Preliminary Hazard Analysis and Mitigation for the Prevention of Catalyst Regeneration Vessel's Catastrophic Rupture

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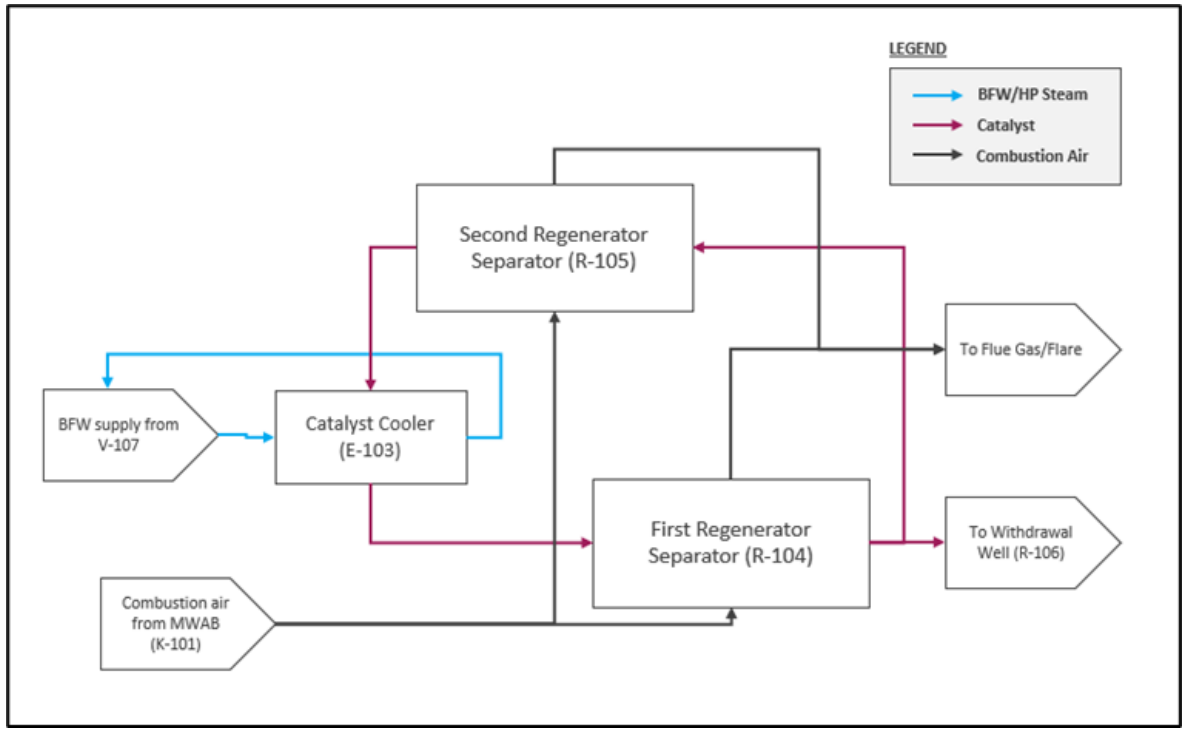
Background: Residue Fluid Catalytic Cracking

What is RFCC?

Residue Fluid Catalytic Cracking (RFCC) is a process where heavy feedstocks or reduced crudes are effectively converted into valuable products such as C3-C4 LPG and gasoline using specialized catalyst. The RFCC catalyst is a solid complex composite acid. The RFCC unit comprises multiple sections, but the scope of this presentation is limited to the Reaction and Regeneration (R2R) section.

Reaction & Regeneration

The R2R section incorporates a two-stage regeneration system, a proprietary catalyst separator, a catalyst cooler, a catalyst withdrawal well, several catalyst transfers lines and slide valves control systems.



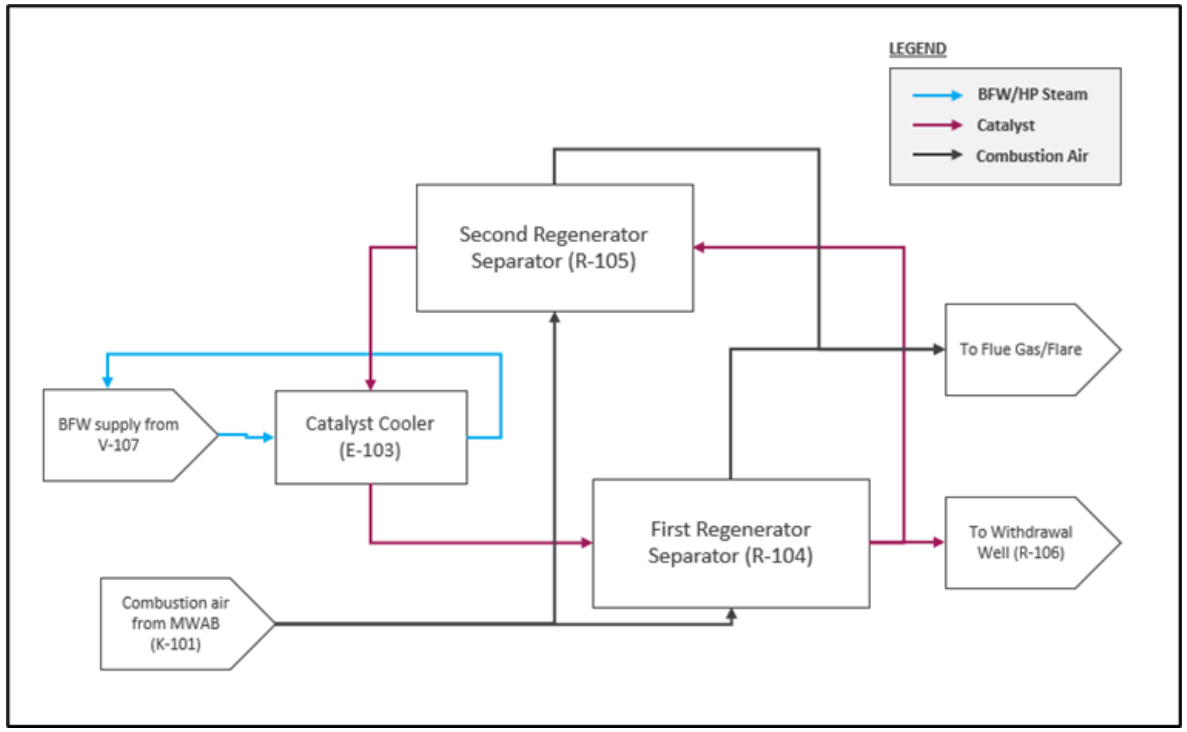
Background: Residue Fluid Catalytic Cracking

Catalyst Cooler

The Catalyst Cooler system consists of two parts: the catalyst circulation and the steam generation.

Catalyst Circulation:
The hot catalyst is withdrawn from the dense catalyst bed of the second regenerator and enters the cooler through an inclined transfer line.

Steam Generation:
There are a total of 32 tube clusters inside the Catalyst Cooler, and separate piping is provided to and from each of the tube clusters. Saturated high pressure (HP) boiler feed water from the Catalyst Cooler Steam Drum enters to the tube clusters from the top of the Catalyst cooler and HP steam is generated in the Catalyst Cooler. The steam and water mixture is then returned to the Catalyst Cooler Steam Drum where the water and steam are separated.



Problem Statement: Catalyst Cooler Tube Leak due to an Upstream Equipment Trip

Scenario

The objective of this work is to identify the magnitude of disturbance at the first and second stage regenerator separators in event where the upstream Main Air Blower trips. The immediate response of this scenario is the cut back of combustion air flow to regenerator separators and drastic pressure drop inside the regenerator separators, which eventually will close the flue gas safety valve (FGSV) that leads to a flare line. This study assesses the minimum opening limit of pressure controller valve connecting the vapor line of second regenerator to the flare line during abnormal situations of Catalyst Cooler tube rupture to prevent overpressure of regenerator separators.

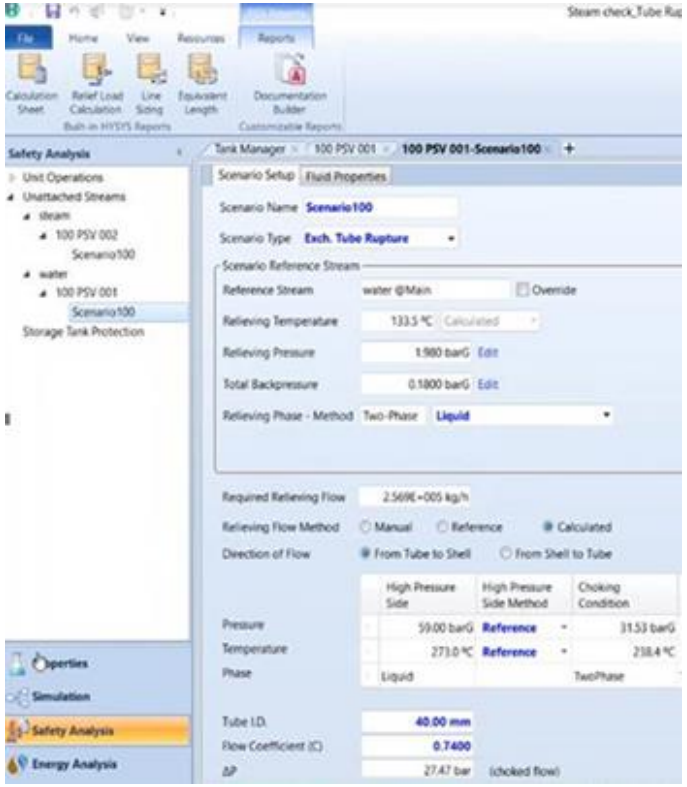
The followings are the important assessments that are required to be carried out to meet the above objective:

i. Assessment of stability shall be on the pressure controller to handle disturbance.
ii. Assessment of stability includes the length and frequency of fluctuation arise post disturbance.

In addition, Layer of protection analysis (LOPA) and IPF review will be carried out to justify and review additional recommended safeguards.

Methodology

Estimation of Steam Flowrate entering the process line during Catalyst Cooler Tube Leak



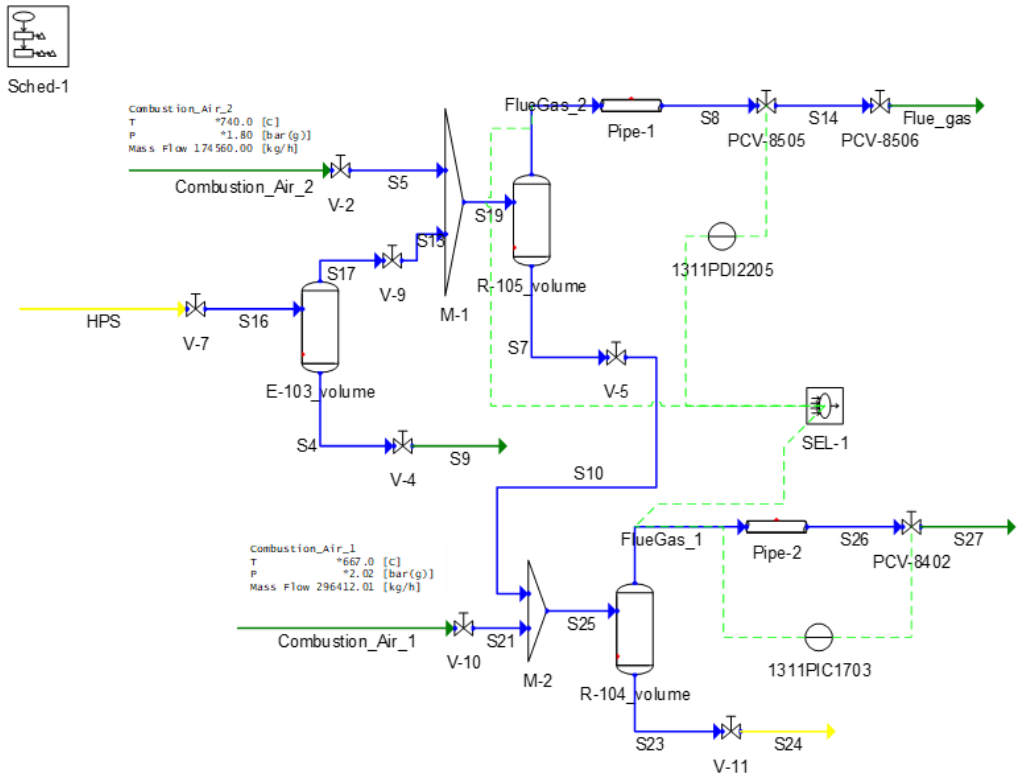
The rate of steam/water leak from the ruptured tube is calculated using the following assumptions:

1. Orifice equation is used to calculate leakage through hole
2. Water leaks out and flashed into steam inside the catalyst cooler/regenerator
3. The leakage occurs midway along the tube and only one tube is assumed to rupture.
4. Water pressure at leak location is estimated to be > 50 barg and catalyst cooler pressure is estimated to be < 5 barg.
5. Pressure drop across the rupture hole is constant

Amount of High-Pressure Steam entering the system is approximately 250 MT/hr. This amount is verified using ASPEN.

Methodology

Dynamic Simulation



Two cases were considered in this study:

1. Discontinued combustion air flow from Main Air Blowers, introduction of HP Steam from E-103 tube leak

2. Continued combustion air flow from Main Air Blowers combined with HP Steam from E-103 tube leak

The pressure controller which governs the opening of the FGSV is set at manual mode with prolonged HP Steam leak into the system.

Several case studies were performed for which the FGSV is presumed to be stuck open at varying % opening to identify what is the minimum allowable opening to prevent overpressure of the regenerator separators.

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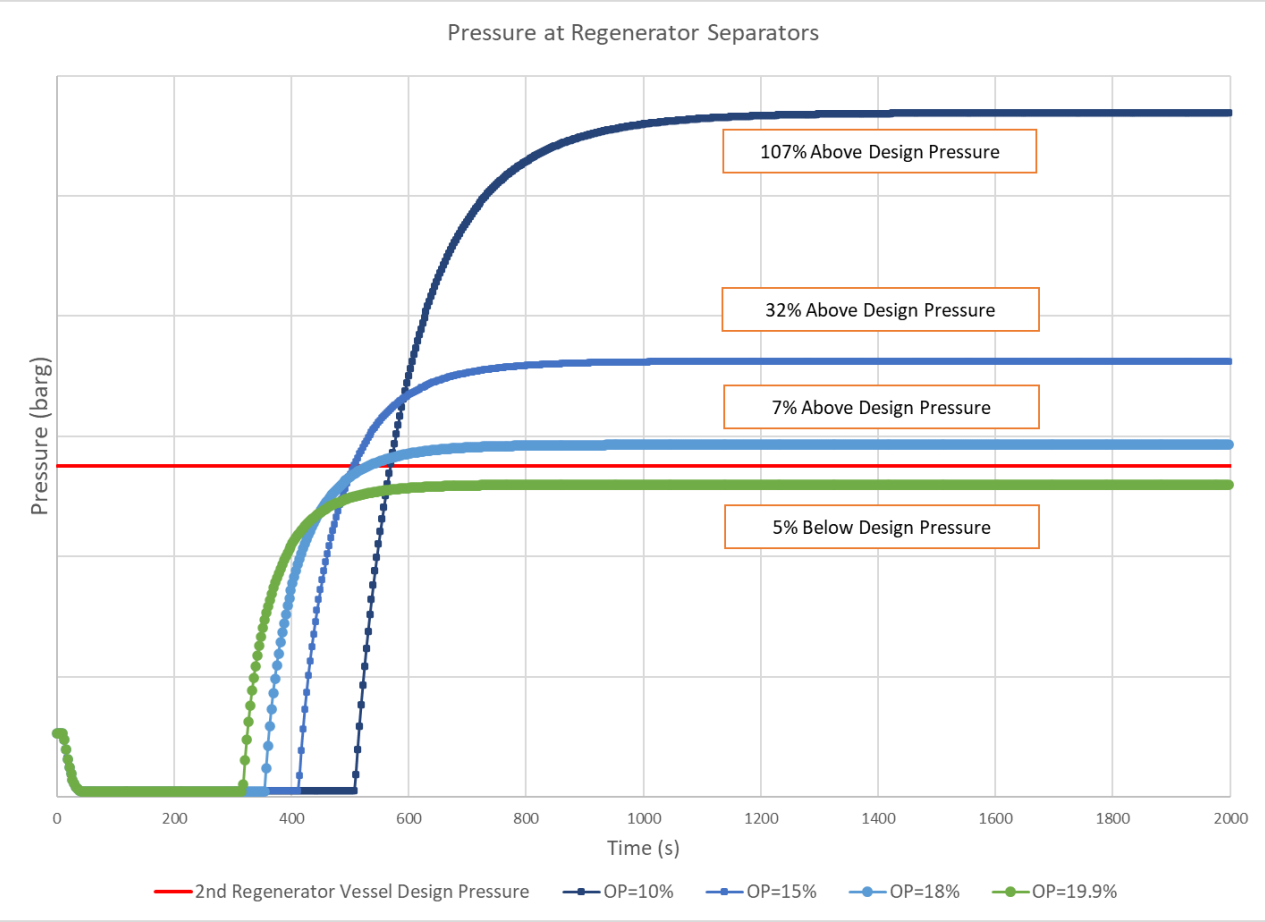
Results

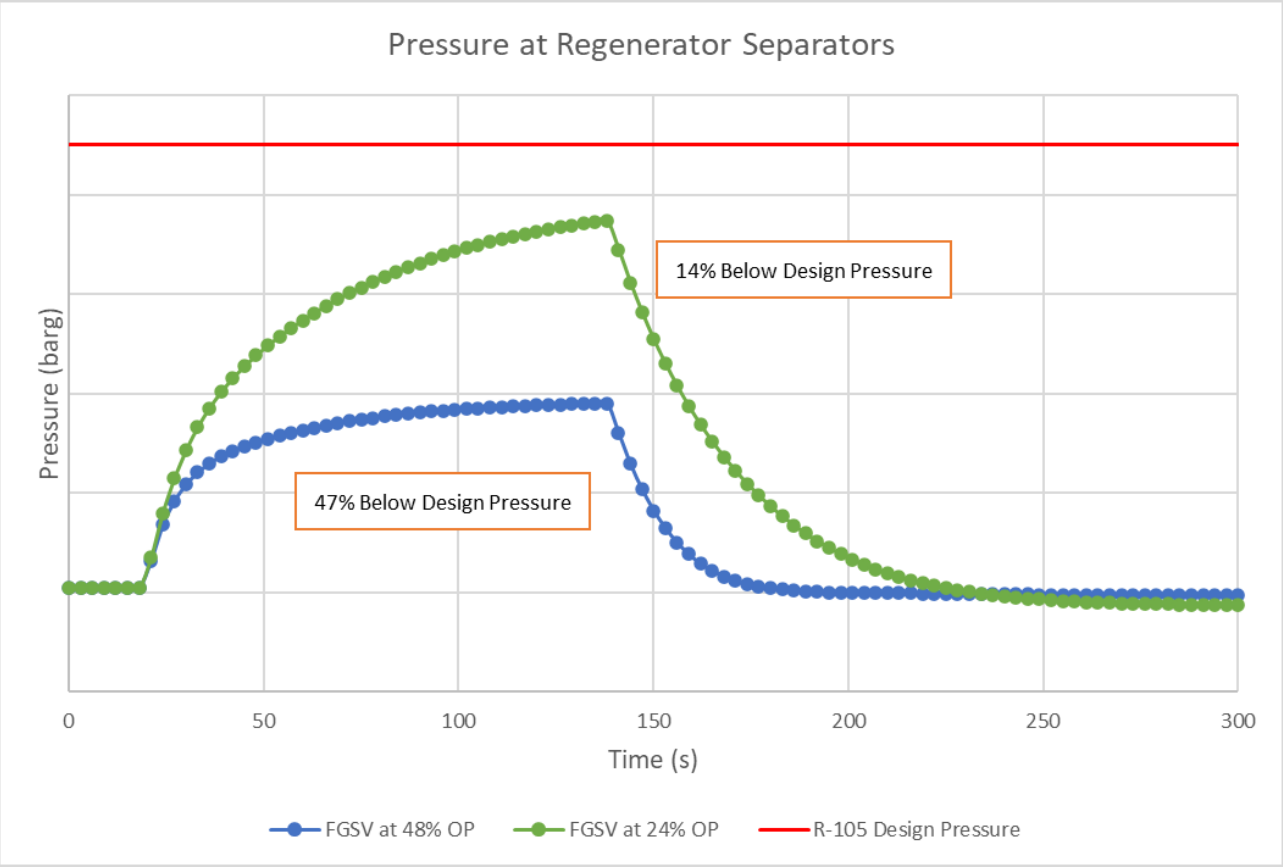
Case 1



- In Case 1, the FGSV is presumed to be stuck open at varying openings (OP%) when the HP Steam from catalyst cooler leak is introduced.
- When the FGSV is stuck between 10-18%, the pressure at regenerator separators exceeds its design pressure limit.
- With FGSV opening at 19.9%, it was found that the pressure at regenerator separators were 5% below the design pressure limit and is therefore the minimum allowable opening for FGSV in event of catalyst cooler leakage.

Results

Case 2



- In Case 2, the FGSV is set to be open at 48% as per normal operation when the Main Air Blower is online and the flue gas flow is at its design flowrate.
- The HP Steam from catalyst cooler leak is introduced at t = 20s and for 2 minutes long; the pressure controller governing the opening of FGSV is set at automatic mode.
- Once the HP Steam is introduced to the system, the instantaneous peak pressure at regenerator separators reaches to a value of 47% below vessel design pressure.
- Comparatively, if the FGSV is initially set to be open at 24% or when the flue gas flow is half of its design flowrate, the instantaneous peak pressure at regenerator separators reaches to a value of 14% below vessel design pressure when HP Steam is introduced to the system.

Conclusion

Process simulation is used to assess and evaluate the dynamic stability of existing Regenerator section's control scheme under various abnormal simulation scenarios of high-pressure steam leak caused by tube rupture in catalyst cooler.

The conclusions from the dynamic simulation study are as follows:

a. If operated automatically, the existing FGSV is adequate to cater for pressure relief load that is generated from HP Steam leak through the catalyst cooler tube rupture.

b. If the existing FGSV is presumed to be stuck open under abnormal situations, the FGSV is adequate when OP% ≥ 20% to relief the pressure in system and to prevent the regenerator separators from overpressure if the tube leak is not detected in time.

c. For OP% ≤ 19%, a prolong leak of HP Steam will lead to overpressure or loss of containment of regenerator separators.

d. For catalyst cooler tube rupture that occurs during normal operation of main air blowers, the instantaneous peak pressure is 14% below the vessel design limit even when the flue gas flowrate is half of its design flowrate.

Thank You.
Q & A

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