Reliable Multipoint Temperature Profiling in Hydro-processing Units

Advanced temperature measurement technology leads to cleaner, safer, and more profitable downstream operations.

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In the refining industry, catalytic hydro-processing element—such as hydrotreater, hydrodesulfurization, and hydrocracker units—rely on high-performance catalyst technologies to maximize product conversion (Figure 1). Simultaneously, efficient reaction control seeks to minimize the environmental footprint and cost. Precise and reliable temperature mapping of these densely packed reactor catalyst beds is required for stable and profitable unit operations.

Multipoint temperature instruments with thermocouple sensors are widely used in the industry to monitor for optimum heat distribution, and to prevent hotspots and premature catalyst deactivation under high-temperature, high-pressure and corrosive conditions.

Figure 1: Refineries need reliable temperature measurements to optimize operations.

However, most conventional multipoint thermocouple probe designs have two major weaknesses:

- **Reliability**: Hydrogen sulfide (H_2S) contamination affects conventional magnesium oxide (MgO) cables under extreme process conditions. H_2S contamination can alter measurement accuracy, or even lead to a loss of control over the reaction.
- **Size**: They are comparatively invasive, taking up valuable space in catalyst beds, leading to undesired pressure drops and channeling effects.

A new, robust multipoint thermocouple probe design addresses these issues by combining thermowell and thermocouple sensors in a single space-saving probe, addressing failure vulnerabilities while providing more efficient catalytic reaction. The patented technology helps the automation system provide more reliable, precise, and accurate process control, directly contributing to improved safety, profitability, and uptime.

Thermocouple drift and migration

The harsh environments typically encountered in catalytic hydrocracker units pose a difficult challenge for process instrumentation. While all thermocouple probes are known to drift over time, mechanical stress, abrasion and H2S contamination are often not factored in when specifying design limits and making instrument vendor selections. Unfortunately, these issues can lead to a total loss of data—threatening process safety, reaction control, and efficiency.

In these types of applications, industry expectations of a multipoint temperature instrument's useable life for its wetted parts are typically one- or two-unit operation cycles or turnarounds, or 36 to 48 months. As the industry changes, there are desires for even longer life cycles of five to seven years, prompting increased demand for longer instrumentation and equipment life cycles.

Defective thermocouple probes have been found in a significant number of applications throughout the industry and are systematically affecting all instrument manufacturers. This occurrence has been examined scientifically, resulting in the discovery of two phenomena that degrade thermocouple measurement performance, with each occurring separately or in combination:

- **Thermocouple drift**. Chemical contamination of the MgO powder induces a change in the composition of the two dissimilar metals that make up the thermocouple conductor wires, leading to a shift in potential difference due to the Seebeck or thermoelectric effect. While the local hot junction remains intact, a change in conductivity of one or both metals will alter the measured voltage and thus negatively impact measurement accuracy.
- **Hot junction migration**. Permeation of H_2S into the MgO powder can cause new conductive bonds (electrical short circuits) to form between the thermocouple wires at undesired locations away from the hot junction. The thermocouple will still work but will present incorrect values that seem true.

If one or several defective thermocouple sensors have been identified, process owners might decide to address the issue during the next scheduled unit turnaround. Depending on the severity of the failures and their safety criticality, extraordinary maintenance for sensor replacement might be required, which could entail an unscheduled unit shutdown.

H_2S contamination

Sensor drift or damage causes erroneous readings that may go undetected by operation and process control staff. This scenario is particularly dangerous because misinformation or a lack of information in the measurement chain can lead to operational decisions with poor outcomes for reaction efficiency or worse.

According to technical investigations and relevant scientific literature, deviations in measurement accuracy (drift) of contaminated thermocouple sensors is typically negative. Therefore, the value displayed will be lower than the actual temperature, and the process may be running hotter than intended. Besides being a major cost issue, such an out-of-spec state poses a considerable safety threat.

Legacy designs assume that sensors protected by singular MgO insulation provide sufficient measurement accuracy and precision. However, these standard multipoint thermocouple probes have been seen to fail under more challenging process conditions.

Hydrogen stress-induced cracking

It is standard practice to bend and route sensor cable probes inside a reactor to match the required layout because this flexible installation method ensures measurement points are adequately distributed. However, the bending of metal induces expansion and compression stress, causing weak spots, particularly along sharp bends.

In hydrogen-rich atmospheres, hydrogen stress-induced cracking may occur at these weak spots, which in time can increase enough to break through the metal sheath entirely. This loss of integrity leads to larger molecules of the process fluid, such as H_2S, permeating through and contaminating the insulating MgO powder.

MgO powder reacts with certain chemicals, including sulfur and nickel. The now contaminated MgO powder promotes the formation of highly conductive Ni_3S_2 by combining nickel from the thermocouple conductor leads and the metal sheath with sulfur from the process.

As the contaminated area grows, the exposed electrical leads form a short circuit, negatively impacting sensor accuracy, or migrating the location of the thermocouple hot junction. The complete probe risks becoming blind to process temperature changes.

Sensor designs address issues

The minimally invasive Endress+Hauser iTHERM ProfileSens TS901 multipoint cable probes consist of two or more independent temperature sensors embedded in a common outer metallic sheath. The outer sheath acts as an integrated thermowell, while the space between the sensors is filled with highly compacted insulating MgO mineral powder (see Figure 2).

Since the two sensors are completely independent from each other, contamination of the outer MgO powder does not affect the inner sensors' electrical circuits and their operation. New, patented technology introduces a second layer of protection. An additional metal barrier isolates each measuring circuit within its own MgO bed, providing full sensor independence. This double protection layer results in extremely high sensor reliability, similar to a separate thermowell, while maintaining the flexibility characteristics of bendable cable probes.

Multiple thermocouple sensors can be grouped within a single probe, each delivering the required measurement performance. The probe layout and routing, length, and the number of sensors is individually adapted to process

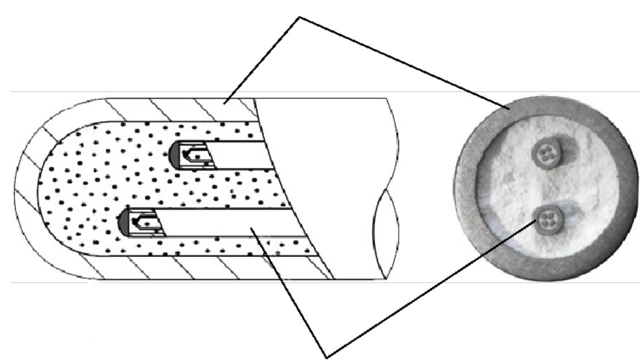

Figure 2: This Endress+Hauser iTHERM ProfileSens probe uses MgO, high-purity, compacted powder to separate each temperature sensor.

specifications. This type of design is proven in use to significantly lower the risk of premature sensor drift, corrosion, and short circuits.

Spatial footprint impacts product conversion

Reducing space taken up by invasive reactor instrumentation is an evident way to increase conversion rate and productivity. The amount of necessary hardware directly impacts the catalyst charge density. Three key factors influence the spatial footprint:

- Probe design
- Sensor routing
- Mounting hardware

Probe design

Standard multipoint thermocouple probe technology has long been considered mature, but recent research efforts have reevaluated the mechanical design. This led to the use of advanced manufacturing processes to add safety layers and significantly miniaturize MgO cables, without compromising their existing qualities. The gain in robustness and spatial volume translates into a better use of catalyst bed packing. By simply reducing the number of thermocouple cables across the reactor bed, negative effects are also reduced, improving catalyst reactivity and profitability.

Sensor routing

Through smart sensor routing, measurement points can be distributed in the most effective way, while reducing the overall invasiveness. State-of-the-art CAD modelling software and routing calculations are used by seasoned engineers, applying years of experience in reactor layout to achieve best results.

Mounting hardware

Placing multipoint thermocouple probes in reactor beds typically requires mounting hardware, adding to the overall spatial footprint of the instrument. However, new cable probe technology factors in this requirement and reduces the number of brackets and mounting clips. The robust probe mechanical structure provides a higher degree of self-support for the cable, resulting in fewer required supporting elements, while remaining bendable. This reduces the instrument footprint, while cutting overall hardware cost and installation time. The higher product conversion, yield, and process efficiency quickly offsets the initial investment.

ROI and added value

In addition to improved process safety, control and reliability, this new technology unlocks profitability potential by:

- Saving space for a higher catalyst charge density
- Preventing untimely shutdowns or required maintenance caused by instrument failure
- Allowing operation of units closer to their performance optimum

To demonstrate how much impact a less invasive instrument can have on profitability, consider a typical hydrocracker reactor with three catalyst beds. Each bed is equipped with one entry nozzle and twelve measurement points.

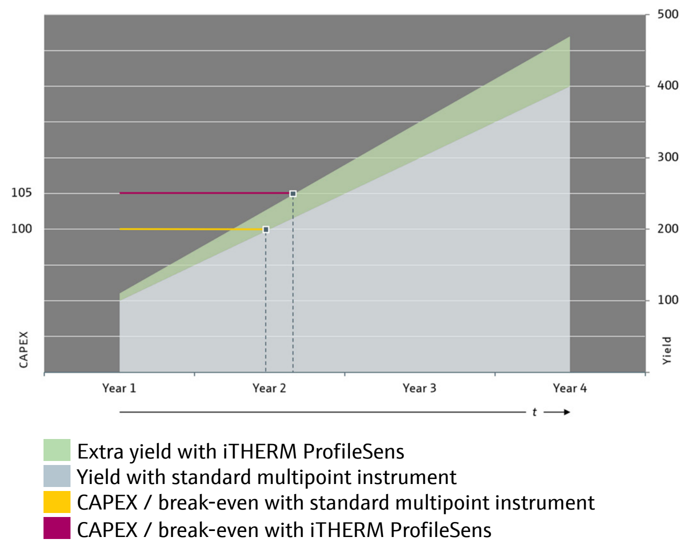

Figure 3: CAPEX is the instrument and installation cost. Example of typical cost delta, actual cost may vary depending on product specification, configuration, and services.

Standard multipoint instruments would use:

- Twelve 8 mm thermocouples and probes per bed
- One thermocouple sensor per cable, for a total of twelve cables
- 8 m average length

New design uses:

- Three 9.5 mm multipoint cable probes per bed, each with four thermocouple sensors per probe, for a total of nine cables
- Up to 13 m length

The newer design increases the usable catalyst bed volume by 50 percent and cuts installation time by 75 percent. The increased volume can be used to boost the catalyst load, and the saved installation time directly translates into quicker turnarounds and lower cost.

Measured against an average daily unit profitability and a continuous operation of 36-48 months, the resulting extra revenue generated fully offsets the CAPEX (Figure 3).

With iTHERM ProfileSens, the initial CAPEX (left y axis, base 100: standard multipoint installation), while minimally higher, is quickly offset through higher yield (right y axis, base 100: standard multipoint installation) and savings. The major factors leading to this quick return on investment are:

- Higher unit performance and conversion
- Higher efficiency
- Faster installation and turnaround
- Lower OPEX

As the number of measurement points increase, the savings effect grows to the point where the initial investment becomes negligible when compared to the increased returns. The new technology's robustness, reliability, and longer operating life makes it a compelling choice for harsh process conditions.

Conclusion

While drifting thermocouple measurements are a known phenomenon, the underlying causes of sensor misbehavior beyond typical drift are still widely unknown to many refinery operators. Migrating hot junctions go undetected in most cases, leaving process control engineers unaware of the lost potential.

Extensive tests and scientific studies have shown that mechanical stress, abrasion, corrosion, hydrogen stress-induced cracking, and subsequent H2S contamination is a leading cause for total loss of data—reducing process efficiency, while posing risks to safety and reaction control.

The iTHERM ProfileSens addresses these issues to provide improved process safety, control, and reliability. It also unlocks hidden profitability potential, offering refiners a smart choice to get the most out of new or existing units.

All figures courtesy of Endress+Hauser

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