PRACTICE SHARING

FCC Safe ESP Operation

Purpose and Use:

The purpose of this document is to discuss and share operational considerations associated with Fluid Catalytic Cracking Units (FCCUs) equipped with Electrostatic Precipitators (ESPs), as part of an industry-wide effort to promote safe operation and minimize risks associated with operating ESPs.

ESP risks are generally associated with failure to maintain correct process conditions during the sequential startup of an FCCU and downstream ESP(s). At that time, there is increased potential for elevated carbon monoxide (CO) or hydrocarbons in the flue gases entering the ESPs from the FCCU that can exceed some regulatory standards, as well as creating an explosive hydrocarbon environment in the ESP and/or ductwork. Similarly, operating an ESP during abnormal or unplanned FCCU operating conditions should be managed with caution, using well thought-out procedures that are developed, routinely reviewed, and trained-on by Operations personnel.

DISCLAIMER:

Practice Sharing Documents are meant to share information on process safety practices in order to help improve process safety performance and awareness throughout industry. The goal is to capture and share knowledge that could be used by other companies or sites when developing new process safety practices or improving existing ones. The Practice being shared has been used by an industry member, but this does not mean it should be used or that it will produce similar results at any other site. Rather, it is an option to consider when implementing or adjusting programs and practices at a site.

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Scope:

This Practice Share document applies to FCCUs employing ESPs as a device for minimizing particulate matter emissions and directing the FCCU flue gas (spent gas) stream into the atmosphere. After thoroughly reviewing this document, FCCU operators may decide to modify their operating procedures, operator training manuals and modules, and/or operator training requirements to assure key operational considerations and process conditions associated with ESP operations are fully reviewed, understood, and used for training operations personnel.

Description and Implementation:

A typical FCCU utilizes a powdery, alumina silicate-based catalyst to continuously react ("crack") heavy bottoms oil into lighter gases in the unit's reactor, which routes the cracked gases to the FCCU's downstream fractionator for further processing into product streams.

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Cracking the heavy oil results in the catalyst picking up residual carbon and trace hydrocarbons called "coke," which can inhibit the cracking process. To renew and reuse the "coked catalyst," it is sent from the Reactor to the FCC Regenerator, which utilizes ambient air at high temperatures to combust and burn off any residual carbon and hydrocarbon "coke" from the catalyst, see Figure 1.

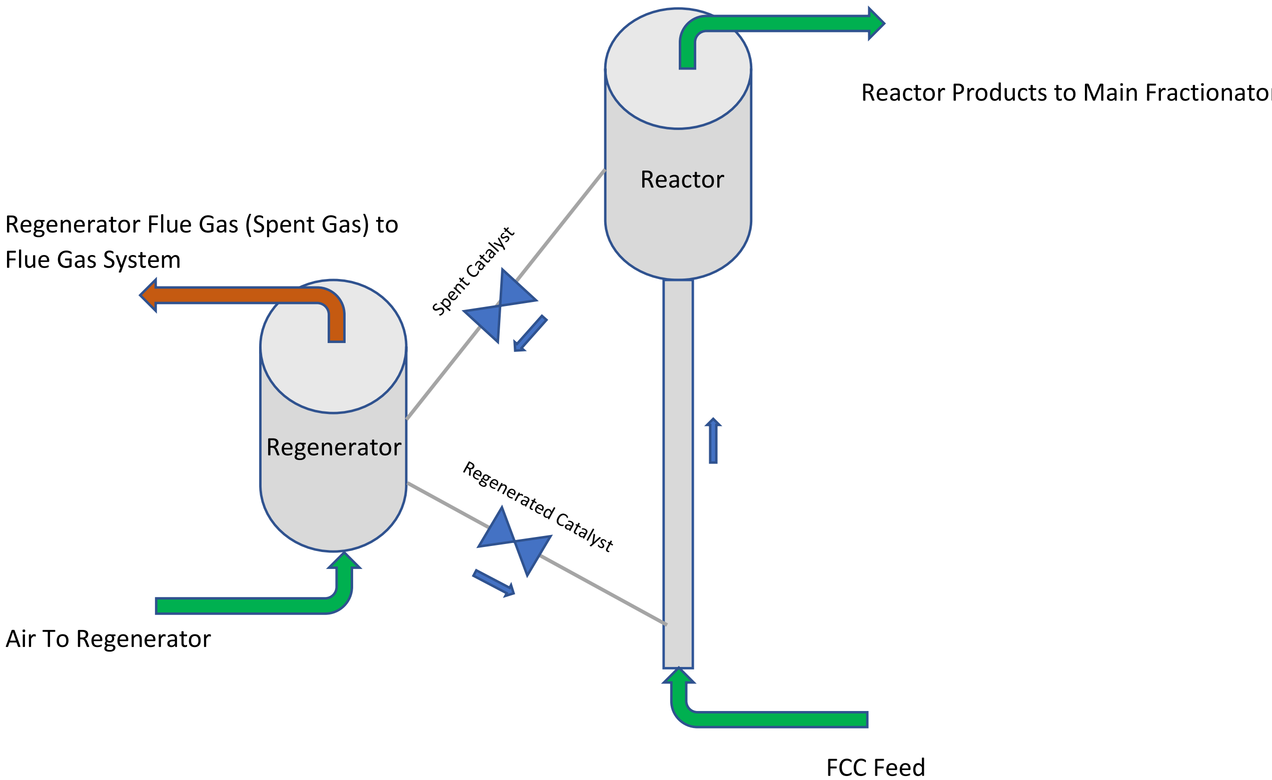

Figure 1. FCC Reactor/Regenerator Schematic

Flue gas (spent gas) generated by the combustion reactions in the regenerator exits to the flue gas section of the FCC through ductwork that typically leads to emissions control equipment. Many refineries use EPSs for controlling and reducing emissions from the FCCU.

Typical components of the flue gas stream during a full-burn FCCU operation include:

- Carbon Dioxide (CO_2), Oxygen (O_2), Water vapor, Sulfur Oxides (Sox), and Nitrogen Oxides (NOx), Particulate Matter (PM)

Typical components of the flue gas stream for partial burn FCCU operation include:

- CO_2, Carbon Monoxide (CO), Water vapor, SOx, NOx, PM

The flue gas (spent gas) section of the FCCU typically includes equipment that performs the following functions:

Pressure Reduction

- Performed by either a turbo-expander that generates electricity or a pressure-reducing orifice chamber in a non-power recovery configuration.

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Heat Recovery / Cooling of the Flue Gas (Spent Gas)

- Completed using Waste Heat Boilers (WHB) or heat exchangers in full burn operation, or CO boilers, also known as auxiliary, fired boilers, used in full or partial burn operation.

Removal of Particulates / Conditioning of Flue Gas (Spent Gas) directed to the atmosphere

- Particulates (catalyst fines) are typically removed by inline separators / cyclones in the regenerator and further captured by ESPs or other emission control devices.
  - This Practice Share document focuses on FCCUs that rely on ESPs to control and reduce emissions, see Figure 2.

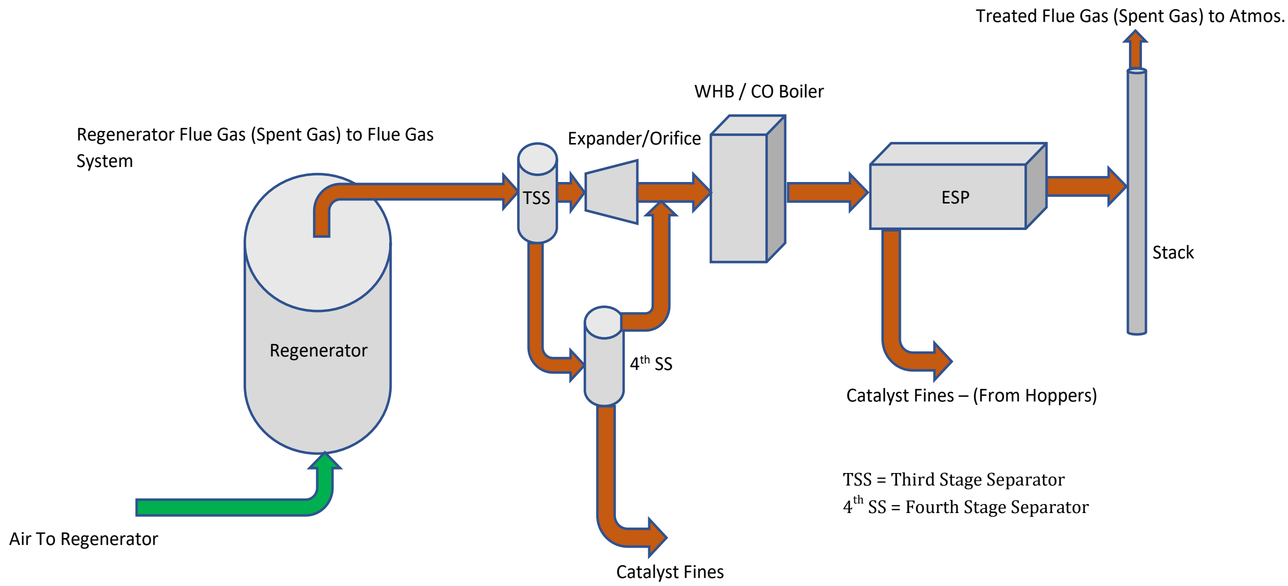

Figure 2. FCC Flue Gas (Spent Gas) schematic (ESP Configuration)

For FCCUs utilizing either a wet or dry ESP configuration, the ESP is the primary device used for removing particulate matter entrained in the flue gas (spent gas) stream prior to atmospheric discharge through the ESP stack. ESPs generate an electrical field using high-voltage electricity at ~35,000 volts that charges particulate matter, which is primarily catalyst, entrained in the flue gas. The electrical charge enables the catalyst particles to adhere to metal plates inside the ESP as depicted in Figure 3. The particles are removed from the ESP by knocking / rapping / washing the plates, which loosens the particulate matter which is then collected in dust hoppers located at the bottom of the ESP.

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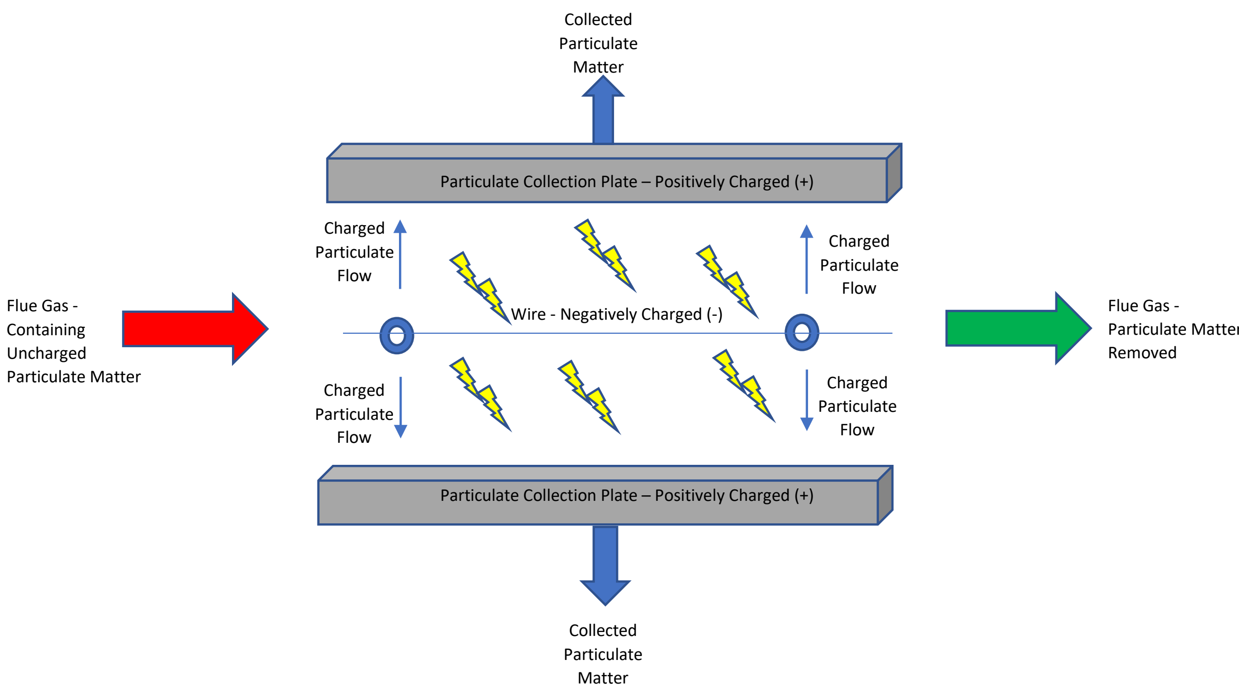

Figure 3. Depiction of Electrostatic Precipitator (ESP)

Although there are multiple types of ESP designs, they all employ similar principles to remove particulate matter from the flue gas (spent gas) stream.

ESP Types:

- Plate-Wire Precipitators
- Flat-Plate Precipitators
- Tubular Precipitators
- Wet Precipitators
- Two Stage Precipitators
- Dry Precipitators

ESP performance in an FCCU operation can be further enhanced using a flue gas conditioning agent, which is typically an ammonia injection into the flue gas (spent gas) stream upstream of the ESP.

Operational Considerations

Full understanding and monitoring of ESP conditions during different unit operating scenarios helps ensure safe operations and minimize potential for introducing explosive hydrocarbon / flue gas mixtures from entering the ESP(s).

An explosive hydrocarbon environment in the ESP requires fuel, oxygen, and an ignition source. Note that during routine ESP operations, both oxygen and an ignition source are always present. Fuel is all that is needed for an explosion. Maintaining safe operations requires preventing elevated CO or hydrocarbons from entering the ESP while energized.

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Given the complexities of operating ESPs during transient or abnormal conditions, operators should be at heightened awareness during these modes of operation, which include, but are not limited to:

- Unit upsets
- Unit startups: planned and unplanned
- Unit Shutdowns: planned and unplanned
- Unit in hot stand-by operation: maintaining catalyst circulation for extended periods of time on torch oil or auxiliary-fired air preheaters
- Utility unit outages: CO Boiler, etc.
- Transient unit operation: significant condition changes include raising feed or changing operation modes, such as converting between full and partial burn, etc.
- Other non-routine unit operations
- Unit maintenance: initial blinding / blanking, etc.

When an ESP continues operating during transient or other abnormal operations, pay special attention to monitoring, understanding, and eliminating the potential for elevated CO or hydrocarbons generated in the FCCU's regenerator from entering the ESP. As noted, risk increases during FCCU restarts, abnormal operations, and/or unit recovery attempts due to the potential for fuel and elevated oxygen levels entering the ESP in the flue gas (spent gas) stream. Possible fuel sources and/or elevated oxygen levels entering the flue gas are listed below in a partial list of examples:

- Potential presence of high concentrations of CO or hydrocarbons in the ESP due to incomplete combustion of fuel gas or other hydrocarbon used to fire the FCCU regenerator air preheater.
- Potential presence of high concentrations of CO or hydrocarbons in the ESP due to incomplete combustion of torch oil used to heat up the regenerator vessel and circulate catalyst.
- Potential for pressure balance upsets leading to hydrocarbons from the fractionator making their way through the regenerator and into the flue gas line.
- Potential for CO Boiler air or auxiliary fuel upsets resulting in incomplete combustion of hydrocarbons or CO in the exiting flue gas stream.
- Potential for elevated oxygen concentrations in the flue gas due to minimal coke load / combustion demand from the regenerator.

Given the risk to personnel safety and equipment integrity, the safest, prudent course of action is to follow a conservative approach to ESP operations to minimize the risk of an explosion or fire from an energized FCC ESP due to the presence of hydrocarbon or CO gas concentrations above the lower explosive limit (LEL) by de-energizing the ESP.

Additional Considerations for ESP Operations

- Operating procedures should clearly identify and state when to re-energize the ESP(s):
  - Utilize company-specific Management of Change (MOC) and Hazard Review Processes for the following:
    - Follow company-specific guidance when identifying ESP initial-energization and re-energization steps in unit operating procedures.
      - Incorporate monitoring practices and process parameters / limits into operating procedures, as appropriate.
- Maintain ESP shutdown system functionality during abnormal operation:
  - Utilize company specific MOC and Hazard Review Processes for the following:
    - Ensuring proper shutdown system functionality is maintained / active.
    - Identifying required frequency / level of shutdown system testing/monitoring.

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        - Documenting / Reviewing any future changes to the shutdown system configuration.
- Avoid automatically re-energizing the ESPs:
    - Utilize company specific MOC and Hazard Review Processes for the following:
        - Follow company-specific guidance to review and clearly identify steps / conditions for re-energizing the ESP(s).
            - Focus on ensuring that there is a non-explosive atmosphere entering or present in the ESP prior to re-energizing.
        - Follow company specific guidance to review process operating procedures and incorporate any identified step(s) for commencing ESP operations.
- Follow company specific guidance to clearly identify the procedure for de-energizing the ESP.
    - Consider including a manual method for de-energizing the ESP(s).
- Limit personnel proximity and access to the ESP(s) during start-ups, shutdowns, transient operations, de-energizing, and re-energizing
    - Utilize company specific MOC and Hazard Review Processes for the following:
        - Follow company specific guidance to review and clearly identify area access control procedures during abnormal operations and when re-energizing an ESP(s)
        - Refer to company-specific exclusion zone procedures for limiting personnel access.
            - Address both essential & non-essential personnel
- Monitor Process conditions and flue gas composition / parameters:
    - Utilize company specific MOC and Hazard Review Processes for the following:
        - Follow company specific guidance to identify appropriate monitoring techniques / practices and process condition limits.
            - Examples include:
                - Flue gas (spent gas) stream composition: CO content, combustibles content, excess oxygen content, etc.
                - Unit pressure balance is established to ensure no reactor side hydrocarbons can migrate into the ESP.
        - Incorporate monitoring practices and limits into operating procedures, as appropriate.
- Utilize company specific MOC and Hazard Review Processes guidance to evaluate incorporating monitoring parameters into ESP operation and re-energization interlocks / permissives.
    - Examples of interlocks or permissives include the following partial list of examples:
        - Regenerator Air Pre-Heater Safety Instrumented System (SIS) interlocks: Low combustion air, flame out, etc.
        - FCC SIS activation.
        - CO Boiler interlocks: Loss of supplemental air / boiler fan, low oxygen levels, combustibles, and/or CO in exiting flue gas, etc.).
        - Detecting combustibles and/or CO in flue gas entering the ESP.
- Properly operating ESPs can significantly reduce the amount of particulate matter exiting the ESP(s) emitted with the flue gas (spent gas) stream directed to the atmosphere, supporting unit environmental / regulatory compliance. As a result, ESPs are intended to maintain a high on-stream factor during FCCU operations and are targeted to be placed online as soon as acceptable process parameters are met to safely energize the ESP following the refinery's operating procedures.
- When considering changes to ESP procedures, as with any operating procedure, utilize your company-specific Process Hazard Review Process coupled with your risk evaluations program and safeguards to minimize the potential for ESP incidents during all modes of operation.

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Implementation Checklist:

Regulatory Requirements
- Gather all federal, state, and local regulatory requirements applicable to operation of the ESP to ensure they are available and understood by those developing procedures, training, and equipment/control practices.
- Gather the Process Safety Information (PSI) applicable to operation of the ESP and make it readily available to those developing procedures, training, and equipment/control practices. The PSI includes documentation, including a Cause-Effects Matrix, which describes the operation of the SIS, if one is applied to the ESP.

Procedures
- Procedures for operation of the ESP include an appendix or link to the documentation to any and all Safety Instrumented Functions (SIFs) or SIS acting on the ESP.
- Procedures address all operating modes, including Startup (both cold and hot), Shutdown to all non-operating modes, Emergencies, including loss of air blower(s), and any Temporary operating modes as either stand-alone procedures or as elements of FCC unit procedures.
- Procedures address all conditions or situations in which operators are expected to manually de-energize the ESP, and how to perform that action.
- Procedures address all conditions or situations in which operators are expected to bypass an SIF applicable to the ESP and when/how to re-activate the SIF.
- Procedures address all Safe Operating Limits applicable to the ESP that are controlled by operator actions.

Training
- The target audience for training on ESP operations includes console and field operators.
- The training includes coverage of each operating mode as identified above in the “Procedures” section.
- The training includes coverage of any SIS applied to the ESP, the steps taken for bypassing any SIF and how/when to reset the SIS.
- The training includes steps taken to manually de-energize the ESP.
- The training addresses all Safe Operating Limits applicable to the ESP and steps operators are expected to take to remain within those limits.

Equipment, Piping and Design
- A scheduled maintenance program is employed to check the accuracy and function of each input to any SIS applied to the ESP and the effectiveness of all output devices activated by the SIS.
- A scheduled maintenance program is employed to verify the integrity of all ducting to/from the ESP and all containment surfaces that make up the ESP.

Control System
- The unit Distributed Control System (DCS) has an alarm to show when any SIF or SIS applicable to the ESP is bypassed, or when any included controls are individually bypassed.
- The DCS provides readily accessible displays for all Safe Operating Limits applicable to ESP operation.

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References:

US Chemical Safety Board report, *ExxonMobil Torrance Refinery Explosion*, published May 3, 2017, and available at https://www.csb.gov/exxonmobil-torrance-refinery-explosion-/

AFPM Event Sharing Database items #24 and #575 on the AFPM Safety Portal.

Revision	Date	Summary of Changes
Initial Draft	August 2024	Initial Version
Revision	August 2024	HIPS Review
Revision	September 2024	PSW Review
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Final	March 2025	Published