Benchmarking Study

Fired Heater Flue Gas Analysis Shutdowns

As part of our extensive consulting work in process safety, Kenexis frequently performs benchmarking studies where we survey engineers at groups of peer companies in order to compare and contrast the approaches that these organizations use to address various topics in technical safety and the design of engineered safeguards in process plants. The topic of this benchmarking results report is related to the state of implementation of automatic shutdowns of fired heaters based on detection of high concentrations of carbon monoxide (CO) in flue gas, and the handling of anomalies in the concentrations of various materials in the flue gas in general. Recent advancements in the ability to measure concentrations of CO accurately and quickly using tunable diode laser (TDL) analyzers, combined with the nature of CO as a leading indicator of incomplete and unstable combustion, have driven a great deal of interest in application of the technology.

A large number of companies were contacted to participate in the benchmarking effort. These companies were chosen to represent a peer group comprised of larger and multinational petrochemical and oil refining/upgrading facilities. The sample included downstream facilities of super-major oil and gas companies, oil refining organizations, large natural gas processing companies, and large petrochemical/polymer production companies. The benchmarking included discussions with thirteen (13) of these organizations. In addition, a large process licensor/engineering company was also contacted regarding their position on fired heater stack gas interlocks that are specified in their licensed packages.

The benchmarking effort that was undertaken originally asked two questions:

1. Does your company's corporate standard require shutdown of heaters based upon detection of high CO concentrations?
2. Are you aware of any events in your organization where an explosion (of any magnitude) occurred as the result of incomplete combustion that resulted in ignition of a cloud of gas containing a high concentration of CO, but that was not detected by other stack gas measurements such as low oxygen or high combustibles?

Based on the content of the questions, it is obvious that the primary area of interest was the use of analysis of CO in flue gas to perform shutdowns. As the discussions with operating companies progressed, the range of questions was expanded based on the different approaches that the various operating companies applied to address the

hazards that are associated with incomplete combustion and accumulation of flammable gases in heater fireboxes and stacks. The first question was broken down into shutdown based upon detection of high CO concentrations in the normal operating mode and also during the startup mode. Another similar set of two questions was added asking whether or not a similar "combustion difficulty (e.g., incomplete combustion / combustible gas accumulation)" shutdown was implemented based on measurement of low oxygen and/or high combustibles, instead of high CO, both in normal operation and during startup. Additionally, two more questions were included regarding other non-SIS IPL for addressing "combustion difficulty". Specifically, the implementation of a basic process control system (BPCS) interlock that will detect combustion difficulty and based on that measurement, taken BPCS action to move to a safe state, such as setting the combustion controls into manual and ramping down fuel gas until the combustion difficult situation clears. The benchmarking asked whether or not this functionality is being used either based on 1) CO measurement, or 2) high combustibles/low O2.

The responses to the benchmarking survey are shown below with additional commentary based on the conversations.

High CO Shutdown Implementation – Normal Operation

0% **0/13**

None of the respondents indicated that they have standardized on high CO shutdowns during normal operation for their heaters. Most of the respondents indicated that very few, if any, of their heaters employ a CO measurement of any kind. In the few instances where CO measurements are taken, it was indicated that this measurement is addressed by operator response to an alarm instead of an automatic action. Two respondents indicated that high CO shutdowns and/or high combustibles/low O2 shutdowns are not taken. In fact, one respondent indicated that high CO shutdowns are "expressly forbidden". Their concern is that if a fired heater is operating in a bogged[1] condition and the fuel gas is suddenly stopped, it will result in an inrush of air that will actually cause the firebox explosion that the shutdown function is intended to protect against. The participants who implement "combustion difficulty" shutdowns (discussed later) that do not employ CO argue that the shutdown function will occur before the firebox gets to a critical stage of bogging, and thus the shutdown can be done safely.

[1] "Bogged" is a term used to describe the condition where combustible materials have accumulated in the firebox as the result of incomplete combustion of fuel at the burners, usually due to insufficient combustion air. Other terms are used to describe the same phenomenon such as "Loaded", "fuel rich", etc. This is the same condition that this document is referring to as "combustion difficulty".

High CO Shutdown Implementation – Startup

0% **0/13**

None of the respondents indicated that they have standardized on high CO shutdowns during startup for their heaters. The rationale for this choice is essentially the same as for the normal operation case.

High Combustibles / Low O2 Shutdown Implementation – Normal Operation

8% **1/13**

In lieu of a high CO shutdown, one organization has standardized on a different type of "combustion difficulty" shutdown during normal operation. Instead of measurement of CO, flue gas is analyzed for oxygen concentration and combustibles concentration. Through a voting arrangement where redundant analyzers are used the heater is shutdown if two analyzers agree that either the oxygen is low or the combustibles are high, the fired heater will be shut down. The balance of the organizations rely on operator intervention based on alarms to respond to the combustion difficulty situation.

High Combustibles / Low O2 Shutdown Implementation – Startup

15% **2/13**

While only one organization standardizes on an automated shutdown based on high combustibles or low oxygen in the flue gas, another organization (for a total of two) apply this technique during heater light off. It should be noted that this second organization employs this functionality on some of their newer heaters, but the safeguard is not standardized across the entire organization.

High Combustibles / Low O2 BPCS Over-Ride Implementation

23% **3/13**

In order to address the risk posed by bogged fireboxes, some organizations are implementing basic process control actions to prevent or remediate bogging. This action is based on the oxygen and/or combustibles measurement of the flue gas. The action that is taken is generally to put combustion controls into manual operation, and then automatically ramp down the fuel gas flow (or pressure) until the combustion difficulty situation has cleared. Three respondents indicated that this functionality is

standardized across their organization. One respondent indicated that the function has "activated several times and has worked flawlessly".

High CO BPCS Over-Ride Implementation

0% **0/13**

While no respondents are currently standardized on an anti-bogging BPCS function that is based on a CO measurement instead of the low O2 or high combustibles, there is interest in exploring this route because the CO measurement is a better leading indicator of combustion difficulty than the other options.

High CO Explosion Event

0% **0/13**

While almost every organization that was contacted indicated that heater bogging is an ongoing significant problem that has resulted in numerous incidents, no organizations indicated they are aware of any incidents where an explosion (of any magnitude) occurred because of combustion difficulty at one or more burners resulted in a flammable cloud in the firebox, but that situation was not detected by either low oxygen or high combustibles. One respondent stated that it might have been possible as the result of a high quantity of tramp air entering the firebox before the flue gas measurement, but there is nothing conclusive. Ultimately, in virtually every event that has occurred, the bogging of the firebox was known through other measurements. The only reason the events occurred was because operators took an improper response to the situations (i.e., adding air instead of cutting fuel).

Before closing the discussion, a couple of other things that were evidenced in the discussion should be noted. Heater bogging is a well-known problem that is not being adequately addressed by existing methods. One organization has taken measures to improve operator performance by improved reporting and tracking. In this organization, low firebox O2 is treated as a violation of safe operating limits that generates follow up actions. This event is treated as a Tier 3 reportable according to API 754 which is reported up through the highest levels of management. In addition, this type of event requires a documented investigation. This is a good starting point for trying to improve human performance with respect to this hazard.

CO analysis of flue gases is gaining traction. CO measurement is an excellent indicator of heater performance. Unfortunately, it is also an expensive measurement to make. One respondent indicated that CO measurement is expected to become much more prevalent because it will allow for improved performance of heaters. In order to run closer and closer to stoichiometric limits, fast response to combustion difficulty is

essentially. As such, as operating companies attempt to drive down excess oxygen concentrations to 2% or less to improve efficiency, CO measurements are being installed to allow heaters to operate closer to the edge, but safely. This is not a pure safety driver, as the basis of safety could just as easily be operating at a higher excess O2 instead of use of CO measurement. Nevertheless, a financial consideration could be made for implementation of CO over-ride control and high CO shutdown if the benefits of running lower than normal excess O2 will outweigh the cost of installing CO analyzers.