Enhancing Shell's Fluidization Design Using Computational Methods

CPFD User Conference 2024

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Shell's net carbon intensity

Also, in this presentation we may refer to Shell's "Net Carbon Intensity", which includes Shell's carbon emissions from the production of our energy products, our suppliers' carbon emissions in supplying energy for that production and our customers' carbon emissions associated with their use of the energy products we sell. Shell only controls its own emissions. The use of the term Shell's "Net Carbon Intensity" is for convenience only and not intended to suggest these emissions are those of Shell plc or its subsidiaries.

Shell's net-Zero Emissions Target

Shell's operating plan, outlook and budgets are forecasted for a ten-year period and are updated every year. They reflect the current economic environment and what we can reasonably expect to see over the next ten years. Accordingly, they reflect our Scope 1, Scope 2 and Net Carbon Intensity (NCI) targets over the next ten years. However, Shell's operating plans cannot reflect our 2050 net-zero emissions target and 2035 NCI target, as these targets are currently outside our planning period. In the future, as society moves towards net-zero emissions, we expect Shell's operating plans to reflect this movement. However, if society is not net zero in 2050, as of today, there would be significant risk that Shell may not meet this target.

Forward Looking Non-GAAP measures GAAP financial measures is dependent on future events some of which are outside the control of Shell, such as oil and gas prices, interest rates and exchange rates. Moreover, estimating such GAA
This presentation may contain certain forward-looking non-GAAP measures such as cash capital expenditure and divestments. We are unable to provide a reconciliation of these forward-looking Non-GAAP measures to the most comparable GAAP financial measures because certain information needed to reconcile those Non-GAAP measures to the most comparable P measures with the required precision necessary to provide a meaningful reconciliation is extremely difficult and could not be accomplished without unreasonable effort. Non-GAAP measures in respect of future periods which cannot be reconciled to the most comparable GAAP financial measure are calculated in a manner which is consistent with the accounting policies applied in Shell plc's consolidated financial statements.

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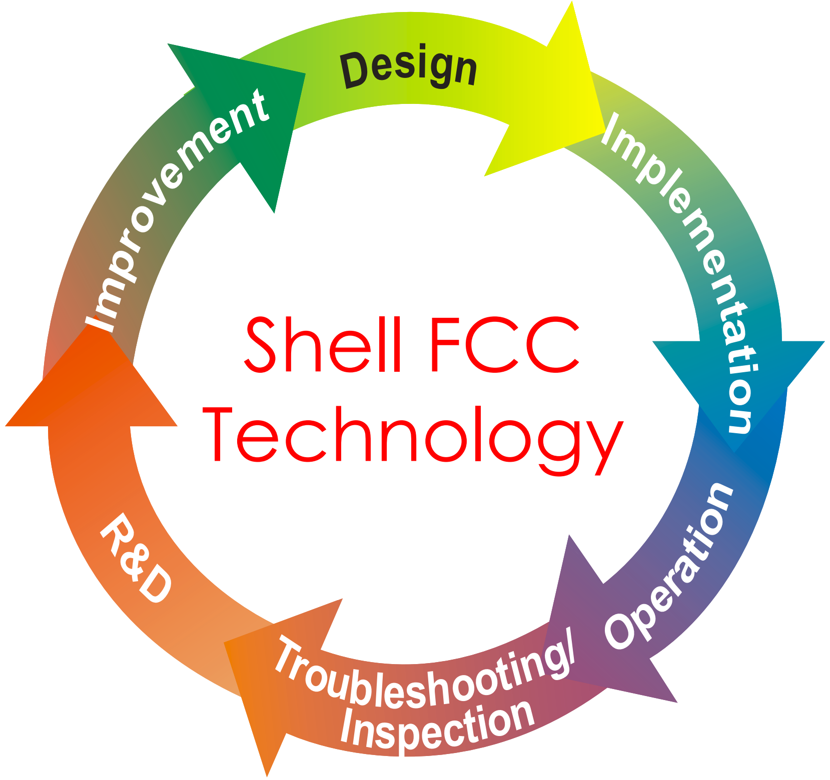
Agenda

- Brief Overview
  - Shell FCC technology
  - FCC troubleshooting/digitalization tools
- Case Studies
  1. Cyclone dipleg leak troubleshooting
  2. Regenerator SCD upgrade to improve catalyst distribution
  3. Coprocessing nozzle design optimization

Shell is Unique

- FCC Licensor:
  - FCC Technology Driven by Owner/Operator Perspectives → Reliability, Flexibility, Performance
  - Operationally Proven FCC Technology
  - Active FCC R&D program (70+ years)
  - FCC Designs: 30+ grassroots units, 150+ revamped units, ~80 TSS units

- FCC Operator:
  - Decades of FCC operational experience
  - Hundreds of FCC turnarounds



The only FCC technology licensor with FCC Operational Experience + FCC Research & Development Expertise and Facilities + Design Capabilities

Shell FCC Offerings

Our proven skillset is currently serving Shell's FCCUs, as well as various third-party sites, through a broad range of capabilities.

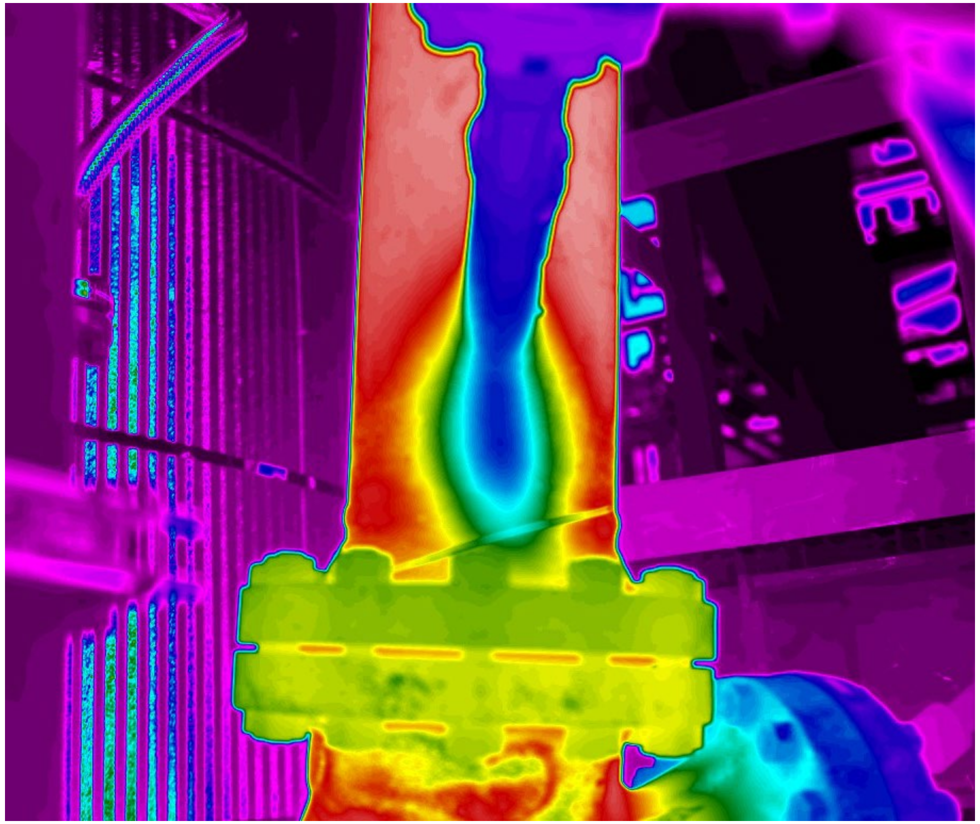
- Technical Support and Diagnosis
- SHARC Process Modeling
- Hardware Design
- CFD Modeling
- Pilot Plant Testing / Catalyst Assessment
- Feed Nozzle Testing/Design
- Training

Case Study 1

Cyclone dipleg leak troubleshooting

Background

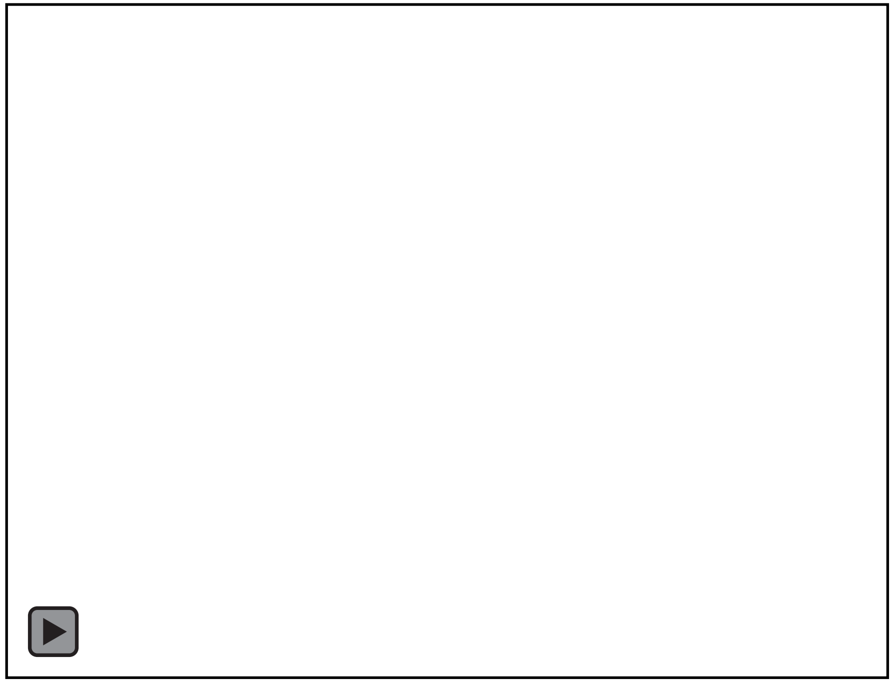
- Reactor Side Design layout
  - 2 separate risers, 2 primary cyclone
  - 8 external secondary cyclones
  - Tilted dipleg, certain degree from vertical
  - Purging nozzles to keep path clear
- Dipleg Leak – on a secondary cyclone
  - Right below the purging nozzle (steam)
  - 8" above isolation valve flange
  - In Dilute phase region
- Initial Investigation
  - Infrared camera image shows thermal gradient, potentially leading to thermal fatigue.
  - Piping material is capable of handling the design temperature.

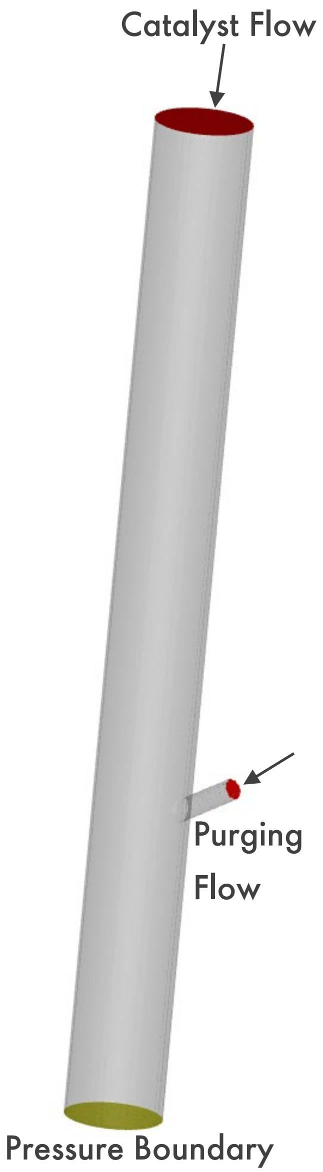


CFD Analysis

Key Objectives:

- To understand impacts of catalyst flow/ flow mixing on temperature gradient.
- To develop mitigation plan to reduce severity/ eliminate thermal fatigue.





Initial Findings:

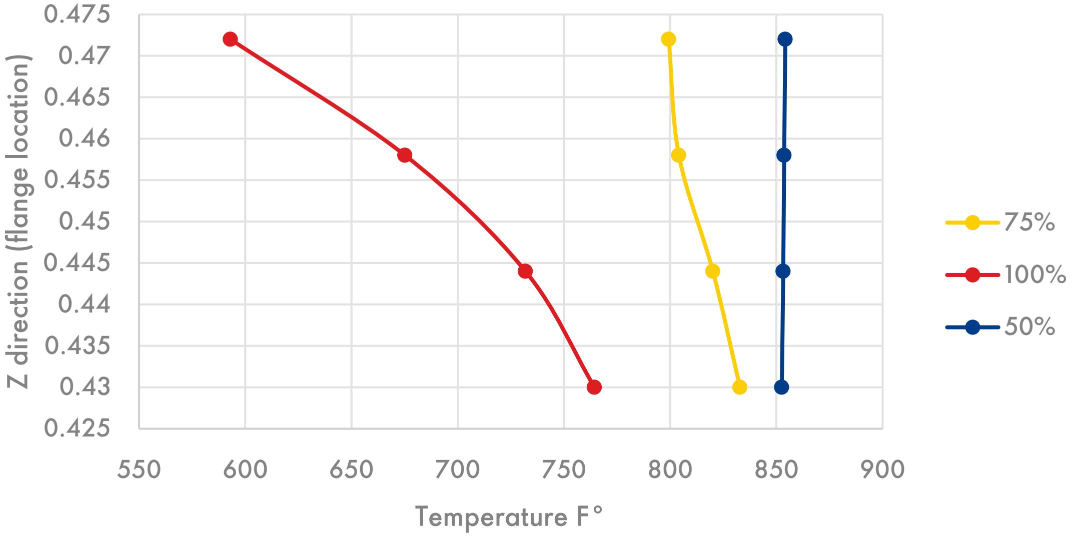
- CFD showed similar thermal gradient profile
- Thermal cycling behavior

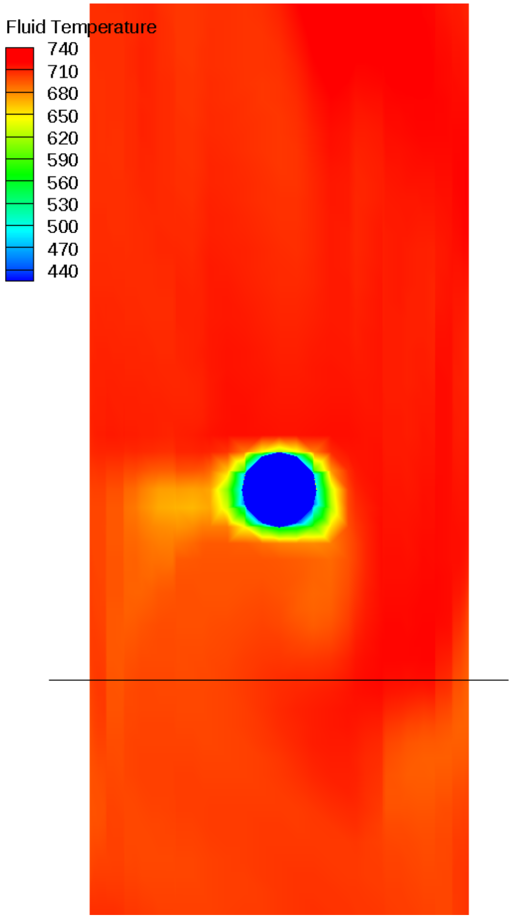
More Questions:

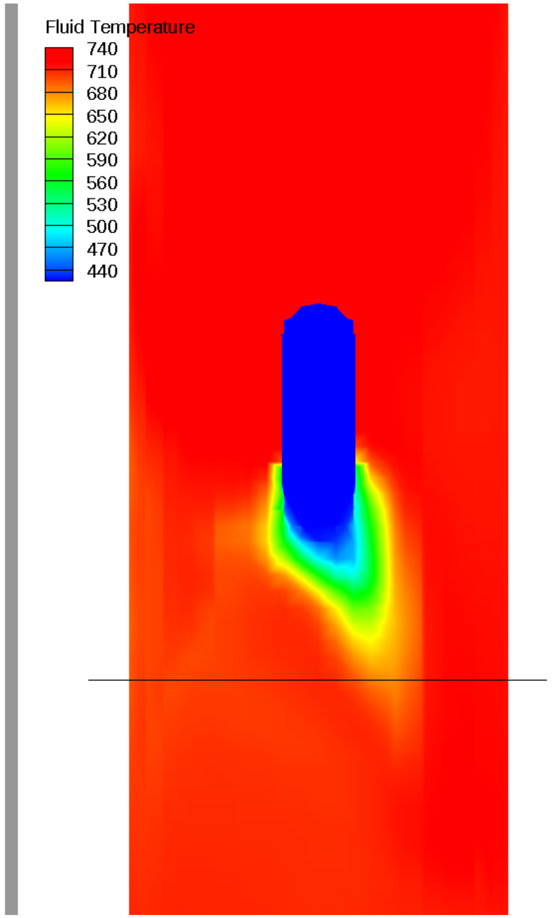
- Why repeated leak and fail in certain locations?
- Sensitivity on nozzle angle?
- Sensitivity on radial orientation?
- Sensitivity on purging medium?

Modeling Results

- Purge nozzle angle to dipleg had an impact on the thermal profile.
- Purge flow exit velocity had an impact on the thermal gradient intensity.

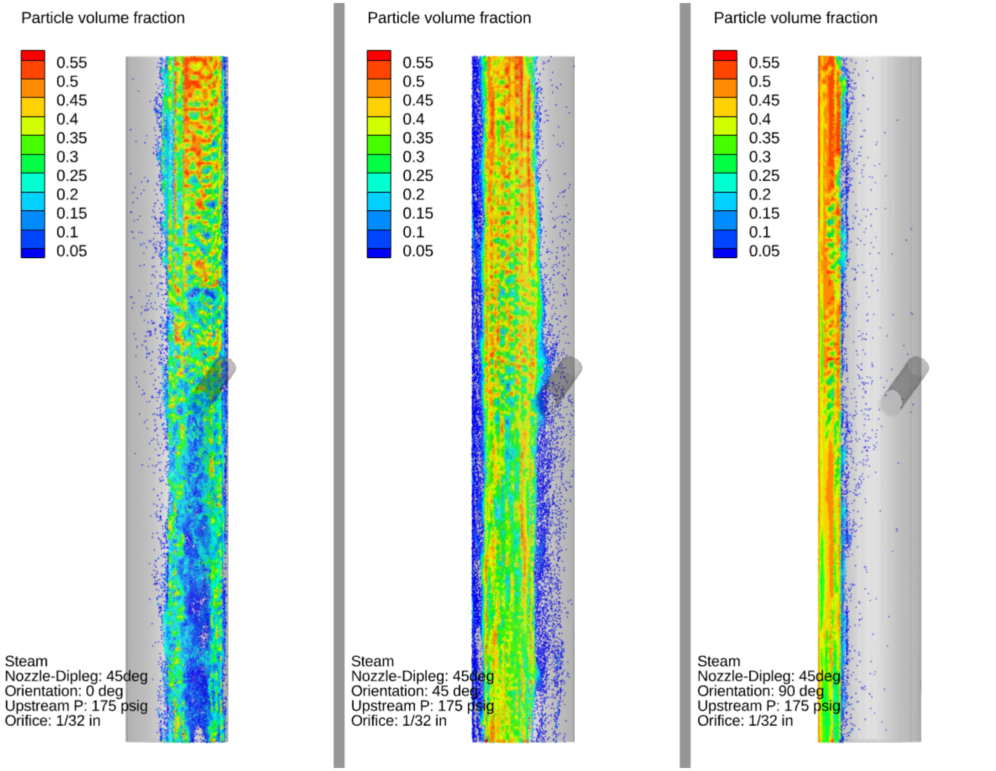


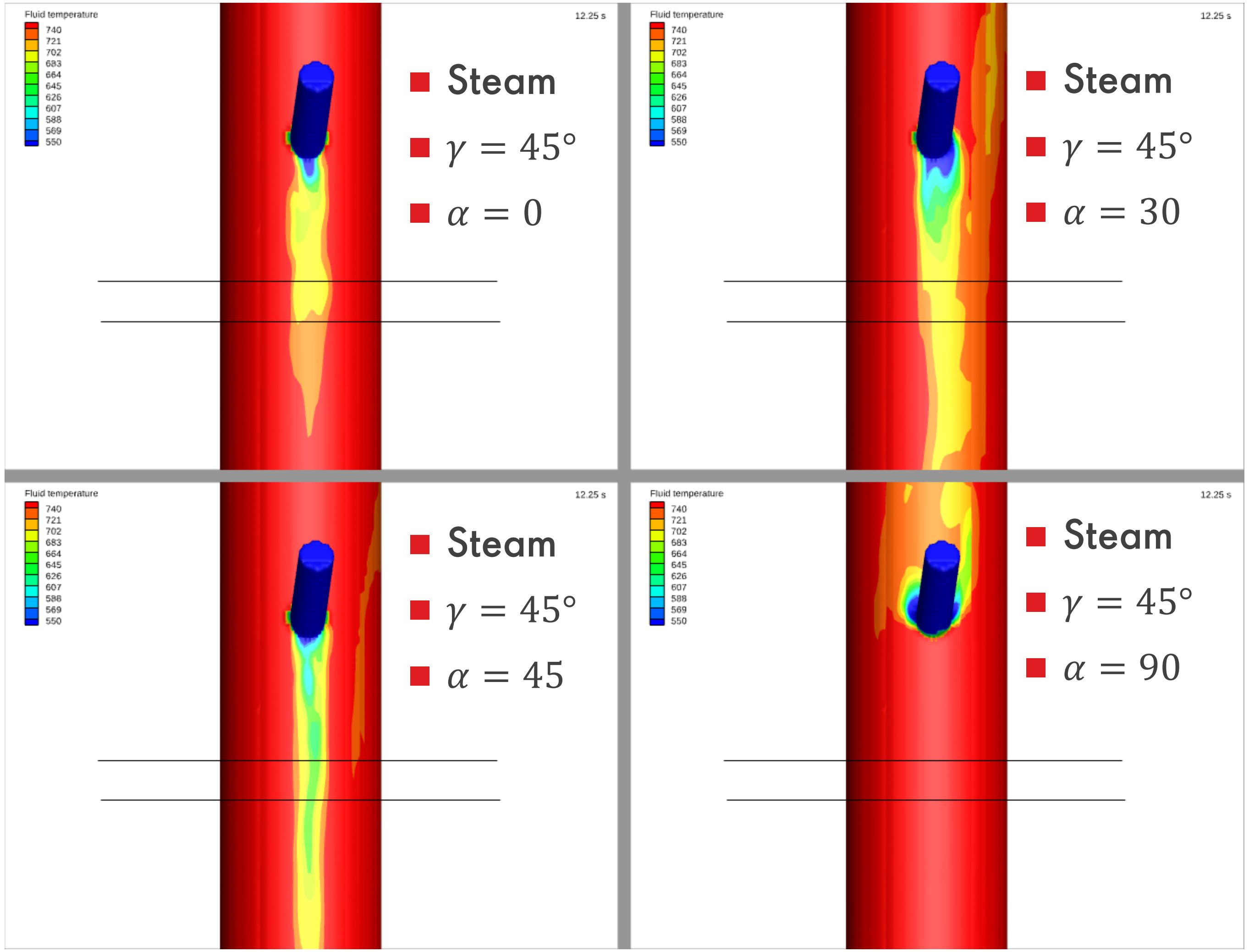




Modeling Results

- The relative angle used to install the purge nozzle had impacts on the thermal profile.





Summary

Benchmarking and sensitivity analysis conducted using CFD

- Simulation provided deeper insights on thermal cycling and nozzle's angle impact
- Purging nozzle was relocated to reduce thermal gradient cycling at vulnerable locations
- Change order was issued to change the nozzle angle
- Installation instruction was provided for the proper radial angle
- Purging medium was changed to reduce cement-like formation from catalyst and wet steam

Unit is currently in operation with no dipleg leak issue.

Case Study 2

Regenerator SCD upgraded to improve catalyst distribution

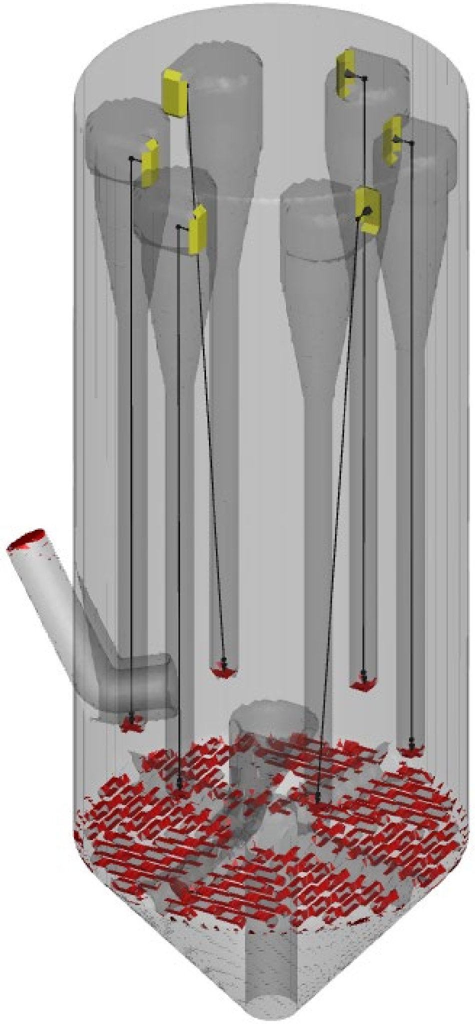
Background

Spent Catalyst Distributor (SCD):

- Used to spread coke-laden catalyst evenly over regenerator bed area.
- Two main types: side entry and bottom entry.
- Important roles: improve air utilization, reduce NOx release, and reduce local afterburn.

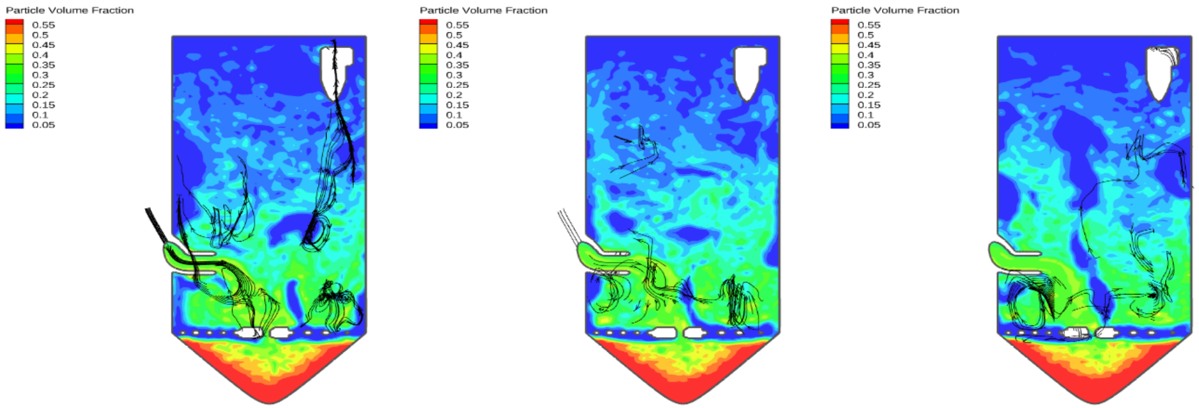
Challenges:

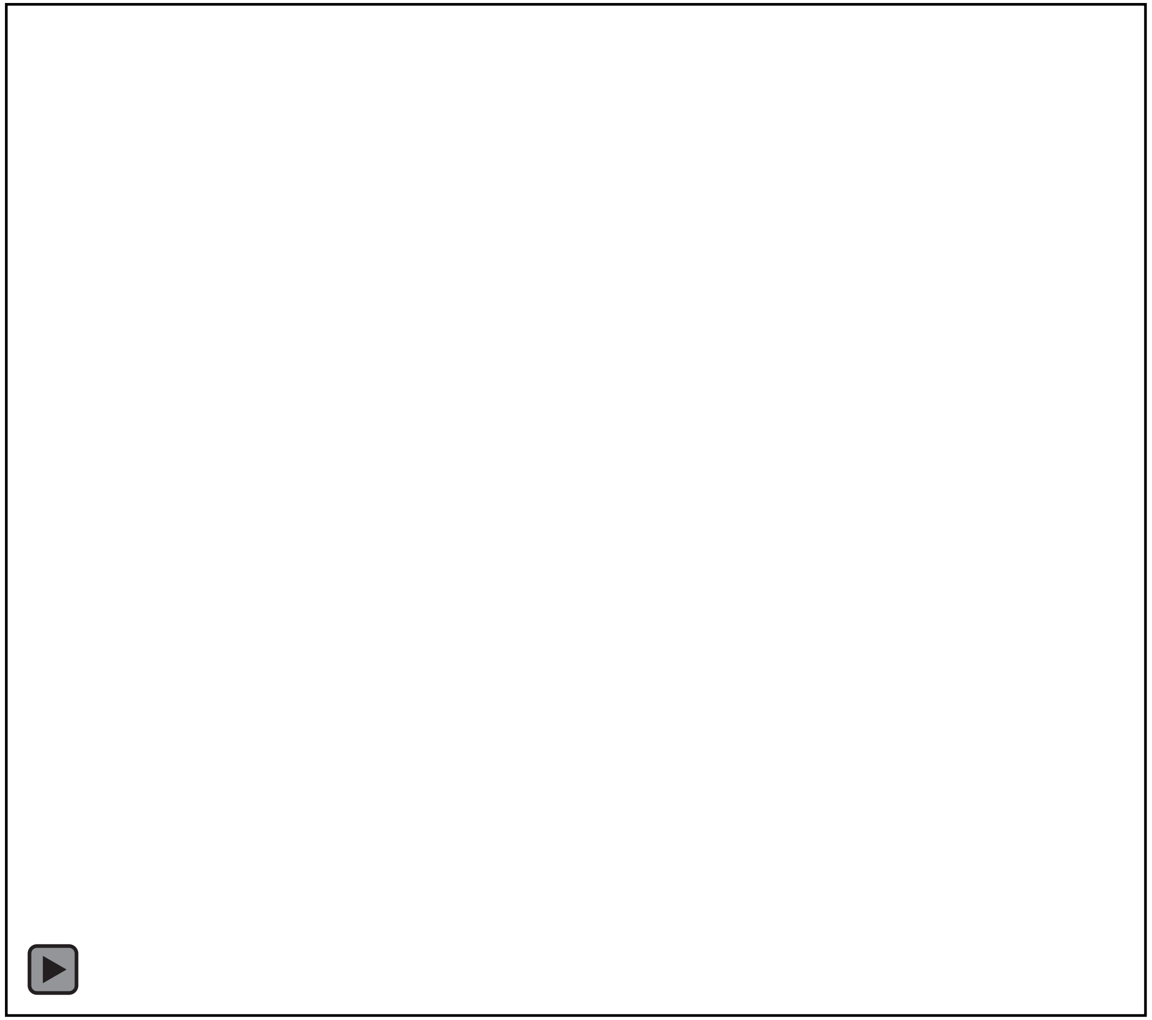
- Customer was seeking new SCD design due to reliability issue associated with localized afterburn.
- Current design: the standpipe entered through the regenerator wall with an open pipe.
- Multiple constraints: Small vessel size, limited space due to the existence of primary cyclone and secondary cyclone diplegs, air supply pipe occupying the center, withdraw well location.



CFD Benchmark and Analysis

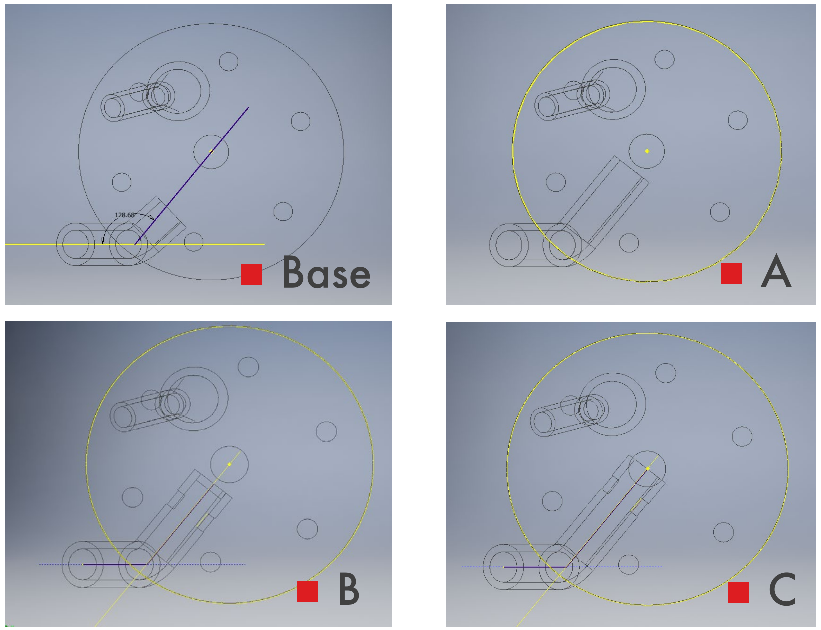
- Realistic and representative CFD model was created based on the drawing and process conditions provided by the customer.
- The CFD model was calibrated with actual site data.
- Preliminary analysis found circulation zones were formed in the regen, allowing air bypassing.

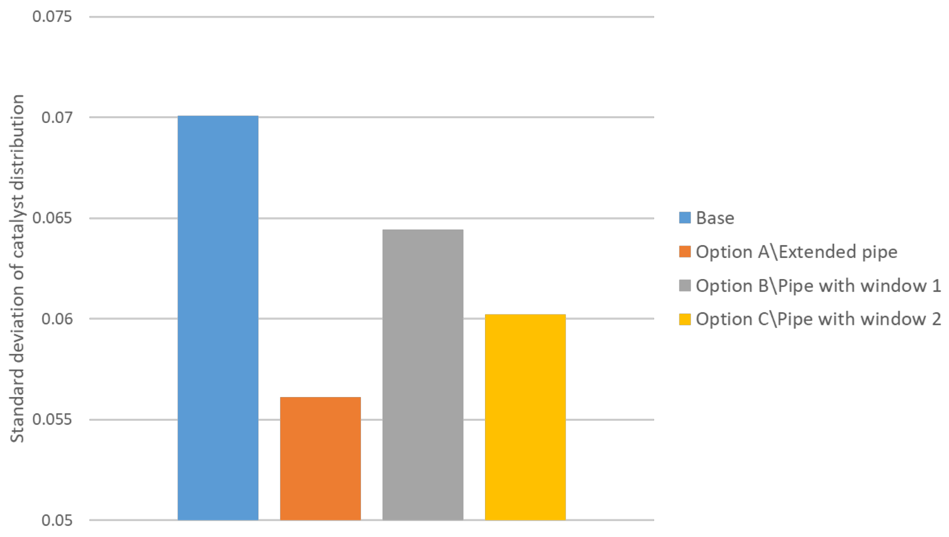


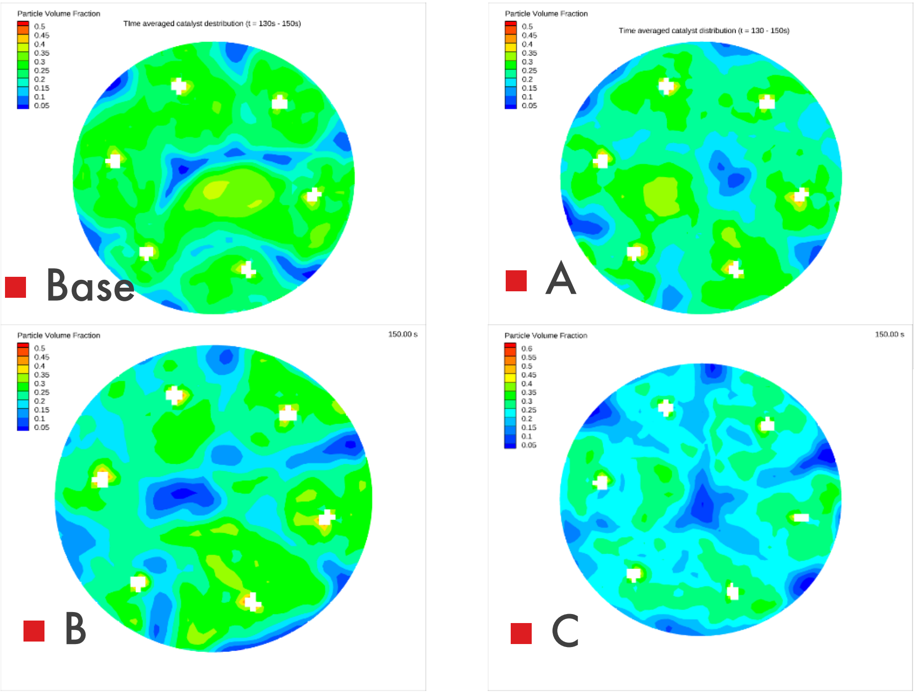


SCD Optimization

- Multiple design options, including combinations of extended pipes, opening side windows, and reorienting the pipe, were proposed and tested using CFD.
- All new options exhibited improved catalyst distribution/air uniformity (less color contrast and lower standard deviation) compared to current design.







Summary

- Current unit design was reviewed regarding space constraints and potential areas of improvement.
- A realistic and representative CFD model was created to benchmark the current design’s performance.
- Multiple design options were tested using CFD within a short time.
- CFD also used for all new design and technology developments, especially enhancing the performance of equipment, reducing performance & reliability risks.

Validated through experimental or inspection data, CFD is
a great tool to proof concept and drive design optimizations.

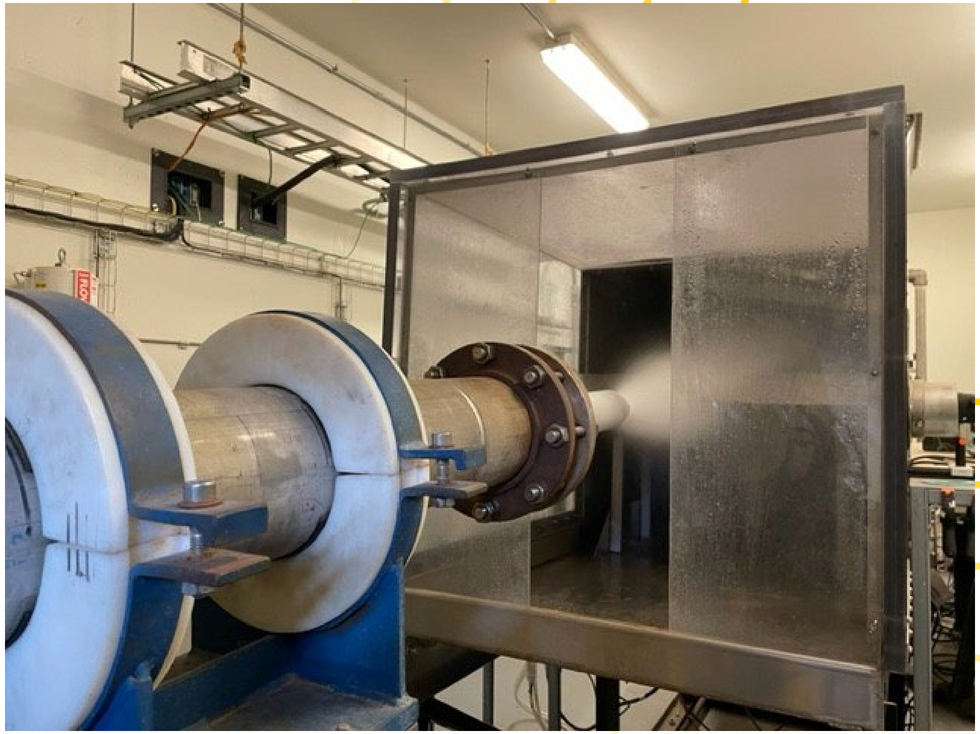
Case Study 3

Coprocessing nozzle design optimization

Background

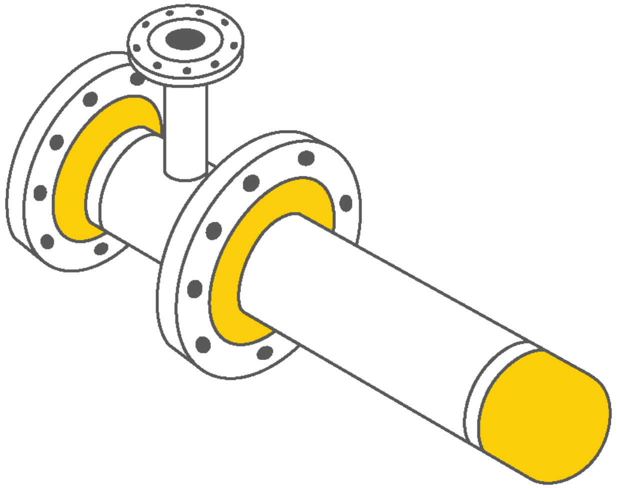
Shell is investing in low carbon products, driving CO_2 emission reduction through technology advancement.

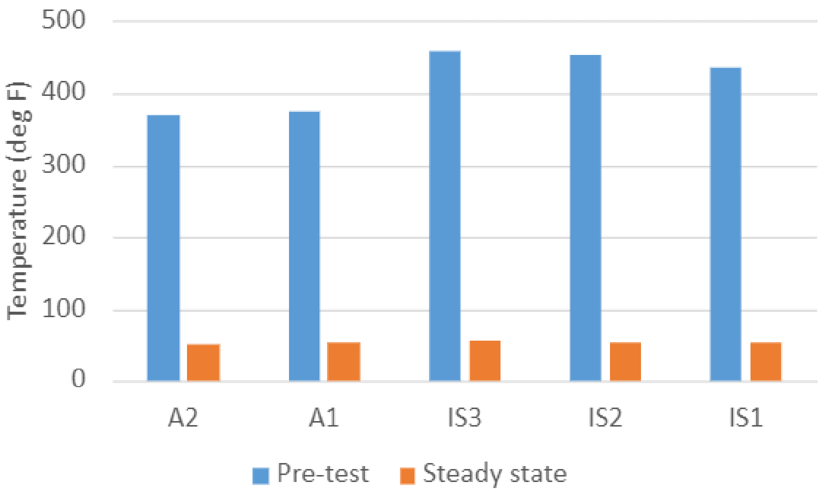
- Biogenic source coprocessing:
  - Important to deliver non-fossil transportation oil & chemical products.
- Shell developed proprietary coprocessing nozzle:
  - Wider range of feedstocks that cat cracker can handle.
  - Protects heat-sensitive feeds, prevents operational problems.
  - Increases flexibility for diverse renewable feeds.



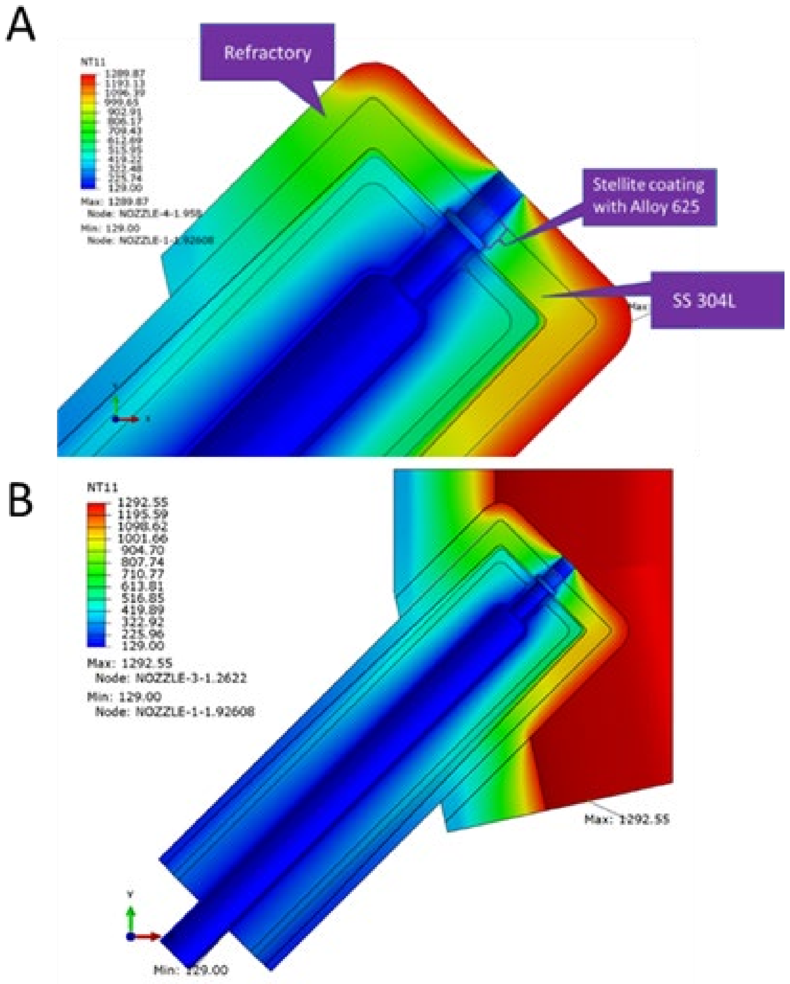
Technical Details

- The nozzle employs specialized metallurgies for nozzle internals, which can address issues related to thermal degradation.
- To further protect the coprocessing nozzle, we installed the coprocessing nozzle inside an emergency steam nozzle. (Steam temperature used as a shield to further protect from riser temperature.)



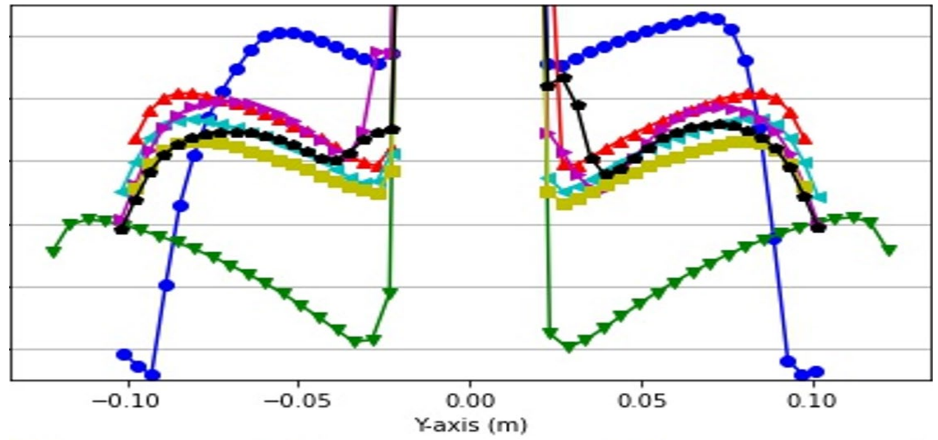


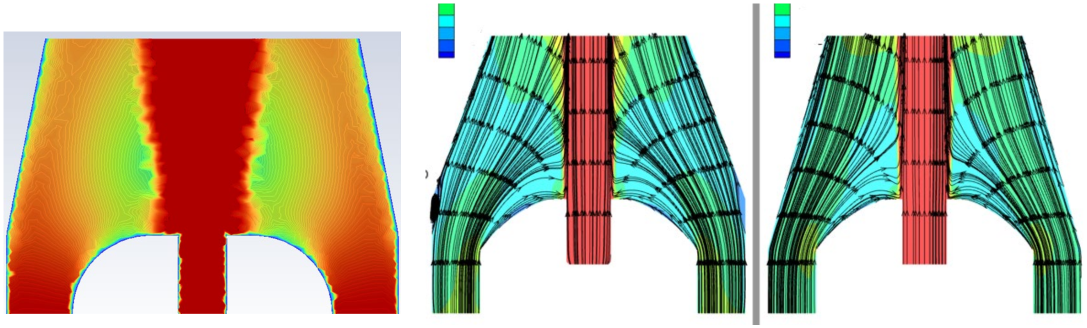
A2, A1, IS3, IS2, IS1: Various locations of the thermal sensor, installed on the internal skin touching the feed



CFD Evaluation

- When deploying the coprocessing nozzle inside an emergency steam nozzle, there are interactions between the renewable feed and steam, one having much higher velocity than the other.
- The large differential velocity creates a differential pressure that pulls the steam flow towards the feed, leaving low velocity regions close to the wall (a weak point for catalyst ingression).
- CFD was used to comprehend the interaction and flow dynamics, guiding the optimization process for the geometrical design.
- The geometrical design is optimized to eradicate areas of low velocity and prevent formation of large eddies.





Summary

- Coprocessing nozzle is an important technology that enables FCC to coprocess difficult biogenic or renewable feedstocks on existing FCC, as it can improve yield shift while ensuring high reliability and stability, contributing to a greener world with less CO2 emission.
- CFD was used to understand the flow behavior (velocity profile and eddy formation) inside the emergency steam nozzle.
- Multiple geometry configurations have been tested to optimize and identify the most suitable geometry that meets process requirement while minimizing eddies.
- We also developed a design of a solid-based CO2 capture technology, utilizing fluidization know-how and CFD to guide the fluidization process design and pilot testing program.
- We are extending our CFD capabilities to solve other challenging energy transition problems.

Final Thoughts

- CFD is a great tool for optimizing design and proof concept. It is an add-on to our existing pilot plants, operating assets, experimental capability through PSRI.
- Computational Fluid Dynamics (CFD) is a transformative and digitalization tool in engineering, harnessing numerical analysis to simulate fluid flow within various systems, crucial for performance and efficiency.
- CFD provides insights into fluid behavior and interactions, aiding in optimizing processes and mitigating risks more cost effectively than physical experiments.
- We have successfully deployed CFD to assist in diagnosing and troubleshooting asset support issues, proposing and validating design optimization for licensing technologies/concept design and driving technology improvements in energy transition sectors.

Q&A