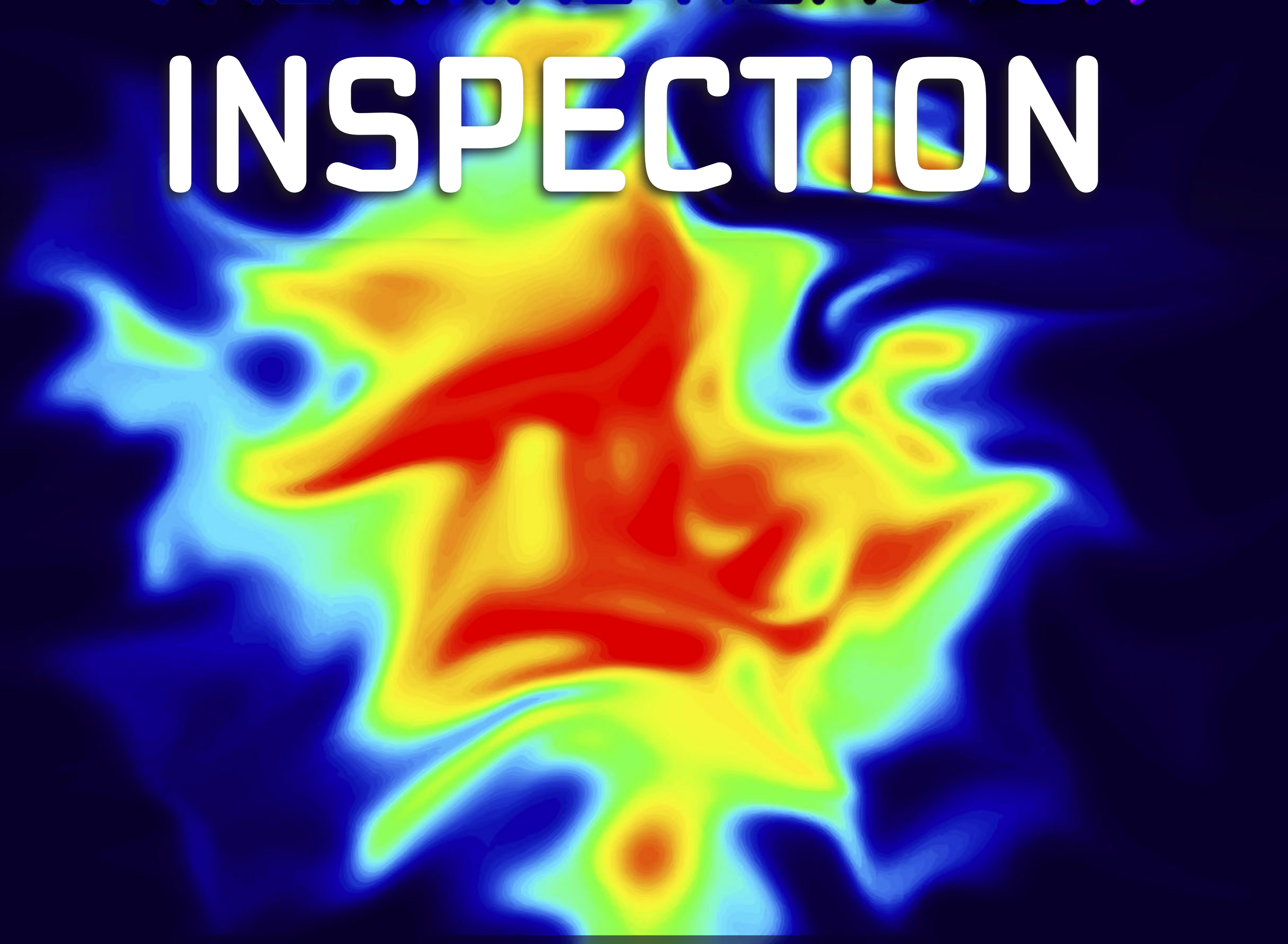
ADVANCED THERMAL REACTOR INSPECTION



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explains how a process inspection camera designed for continuous online inspection of SRU thermal reactors can help operators monitor the performance of units.

Sulfur plant operations are becoming increasingly more challenging as the industry has shifted from not only achieving environmental requirements, but also emphasising high reliability targets. As runtimes between planned shutdowns are extended, unreliability in sulfur plant operations has negative financial implications. Especially in the Claus thermal reactor, where intense operating conditions make failures more likely, methods to improve reliability will have positive effects on the entire sulfur recovery unit (SRU) performance. Increasing reliability in the Claus thermal reactor in the SRU is important as the thermal stage is prone to failure due to the intense operating conditions. Therefore, improvements made in the thermal stage are beneficial to the entire SRU performance.

One method of improving process awareness is to increase instrumentation of the thermal reactor. Instrumentation, including analysers, flame scanners, and temperature indicating devices such as pyrometers and thermocouples, is often connected to the safety instrumented system and is key to understanding the process status. While these instruments provide critical process data, many unknowns remain when it comes to the health and performance of the thermal reactor. Current instrumentation cannot effectively detect damage to critical reactor components such as the burner, refractory or tubesheet protection system. Damage is often undetected until the unit is shutdown and the reactor is open for a visual inspection. While the unit is operational, an operator's visual inspection of critical reactor components is limited to traditional sight ports, which offer a narrow field of view due to the bore diameter along the sight path. Additionally, sulfur often condenses or solidifies on the glass or in the bore, which eliminates the view.

An inside view

In the effort to increase reliability, the challenge becomes how to predict and identify a root cause before symptoms appear or are detected by current instruments. The ability to view the inside of a vessel allows operators to make pre-emptive operational decisions based on the condition of critical reactor components. High resolution images and a video feed of these reactor components provides the data required to make informed decisions, avoid major equipment failures, and reduce vessel downtime.

Delta Controls recently introduced a process inspection camera that is designed for continuous online inspection of the SRU thermal reactor and has now produced the first images taken inside an online thermal reactor.

The primary design considerations for the process inspection camera include reliability, achieving the best view of the vessel's interior and, most importantly, safety. The view of the critical interior reactor components is optimised by placing a wide-angle lens at the refractory hot face.

A number of significant challenges for this design were taken into consideration by the design team. For example, the camera and lens have a melting point near 65°C, which requires the use of a cooling system to survive the internal operating temperature of the Claus reactor. An additional challenge was developing a probe assembly that could be sufficiently cooled while accurately maintaining a surface temperature above which sulfur would condense and occlude the lens, as well as avoid low and high temperature sulfur corrosion mechanisms (Figure 1).

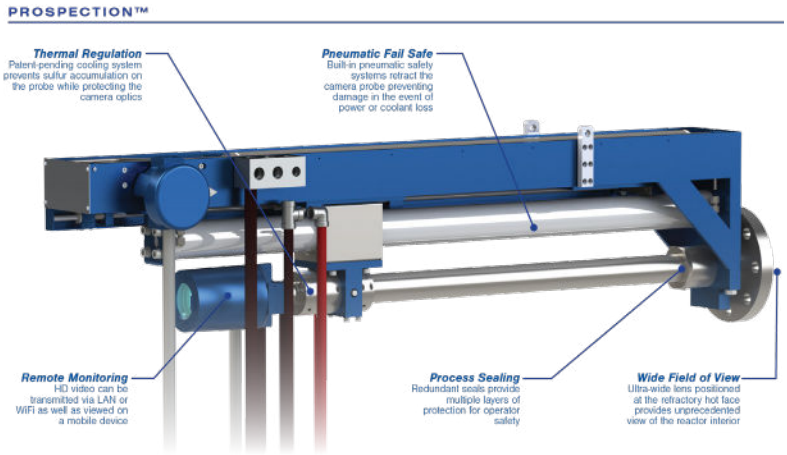

Figure 1. The instrument incorporates several functional, reliability, and safety features.

To overcome the corrosion, and temperature limitations, the camera design incorporates a patent pending thermal regulation system that uses water circulated through a series of channels to precisely regulate the probe's surface temperature. The operating temperature of the probe surface must remain between the limits of sulfur dewpoint corrosion and high temperature sulfidation corrosion, as well as maintain the internal camera circuitry within the maximum temperature limit. Furthermore, the thermal regulation system maintains the lens temperature above sulfur's freezing point to prevent lens occlusion and accumulation on the probe surface.

The camera probe assembly is designed to be mounted on a standard process nozzle fitted with an isolation valve. The camera can be operated while a reactor is online and is either left installed indefinitely for long-term monitoring, or used for a temporary inspection. A flanged seal assembly mounts to a 3 in. (or larger) nozzle flange and incorporates multiple redundant seals to allow for the camera to insert and retract without process leakage. To ensure safety, a nitrogen supply applies a positive back pressure to the seals that is higher than the process pressure. Therefore, in the event that a seal is compromised, nitrogen would flow through the damaged seal and into the reactor. An inline flow meter would indicate flow and if a seal had been compromised. This system serves to prevent any process gas leakage and provides an indication of seal integrity.

To automate the insertion and retraction of the camera probe assembly, the camera utilises a pneumatically driven extraction system that actuates the camera into and out of the vessel through the flanged seal assembly. This system allows for failsafe features to be implemented. The camera can automatically order its own retraction from the process for any number of fault conditions such as loss of coolant, rising camera temperature, loss of power, or loss of instrument air.

The camera's optical design is optimised for the incandescent environment found inside an SRU. A series of optical filters protect the camera lens from infrared energy and filter specific light wavelengths. Video and images are sent to the control room and can be set to provide continuous live video or capture still images at specified intervals.

Process inspection

The process inspection camera allows new views into online reactors that provide more information and can better guide decision-making. Critical reactor components of interest include the burner, refractory lining and tubesheet protection system.

Catching early failures in any one of these areas can be of great benefit to the unit operator. Starting with the burner, continuous monitoring with a camera can provide significant data improvements over existing instrumentation. Burners are oftentimes the root cause of many larger failures seen in sulfur plants. A failing or incorrectly performing burner can not only cause poor chemistry, but also damage to the refractory, waste heat boiler, checker wall and tubesheet. Burner components can suffer from other failure mechanisms, such as back burning and the metal componentry being consumed by the flame front. Changes in the burner structure would be visible only by comparing sequential images from routine inspections using the camera.

Identifying refractory damage early can prevent major failures such as burn throughs, corrosion problems, and further refractory collapse. The camera's wide-angle view at the refractory hot face can identify sagging or shifting within the vessel. It can also identify early stages of refractory damage such as vitrification of the refractory brick from direct burner impingement, which could lead to cracking. Many isolated refractory failures can be difficult to detect with traditional temperature instrumentation but would easily be visible with the inspection camera. Comparing images taken at regular intervals over a period of time allows operators to detect subtle shifts in the refractory. Additionally, the camera may prevent the need for a shutdown if there is a suspected problem. Users can identify problems with the refractory before it devolves into larger issues such as a shell burn through or complete refractory failure.

A final focus for camera inspection is the transition to the waste heat boiler: the tubesheet protection system, including ceramic ferrules. Regular inspection can provide insights into reactor performance and avoid major failures related to the waste heat boiler operation. Visual inspection can be used to detect staining on the ceramic tube sheet ferrules from a leaking boiler tube. Other process issues can also be detected on the ceramic ferrules such as high temperature vitrification indicating hot spots or carbon deposits indicating poor hydrocarbon destruction. Identifying problems in service will help spot any issues in the early stages and potentially prevent extensive damage of the boiler equipment.

Testing process

To complete the initial field testing of the process camera, Delta Controls partnered with a refinery in Alberta, Canada. The testing process consisted of several phases including nozzle location evaluation, equipment installation, hardware verification and software verification. Following a site analysis, the nozzle location was selected in zone 1 of the reactor with an angulation approximately 45° towards the main process burner. This orientation provided a view of the process burner componentry as well as the refractory on the burner wall. This nozzle was equipped with two isolation valves, allowing for a double block and bleed setup. The installation proceeded

Figure 2. The extractor and probe assembly bolted to the vessel's isolation valve and required utilities established.

Figure 3. First image produced showing material deposition along the test nozzle bore.

Figure 4. The process camera provides online images of the burner, refractory lining or tubesheet protection system.

with the extractor and probe assembly bolted to the isolation valve and the required utilities established as seen in Figure 2.

Initial testing consisted of verifying basic functionality of both the hardware and software. The probe was actuated to a location in the nozzle bore that was experiencing temperatures lower than the peak process temperature at the hot face of the refractory. A procedure was followed to expose the camera probe to incrementally increasing temperatures to ensure the internal probe temperature would remain within design parameters. The test team monitored and data logged critical temperatures of the device for the totality of the testing. Following the verification of mechanical performance, the software was assessed for functionality and stability.

The preliminary images produced by the inspection camera showed that the test nozzle was suffering from material deposition along the bore (Figure 3). This buildup was likely in place prior to the camera installation. After determining that the camera view and ability to insert were compromised, action was taken to clear the debris from the nozzle bore to allow full access. Once the camera was able to be fully installed in the bore, the camera was able to obtain consistent high-quality images (Figure 4). Figures 3 and 4 are some of the first images ever taken inside of an online SRU thermal reactor. Extended tests were performed over a period of weeks, including long-term tests that validated the cooling system performance when left exposed to full process temperatures for periods of 8 to 10 hours.

The tests performed verified the functionality, performance and safety of the primary camera systems. Furthermore, the data obtained on sulfur deposition on the probe body and lens advanced understanding of the required probe surface temperature parameters. As a result, the engineering team is developing protocols for thermal management, nozzle purge rate, and insertion rate to ensure sulfur accumulation is prevented. The testing also demonstrated the redundant seal design under standard operating temperatures and pressures, which is of critical importance in sulfur service. Lastly the team was able to gather significant feedback on the user interface which guides the development team for usability upgrades and the addition of software features.

Conclusion

Field testing of the process inspection camera validated the functionality and safety of the instrument while also providing valuable data for product improvement. The camera allows operators to make more informed operational decisions and potentially avoid shutdowns and equipment failures. Preventing unnecessary downtime using photo or video inspections will lead to large cost savings. In addition, reactor inspections can now be carried out without reactor shut down, allowing users to shorten turnarounds with fewer surprises in the thermal reactor. New process inspection cameras will be of significant value to the sulfur processing industry by providing more data about online reactors than previously available.

Enhancing the reliability of the sulfur plant starts in the thermal stage. Now, plant operators can shorten downtime, avoid major equipment failures, and make more informed decisions with advanced inspection cameras.