AFPM PROCESS SAFETY BULLETIN

AFPM
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Flammable Mixture Accumulation in FCC Units During Non-Routine Operations

This AFPM Process Safety Bulletin is a communication of the AFPM Event Sharing program. Bulletins are intended to communicate causal factors and lessons learned from API RP 754 Tier 1 and Tier 2 process safety events (PSE), as well as PSEs judged to have high learning value, and to notify industry of hazards and circumstances that may potentially lead to a PSE. This Process Safety Bulletin does not constitute legal or technical advice or recommendations of any kind, nor does it alter any legal requirements. Although care has been taken to provide accurate information, AFPM makes no express or implied representations or warranties, including without limitation fitness for a specific purpose or compliance with applicable laws, concerning the information contained in this Process Safety Bulletin.

General Hazard Information

Whenever a fuel is mixed with an oxidizer, carefully controlling the process can help prevent the accumulation of a flammable mixture. When the proper controls have not been put in place or fail to prevent the accumulation of a flammable mixture, an explosion may occur if the mixture encounters an ignition source. Process equipment such as furnaces, electrostatic precipitators, boilers, and the ductwork connecting these pieces of equipment are not typically designed to contain internal explosions, which can lead to their catastrophic failure.

Specific Issue/Hazard

Fluid Catalytic Cracking (FCC) units include a reactor in which hydrocarbon feed is cracked in the presence of a catalyst to form lighter compounds. The reaction deposits carbon on the catalyst resulting in deactivation of the catalyst. The carbon is burned from the catalyst in a regenerator. Catalyst is continuously circulated between the reactor and regenerator. During routine operation, the reactor and regenerator pressure balance and the catalyst level in the reactor provides head build in the standpipe which aids in maintaining the separation between the regenerator (containing air) and the reactor (containing hydrocarbon). Furthermore, during routine operations both the regenerator and reactor operate at temperatures sufficient to assure combustion will occur if small amounts of air enter the reactor or if trace amounts of hydrocarbons enter the regenerator. In non-routine operations, however, the temperatures of both the reactor and regenerator may be insufficient to ensure combustion of the leak-by (hydrocarbon or air) resulting in the potential for subsequent explosion if the other gases are permitted to accumulate or if they encounter an ignition source.

When hydrocarbon enters the regenerator from the reactor at sufficient rates at temperatures that do not support immediate combustion, a flammable mixture will form. This flammable mixture then flows to downstream processing equipment. Equipment such as carbon monoxide (CO) boilers and electrostatic precipitators (ESP) constitute likely sources of ignition for a flammable mixture.

When air enters the reactor from the regenerator, this air will flow from the reactor to the fractionator where it can accumulate in the overhead. Over time the concentration of oxygen increases in the overhead vapor until the flammable limit is reached and an explosion becomes possible. The likely ignition source triggering the explosion is the presence of pyrophoric Iron Sulfide (FeS). The FeS begins to exotherm in the presence of oxygen, eventually becoming hot enough to ignite the flammable mixture accumulating in the fractionator overhead system, or other downstream equipment such as flare drums or fractionation towers. The result can be a catastrophic equipment failure with further damage due to loss of containment and ignition of the contained hydrocarbons.

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Flammable Mixture Accumulation in FCC Units During Non-Routine Operations

During some non-routine operations, a Direct Fired Air Heater (DFAH) and/or torch oil may be used to inject heat directly to the contents of the regenerator, or to raise its temperature in preparation for start-up. A flammable mixture may accumulate if the DFAH experiences flame-out or the torch oil does not ignite. For an external DFAH, this risk may be somewhat mitigated using flame detectors with a Safety Instrumented System (SIS). However, for internal torch oil nozzles, this is not possible.

Events (9)

The following events occurred due to accumulation of a flammable mixture internal to FCC units during non-routine operations.

Event # 1 (CSB Report - Refinery Explosion)

An explosion occurred in the FCC's ESP, a pollution control device that removes catalyst particles using charged plates that produce sparks (potential ignition sources) during normal operation. The incident occurred during an attempt to isolate equipment for maintenance while the unit was in a standby mode of operation. Improper pressure balance allowed hydrocarbons to flow to the regenerator and ignite in the ESP. The CSB found that safe operating limits for operating the unit in Safe Park (a standby mode of operation) were not established, and therefore the unit was placed in an unsafe condition when steam flow to the reactor was reduced below a safe level.

Event # 2 (CSB Report - Refinery Explosion and Fire)

During the shutdown of the refinery in preparation for a 5-week turnaround, an explosion occurred in proximity to the FCC unit. Catalyst de-inventoried into the regenerator and an improper pressure balance resulted in the transfer of air from the regenerator into the reactor. The air accumulated in equipment downstream of the reactor until a flammable mixture was reached and found an ignition source. Projectiles from the resulting explosion punctured an asphalt tank about 200 feet away. The asphalt pouring from the hole flowed beyond the protective berm and began to accumulate in the FCC and crude fractionator processing areas. The asphalt ignited resulting in a smoky fire causing the evacuation of a portion of the nearby community.

Event # 3

An in-line preheater was being used to heat the unit while it was in circulation mode in preparation for re-start following unplanned S/D. The preheater burner has a natural gas fired pilot and the main burner uses torch oil (gas oil). The burner appeared to have lost flame which went undetected for about 1 1/2 hours without isolation of the pilot or main burner fuels, allowing for accumulation of a flammable mixture. The air/natural gas/gas oil mixture ignited, causing a breach in the preheater wall. The air blower was shut down immediately, at which point catalyst flowed from the regenerator through the hole in the preheater and onto the FCCU pad resulting in a small fire in the area.

Event # 4

A unit shutdown occurred due to loss of boiler feed water at the CO boilers. During the shutdown, hydrocarbons back-flowed from the Main Fractionator through the Reactor-Regenerator system into the flue gas system. Post event inspection found that the Spent Catalyst Slide Valve (SCSV) had sheared due to elevated purge steam rates. The high purge steam rates occurred due to the absence of a flow-reducing orifice.

Flammable Mixture Accumulation in FCC Units During Non-Routine Operations

Under normal shutdown conditions slide valves control the flow of catalyst between the reactor and the regenerator. They should not be considered gas tight, as the pressure balance must be maintained to maintain separation between hydrocarbon and air. An imbalanced pressure profile allowed a reverse flow of hydrocarbon from the Main Fractionator through to the Wet Gas Scrubber (WGS) stack. The hydrocarbons started a fire in the Selective Catalytic Reactor (SCR) NOx emissions control catalyst which was inadvertently supplied with additional air by the boiler purge cycle during the effort to restart the FCC. The fire damaged the SCR catalyst, duct work and caused deformation of the support structure within the SCR reactor.

Event # 5

During a series of power interruptions, an explosion occurred inside the FCC electrostatic precipitator. The explosion damaged the precipitator and resulted in a small fire. The power blips caused two of the refinery boilers to trip, reducing the available steam. The FCC Main Air Blower, driven by a condensing turbine, began to slow and eventually tripped on low air flow. The torch oil control valve, feed isolation valve, and catalyst circulation slide valves were closed by the interlock system. Approximately 1.5 hours later, while trying to maintain the regenerator temperature, the torch oil control valve bypass was opened manually. There was insufficient air to burn all the torch oil resulting in unburned hydrocarbons and CO in the flue gas that flowed from the regenerator to the ESP. Fresh purge air entering the ESP from the electrical penthouse mixed with the flue gas creating a flammable mixture near the back end of the ESP. Six minutes after the torch oil control valve bypass was opened a detonation occurred near the ESP outlet vent.

Event # 6

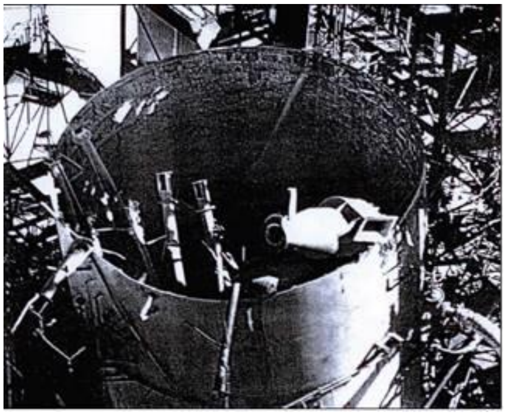
The FCC reactor/regenerator catalyst was being de-inventoried in preparation for repair of a mechanical failure on the regenerator slide valve following a safety instrumented system (SIS) trip of the unit. Contrary to the site's procedure, the catalyst de-inventoried prior to isolation of the reactor from the main column. Pressure imbalance led to air from the main air blower entering the reactor, flowing to the main column and ultimately reaching the flare system. Pyrophoric material in the overhead fin fans, flare drum or associated piping ignited the flammable mixture. The flare knockout drum and associated piping experienced deformation.

Event # 7

While the unit was in the initial regenerator heat up phase during a unit start-up an explosion occurred in the ESP. During this period, the regenerator air heater was operated in an incomplete combustion mode due to a sheared linkage pin on the heater damper preventing it from opening properly. This incomplete combustion resulted in the formation of hydrogen and CO in the flue gas. The hydrogen is thought to have built up at the top of the ESP and ignited when it was energized. Procedures did not address purging requirements during this non-routine operation.

Event # 8

During an FCC unit shutdown, the steam flows to the reactor were gradually reduced over the course of 5 hours for various reasons while catalyst was unloaded from the regenerator. During this time, fuel gas was continuously injected in the top of the main fractionator to maintain the system pressure. Condensation of the steam in the main fractionator overhead and the removal of all significant steam sources in the reactor allowed fuel gas to flow back to the regenerator and form an explosive mixture. A large explosion occurred in the regenerator approximately 2.5 hrs. after the final reductions in steam. The regenerator head, weighing approximately 165 tons was launched approximately 125 ft causing damage to piping in the area. The event took place in 1963, with no casualties or subsequent fires occurring in conjunction with the incident.



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Event # 9

Following a trip of the FCC main air blower, torch oil was permitted to continue to flow into the regenerator over the course of 3.5 hrs. This resulted in approximately 5 m^3 of torch oil saturating the catalyst in the regenerator. When the air blower was returned to service, the extent of the oil contamination was not fully understood, and the operator reintroduced air to the regenerator. Upon re-fluidizing the catalyst bed, the temperatures in the regenerator increased quickly due to the heat retention of the catalyst, which is believed to have provided an ignition source. A low intensity explosion occurred within the regenerator approximately 20 min after air was introduced. A subsequent deflagration 12 min later blew a door sheet off the FCC stack, damaged flue gas ducting, and sent flames out of the top of the stack. The event took place in 1999, and no casualties occurred.

Considerations

Non-routine operations in FCC units during which the reactor and regenerator temperatures may be below, or may dip below temperatures that ensure combustion:

- Startup
- Shutdown
- Emergency shutdown
- Rates reduced to or below minimum operating limits
- Upsets due to:
    - i. Mechanical problems
    - ii. Air blower trips, slowdowns of turbine driven machines, or surge controller malfunctions
    - iii. Weather issues: Storms moving in, Sub- zero temperatures, High temperatures, Rain showers (cooling)
    - iv. Upstream or downstream unit problems that affect flows to/from the FCC unit
    - v. Feed composition changes (contaminants such as light ends, water, or slop oil) reaching the FCC
    - vi. Loss of utilities systems such as power or steam

During non-routine operations, the safeguards applied to maintain separation of the reactor and regenerator contents may include the following:

- Close both the regenerator and spent catalyst slide valves. **Remember that slide valves are not gas tight**. The purpose of a slide valve is to control the flow of catalyst during normal operations and gas always leaks from high pressure to low.
- Maintain a positive differential pressure across both slide valves to assure gas cannot leak upwards through the valves and bubble up through the standpipes into alternate vessels.
- Ensure reactor and regenerator levels are maintained to restrict flow between the reactor and the regenerator. While catalyst itself does not create a barrier to flow, it does act as a restriction orifice and makes it easier to maintain the pressure in the reactor at a value above that in the regenerator.
- Control the pressure of the reactor to make it the high pressure point in the system (Fractionator**<Reactor>**Regenerator) to minimize air entering the reactor and hydrocarbon entering the regenerator.
- Addition of steam to the reactor displaces hydrocarbon vapors from the reactor to the main fractionator and provides a source of pressure to the reactor side during times when feed flow has been isolated.
- Isolate hydrocarbon sources to the reactor, including fresh feed, product recycles, slop injection, and fuel gas or natural gas sources.

Ensure procedures incorporate the following:

- Safeguards, such as those above, are incorporated into procedures for startup and shutdown activities. Involve subject matter experts and operators, both field and console, in the development of these procedures.
- Expectations are established and followed to manage situations requiring deviation from established procedures including both hazard review and approval. For ideas on improving Procedure Operations Excellence, see AFPM Practice Sharing – ‘Improving Human Reliability: Operating Procedure Development, Use and Continuous Improvement.’

The console operator is typically provided indicators that each of these safeguards has functioned or is functioning while the unit is in non-routine operation. These may include simple indicators such as slide valve positions and differential pressures, or vessel pressures (Reactor/Regenerator/Main Fractionator). Flow of steam and/or nitrogen from the reactor to the main column indicates an effective inert gas barrier against hydrocarbon backflow. This can be confirmed via monitoring of the main column accumulator sour water flow rate or interface level control and/or pressure control variables.

When a DFAH is used to heat the regenerator, application of the safeguards applicable to any fired heater (e.g., furnace, boiler, thermal oxidizer) may be used. This includes detection for loss of flame and automatic isolation of burner fuels. For torch oil combustion in the regenerator bed, proper excess O2, temperature control, and regenerator catalyst level are key monitoring points.

References

The following references offer additional information related to incidents.

- CSB report on ExxonMobil Torrance Refinery Electrostatic Precipitator Explosion available at https://www.csb.gov/exxonmobil-refinery-explosion-/
- CSB video on Husky Energy Refinery Explosion and Fire available at https://www.csb.gov/husky-energy-refinery-explosion-and-fire/ (The CSB investigation is ongoing at the time of this Safety Bulletin)
- Search the AFPM Safety Portal. Access limited to AFPM members only.
    - ‘Safeguarding the FCCU during Transient Operations’ Presentation
    - ‘FCC units’ for additional resources