HAZARD IDENTIFICATION

Flammable Mixture Accumulation in FCC Units

Purpose and Use:

Process Safety Hazard Identification documents serve to help facilities identify potential risks associated with work practices, safety practices, process equipment, and technology. Hazard Identification documents are meant to:

- Improve process safety awareness with a focus on higher potential consequence risks,
- Provide information and ready reference guides for potentially overlooked or under-communicated process safety hazards,
- Share lessons from industry related incidents and near misses, and
- Improve human reliability.

Scope:

Accumulation of flammable mixtures inside Fluid Catalytic Cracking (FCC) units during non-routine operations.

Category:

Safety Procedures, Operating Procedures, Emergency Procedures, Process Equipment, Process Technology

Examples of Potential Concerns and/or Hazards:

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 surface of the catalyst resulting in catalyst deactivation. The carbon is burned from the surface of the catalyst in the 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 gain of pressure down the standpipe that aids in maintaining the separation between the regenerator (containing air) and the reactor (containing hydrocarbon). In non-routine operations 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.

When hydrocarbon leaks from the reactor to the regenerator at sufficient rates to form a flammable mixture and at temperatures that do not support immediate combustion, the flammable mixture flows to downstream processing equipment. Downstream equipment, such as carbon monoxide (CO) boilers and electrostatic precipitators (ESP), constitute likely sources of ignition for a flammable mixture and are incapable of containing the explosion. The result can be catastrophic failure of that equipment and/or the ductwork that connects it with potential impact to nearby personnel and facilities.

When air leaks from the regenerator to the reactor at temperatures that do not support combustion, the air flows from the reactor to the fractionator where it accumulates overhead. The air accumulates because it does not condense at the column's operating temperature and pressure, therefore it has no way out. Over time, the oxygen concentration 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 cause ignition. Ignition results in an explosion or detonation which cannot be contained within the fractionator overhead system. The result is catastrophic equipment failure with potential impact to personnel and facilities at considerable distances.

During some non-routine operations, a Direct Fired Air Heater (DFAH) or torch oil may be used to inject heat directly to the regenerator in preparation for start-up. A flammable mixture may accumulate if the DFAH experiences flame-out and all fuel sources are not immediately isolated, or if insufficient air is introduced to the regenerator to assure that the fuel is completely combusted to carbon dioxide and water. Additionally, the regenerator temperature may not be high enough to ignite the torch oil resulting in accumulation of a flammable mixture.

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Non-routine FCC operating conditions during which reactor and/or regenerator conditions could allow accumulation of a flammable mixture via one of the ways outlined above include:

1. Standby or Safe Park operations
2. Start-up
3. Normal shutdown
4. Emergency shutdown
5. Rates reduced to or below minimum operating limits
6. Upsets due to:
    a. Mechanical problems
    b. Weather issues: Storms moving in, Sub-zero temperatures, High temperatures, Rain showers (cooling)
    c. Upstream or downstream unit problems that affect flows to/from the FCC unit
    d. Feed composition changes (contaminants such as light ends, water, or slop oil) reaching the FCC
    e. Loss of utility systems such as power or steam

In summary, accumulation of a flammable mixture within an FCC unit can be created by:

- Transmission of hydrocarbon from the reactor to the regenerator during non-routine operations.
- Transmission of air from the regenerator to the reactor during non-routine operations.
- Flame-out of a DFAH used to inject heat directly into the regenerator without isolation of its fuel, or injection of torch oil at conditions that are insufficient to achieve complete combustion within the regenerator bed.
- Flooding of the burner used to inject heat directly into the regenerator with subsequent re-introduction of sufficient air to rapidly burn the un-combusted fuel.

Potential Hazards:

The accumulation of a flammable mixture inside process equipment creates the potential for an explosion or even detonation when ignition occurs. There are several ways for this to occur in an FCC unit during non-routine operations. Each is described below.

	Potential Concerns	Considerations
1.0	Transmission of hydrocarbon from the reactor to the regenerator	1.1 Malfunction/erosion of the spent catalyst slide valve results in losing the level in the reactor and makes it difficult to keep reactor pressure higher than the regenerator and main fractionator. 1.2 Failure to control the pressure balance between the reactor and the regenerator results in excessive reactor – regen differential pressure and slide valve DP, creating the driving force for flow from the reactor to the regenerator. 1.2.1 Failure to isolate reactor feed in the event of loss of pressure balance control. 1.3 Insufficient steam (inert) flow to the reactor fails to displace hydrocarbons toward the fractionator.
2.0	Transmission of air from the regenerator to the reactor	2.1 Malfunction/erosion of a regen slide valve results in losing the level in the reactor and makes it difficult to keep reactor pressure higher than the regenerator and main fractionator. 2.2 Failure to control the pressure balance between the reactor and the regenerator creates the driving force for flow from the regenerator to the reactor. 2.2.1 Failure to relieve excess air pressure at the blower discharge in the event of a loss of pressure balance control.

Note: This hazard identification document is a generic, non-comprehensive synthesis of inherent concerns and/or hazards for the related topic. It in no way alters any legal requirements. It is not intended to replace sound engineering analysis or judgment.

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3.0	Regenerator Direct Fired Air Heater (DFAH) flame-out without isolation of fuel	3.1 Visual observation of flame was not maintained, if applicable 3.2 Flame detection with automated fuel isolation is not provided. 3.3 Safety instrumented system that provides fuel isolation on flame-out is bypassed or fails.
4.0	Regenerator DFAH flooding with subsequent introduction of air	4.1 Regenerator exit stream is not monitored for O_2 or combustibles content to detect flooding. 4.2 Operating procedures and training do not provide instruction on detection of burner flooding (e.g., further increases in fuel rate result in decreasing outlet temperature). 4.3 Operating procedures and training do not provide instruction on response to burner flooding in the regenerator.
5.0	Torch Oil injected into the regenerator is not fully combustible	5.1 Regenerator catalyst temperature too low when torch oil is injected. 5.2 Regenerator temperature not monitored for continued evidence of torch oil combustion. 5.3 Regenerator catalyst level insufficient to submerge torch oil nozzles while in use. 5.4 Incomplete combustion of torch oil due to insufficient air, poor atomization, or maldistribution, resulting in hydrocarbons in flue gas.

References:

Safety Bulletin on American Fuel & Petrochemical Manufacturers Safety Portal on Flammable Mixture Accumulation in FCC Units during Non-Routine Operations.

Industry Incidents:

February 18, 2015 explosion at the ExxonMobil Torrance, California refinery ESP. Chemical Safety Board investigation report available at https://www.csb.gov/exxonmobil-refinery-explosion-/

April 26, 2018 explosion at the Husky Energy refinery in Superior, Wisconsin. Preliminary Chemical Safety Board investigation information available at https://www.csb.gov/husky-energy-refinery-explosion-and-fire/

Search the AFPM Safety Portal for additional resources related to FCCs.

Revision	Date	Summary of Changes
Initial Draft	January 2021	Initial Version
Revision	May 2021	HIPS and SME Review
Revision	June 2021	PSW Review
Legal Review	June 2021	AFPM Legal Review
Final	June 2021	Published

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