# TEMPERATURE DEPENDENT CATALYSTS: Optimizing Performance and ROI with Advanced Temperature Measurement Systems

Daily Thermetrics Corporation

*Abstract*

*In optimizing performance and ROI within a catalytic processing unit, catalyst* ***utilization and condition*** *are highly important to monitor accurately. Reliance on inadequate, poor, or unreliable temperature measurements have a severe adverse effect on the bottom line/profitability. Today's high activity catalysts require temperature operating tolerances and sensor density that simply cannot be met with outdated catalyst profiling systems.*

*Only with the most advanced, up-to-date equipment can a refiner or petrochemical processor expect to get the most from the processing unit and investment into catalyst. Employing advanced techniques and technologies* ***give the modern refiner or processor an edge on productivity*** *as margins become an* ***increasing concern for profitability****.*

*Regardless of the type of catalyst used, the newest generation of flexible radial temperature sensors, the CatTracker®, serves to protect the end user's investment by notifying operators of undesirable process phenomena such as hot-spots, maldistribution, and channeling, while also providing the most accurate way to determine catalyst end life.*

*Following over a decade of improvements to temperature measurement and monitoring in catalyst beds of hydroprocessing and syngas reactors, refiners and petrochemical processors have standardized on a high density of Ultra High Precision™ CatTracker® temperature sensors and temperature measurement systems.*

## INTRODUCTION

Finding successful ways to extend investment output and increase profits within competitive markets have become the forefront responsibility of both process operation engineers and financial managers in petrochemical, refining, and syngas downstream operations. Identifying large "consumable" investments within the plant and how best to maximize the return on such investments now play one of the greatest roles in defining the profitability and long term growth/sustainability of the plant/processing unit.

One such "consumable" investment that garners a large percentage of annual capital is processing unit catalyst. A vital role in downstream production, catalyst makes up a significant portion of investment and has a direct correlation to product quality and output. In addition to the hard dollar investment into such catalysts, necessary costs also include a combination of investments in automation equipment and engineering personnel dedicated to operational monitoring, analysis, and condition evaluation, which all works to establish production estimates for a processing unit over a specified amount of time.

Within the past two decades, catalyst manufacturers have significantly improved both activity of the catalyst, more simply defined in terms of output potential, and competitive marketing strategies for these high investment, high output products. Many variables are taken into account with the different catalyst offerings including processing unit configuration, feedstock, and utility/energy availability. While there are a plethora of catalysts that can produce products efficiently, independent of temperature requirements, this paper focuses on best practices for monitoring and controlling catalysts which have a direct relationship in productivity to the temperature at which it operates.

## ONE CATALYST BED, ONE TEMPERATURE SENSOR, ONE BIG RISK

Temperature dependent catalysts operate efficiently within a specific temperature range (for purposes of discussion, we will assume the catalyst activity will decrease over time and in order to compensate for the decreased activity, an increase in temperature is required to produce the same output). At the beginning of the catalyst life, best practice is to operate the processing unit at the lowest temperature that will result in the desired/expected/marketed output. Over time, as the catalyst activity decreases, the processing unit must respond by raising feedstock temperatures in order to raise catalyst reaction temperatures to produce consistent output levels. The catalyst life is determined spent once the catalyst temperature reaches a certain mark. Depending on the catalyst, at this mark the catalyst may deactivate to levels too low for acceptable production, may reach the pressure vessel maximum allowable temperatures, reach a point where reaction is no longer controllable (i.e. a temperature excursion or runaway), or other similar unfavorable event. Using this temperature range, and tracking the temperature escalation over time, a process engineer can then accurately estimate the remaining reaction life left for the current catalyst run. In effect, the catalyst life realized should meet the marketed operating life and resulting return on investment (ROI).

In theory, an evenly distributed, efficient reactor should only require one (1) temperature sensor (by default, typically an outlet temperature) to measure the catalyst bed temperature, and that measurement then used to accurately estimate the end of a catalyst life. Taking into account certain natural differences in temperatures at different areas of the reactor (example being a down-flow trickle bed where temperatures at the top elevation of the catalyst bed is expected to be a certain percentage lower than the bottom elevation of the catalyst bed), and where said single measurement is realized, the task to measure the overall bed temperature can be a fairly simple exercise. For the operations/process engineer, this industry accepted practice, better known as the Weighted Average Bed Temperature (WABT), directly drives everything from scheduled shutdown and maintenance to safety settings and automatic depressurization trips.

Unfortunately, dozens of variables exist within a catalytic processing unit, both internal and external, and each variable has a certain probability that may negatively affect the temperature(s) of the catalyst bed and resulting catalyst life/production output. These variables, ranging anywhere from poisoned/inconsistent feedstock and inefficient feed furnaces to fouling/poor sealing of distribution systems and uneven catalyst loading; have the potential to cause problematic patterns in the catalyst that can continue to build on itself over time. Continuing with the example of a down-flow tickle bed, uneven distribution of feed into the catalyst bed can result in certain quadrants of the catalyst becoming over worked, creating an imbalance in catalyst activity compared to other areas of the catalyst bed. A similar result can occur from an improper loading of the catalyst, a leak in the distribution system, a feedstock that deactivated certain sections of catalyst due to poisoning from a high concentration of metals, or a handful of other occurrences that are all highly possible, if not common over the catalyst life.


(IMAGE 1) Rigid Reactor Multi-Point

If it is accepted that these negative conditions, one or multiple, occur over the catalyst life, then the expectation that the use of WABT based on a single outlet temperature measurement cannot accurately estimate the end life of the catalyst, let alone offer any hint to the vital signs of the catalyst bed and surrounding hardware. The need for a real-time, complete visualization of the temperature variations within the catalyst bed is then justified, and a strong argument made that significant catalyst investment with expectations to meet or beat ROI warrant a more responsible approach to monitoring and controlling such an investment.

## AN EVOLUTION OF CATALYST TEMPERATURE MEASUREMENT

*Mid 1900's*

Evolving from the use of one or very few catalyst bed temperature measurements (outlet or inlet/outlet measurements) to the use of multiple sensors, either in axial or horizontal arrangement, would be a natural progression if such negative conditions (as described in the above section) were suspect in causing shorter than expected catalyst life cycles. As it happens, process engineers identified that the need for increased visibility in the catalyst bed was needed to investigate efficiency problems and lower than expected ROI (as well as improve safety controls for exothermic processes). In order to provide such visibility, an increase in the number of temperature measurement locations became standard practice and accepted by process licensors worldwide.

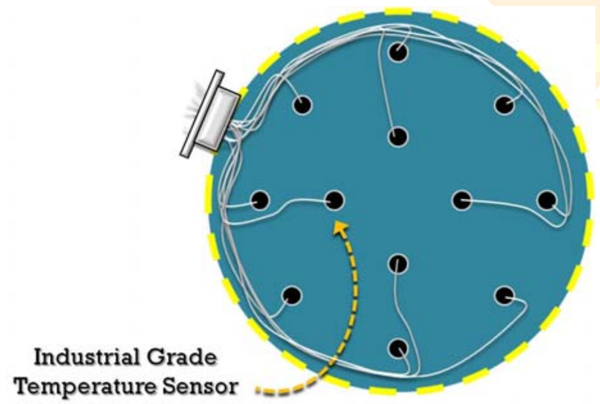
To employ increased temperature measurement locations, an adaptation to the traditional thermowell/temperature sensor assembly (a single sensor inserted into a rigid protective well which has direct contact with the catalyst) was developed to allow multiple temperature sensors to be positioned along the rigid well as pictured in Image 1, better known as a Rigid Multi-Point assembly. Due to low reliability of industrial grade temperature sensors, the rigid multi-point system was designed to provide online replacement of the temperature sensor by retracting the sensor probe from the protective well and inserting a replacement as the sensor had a tendency of falling out of calibration, reading erratic, or becoming unresponsive.

While a considerable improvement from only measuring one or two locations, these rigid multi-point systems provided three major problems; (1) due to rigidity of the protective well, limitations existed for sensor location, (2) employing the rigid multi-point increased the probability of catalyst loading issues, process flow, and maldistribution, and (3) heat transfer from catalyst temperature through the protective well to the sensor was exceptionally slow causing a long delay in response time from temperature change to data recognition.

*Year 1987*

An innovative next step in design was then to eliminate the common root cause of the three major problems of the rigid multi-point assembly: the rigid protective thermowell. Therefore, the significant design, commercially to market for the first time in the year 1987 by Gayesco International Inc. (later copied by a number of other manufacturers) and often referred to as the 1st Generation Flexible Radial Multi-Point (Image 2), was designed to route *multiple industrial grade tip sensitive temperature sensors* into a more elaborate radial profile at the outlet of a catalyst bed, supported by fixed structures attached to internal mechanical reactor components or the vessel itself. Due to minimizing the limitations of measurement location in comparison to the Rigid Multi-Point, this 1st Generation Flexible design offered more visibility within the catalyst bed at a single elevation. This added visibility at a single elevation became known as ***radial profiling***, a term widely accepted by the process industry today.

(IMAGE 2) 1st Generation Flexible Radial Multi-Point




While no significant improvement to the reliability of the industrial grade temperature sensor in this 1st Generation Flexible design, and no ability to remove and replace the temperature sensor online once failed (due to the elimination of the protective well), the design did allow for an increased amount of sensors as an attempt to offset the rate of failure of the sensor and again increase monitoring visibility of the catalyst.

In addition to unresolved reliability issues, these individual flexible temperature sensors required a significant amount of metallic support bars and support structures to maintain its desired position and placement in the catalyst bed. Depending on the elevation, number of sensors, and process licensed design, the amount of hardware required for the 1st Generation Flexible design risk reviving the problematic process flow and uneven catalyst loading issues that were originally expected to be minimized by the elimination of the rigid protective well. With the resurgence of these negative conditions, the benefits of increased visibility are undermined by the undesirable negative effects of this 1st Generation Flexible hardware on the catalyst ROI.

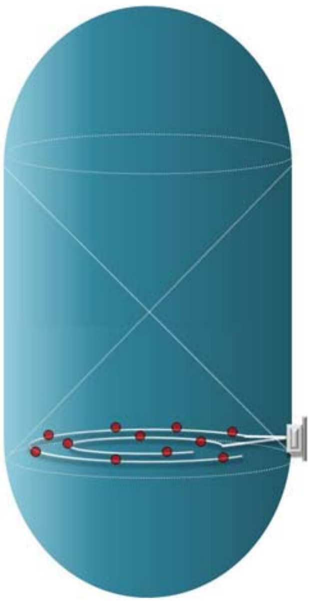
Recently, certain manufacturers of this 1st Generation Flexible Radial Multi-Point design have attempted to sidestep the temperature sensor reliability issues by offering field repair services on the individual sensor probes. Unfortunately, this procedure does not resolve or *fix* a sensor failure and carries a significant probability of measurement reliability risk and failure relapse during future operation. For more information please refer to the article *Not In My Reactor! The Hidden Dangers & Risks in Reactor Thermocouple Field Repair*, Daily Thermetrics Corporation, 2011.

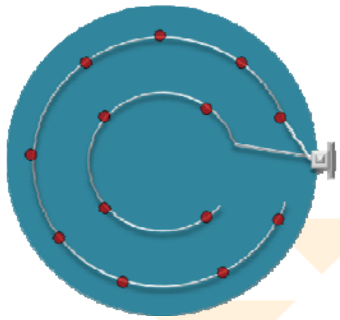
*Year 2001*

Following an absence of innovation for 14 years, it was identified that a desirable 2nd Generation Flexible design would need to (1) decrease hardware usage for both measurement and support, (2) significantly increase the reliability of the temperature sensor, and (3) create a new standard relating to an aspect of catalyst measurement never approached before: precision of any one sensor in relation to all sensors used to monitor the catalyst bed. This 2nd Generation Flexible Radial Multi-Point, commercially entering the catalyst profiling market for the first time in the year 2001 by Daily Thermetrics Corporation, and most commonly known as the "CatTracker®" Catalyst Tracking System, successfully exceeded all these desirable features.

The CatTracker® (Image 3), developed jointly between process industry temperature sensor manufacturer Daily Thermetrics Corp. and aerospace thermocouple design and manufacturing experts at Thermocontrol Inc., is a flexible probe that employs multiple independent, isolated temperature sensors (up to eleven (11) in a single probe). Multiple flexible CatTracker® probes can be inserted and routed into a reactor using the same entry nozzles as the Rigid Multi-Point and 1st Generation Flexible designs.

**In effect, the CatTracker® system can accomplish a radial temperature measurement**





(IMAGE 3) 2nd Generation Flexible Radial Multi-Point (CatTracker®)

**profile with as little as 12% of the equipment needed for the same profile using a 1st Generation Flexible design.**

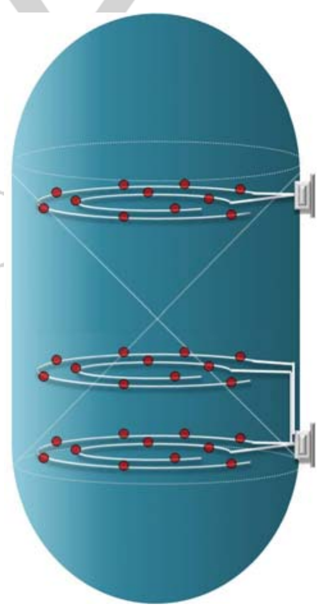
By using practices standard to the aerospace thermocouple industry, the CatTracker® eliminates the reliability issues faced by the design limitations of the 1st Generation Flexible Industrial Grade temperature sensors. In fact, the **CatTracker® boasts greater than a 99.9% reliability rating** based on every historical sensor installed, a figure unapproachable with the use of either the Rigid Multi-Point or 1st Generation Flexible designs.

In addition to hardware/equipment reduction to promote better process flow, minimize uneven catalyst loading, and superior reliability/near zero failure, the CatTracker® design offers process engineers *Ultra High Precision™*, a proprietary technology unavailable with any other design. *Ultra High Precision™*, a product of the combination of aerospace practices and proprietary thermocouple manufacturing techniques, **guarantees** that **every CatTracker® temperature sensor in the entire reactor** (in the event multiple catalyst beds exist in a single reactor) **is designed and manufactured to read within 1°C of each other at 427°C.** Simply put, the lowest reading measurement sensor will read no lower than 1°C from the highest reading measurement point at 427°C in the entire reactor. In comparison, the 1st Generation Flexible designs do not come close to this level of precision as its acceptable tolerances allow for as much as a 12°C differential between any two (2) sensors measured at a stable 427°C. Further, the Rigid Multi-Point design experiences even wider differentials due to the use of the same sensor technology as the 1st Generation Flexible then adding more complexity to the reading with variations in heat transfer along the protective well wall.

The CatTracker® design is recognized by all leading process licensors, more than any other flexible radial multi-point manufacturer, as a recommended or in some cases mandatory Monitor & Control System and currently operates in hundreds of reactors worldwide.

## PLENARY™ TECHNOLOGY: MEASUREMENT DENSITY FOR MAXIMUM VISIBILITY AND CONTROL

The 2nd Generation Flexible design, CatTracker®, was the first to offer process engineers and catalyst specialists with a system that provided radial profiling *without* impeding process flow, catalyst loading, or measurement reliability. With the use of this 2nd Generation Flexible system, process evaluation at a given elevation across the entire radial of a catalyst bed can be realized and a far more accurate analysis of the catalyst condition and utilization can be measured. Using a radial elevation at the bottom of the bed, processors can then identify which sections of the catalyst at the radial are being over worked or underutilized.



The last unknown within a catalyst bed should then be obvious: *How do we identify where exactly a problem started at the axial (vertical)?* **Plenary™ CatTracker® Technology**, the concept of increasing measurement density within a catalyst bed by means of multiple elevations of radial profiling, answers this question. By employing multiple elevations of the same CatTracker® radial profile, a processor then has the ability to visualize both horizontal and vertical temperature variations within a catalyst bed in real time.

Developing a type of three dimensional network of *Ultra High Precision™* measurement sensors can provide a wealth of information to processors when determining such daily issues as location and magnitude of temperature excursions and runaways, location and severity of distribution system malfunctions, and improper catalyst loading, to name a few.

Just as important, Plenary™ CatTracker® Technology also provides reinforcement for practices used that work well and should be continued such as proper balance of certain grades of catalyst, extended life of catalyst from heightened monitoring, and efficient use of utilities and secondary feed (such as hydrogen). Processors who operate Plenary™ CatTracker® Technology easily justify the increased investment in hardware via improved production/extended catalyst, or in other cases where problems are identified, by better preparing for turnarounds and shortening the maintenance time needed before the next catalyst cycle begin.

## SUMMARY

No matter the type of catalyst, variation in operating temperature, or kind of processing unit, when significantly investing into consumables such as temperature dependent catalysts, control is primary. The responsibility of such investment's ROI is not the responsibility of the catalyst manufacturer; rather, the responsibility falls to the processors and financial managers overseeing operations and key investments in Monitoring & Control Systems. Managing the vital signs of the reactor is in large part managing the temperature of the catalyst. Employing equipment such as CatTracker® radial temperature measurements and concepts such as Plenary™ Technology will better protect your catalyst bed today and many catalyst bed change outs in the future.

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