Safe Startup for World Scale H2 Plants with Topsoe Furnace Manager

Large, world-scale H2 plant steam methane reformer (SMR) fireboxes represent safety challenges due to size and complexity, such as personnel safety issues while interfacing with the firebox during the startup and light off of hundreds of burners

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Introduction

In 2018, Chevron finished construction and started up two, world-scale hydrogen plants in one of its refineries.

Hydrogen (H2) supply is vital to the refinery operation, and steam production from the steam-methane-reformers (SMR's) is a very important utility to the refinery. Simply, it is critical that the new hydrogen plants were constructed and operated reliably and safely.

The heart of these plants were the reforming furnaces. Full understanding of the design and operation of the furnaces was necessary for seamless integration of the new hydrogen plants. Furnace protection is especially important from a business asset perspective since this equipment represents about 35% of the total hydrogen plant asset value.

Plant Configuration and Startup

The SMR's in the new hydrogen plants are top-fired, or down-fired, with burners in the arch only. The burners are relatively large to minimize the number of them and required a standard staged lighting across the entire SMR during initial startup to provide even heat distribution.

Startup of the SMR's utilized natural gas fuel only, with nitrogen (N2) circulation to remove process heat during startup. Steam for the process was self-generated by the SMR's, and available for circulation in the process once SMR heat up had achieved temperatures where adequate steam supply was available.

The new H2 plants were designed with the typical integration of pressure-swing-adsorbers (PSA) for purification of the syngas generated by the SMR's and front end of the plant. The PSA off-gas is rejected during PSA regeneration and recycled back to the SMR fuel system, providing a significant amount of fuel during normal operation. The balance of fuel is natural gas supplied by the local utility company.

Several hundred process control loop response checks, alarm checkout, and process loop tuning tasks were completed by experts assigned 24 hours every day leading up to initial SMR burner light off. During the initial burner lighting, and during the subsequent heat up and dry out of the SMR's, preparation was also made to have the PSA systems available as needed when syngas was produced. The coordination and integration of a large number of contractors and vendor suppliers' personnel with internal Chevron personnel required constant communication. Chevron recognized the numerous operation's tasks associated with large-scale SMR startup. (Figure 1)

H2 Plant Operator Physical Activities

Startup

- Satisfy interlocks & startup conditions
  - flame scanners, piping pressure integrity, firebox purge, process interlocks
  - Establish diluent (N2) flow
  - Establish boiler levels
- Light burners at heights above grade
- Adjust combustion air to burners
- Open/close valves at height & grade
- Start pumps & fans at grade
- Maintain boiler level at height
- View firebox for tube overheating
- Communicate with team
- Record process & equipment status
- Continue heat-up cycle for >6 hours
- Introduce steam after ~8 hours of heat up
- Back out diluent N2 from process & increase steam flow to process
- Introduce NG feed after ~12 hours & > 1300 F
- Line up process to flare
- Startup PSA: pressurize beds, sequence valves, & then start syngas feed flow & attain H2 purity
- Line up PSA off gas to SMR fuel & repeat some steps above without tripping plant or PSA offline!
- Increase plant rates to >50%

Figure 1. Operator Startup Duties on Large SMR's

To safely accomplish the SMR operational tasks for these new plants, Chevron utilized technology which would provide the right information to those who needed it at the time.

Firebox Technology Selection

Early in the construction process, Chevron H2 subject matter experts (SME's) were involved with operations to integrate technology for firebox management. Considering the physically large fireboxes, with burners located on the top of the firebox, the efficiency of operator surveillance and monitoring of the SMR's was evaluated. Several considerations were explored, including extent of coverage of the firebox by people looking into viewport windows, including firebox data collection, duration of firebox surveillance, and evaluation of results of burner or process adjustments.

Additionally, the frequency of firebox interactions by humans looking into viewport windows was considered. Minimization of this interaction was important from a personnel safety standpoint. Technology that could reduce this interaction frequency, and provide more persistent coverage of the firebox than short intervals (<1 minute in duration) of "eyeball viewing" through viewports were evaluated.

Haldor Topsoe worked closely with Chevron to integrate Topsoe Furnace Manager (TFM) into the SMR fireboxes to assist with firebox management. Chevron chose TFM in late 2017 for installation and startup in 2018.

Topsoe Furnace Manager (TFM)

Topsoe Furnace Manager (TFM) provides an alternative to direct human interaction with SMR fireboxes. (Figure 2) TFM is an array of permanently installed image collectors acquiring images every second, 24/7. TFM collects millions of data points annually, with deviation alarms, stored in an easy-to-use historian, and is remotely available to the organization outside of the plant. TFM monitors the firebox with minimal safety risks. The reduction of human-firebox interaction allows personnel to perform higher value work, such as image and data analysis, collaboration, and/or minor maintenance and turnaround planning.

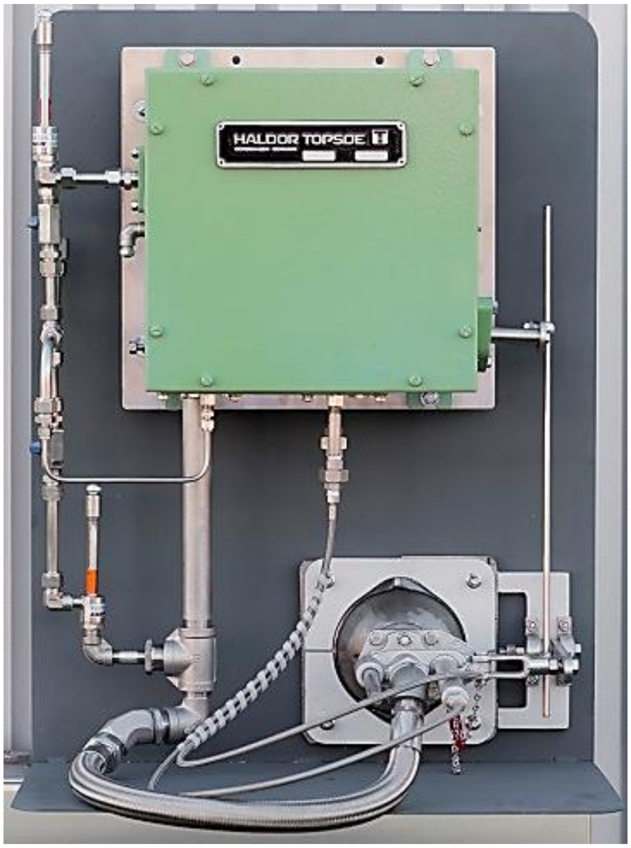

Figure 2. TFM Installation—Image and Data Acquisition Units

In hydrogen plants, the SMR operation encompasses several hazards. Fire, loss of primary containment of process fluids, uncontrolled combustion, mechanical equipment failures, and process upsets are a few. Traditional hazard mitigation for SMR operation has required plant personnel to directly interface with the firebox to verify equipment and process status. This interaction has inherent risks. When personnel interact with a firebox to determine the status inside, they become human data collectors. It is recognized that this interaction is important, and tools have been developed to facilitate the best use of this interaction, including specialized personal protective equipment (PPE) and handheld data collectors. Even under the best of circumstances, the firebox interaction is typically a relative short duration, with only about 1000 hours or less of data collection annually. The amount of data collected in terms of temperatures and imagery is restricted by the duration of the personnel interacting with the firebox. To increase the duration of the interaction to improve data collection an increase in exposure to hazards occurs. Therefore, hydrogen producers are faced with a decision to sacrifice firebox data acquisition to reduce hazard exposure. Extrapolation and leveraging of a limited amount of firebox data is the result of the decision. This extrapolation of limited data is typically historical based, as is the operation and maintenance of the firebox. Notable firebox failures occur from gaps in historical knowledge.

TFM is a system-of-systems including electronics, optics, data handling, data analysis, placement design, visual display, self-protection, compliance, and human-machine-interface. Image acquisition is at the heart of the system. The image collectors send the images to the data collectors, which organize, transmit, store and analyze the data (Figure 2). Alarm safeguards are immediately available to the plant operators, and remotely to the organization outside of the plant supporting operations.

TFM Capabilities:

Image collection: Over 500,000 images per image collector per year

Data collection: Over 50,000,000 data points per collector per year

Alarms: Tube metal temperatures, with associated Integrity Operating Windows (IOW's), and burner flame quality, such as impingement, jetting, and poor mixing.

Benchmarked images of good examples and bad examples of burners and tubes

Historian: Time and date stamped images with data

Remote access to images and data

Wireless computer interface with firebox

24/7 persistence of the entire system

Self-protection for reliability

TFM Evaluation and Selection

Chevron entered into extensive discussions directly with Topsoe, and also worked through a large engineering firm with H2 plant expertise to fully evaluate TFM. Extensive evaluations of TFM were completed, including National Recognized Laboratory Testing (NRTL) certification for a Class 1, Division 2 rating. Commonly known as "UL or CSA" certification, NRTL certification requires extensive documentation and certification of all components in the system. Once registration with the NRTL is completed, documentation is submitted for initial design review. After NRTL design review, several rounds of testing and evaluation by a certified NRTL with qualified and certified safety inspection engineers is performed with the actual equipment. Following successful completion of the certification testing, then next step in the process involves on-site inspection and certification of the equipment manufacturing facilities.

Topsoe communicated with Chevron and the third party H2 plant engineering firm very frequently throughout the selection, testing and certification process of the TFM equipment and manufacturing facilities. Final certification by the NRTL was completed in Spring 2018.

Fastrack TFM Installation

When Chevron selected TFM in late 2017, the construction of the new hydrogen plants was moving on a fast-track basis to meet expected startup target dates in 2018. Simultaneous NRTL certification, TFM manufacturing, and TFM shipment for installation were ongoing. To manage this timetable, Topsoe, Chevron and the H2 engineering firm all worked from the same project schedule. Topsoe communications with Chevron operations was also important to ensure smooth implementation of TFM into the control room. Communications with all key stakeholders, including construction contractors, was obviously very important.

The first step in the installation process was selection of the position and location of the TFM image units on the SMR's. Topsoe reviewed placement options and visited the site working directly with SMR contractors so that the correct location of image units was chosen. Several considerations were taken into account including accessibility, OSHA compliance, proximity to utilities, and firebox view angles for final image unit placement on the SMR fireboxes.

The next step in installation involved mounting of the image units on the SMR fireboxes. This was completed in mid-2018 working with SMR contractors, Chevron, and third party H2 engineering personnel.

Finally, utilities were connected and continuity for image and data transmission was completed in the fall of 2018, in preparation for the first SMR light-off.

Topsoe fully integrated into the Chevron, contractor and third-party engineering team to make sure TFM was ready for the first burner lighting.

First Light off Flame Detection

The first hydrogen SMR burner lighting began in the fall of 2018. Startup of the first SMR also occurred while work finished on mechanical completion of the second plant.

In preparation for SMR burner light off, Topsoe installed TFM software and communications equipment working with Chevron and I&E contractors. An important consideration was proper placement and configuration of the keyboard-video-mouse (KVM) equipment so that TFM could be integrated into the operator's control room. Also, TFM remote viewing in the refinery's Hydroprocessing Division's main control room about a half-mile away was an important requirement involving extension of the TFM communication network.

During the initial light off of the first SMR, flame detection by installed flame scanners was intermittent. It was important to ensure that flame detection was reliable to prevent a furnace "bogging" (fuel rich) event. Installed flame scanners typically experience loss of signal, especially on the initial burner light off before they are properly adjusted and positioned. TFM provided a second source of flame detection, or second layer of protection, during the critical first burner lighting phase. (Figure 3).

Figure 3. First SMR burner light off

Burner Lighting and Heat Up

Burner lighting continued throughout the initial phases of heat up. TFM continued to capture images of all phases of this initial heat up period. It was very important to have a quick view of all burners during the light-off period so that operator actions could be directed and organized.

TFM continued to monitor all burner rows during the initial heat up period ensuring that the burners were lit, had sufficient air (no after burning), and flames were not impinging upon catalyst tubes in the SMR. (Figure 4)

With continuous TFM burner monitoring, operators were freed to complete other important tasks in the plant, minimizing their ascent to the top of the SMR for burner and combustion air valve adjustments.

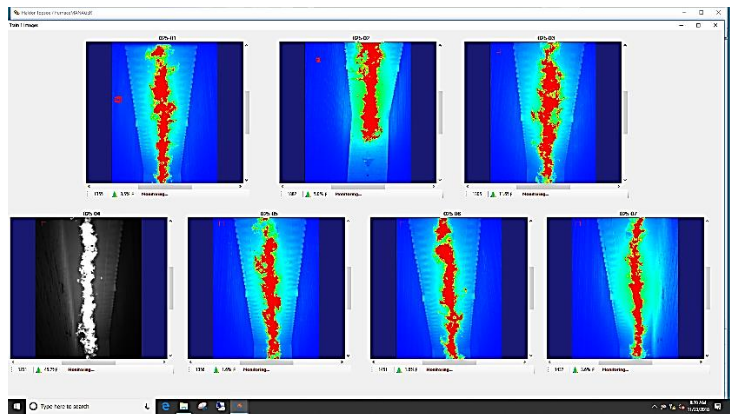

Figure 4. Burner Rows during Heat Up

Firebox Radiation After Plant Trip outs

It is normal, and to be expected, that during the very first startups of complex process equipment plant tryouts will occur.

For an SMR, it is critical to safety to understand the condition of the firebox during a plant tryout. With TFM, the firebox can still be "seen" with images even when burners have tripped offline. The radiation signature from the firebox continues to give off energy that TFM can detect.

This detection of the firebox radiation signature by TFM is important for safety to ensure that pockets of fuel are not present, and to ensure that flames are not present.   TFM acts as an administrative safeguard confirming that the plant's burner management system (BMS) is active and has safely shut off fuel and flames. (Figures 5 and 6).

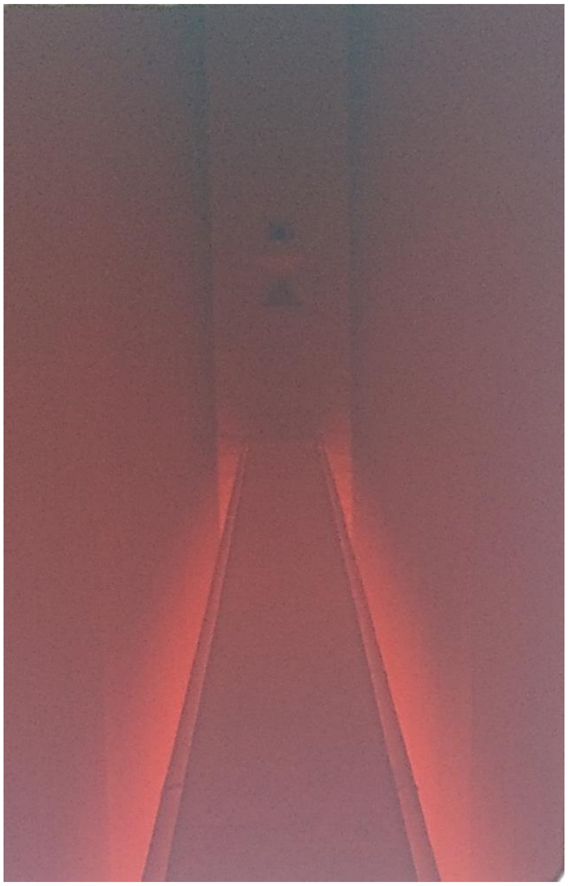

Figure 5. Firebox Radiation after Tryout Looking into Lower Viewport

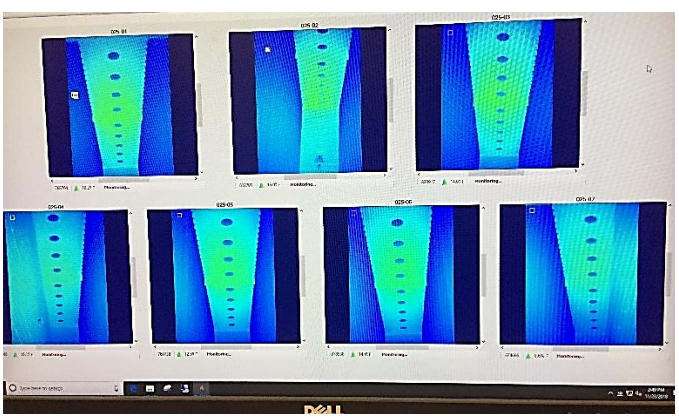

Figure 6. TFM Burner Row Views after Plant Trip out

Burner Heat Signatures

After the initial plant light off and heat up, the next phase of operations was a transition to normal operation with the PSA on line and the PSA off gas recycled back into the SMR firebox. During this transition period, N2 recycle was replaced with process steam. Then process natural gas was fed producing syngas which was then fed to the PSA after high temperature heat exchange, shift conversion of carbon monoxide (CO) to carbon dioxide (CO2) and H2, and cooling.

During this entire transition, TFM continued to monitor the firebox. Once the transition from natural gas fuel to PSA tail gas fuel occurred, the burner heat signatures appeared. (Figure 7)

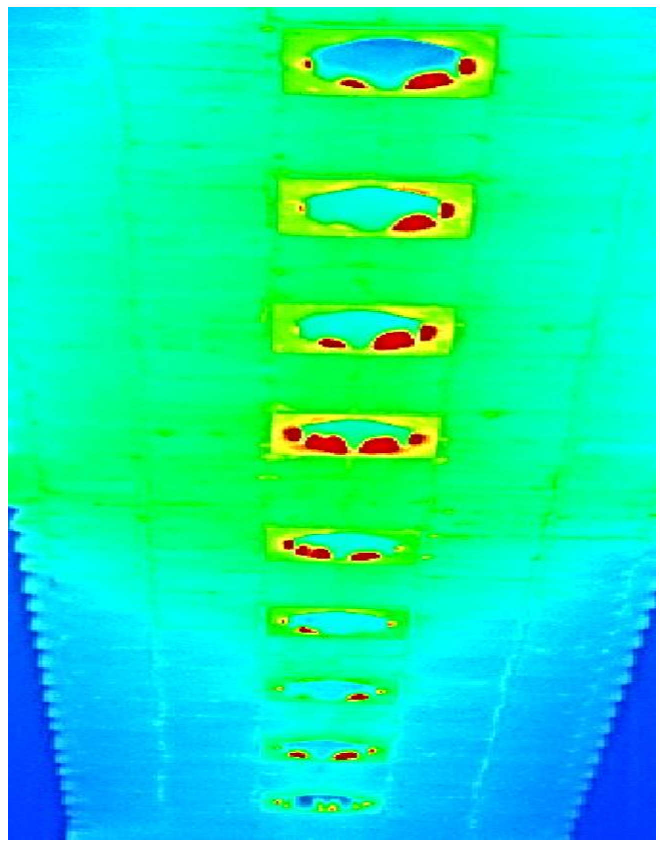

Figure 7. Burner Heat Signatures

TFM captures the subtleties of burner heat signatures, especially important at high temperatures. Without proper burner heat signatures, the mechanical reliability of the burners can degrade, as well as, the heat release and overall burner performance.

Multiple Inspections

After transitioning to normal operation with PSA off gas fed as fuel to the SMR firebox, TFM's movement functionality was utilized to physically view the lower part of the catalyst tubes operating at higher temperatures than the section near the burners. (Figures 8 and 9)

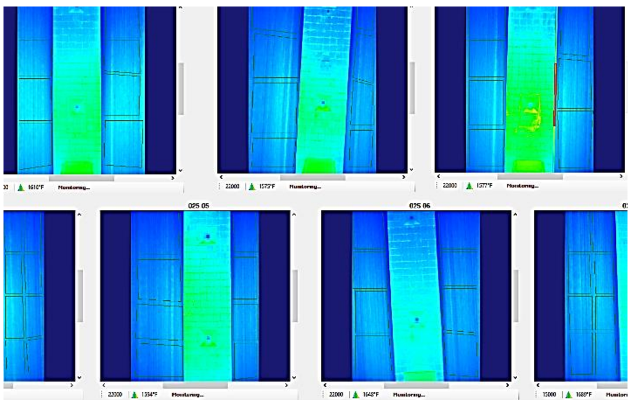

Figure 8. Catalyst Tube View

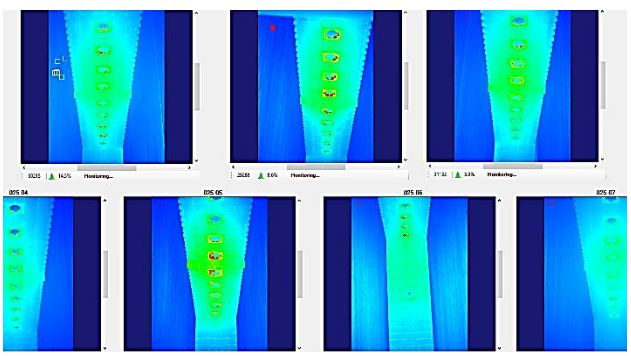

Figure 9. Burner View

Hot Tube Alarm

The ability to quickly see hot tubes is very important in SMR operation. Without persistent 24/7 coverage with imagery inside the firebox, it is not possible to quickly determine when and where hot tubes develop. TFM, with its persistent coverage of the firebox with multiple image collectors, captures the moment a hot tube develops and will also provide alarms to alert the operating team quickly (Figure 10).

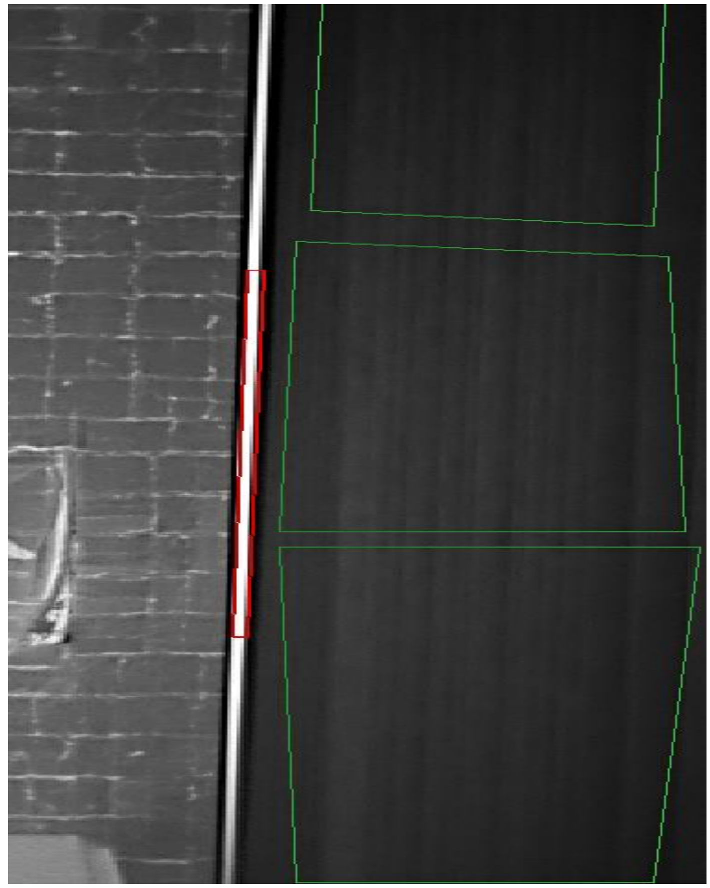

Figure 10. Hot Tube with Red Alarm Box

Tube Temperatures

After PSA off gas was fed as fuel, then plant rates were increased while adjusting various operating parameters such as steam-to-carbon (S/C) ratio and operating temperatures to begin the optimization process. It was very important during this time period to understand the status of the catalyst tube temperatures.

TFM's tube temperature correlation was utilized, based on historic images checked with pyrometer readings at specific locations at specific times.

The first step in the process of correlating tube temperatures is to fully understand the characteristics of each firebox. Topsoe's experience in firebox monitoring based on many years of collecting tube temperature data on all types of SMR's was leveraged to TFM's tube temperature correlation process.

For these SMR fireboxes, tube temperatures were very consistent from the beginning. Burner impingement was not observed, and burners did not require significant adjustments. Process blockage or other process-related problems were not significant. TFM regions-of-interest (ROI's) were established based on the observed temperatures in specific areas of the catalyst tube banks. Alarm settings were established in discussions with Chevron to provide an early warning notification about hot tubes. Where TFM identified specific areas of the SMR's that indicated a partial imbalance in heat distribution, Topsoe notified and discussed with Chevron regarding next steps.

A manufacturing defect was found in one of the furnace tubes in one of the furnaces during the construction phase. This tube was capped prior to startup. During operation it was used as a reference tube for temperature calibrations since it was always the hottest tube in the firebox.

Topsoe worked closely with Chevron to "fingerprint" the tube temperature profile of both SMR's at normal operating conditions. Individual temperature charts and graphs were created to assist Chevron in quickly evaluating tube temperature deviations whenever they developed. (Figure 11)

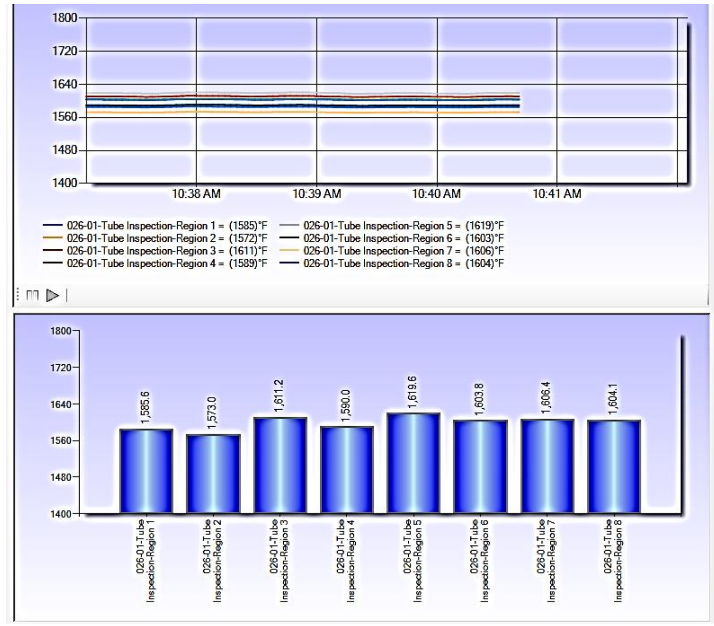

Figure 11. Tube Temperature Chart & Graph

Multiple Plant Firebox Monitoring

Another important requirement for Chevron was to have the ability to manage both H2 plants, including both large SMR's from a single console with one operator using technology for monitoring. TFM provides the imagery for continuous monitoring of both fireboxes.

TFM displays were set up so that both SMR's were monitored continuously in immediate proximity to the plant's DCS control system. (Figure 12) Any firebox upsets or changes required are observed and will be in alarm if outside of normal operating range. In this fashion, TFM provides great insight into firebox condition prior to dispatching an operator to the field to inspect and hunt for a problem by opening viewports.

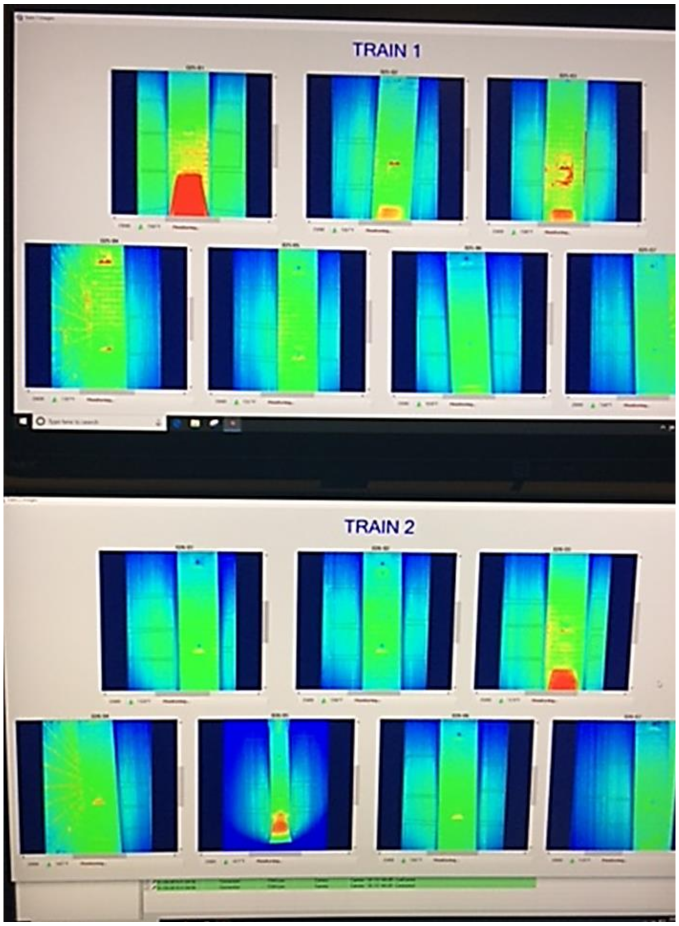

Figure 12. Multiple H2 Plant Firebox Displays

Historian and Event Capture

TFM not only provides instantaneous images of firebox condition, including burner and catalyst tube temperatures, it keeps images in its historian for future reference.

Conclusion and Summary

Chevron chose Topsoe TFM technology to ensure safe and reliable commissioning and startup of their two, new, world-scale hydrogen plants in 2018. TFM successfully monitored firebox conditions from the initial burner lighting of the first SMR up through normal operation of both hydrogen plants without incident or issues.