency of reformers by unlocking key optimisation parameters:

- A good level of process information with higher accuracy can be achieved despite poor instrumentation thanks to data reconciliation.
- Tube temperature measurements with higher accuracy are provided, enabling the reformer to be operated close to the design temperature limit.
- Burners that required power reduction can be evidenced and adjusted accordingly by linking PYCOSO temperature profile to SP-RED optimiser, thus mitigating the heat transfer to the reforming tubes.

This set of tools helps reformer operators to make decisions in their day-to-day work. **WF**