Thermographic Monitoring of Refractory Lined Petroleum Refinery Equipment

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ABSTRACT

Infrared Thermography is used throughout the petroleum refining industry and has a proven track record of cost savings in many areas of the business. This paper describes the examination and monitoring of refractory lined process vessels, piping, fired process furnaces and flue gas ducting.

Refractory is a temperature resistant lining similar to concrete that is used to line refinery equipment that operates at very high temperatures. The refractory lining protects the outer shell of the piping and vessels from the hot gas and catalyst circulating inside the process plant. Failure of refractory linings can have very serious consequences.

In-service monitoring of the condition of the refractory lining is achievable using Infrared Thermography. This paper describes the five-year long monitoring programme initiated on a Fluid Catalytic Cracking Unit (FCCU) at a UK refinery. The programme enabled the refiner to plan their work scope for a planned shutdown well in advance of the actual event. Previously all refractory repairs during planned shutdowns have been as a result of visual internal inspection after the unit has been shutdown. The use of thermographic monitoring reduced unplanned refractory replacement requirements in the areas surveyed to almost nil.

Refractory linings of many different designs are also used for lining process furnaces and their flue gas ducting. The paper describes the monitoring regime, both external and in the firebox for process furnaces. It also demonstrates the potential advantages of surveying flue gas ducting from process furnaces.

Keywords: Refractory, thermography, cost saving, process, furnace, long term, monitoring

INTRODUCTION

Material Choice

Many refinery processes operate at temperatures above the operating range of normal carbon steel. This leaves the designer of the plant with two options. Either he can manufacture the equipment (process vessels and pipe-work) from materials that have a higher allowable operating temperature or he can line the equipment with an insulating lining to bring the surface temperature back into the operating range of carbon steel. Lining the equipment is the most common option for two reasons. Firstly the higher temperature resistant materials are much more expensive than carbon steel and secondly the insulating lining will retain much of the heat in the process fluids which improves energy efficiency and reduces the refinery fuel costs.

The Fluid Catalytic Cracking Process

Fluid Catalytic Cracking Units utilise a zeolite-based catalyst to crack low value long chain hydrocarbon molecules into high value short chain molecules that are used in gasoline and LPG production. Simply put, the plant upgrades heavy fuel oil to gas, gasoline and diesel with a small amount of fuel oil residue. The catalyst continually circulates through a riser, where the oil is mixed with the catalyst and the cracking reactions occur, into a reactor that is primarily a separation vessel to allow the superheated product vapour to separate from the
catalyst. The catalyst then passes into a regenerator vessel where it is regenerated prior to passing back into the riser. The basic components of the catalyst circuit are shown in figure 1.

**Figure 1: The basic components of the catalyst circuit**

The process is self sufficient with regard to heat. During the cracking reactions carbon is deposited on the surface of the catalyst particles, this lowers the activity of the catalyst. To regenerate the catalyst air is blown through a fluidised bed of catalyst in the regenerator vessel. The carbon burns off the surface of the catalyst particles, heating the catalyst to around 750°C (1400°F). This is sufficient to initiate the cracking reactions when the catalyst contacts the oil feed in the riser. As the oil passes up the riser it cools and is around 540°C (1000°F) when it reaches the reactor. At this temperature the carbon on the catalyst ignites as soon as it comes into contact with the air in the regenerator. The air is blown into the regenerator by an axial compressor that is driven by an expander that is turned by the flue gas products of combustion from the regenerator.

**Refractory Lining Failures**

The catalyst is circulating at high velocity and is extremely erosive. The refractory linings of the different parts of the catalyst circuit are resistant either to erosion or provide insulation. Both of these properties are necessary to prevent the outer carbon steel shell of the
equipment from coming into contact with the hot catalyst. The maximum design temperature for carbon steel is 343ºC (650F). Above approximately 540ºC (1004F) its mechanical strength decreases dramatically and therefore it loses its ability to withstand internal pressure. If the refractory lining fails it will be a very short time before the hot catalyst either erodes its way through the shell or weakens the shell to the extent that the internal pressure causes the shell to fail. Any loss of containment poses a significant threat to the safety of personnel and a high risk of fires and damage to process plant.

Catalytic Crackers have been in operation worldwide for over 50 years and during that time the quality and reliability of the refractory linings has improved with operational experience and technological developments. However, refractory lining failure remains one of the most common reasons for unplanned shutdown of FCCUs. The FCCU is one of the most important upgrading units in a fuels refinery complex with a large number of units taking feed from it. Therefore its reliability is critical to the reliability and hence profitability of the refinery as a whole. It is not uncommon for unplanned FCCU shutdowns to cost between $500,000 and $1,000,000 per day depending on the size of unit and market conditions.

LONG TERM MONITORING CASE STUDY

Inspection History

A UK refiner has invested significant time and money over the operating life of its FCCU to improve the reliability of the plant by implementing best practice refractory techniques and utilising new refractory products wherever possible. This effort resulted in significantly improved operating run lengths. However, the plant still experienced several unplanned shutdowns due to refractory lining failures. Thermographic surveys of the refractory lined equipment on the catalyst circuit have been conducted over many years. This has culminated in a planned programme of thermographic inspection every two weeks. The surveys consisted of a general qualitative examination of the surface temperature of the refractory lined equipment to look for hotspots that may indicate breakdown of the refractory lining. This approach has had several success stories when hotspots were located and monitored allowing time to failure to be predicted, new refractory materials ordered and a plant shutdown to replace the lining could be planned more effectively.

Historically the condition of the refractory lining had been determined by visual inspection at each of planned shutdowns of the plant that occur every four years. This is an entirely reactive inspection regime. Before the plant is shutdown an estimate of the quantity and type of refractory material required is made based on previous experience. When the plant is shutdown and the equipment opened for inspection the condition of the refractory is determined and any necessary repairs made. If unexpected repairs are necessary the material must be ordered during the shutdown and extra manpower located to make the repairs. Unplanned maintenance work during a shutdown is always costly in terms of both materials and manpower and always has a detrimental effect on the shutdown schedule. Conversely, if no repairs are required, the plant owner has purchased refractory materials unnecessarily.

Programme Setup

During a planned unit shutdown in 1999 large sections of the catalyst circuit were renewed as part of a unit revamp. Following this shutdown it was decided that the thermographic monitoring programme could be improved by including long term monitoring of the surface temperature of the refractory lined equipment.

The refiner’s Inspection Department identified 124 key locations for the long term monitoring. The criteria for selecting the locations were the Inspection Engineer’s knowledge of the operating history of the plant and areas that have particularly high erosion rates or unusual geometry. The temperature measurement monitoring did not replace the qualitative surveys
of the catalyst circuit. These surveys continued at two-week intervals but were complimented by the surface temperature measurement.

Technicians from the refiner’s NDT contractor who are all ITC Level 1 qualified carried out the thermographic surveys. The monitoring programme was devised and controlled by one of the refiner’s Inspection Engineers who is ITC Level 2 qualified.

SURVEY RESULTS

Surface Temperature Measurements

The results of the temperature measurement were recorded every two weeks on a spreadsheet. The 124 measurement locations were divided into sections that were then trended on graphs. Over time the results show trends in surface temperature that indirectly indicate the condition of the refractory at each location. Large areas of the refractory were new and the condition of all of the lining had been recently inspected so a good base line reading could be determined.

Due to the large number of measurement locations and the surface temperature of the steel (this varies between 180 and 220ºC or 350 and 430F at different locations in the catalyst circuit) it is impractical to measure the emissivity and reflected ambient temperature at each location. Instead a standard set of values for emissivity, reflected ambient temperature, distance and relative humidity were used. It is accepted that this will lead to measurement inaccuracy but providing the standard set of values is used for each survey the trend graphs will indicate any deterioration in lining condition before it becomes a threat to equipment integrity. Any areas that show an upward trend in surface temperature can be examined more rigorously once they are deemed to be a ‘problem’ area.

Environmental effects such as wind direction and speed become less of a problem due to the long-term repetitive nature of the surveys and the high energy in the process system. Although the wind speed and direction will affect the results, over time this averages out and the underlying temperature trend becomes apparent. Wind speed and direction were recorded at each survey for information purposes.

Figures 2 and 3 below are examples from the monitoring spreadsheet and show the surface temperature trend over the last five years for two different areas of the plant. Note that there are some step changes in the readings. This is due to plant shutdowns or process upsets. If an upset occurs which results in a thermal cycle of the catalyst circuit a full survey is conducted because rapid temperature change is the time at which refractory damage is most likely to occur. The monitoring programme contains 10 of these graphs covering all of the refractory lined equipment on the FCCU.
Figure 2: Trend of riser surface temperature results

Figure 3: Trend of regenerator shell surface temperature results

The graphs show a general upward trend for temperatures across the whole plant. This is normal because the catalyst slowly erodes the refractory allowing greater heat transfer to the outer shell of the equipment. Thermal conductivity data for the refractory products used in this equipment is readily available from the manufacturer. This enables the plant owner to calculate the remaining refractory thickness and determine if the lining will need repair during the next planned shutdown.
The refiner used this data to predict the areas of the plant that would require refractory repair with a much greater accuracy than ever before in the operating history of the plant. During the planned shutdown in 2003 the quantity of unplanned refractory repair in the area covered by the survey was reduced to nil. This represented a cost saving to the plant owner of several hundred thousand dollars.

**Qualitative Survey Results**

**Riser Refractory**

During the qualitative part of the thermographic surveys a crack like defect was noted in the Feed Riser refractory (see Fig 4). This defect was first noted in April 2003 and the monitoring frequency was increased to once per week. A fitness for service assessment was made based on the maximum recorded surface temperature and contingency plans formulated for replacement of a section of the riser in the event of a plant shutdown.

*Figure 4: Crack like defect in riser refractory lining*

The weekly monitoring of the defect permitted the plant to continue in operation until the planned shutdown in September 2003. This allowed the refinery to avoid the significant cost involved in an unplanned shutdown. When the riser was inspected internally a section of the refractory was found to have broken away with a V shaped cross section over a distance of approximately 10 metres. This section of the riser was replaced entirely during the planned shutdown in September 2003.

**Air Line Refractory**

The air lines from the axial compressor to the regenerator pass through an air heater furnace that is only used during unit start-up. During start-up the catalyst is initially heated to a temperature that will initiate combustion of torch oil that is injected into the catalyst bed to raise the temperature to operating temperature prior to the introduction of oil feed into the plant. Downstream of the air heater the lines are refractory lined to protect them from high temperatures during the unit start-up. Routine qualitative thermographic surveys of the air lines showed a hot spot where refractory has fallen away inside the line during start-up. This failure was most likely due to a rapid increase in temperature that resulted in differential growth rates between the refractory and the steel shell. This causes the refractory to break away from its support system and fall into the line. Figure 5 clearly shows the hotspot. Figure 6 shows the area of refractory missing from the line during internal inspection in the planned shutdown. Figure 7 is a thermal image of the air line after repair and start up of the unit.
Figure 5: Thermal image of hotspot on air line

Figure 6: Internal refractory damage

Figure 7: Thermal image of air line after start up
FURNACE MONITORING

Many refinery process units use fired heaters to raise the temperature of the oil to allow particular reactions or separations to take place. These fired heaters are refractory lined to protect the steel of the furnace shell. The same refiner uses a monitoring programme similar to the FCCU catalyst circuit for their process furnaces. The programme qualitatively surveys the tube condition in the furnaces looking for flame impingement on the outside and coking inside the tubes. As well as the qualitative scans, temperature measurements are taken each week using a standard set of values for emissivity, reflected ambient temperature, relative humidity and distance. These readings are entered into a spreadsheet and trended (see Fig 8).

![Trend Graph from Furnace Monitoring Programme](image)

*Figure 8: Trend Graph from Furnace Monitoring Programme*

The maximum allowable tube skin temperature is also included on the trend graphs to indicate if the process conditions are approaching this limit. Storing and trending the furnace firebox conditions builds up a useful picture of the operating conditions in the furnace during its operating life.

In addition to the surveys of the furnace firebox, external qualitative surveys are performed to examine the condition of the refractory lining. This information is used in the planning process to define shutdown work scopes and to improve plant reliability.

DUCTING SURVEYS

As well as surveying the external condition of the furnaces the same refiner also inspects the condition of the ductings taking the flue gas to the chimneystacks. These ductings are lined with insulating refractory and if the lining fails the increase in surface temperature leads to paint breakdown and corrosion of the ducting plates. Eventually the plates corrode through allowing rainwater ingress and flue gas egress. During a routine survey of the flue gas ducting it was noted that the ducting was partially obstructed by solids in an elbow (see Fig 9).
Figure 9: Solid Deposits in Ducting Elbow

The build up of solids was due to a change in process conditions in the furnace firebox that produced solid ash that accumulated in the bottom of the ducting elbow. Monitoring over a period of months showed the deposits were getting deeper (see Fig 10).

Figure 10: Increase in solid deposits over time and after the removal of the ash.
The furnace was taken out of service at a convenient time and approximately 50 tonnes of ash were removed from the ducting. The last image in figure 10 shows the ducting after the solids were removed and the furnace put back in service.

**SUMMARY**

Thermographic monitoring of refinery electrical systems and rotating equipment is already well established but thermographic examination of fixed refinery equipment appears to be under utilised throughout the industry. There are huge cost savings to be realised by refiners by thermally surveying their fixed equipment. Logging and trending the results over time improve the benefits of the surveys. This increases the refiner's knowledge of the condition of their equipment and therefore allows them to make more accurate and informed decisions. Including the results of thermal surveys in the maintenance and shutdown planning processes has been proven to make significant cost savings.

In order to maximise reliability, refiners need to move their maintenance systems from the old fashioned reactive systems to more cost effective proactive systems. Infrared Thermography is an ideal tool to aid this transition. It is non-intrusive and the benefits of a well thought out and executed monitoring programme far outweigh the cost.

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