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Steam Reformer Overheating: Absolute Protection Now Available

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One of the most significant reformer incidents is overheating catalyst tubes to the point of failure. Reformer catalyst tubes expand when heated to operational temperatures. The expansion is a proxy for the tube temperature and is sufficiently precise that overheating conditions can be detected in time to avoid damage to the tubes. The concept of a Tube Growth Monitor (TGM) is introduced. This technology is licensed to BD Energy Systems and is available to non-methanol reformers applications. The real time reformer temperature data also allows other applications to improve reformer performance and tube life management.

INTRODUCTION

One of the most significant reformer incidents is overheating catalyst tubes to the point of failure. These events inevitably have a serious impact on the business with significant repair costs and loss of production.

Reformer tubes expand when heated to operational temperatures. The expansion is related to the tube temperature and is sufficiently precise that overheating conditions can be detected in time to avoid damage to the tubes.

Current on line detection of overheating relies on interpretation of process data from which tube temperatures are inferred either by the operator or an algorithm in the control system. These systems are not foolproof and fault tree studies reveal a number of ways they can fail to prevent overheating. However, by directly measuring the variable of interest, the tube temperature, via tube growth, these loopholes are closed and robust overheat protection is provided.

Together with a robust protection against overheating, the TGM real time reformer temperature data allows multiple uses of this data to improve reformer performance and tube life management.

This paper shows the cornerstone on which the TGM is based, a tube growth measurement instrument, and its advantages over current manual and automated protection systems.

PRINCIPLE OF OPERATION

All metals experience thermal growth due to temperature change that is characterized by a "linear expansion coefficient." This is the fractional change in length per degree of temperature change from a reference temperature.

Equation (1) shows the relationship between length (L) and temperature (T):

$$\frac{\Delta L}{L} = \alpha_L \Delta T \quad (1)$$

Where α_L is the linear expansion coefficient which is specific to each metal or, in the case of a reformer furnace, each tube material.

For the purposes of this paper, the theoretical relationship is described as above, but it must be noted that there are some practical factors that require attention:

First, in most reformer furnace designs, the tube is heated in such a way that a temperature profile is obtained with the objective of reaching an optimum in terms of the overall extent of chemical reaction. The change in temperature obtained from the expansion using the equation (1) will account for a change in the bulk or average temperature of the tube, see figure 1. This cannot be used to determine the actual temperature of the tube at any given point, though still will give information about the operational temperature of the tubes in relation to the heat input to the reformer radiant box.

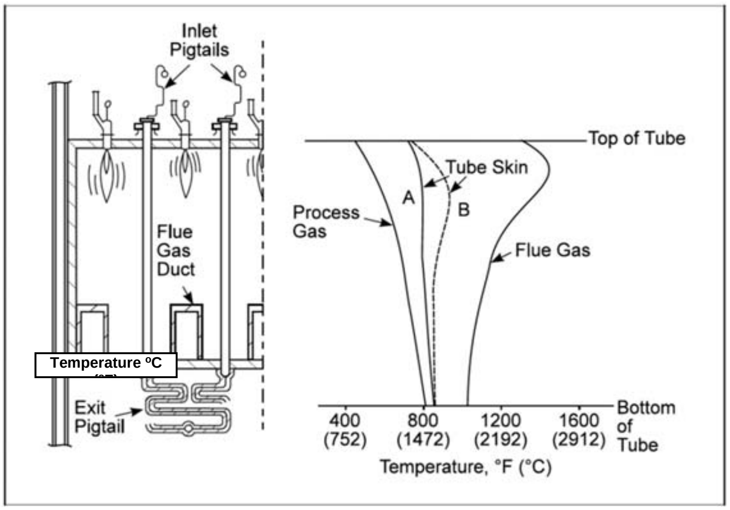

Figure 1: Typical temperature profile for a top fired reformer (2)

Second, locating the point of highest temperature in a reformer tube length, or the highest temperature tube, using infrared pyrometer equipment is time consuming and potentially difficult. These measurements are also subject to inaccuracies due to the complexity of the reformers configuration and the effects of varying degrees of reflected radiation from higher temperature walls within the reformer firebox enclosure. Due to the significant effort involved in gathering pyrometer tube temperature data, this data is generally only available once per shift at best. Therefore, the operating conditions of the reformer may change while the field operators are trying to locate the maximum tube temperature within a reformer.

CURRENT PROTECTION WEAKNESSES

Conventional operator-supervised overheat protection practices and automated systems using process instrumented inputs have inherent weaknesses and limitations that must be understood.

Reliance upon operator supervision for overheat protection places a tremendous burden upon operators to understand the dynamic behavior of a reformer furnace during non-steady state operations. The time considered for action to stop a temperature increase to prevent an overheat event must be enough to allow the temperature "inertia" to dissipate, without over-correction, in order to avoid damage to the tubes. There is limited time available for analyzing data and making a decision during an overheating incident. This understanding comes only with time and experience but is a critical need to enable operators to make correct decisions quickly and to avoid damage.

To avoid placement of such a heavy burden on plant operators, many plants have adopted some type of automated overheat protection system.

Many conventional automated overheat protection systems are based on use of fuel firing limitations programed into the control system. These firing limitations are based on correlations intended to limit the fuel firing rate based on a number of critical measured process operating parameters. The intent of such correlations is to avoid human error during non-steady state operations. However, a remaining weakness is that conventional automated overheat protection relies upon the proper function of multiple instruments that measure those critical process parameters.

Most of the published overheating incidents show root causes related to human behavior or with a great influence of this factor. Hence, the probability of overheat incidents is always present as long as human action is part of the decision and operation process intended to avoid such an event.

A factor that greatly influences the human behavior is the plant reliability. The reformer reliability and plant on-stream reliability has been improving over time. This means that there are much longer periods of stable operation time between unsteady state operations such as startups, shutdowns and the occurrence of serious problems like reformer trips. As a result, operators deal with unsteady conditions less frequently, making these events somewhat unfamiliar (1).

OTHER FACTORS

Another condition to consider is the retention of corporate knowledge that has been built up over many years when there is staff turnover due to retirement, promotion or job relocation(1).

In addition to the safety, health and environmental implications of serious overheating incidents, the plant operator can incur significant costs.

The cumulative costs of preventable incidents in the industry are not known, but it is likely that they amount to as much as $10 billion (1).

The fact remains that, using conventional overheat protection methods, reformers continue to suffer severe overheating incidents. There is strong justification for more robust reformer furnace overheat protection.

A FM Global report issued in 2006, shows (see Figure 2 and 3) that between 1974 and 2001 the monetary losses attributable to overheating and over temperature incidents is high despite the fact the percentage of occurrence is quite low. This shows the importance of preventing such events quickly enough to avoid damage and thereby avoid significant losses.

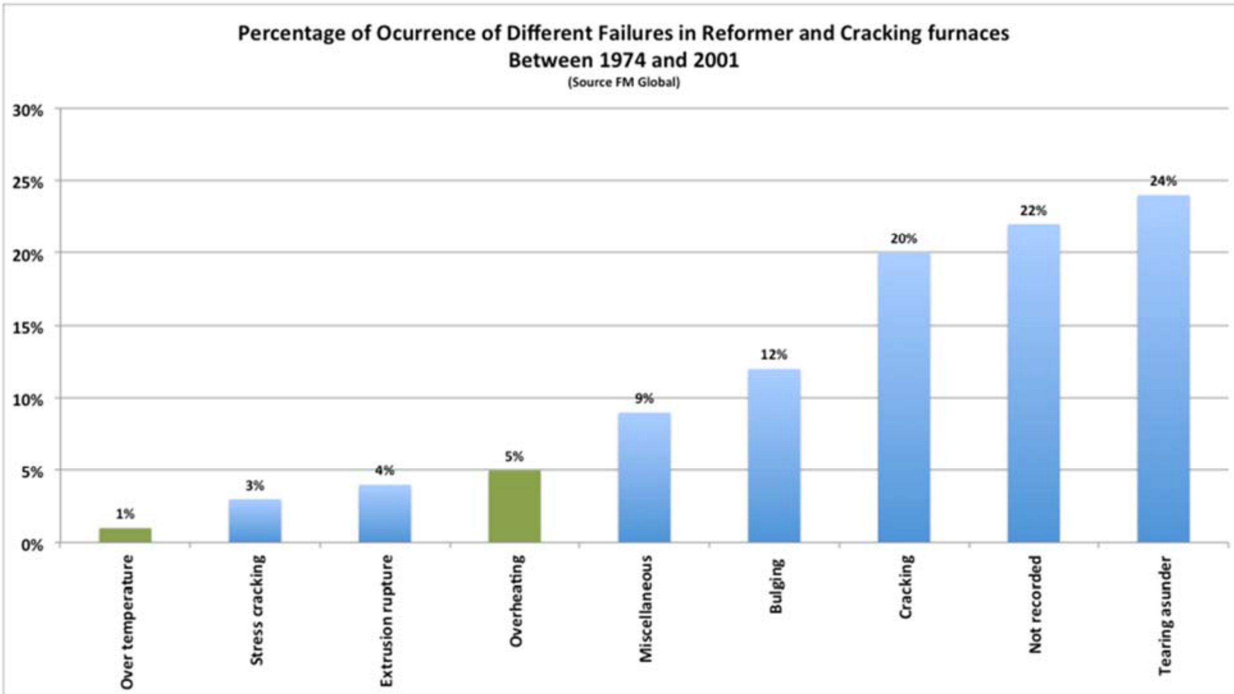

Figure 2: percentage of shutdown incidents due to over temperature (1%) and overheating (5%) between 1974 & 2001 (2)

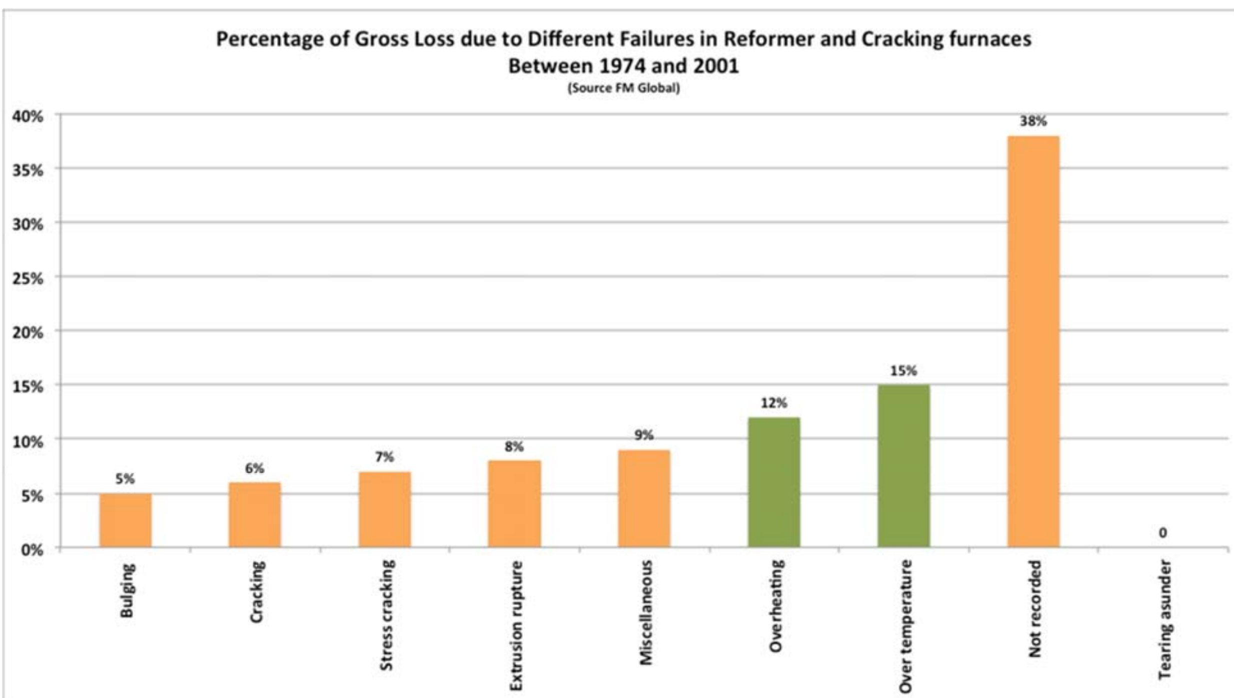

Figure 3: percentage of loss due to over temperature (15%) and overheating (12%) incidents between 1974 & 2001 (2)

FAULT TREE

A case study in a methanol production facility defined 10 potential causes, including some from actual operations experience, of reformer tube failures related to overheating that would not be, or were not, prevented by existing controls. Figure 4 shows the fault tree developed.

A detailed analysis yielded that the probability of prevention by reading the tube thermal expansion is "almost certain" for the following cases:

- Exotherm during steam out oxidation of catalyst
- Incorrect burner light off sequence
- Incorrect burner shut off sequence
- Fuel gas header pressure relying on auto-ramping during rate change resulting in overshoot of temperature
- Low steam flow or maldistribution of steam flow during steam out
- High fuel gas header pressure during steam out as control valve manual bypass is open
- Attempt to introduce feed gas with manual isolation valve closed. Programed protection system allows increase of fuel firing based on feed control valve % open
- Incorrect trend graph loaded into automated ramping software for startup control

For the next two cases the probability of prevention as determined in this case study were defined as "uncertain" and "possible" respectively:

- Collateral damage from end of life tube failure
- Burner tip failing giving jet flow and local tube impingement

However, subsequent to this case study fault tree analysis, experience (see Case Histories) with an installed TGM system clearly detected localized hot spots caused by a carbon accumulation hot banding event resulting from a heavy hydrocarbon feed slug. Based on the experience of this actual event, a repeat of this fault tree analysis would now determine that detection and prevention of overheat with the TGM system would be "probable" for these cases.

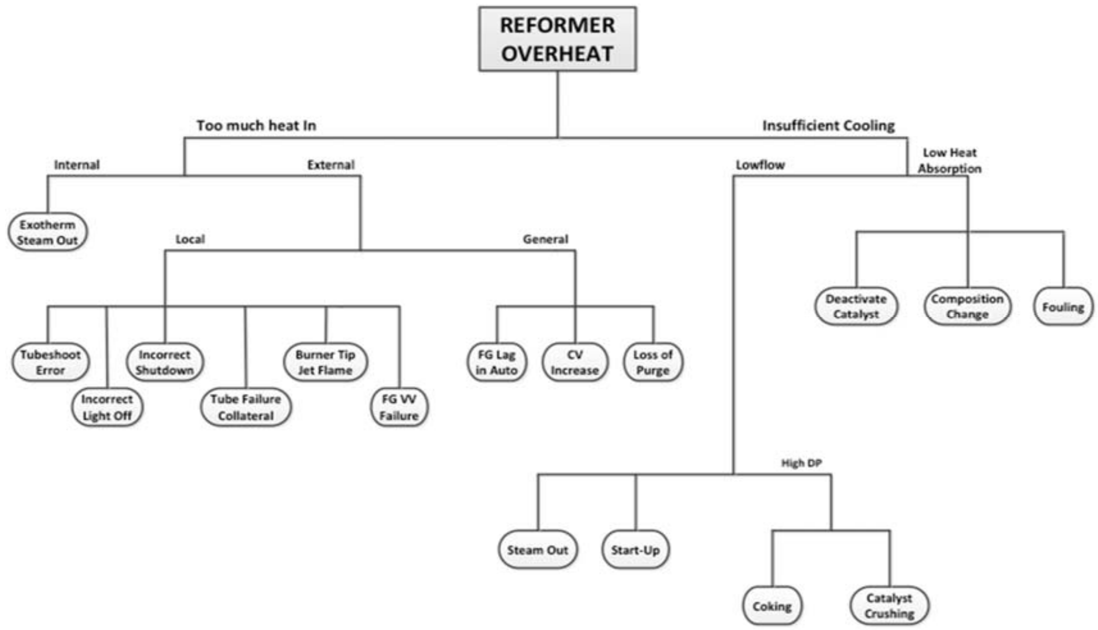

Figure 4: Fault tree developed showing TGM effectiveness to detect overheating incidents.

There are other failure mechanisms for reformers that will not be prevented by TGM installation, thermal shocking the tubes with a slug of water for instance or a firebox explosion, but fortunately these are much less common.

CONCEPTUAL ENGINEERING AND REAL APPLICATION

The Tube Growth Monitor (TGM) concept uses an instrument that is easy to install and set up. The TGM system design must consider the location of burners and how the tubes are supported in the radiant box (springs or counter weight hangers). With this information a rather simple mechanical design can be developed for installation of instruments on each hanger to ensure that they accurately measure the tubes thermal growth.

The system configuration is adaptable to the needs of each furnace operator. It normally requires that a signal of the tube growth is sent to the DCS in order to allow the operators and engineers to have on-line data. Additional trending can be made if the data is available to the plant process historian.

Although it is possible to have a local reading only, this setup is not recommended when the final intent is to protect the tubes from an overheating event as it would require constant attention from an operator to detect changes.

In a top fired design, the TGMs are normally installed on the tubes spring hanger or counter-weight hangers and the signal is sent to the DCS for processing and distribution to other plant systems like data historian and CMMS (Computerized Maintenance Management System), as a standard process data point.

A typical TGM set up for a top fired reformer can be seen in the next figure:

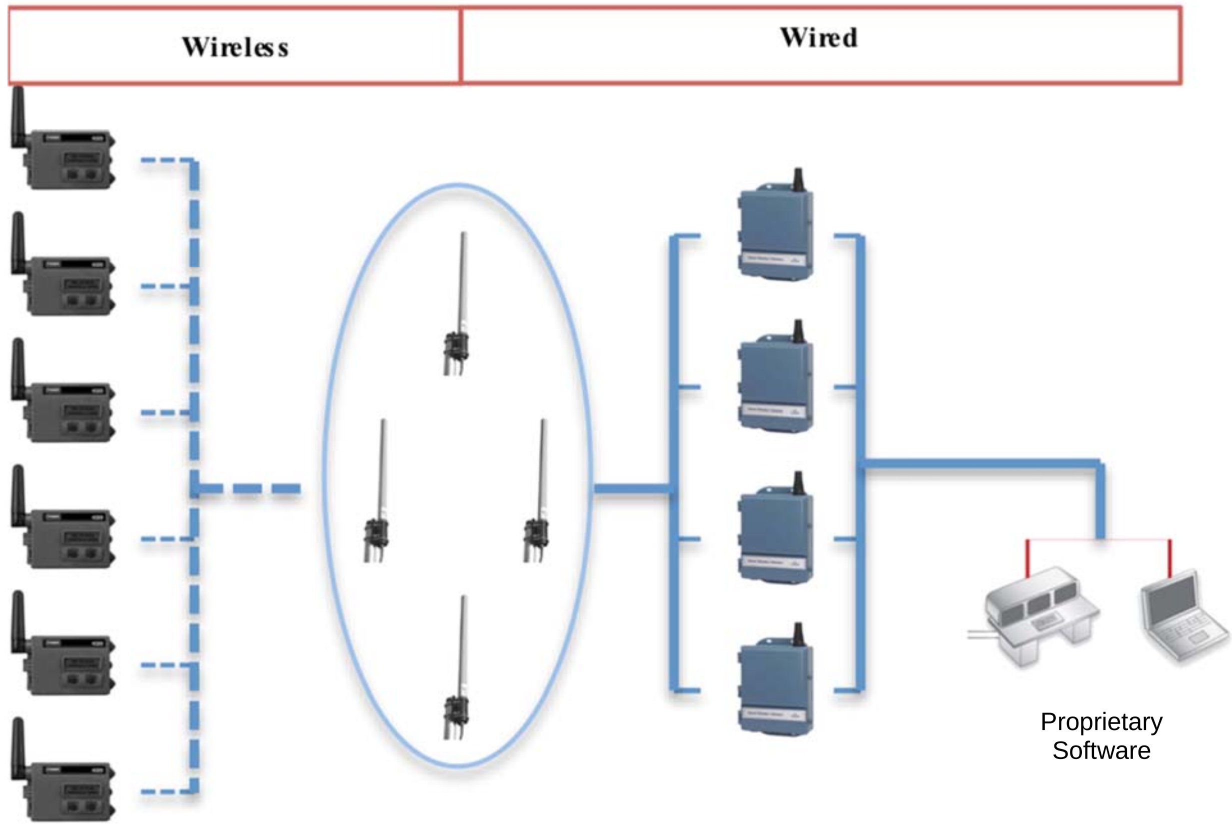

Figure 5: Example of TGM wireless installation in a top fired reformer.

Figure 5 shows a series of TGM (battery powered) connected to the reformer spring hangers. The signals are sent wirelessly to a set of four antennas that receive the signal and send it to four gateways that transmit the data to the system (DCS and data historian). The flexibility of the wireless devices allows for easy customization according to the needs of the reformer operator.

There is also the option of a wired TGM installation, but more work and budget would be required for the wiring and accessories related.

The number of antennas and gateways determines the frequency of the scan rate for each TGM input and therefore the level of reliability and redundancy provided to the data management processing.

For the real application described in this paper, wireless communication TGMs were installed on each spring hanger of a top fired reformer, as shown in figure 6. Each TGM reads the thermal expansion of four (4) tubes, as that is the spring hanger support configuration.

Finally once the information is contained in the DCS and data historian, the data is presented on proprietary software developed to display a representation of the radiant box plant view. This software is able to present a graphic display of the reformer in plan view showing a gradient of colors to indicate displacements of the TGMs installed on the hangers.

The software also presents statistical information about temperature showing the maximum, minimum, average at different times as well as standard deviation and rate of change statistics. Also allows for taking images and saving events amongst other features.

The software also allows for remote connection to the data making it possible to monitor the reformer condition at all time and from remote locations.

The data collected can also be exported to an Excel spreadsheet for further analysis and interpretation. This feature facilitates the development of life management strategies for the catalyst tubes.

Figure 6: Real TGM field set up in a top fired reformer.

Application

This technology is currently installed in two top fired reformers (spring hangers) and one terrace wall reformer (counter weight) with the first installation made in 2012 following the type of configuration shown in figure 5.

The software developed facilitate the operators' surveillance, and for data acquisition and analysis for engineers.

On one of the top fired reformer installations a total of 200 TGM are mounted on the tube spring hangers as shown in figure 6, the signal of each TGM is directed to the DCS and data historian.

There is one display representation for the DCS and another for the data historian. Figures 7 and 8 show both display styles respectively:

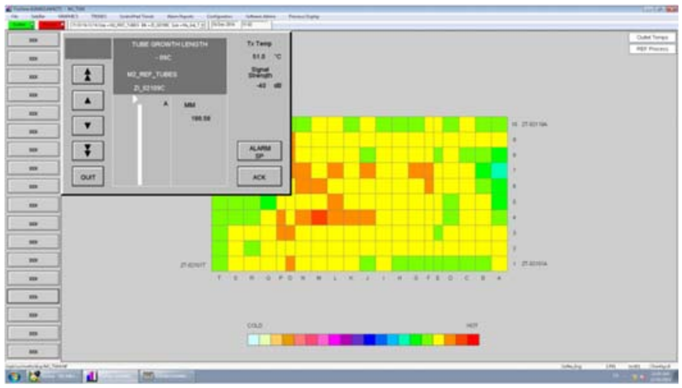

Figure 7: DCS display; typically a local display. Each square represents a TGM or spring hanger

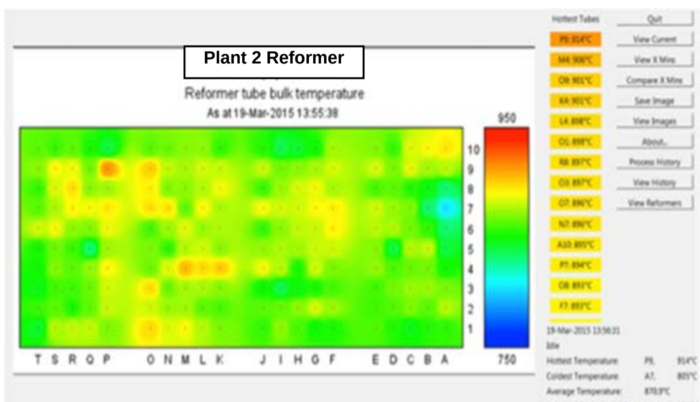

Figure 8: Data historian display: available for study from any network computer. Each dot represents a TGM or spring hanger.

Since the initial installation of the TGM system, a number of temperature excursions have been observed and damage was successfully averted by operator action. The case histories section of this paper details some of these events.

The data gathered, makes it quite clear that TGMs are the first alarms to indicate a temperature excursion. Figure 9 shows an actual excursion event that illustrates the six minute time difference between the first TGM alarms and the first standard process alarms.

Figure 9 also shows the thermal inertia of a reformer and illustrates how vital those six minutes can be.

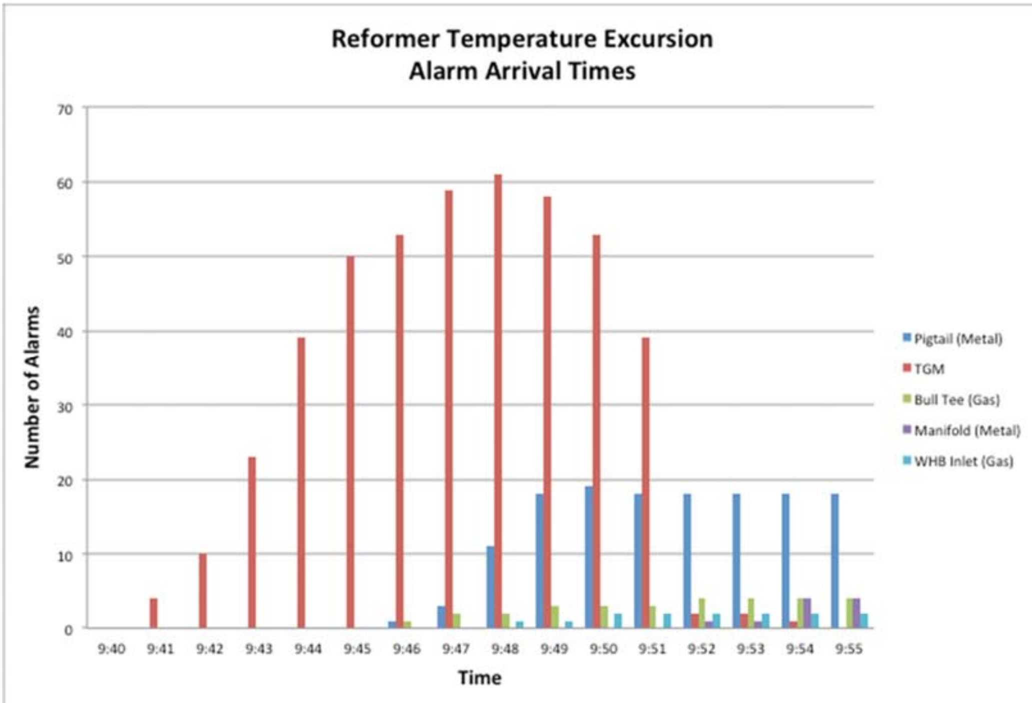

Figure 9: Alarm arrival times for a temperature excursion.

Visibility to Control Room Operators

In this paper it has been stressed that acting on time is vital to avoid major damage in case of an overheat event. To enable the TGM system to deliver the desired protection requires constant and clear visibility to control room operators. This allows for quick reaction time in case any temperature related problem occurs in the reformer. Figures 10 through 13 show a control room set up for the plant view of the reformer TGM system display:

Figure 10: TGM DCS view installed in a control room.

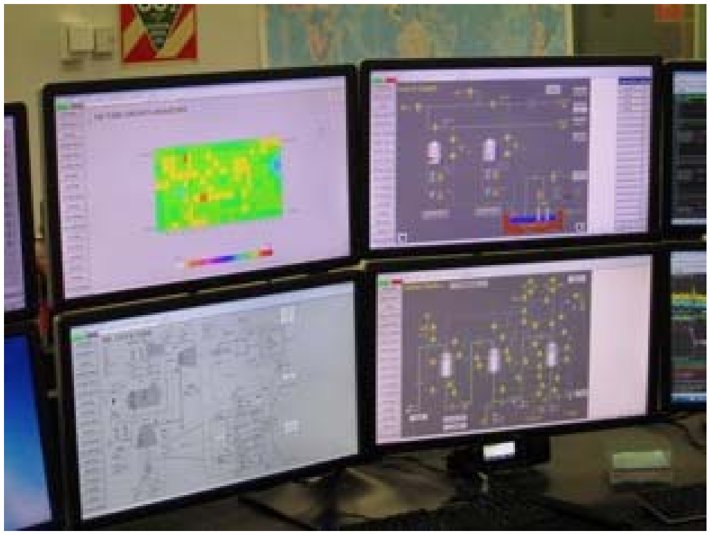

Figure 11: Close up of DCS view in control room.

Figure 12: Software display on all the time and visible to all operators and shift leader.

Figure 13: Software display on all the time and visible to all operators and shift leader.

Software displays are on 100% of the time and located next to the Shift Leader position and viewable by everyone in the control room.

The panel DCS view can be called up and is often used by operators

Quality of the data

The TGM data is able to yield 5ºC accuracy with 1050ºC of span. As explained this is a bulk or average temperature of the tubes supported by each spring or counter weight.

The scan rate for the data is set by the owner and is a tradeoff between battery life and response time. A one-minute update rate has been found to be a compromise that gives reasonable battery life and good response time and data resolution.

Figure 14 shows a plot taken from the data historian illustrating the resolution of the information:

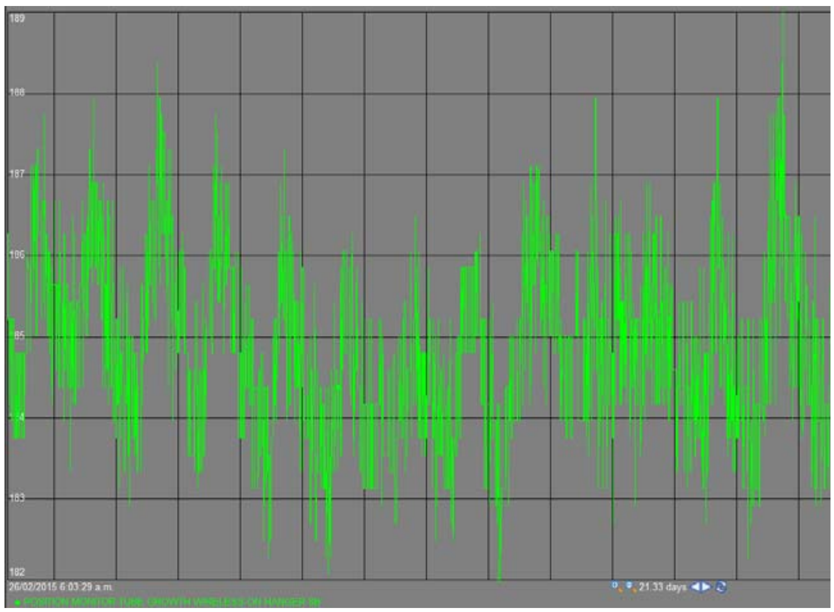

Figure 14: Example of the TGM data quality. Dimensions in (mm). The green line represents the TGM reading. The total range is 7 mm (actual data from plant PI System®).

CASE HISTORIES

Since the installation of the TGMs in a real application, there have been numerous cases examples that have shown the value of these instruments.

The following cases show just two situations where the TGMs have given valuable information to the operators:

Local heating

Many tubes underwent a ‘hot banding’ episode after an instance of heavier feed gas. A reformer went from the condition shown in figure 15 to the condition shown in figure 16 over a 44-minute period of time.

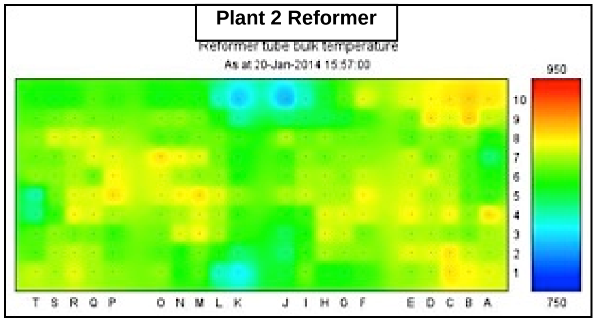

Figure 15: initial condition before the incident.

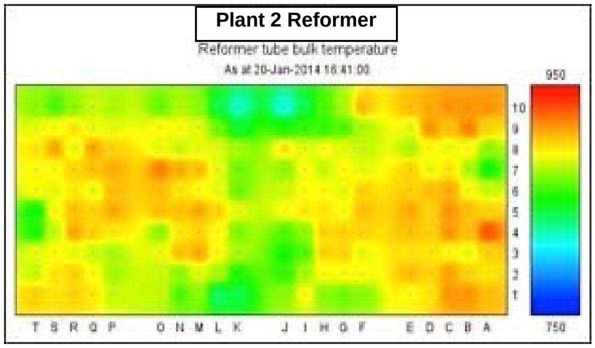

Fig. 16: hot banding condition after the incident

With no change in operating parameters, the rise in temperature was detected by the TGMs and the field operator measured 1000 ºC with the pyrometer but only over a 1 m length of tube. As a result of the information provided by the TGMs, quick action was taken to increase process steam rate for a period of time until the carbon accumulation dissipated and tube temperature returned to normal. By acting quickly, more significant carbon accumulation and catalyst damage was avoided, potential significant overheat of the tubes was avoided, and production loss was limited.

Local hot spot detection and Reformer Instability

The TGMs are also valuable to detect individual tubes in the reformer or regions of tubes in the reformer that flip between hot and cold due to flue gas flow pattern instability. This is a phenomenon sometimes experienced in large-scale down-fired reformer furnaces (3). Figure 17 shows this condition in a reformer.

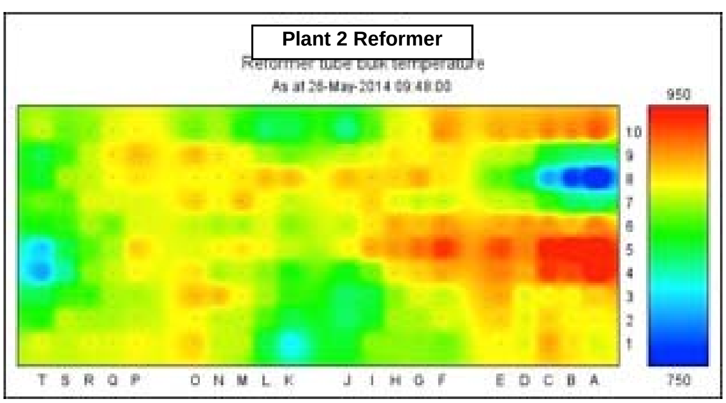

Figure 17: Hot and cold spot areas in the reformer.

CONCLUSIONS

Tube Growth Monitor system detects and alarms changes in reformer tube temperature before dangerous levels are reached earlier than current instrumentation. This makes possible an absolute protection against tube overheating incidents as long as the operators act upon the information promptly. The number of temperature monitors and the nature of the very visual display of the temperature indications and alarms from the TGMs cannot be missed or ignored. The case illustrated in Figure 9 shows that by the time the first process alarm (reformed gas temperature) came in, over 50 TGM alarms were activated with a visual display that was immediately apparent to everyone on the control room.

The use of the software developed to manage the TGM data together with the quantity of data collected allows for tube life management in a more effective way.

The installation and set up of the TGM system is flexible enough to fit the wide range of reformer configurations and operators' requirements.

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(2) FM Global Property Loss Prevention Data Sheets. Reformer and Cracking furnaces. February 2006.

(3) "Flue-Gas Circulation and Heat Distribution in Reformer Furnaces", Daniel Barnett and Deyuan Wu. AIChE Ammonia Safety Symposium, 2001.