Modeling FCCU: Success & Challenges

Raj Singh & Scott Golczynski
Technip Energies USA, Inc.

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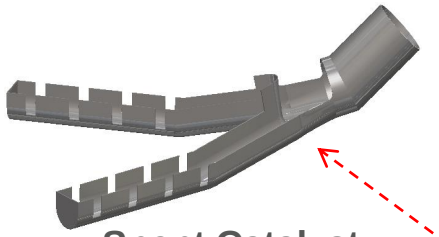
Outline

- **Brief overview of T.EN FCC technology features**
- **Modeling Success Examples**
  1. Improved catalyst retention with optimized RS^2 design
  2. Improved regenerator performance with latest SCD design
  3. Next Gen gas solid distributor design for regenerator application
  4. HS-FCC DFR feed zone optimization
  5. Riser modeling with feed vaporization
- **Modeling Challenges**
- **Summary**

T.EN FCC Technology Features

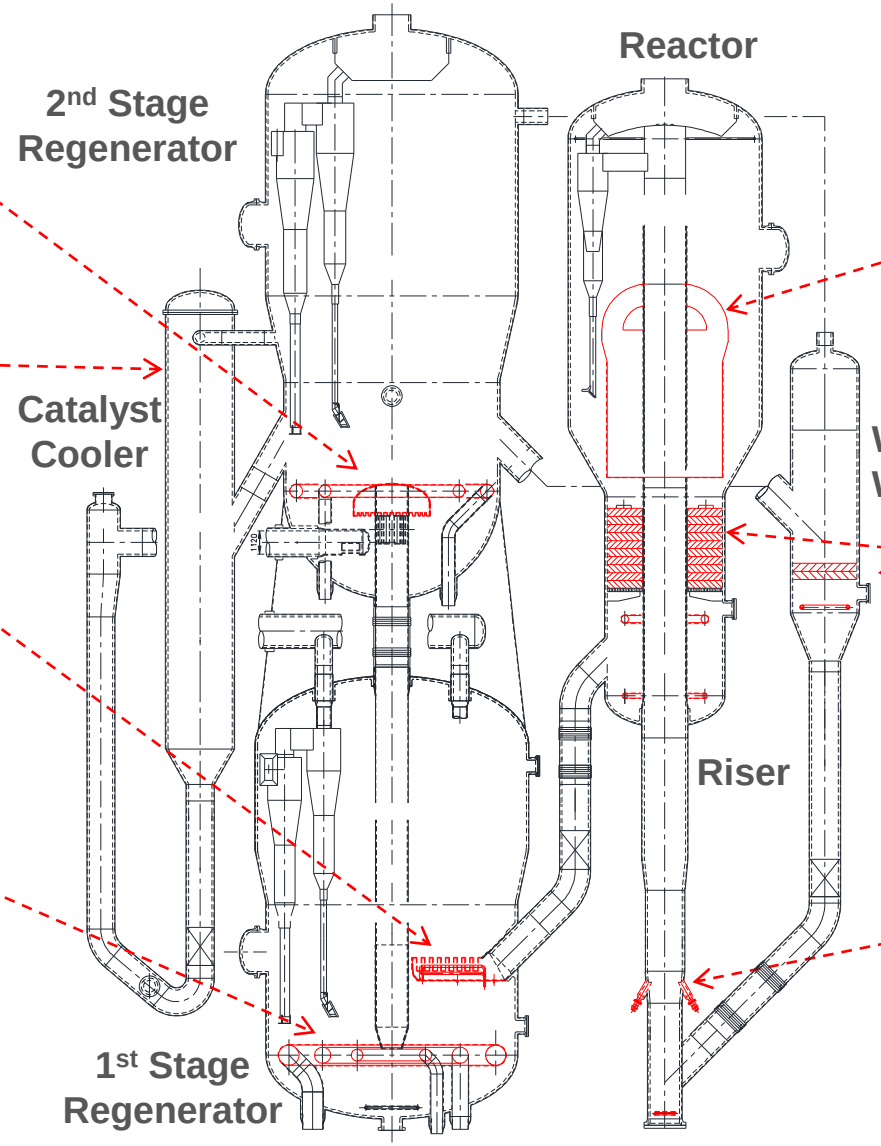
Catalyst Cooler

Mushroom Distributor

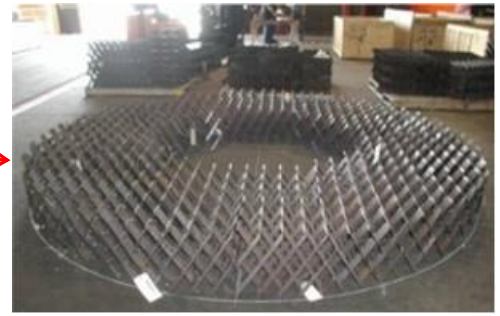


Spent Catalyst Distributor

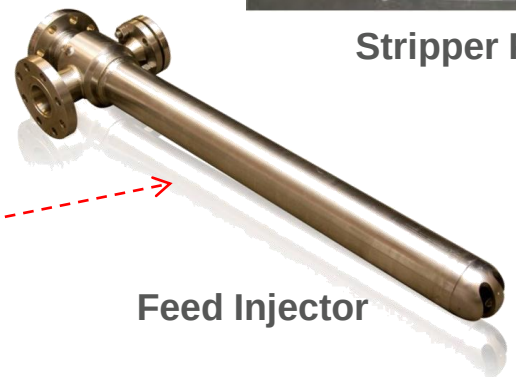
Air Ring



RS² Riser Termination Device



Stripper Packing



Feed Injector

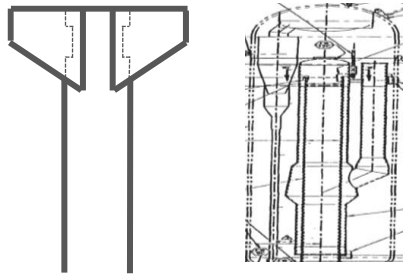
Example #1

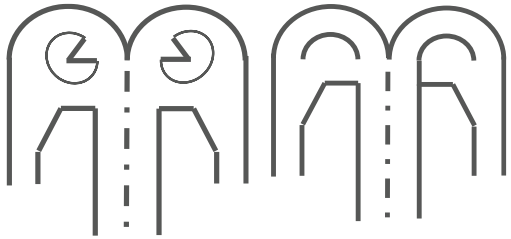
Improved catalyst retention with optimized RS^2 design

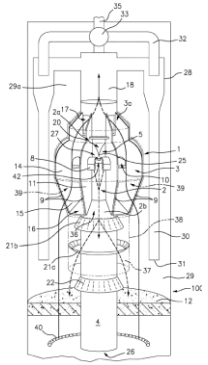
Riser Termination Device Design Development

Uncoupled RTD → **Coupled with Cyclones**

Ballistic Separator | Steerhorn | Ramshorn | LD^2 | RS^2





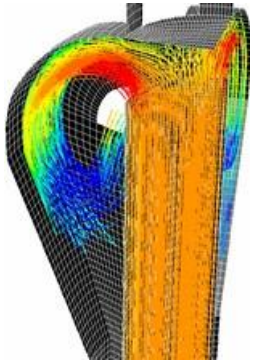


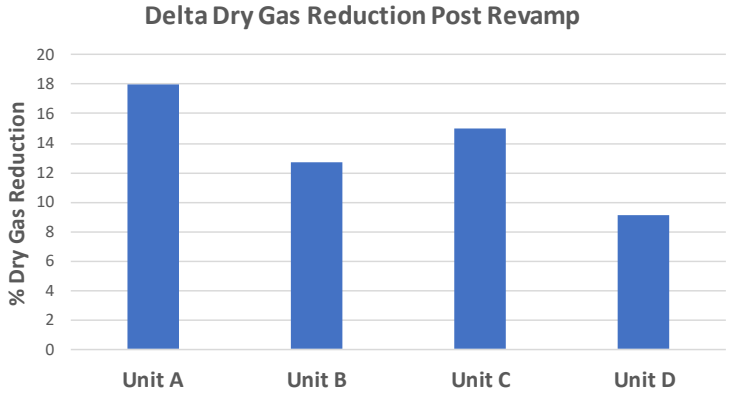
Low Cat losses, high post riser cracking, high dry gas, low gas containment

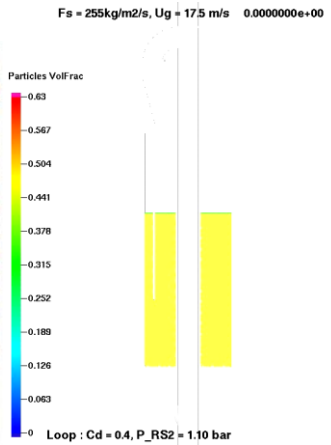
1St to 3rd Gen RS^2
High Gas Containment
Low dry gas

Test Campaign #1 (Yr 1996 – 1998) → **Test Campaign #2 (Yr 2021-2024)**

Cold flow experiments & CFD → **Design** → **Successful Implementation & Performance**





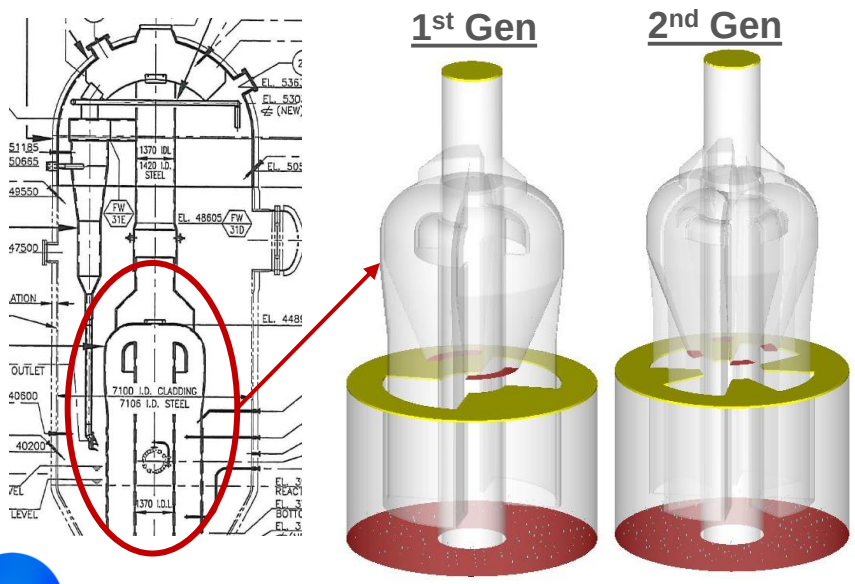


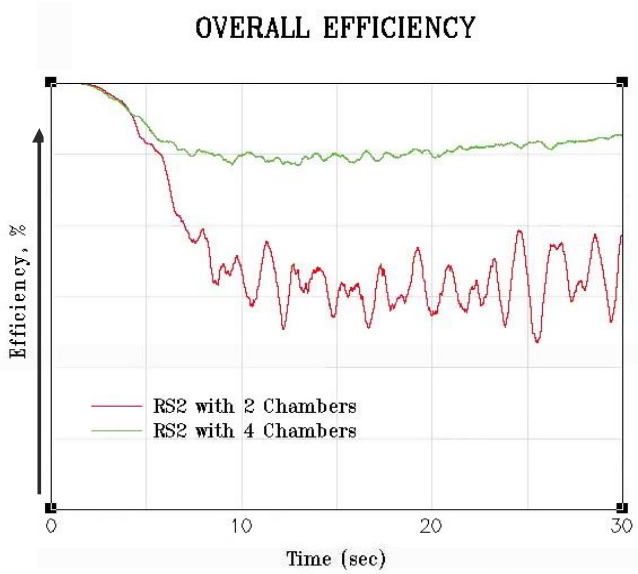
TEN TECHNIP ENERGIES

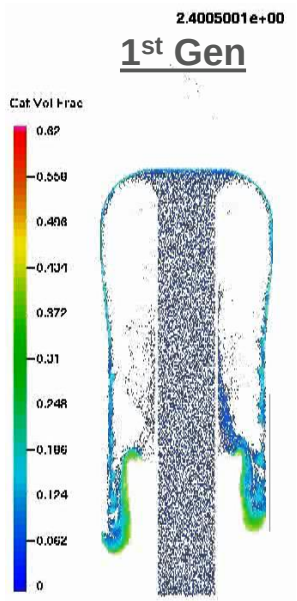
2nd Gen RS² Design Development

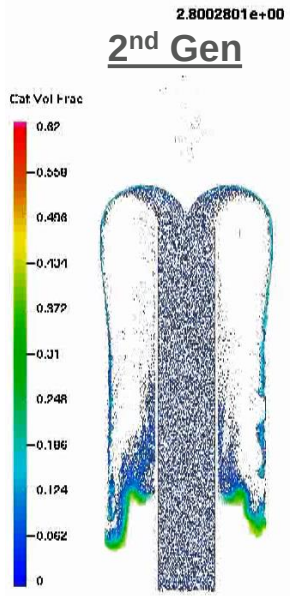
- **More compact design with increased efficiency**
  - 4 vs 2 separation / stripping chamber design
- **Symmetrical flow to and from RS², resulting in symmetrical cyclone layout**
  - Results in improved efficiency

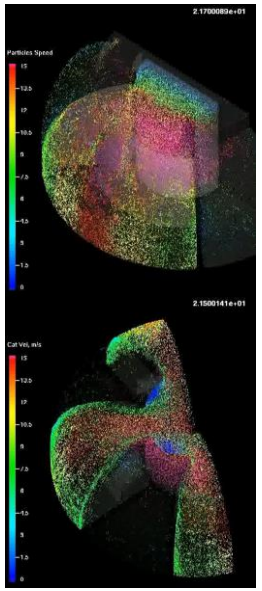
Design Optimization Using CFD











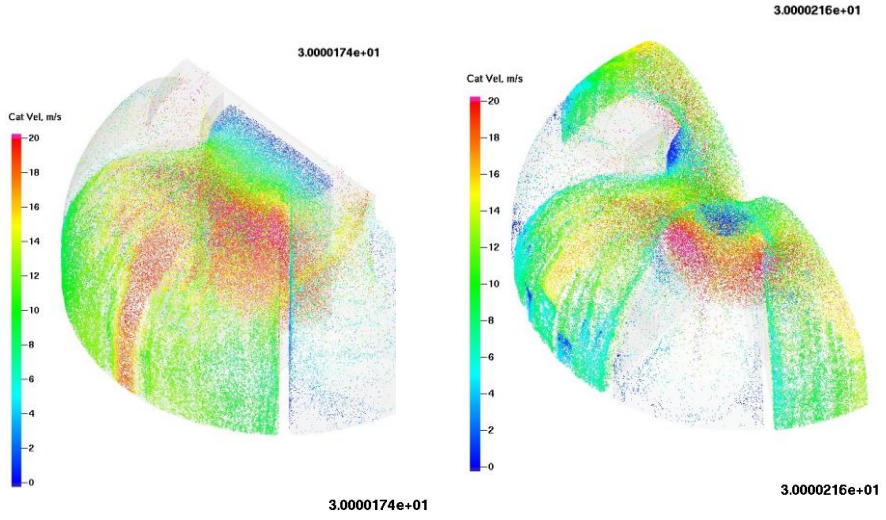
2nd Gen RS² Design Development (cont'd)

- **Improved performance with 4-Chamber design**
  - More uniform span of velocity profile
  - Maintains even solid velocity down the separation chamber to dipleg
  - Helps improve solid separation efficiency

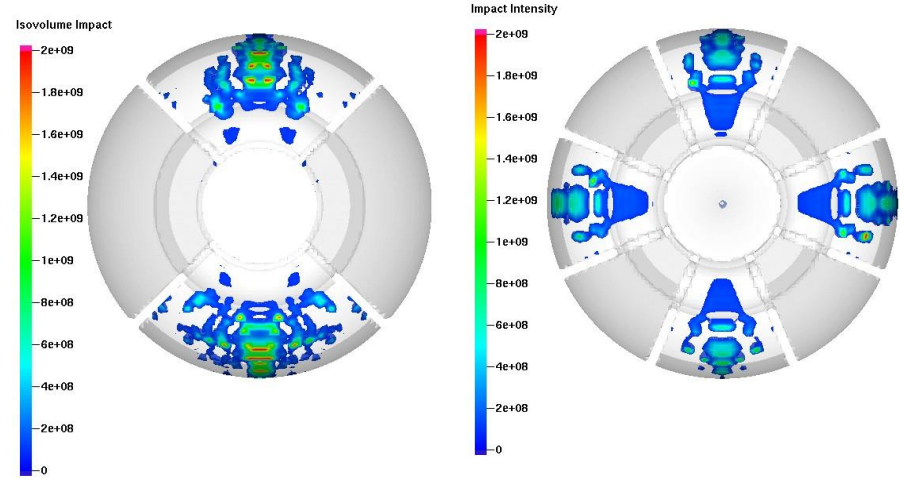
- **Potential areas of wall erosion as per CFD**
  - Separation chamber inlet curvature
  - 4-chamber employs lower impact intensity due to uniform velocity distribution
  - Note: No erosion seen during TA's

2-Chamber Design | **4-Chamber Design**

Catalyst Velocity Profile



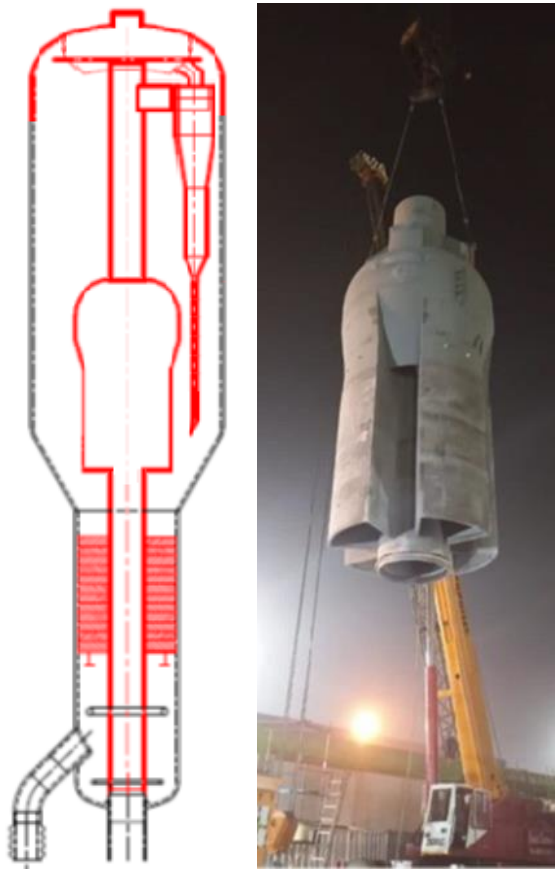
Impact Intensity $\propto m^{1.5}\, u^{3.5}\, \theta$



2nd Gen RS² : Commercial Reference

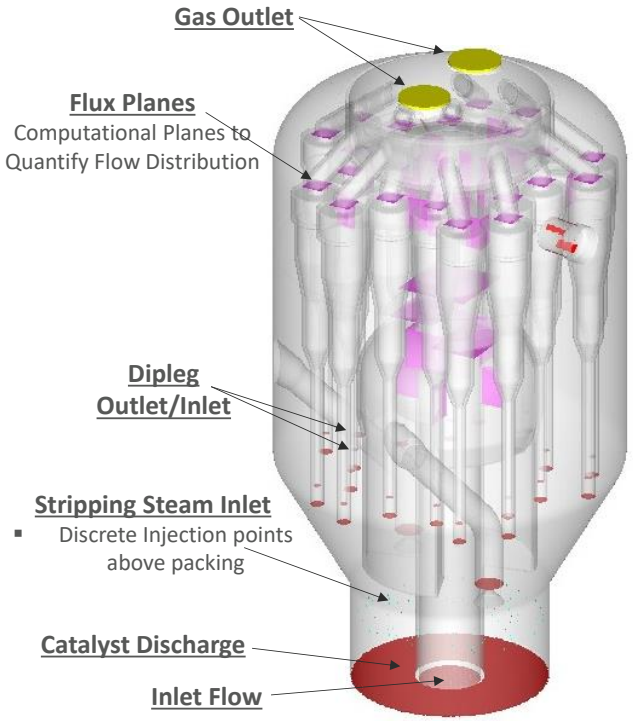
- **T.EN R2R Resid FCC unit**
  - Unit revamped for max C3=
    - High severity operation
  - New RTD installed during turnaround
    - 2nd Gen RS² with closed coupled cyclones
- **Post TA observations:**
  - BS&W in similar range before and after TA
  - Smooth operation for more than a year
  - High severity operation has lower slurry yield and high C/O and riser velocity
    - Overall higher separation efficiency in spite of increased BS&W
    - Overall cat separation efficiency >99.999%

Post-TA

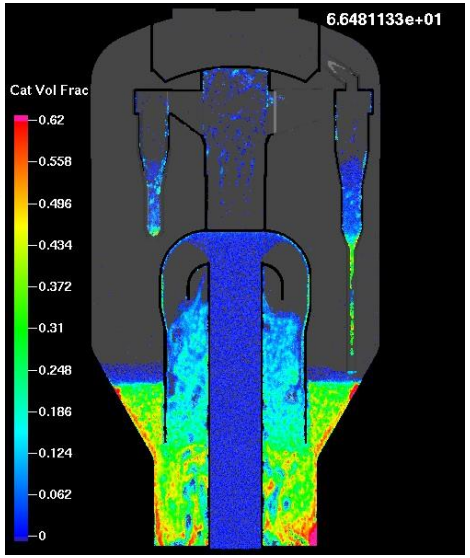


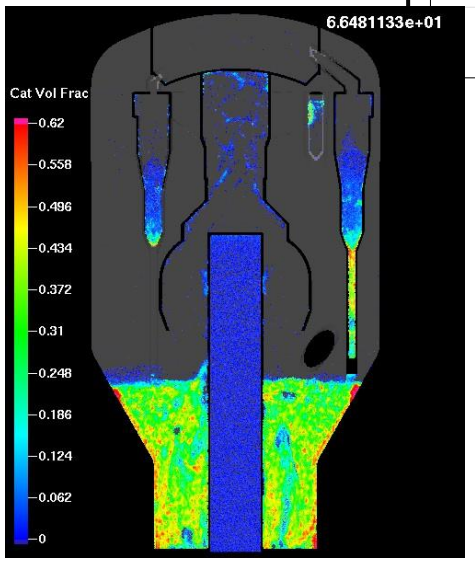
Full Reactor Model with 2-Chamber RS²

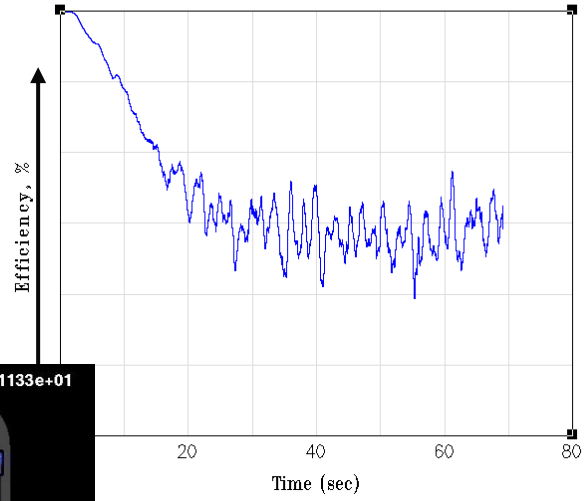
- Flow hydrodynamics more stable than smaller domain RS²
  - Overall observations similar to smaller domain

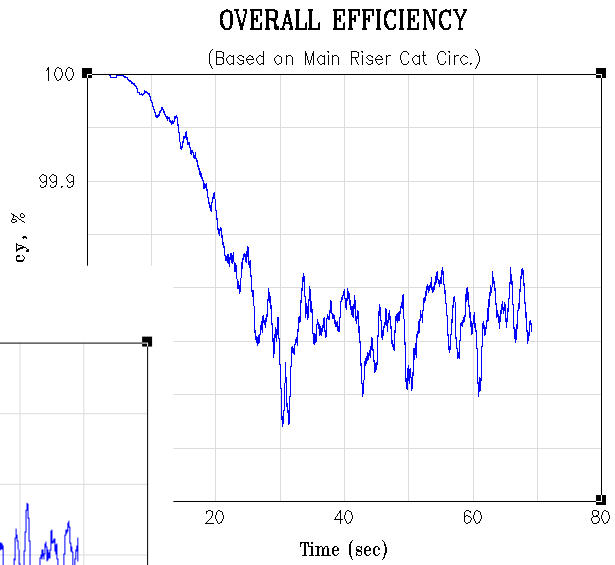


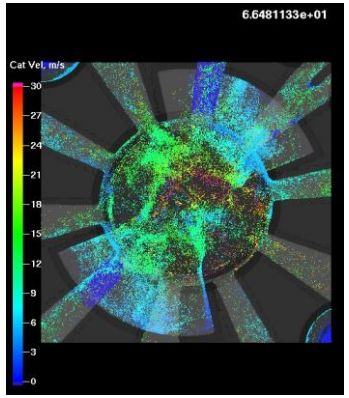
Cell Count: 8 Million
Particle Count: 8 Million

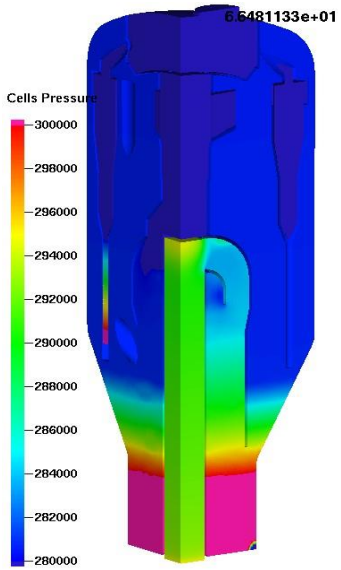










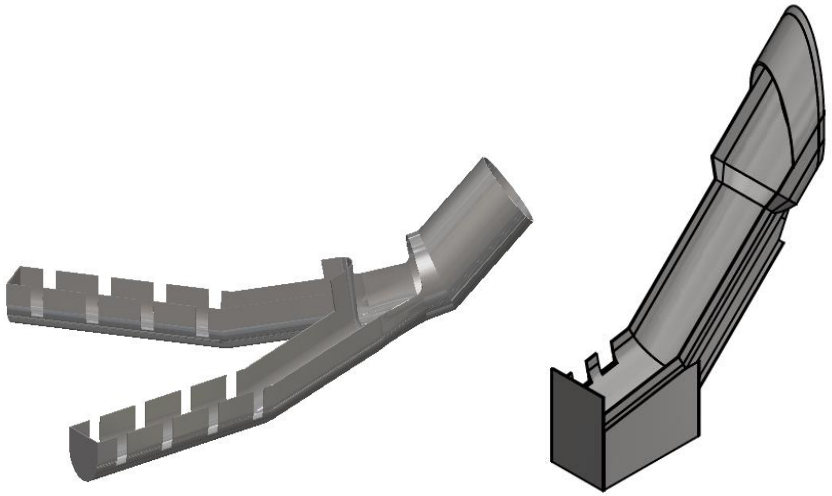


Example #2

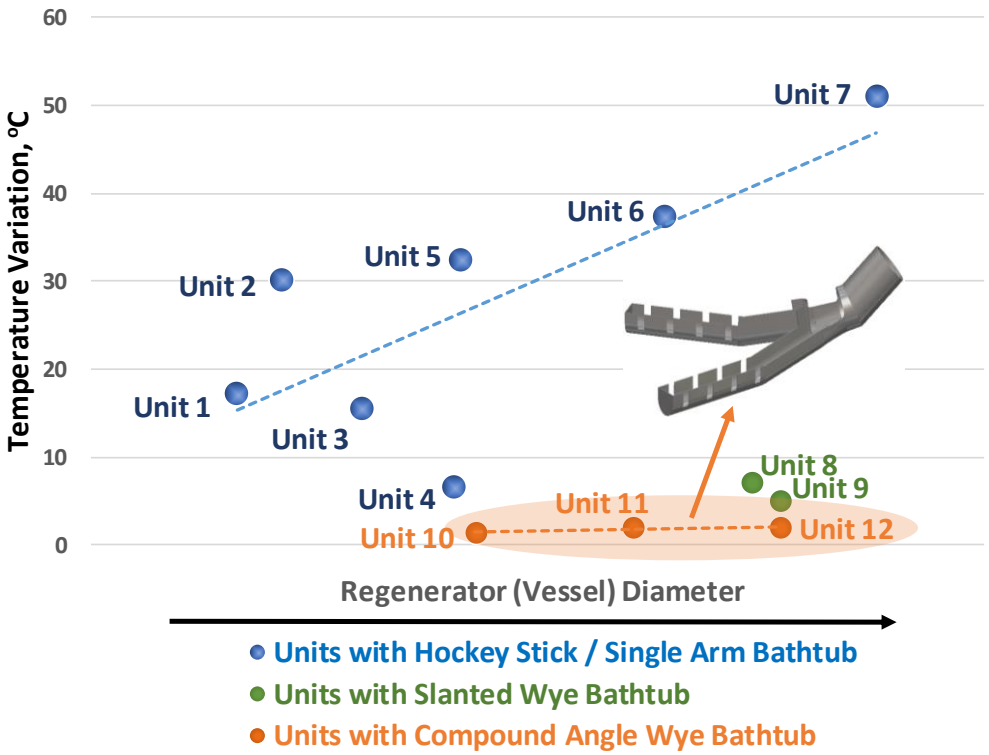
Improved regenerator performance with latest spent catalyst distributor “SCD” design

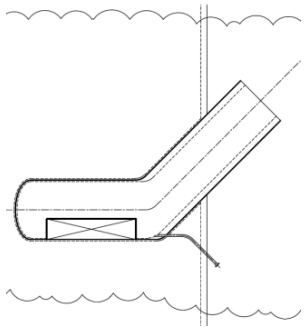
Spent Catalyst Distributor Design Development

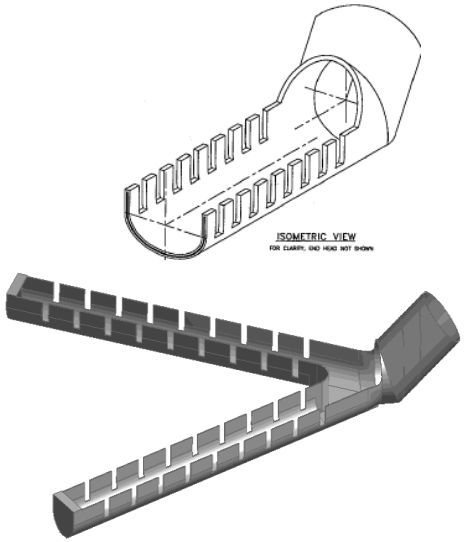
- **Compound angle wye bathtub**
  - Minimal dense bed temperature variation
  - Minimal afterburn
  - Reduces NOx



Latest Design
Compound angle wye bathtub





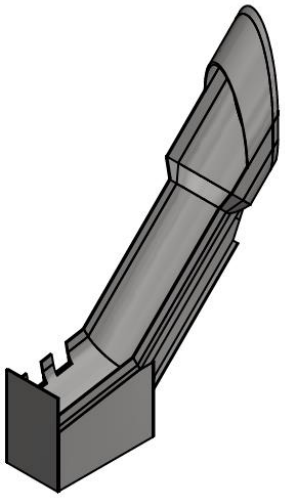


Prior Designs

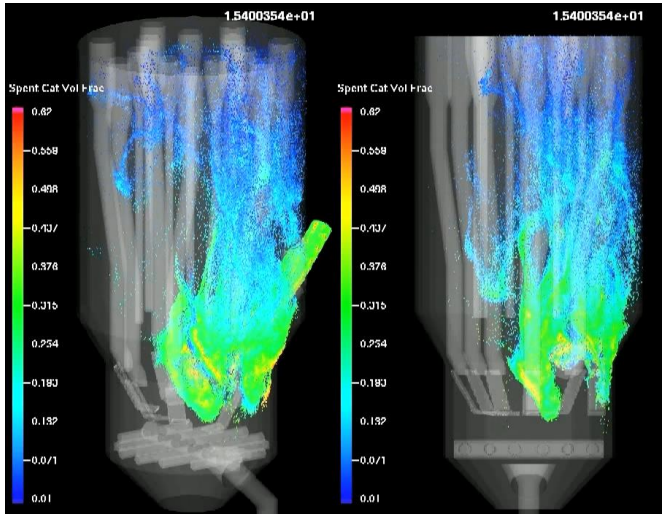
Submerged Spent Catalyst Distributor Technology

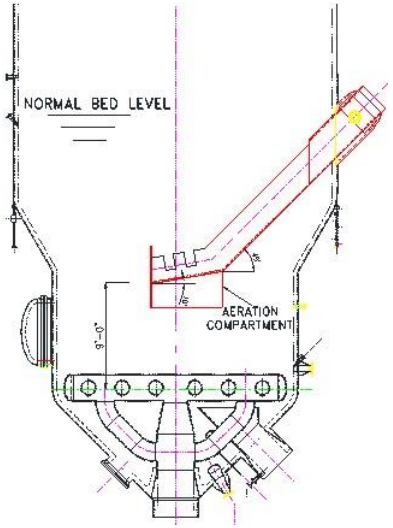
- Improves spent catalyst coverage
- Promotes even combustion throughout the bed
  - Minimizes dense and dilute phase temperature variation
  - Minimizes afterburn
- Sparger-less design

Concept → **CFD validation** → **Design**

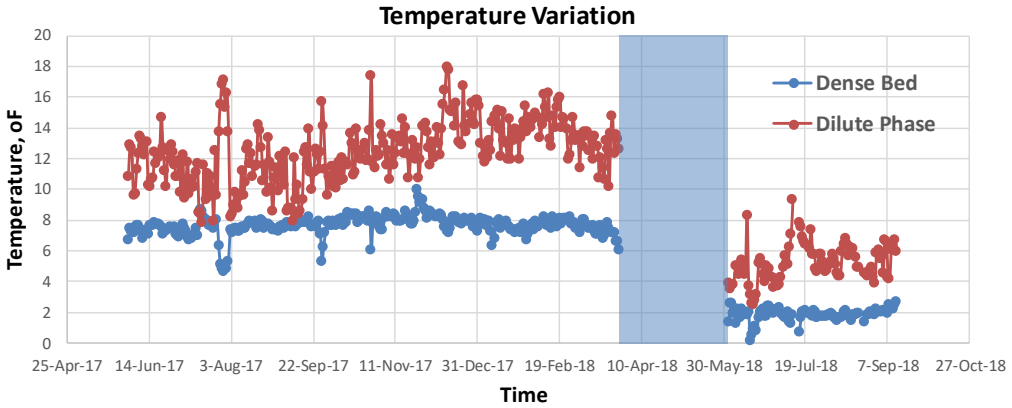


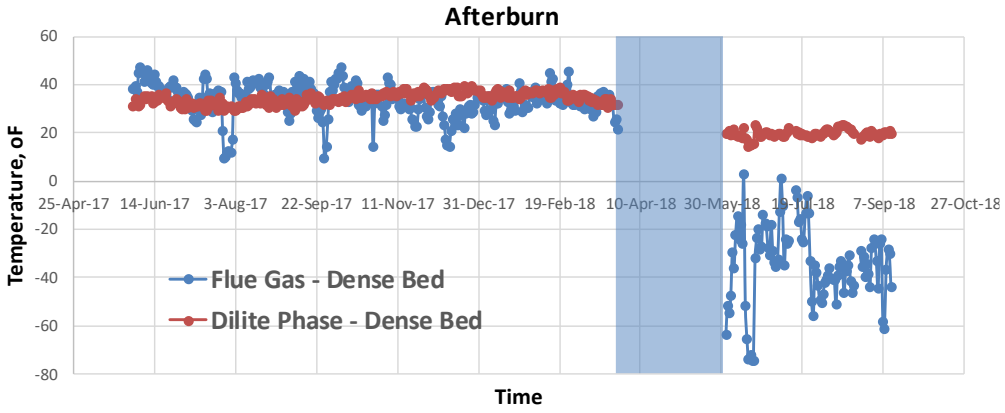
Spent catalyst flow Only





Industrial validation



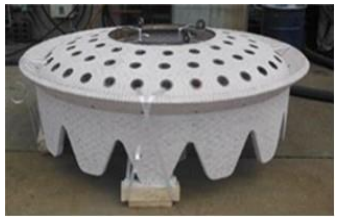


Example #3

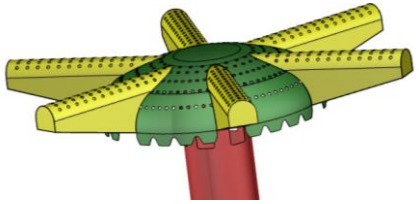
Next gen gas solid distributor design for co-current regenerator application

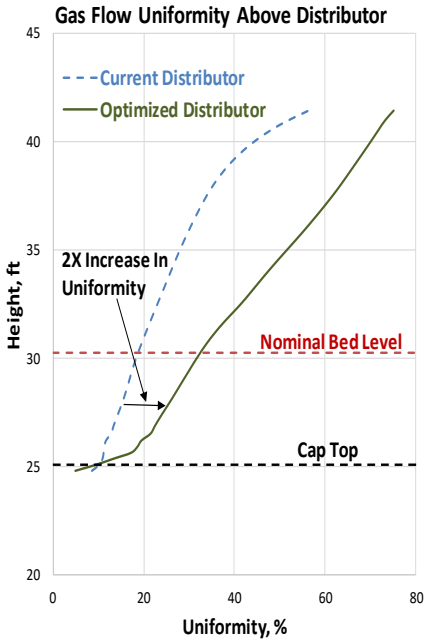
Mushroom Distributor Design Optimization

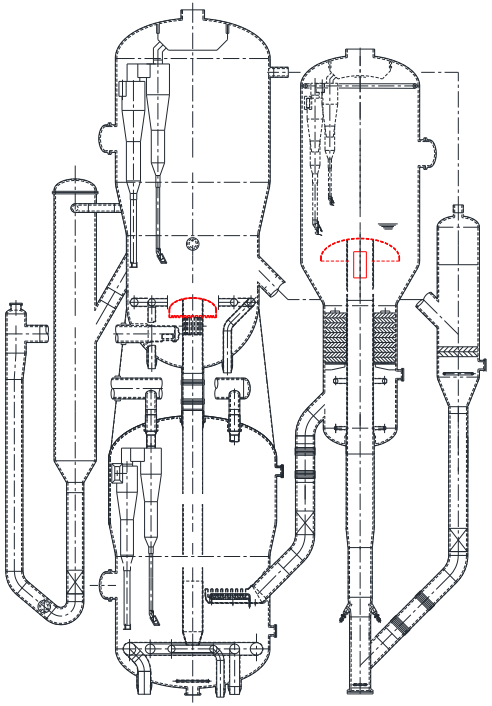
Simple Slotted To Mushroom with Skirt



Mushroom with Branch Arms

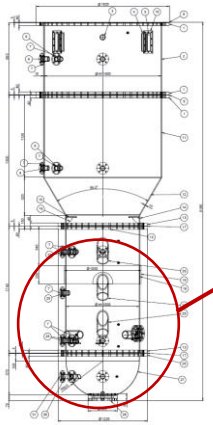


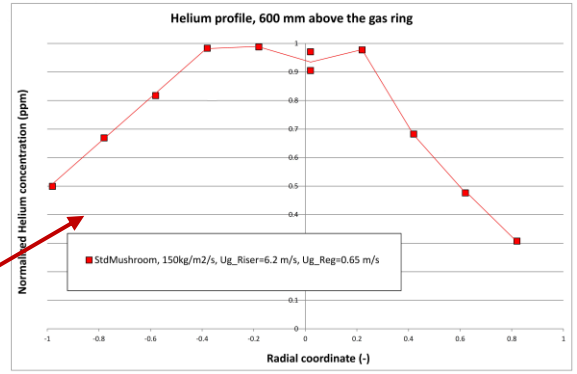




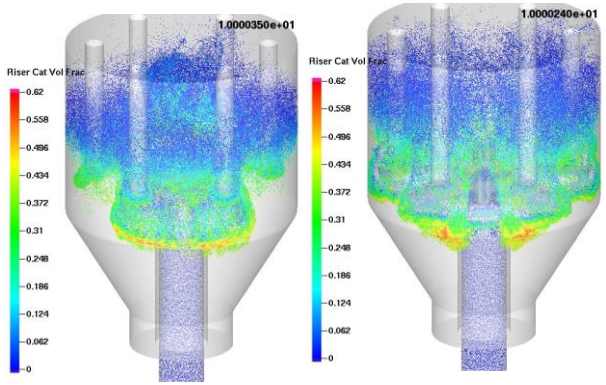
Improve Coverage & Distribution

IFPEN Cold Flow Test Rig





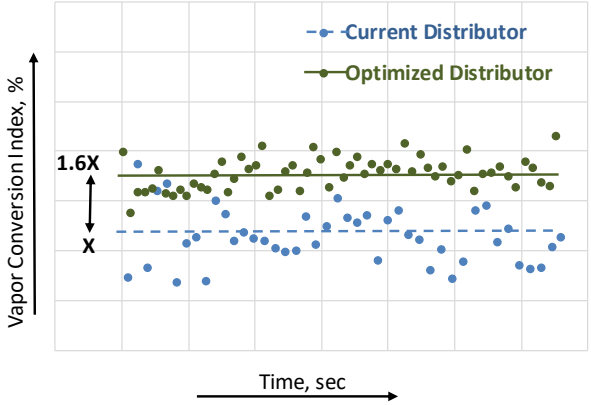
Design Optimization Using CFD



Without Arms

With Arms

Fractional Bed Cracking

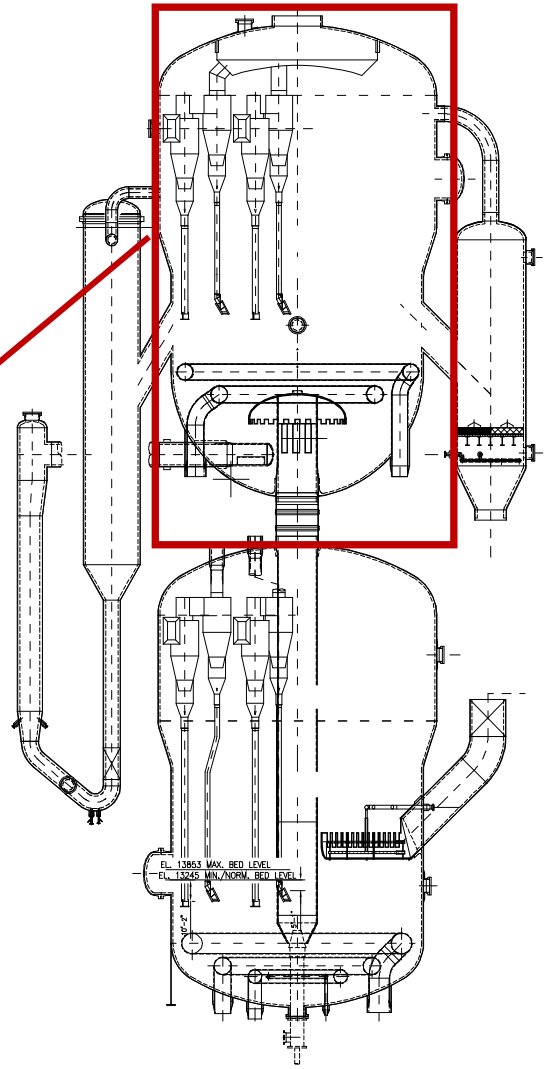


Next Gen Mushroom in Regenerator Application

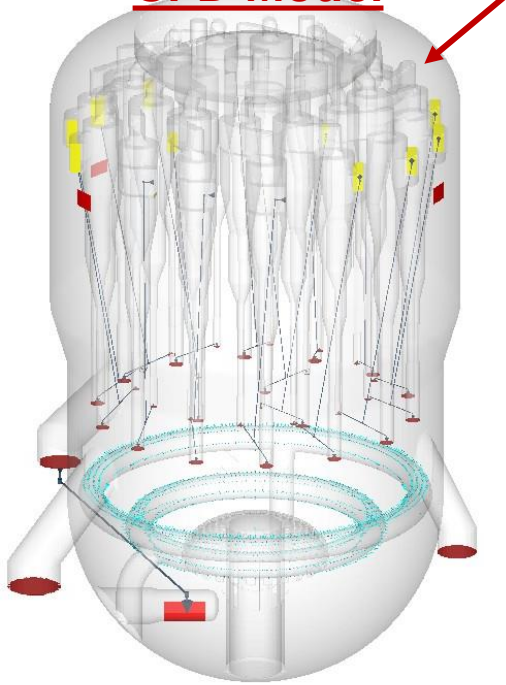
Objective

- Check and confirm the adequacy of the improved design in regenerator
  - Model industrial scale regenerator with standard and new mushroom design
- Quantify improvements in combustion characteristics and afterburn reduction

Modeling Domain

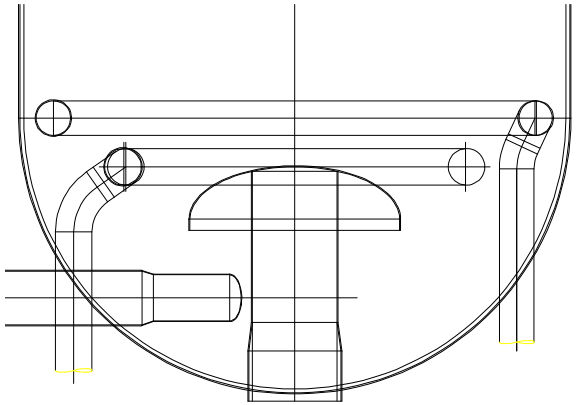


CFD Model



Config #1

Existing Configuration

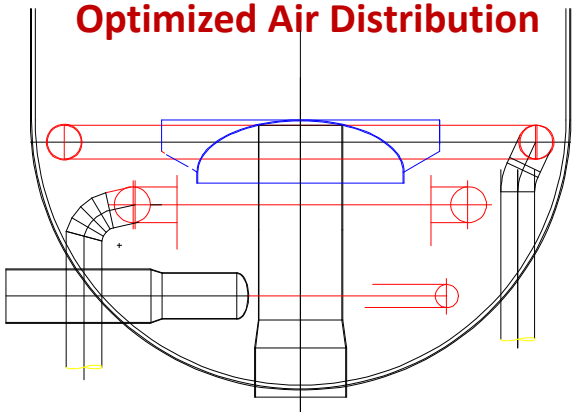


Config #2

Optimized Configuration

New Mushroom Design

Optimized Air Distribution



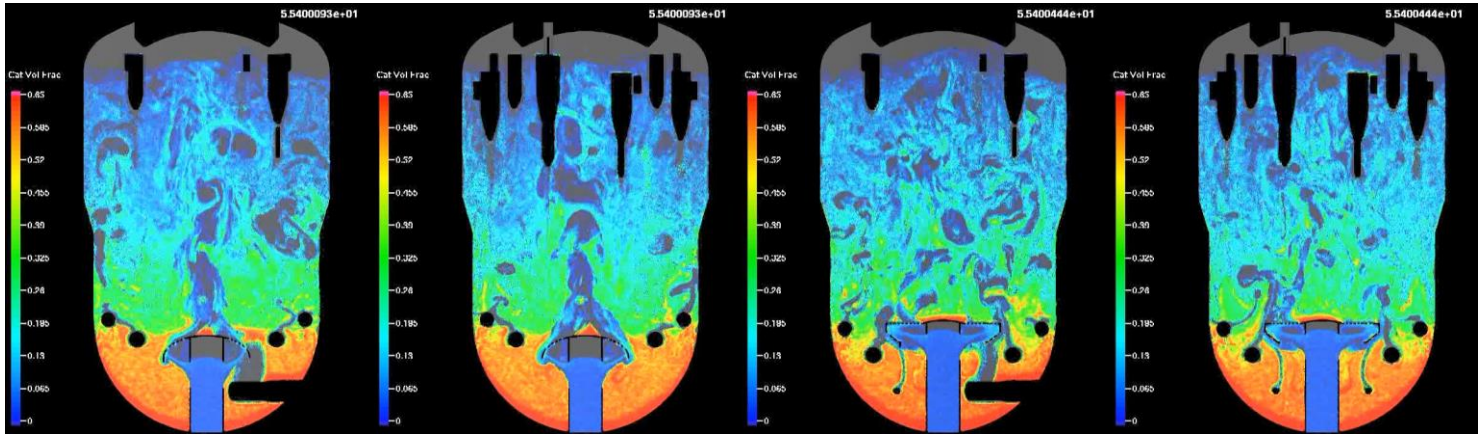
Catalyst Density Profile

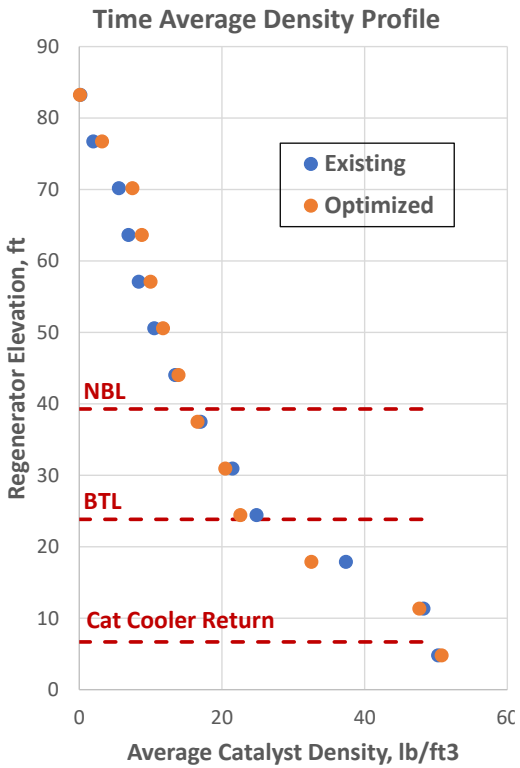
Optimized configuration

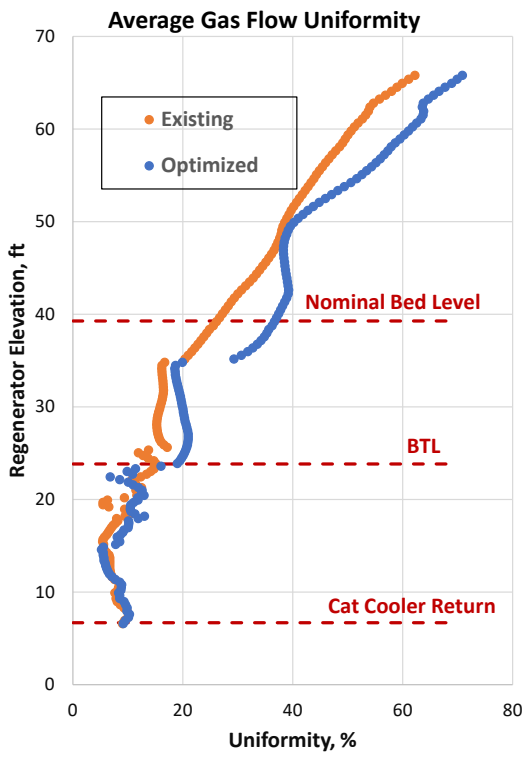
- Improved vapor catalyst distribution across the catalyst bed
  - Improved density distribution
  - Increased gas flow uniformity
- No center vapor plume formation and gas bypassing

Existing | **Optimized**

X-CenterLine | Y-CenterLine | X-CenterLine | Y-CenterLine







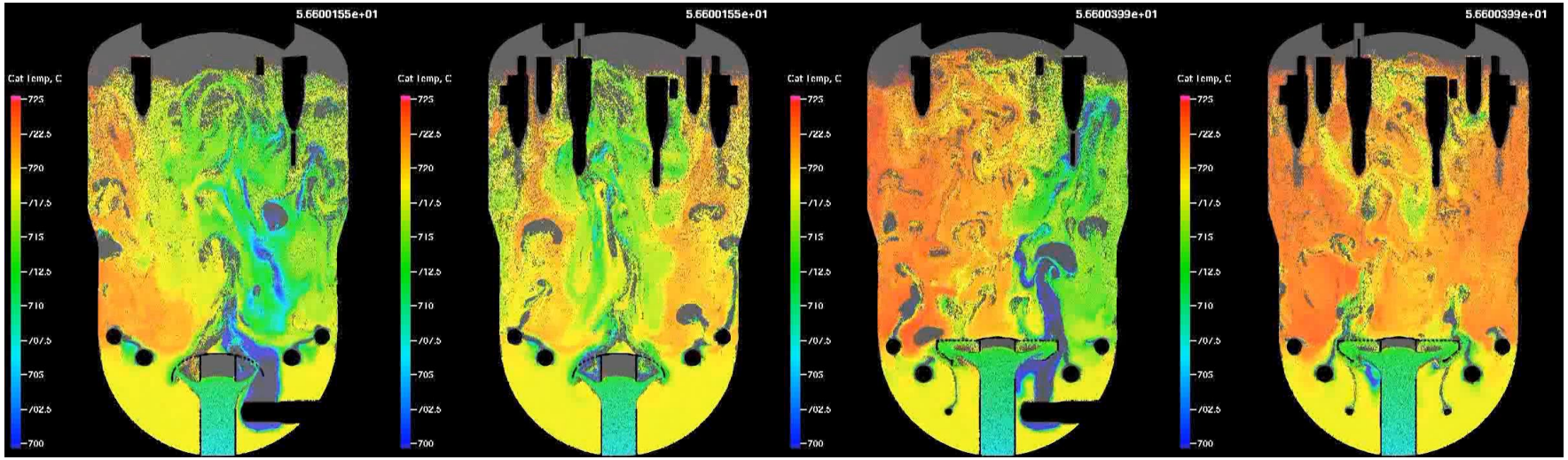
Temperature Profile

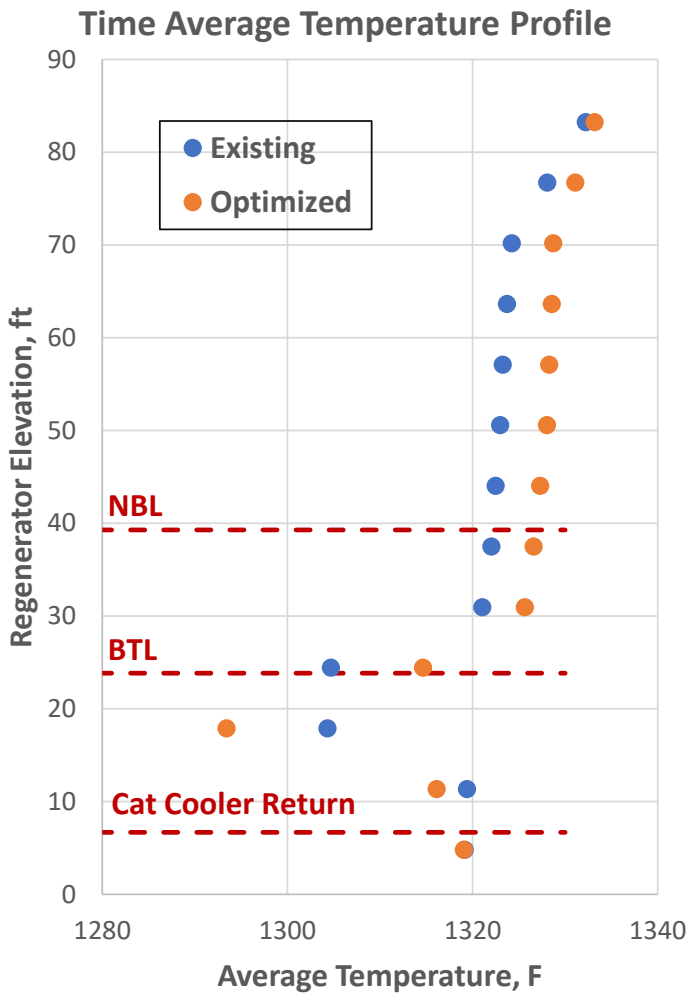
Optimized configuration

- Indicates increased bed temperature
- Improved vapor catalyst distribution leading to increased carbon burnout rate

Existing | **Optimized**

X-CenterLine | Y-CenterLine | X-CenterLine | Y-CenterLine

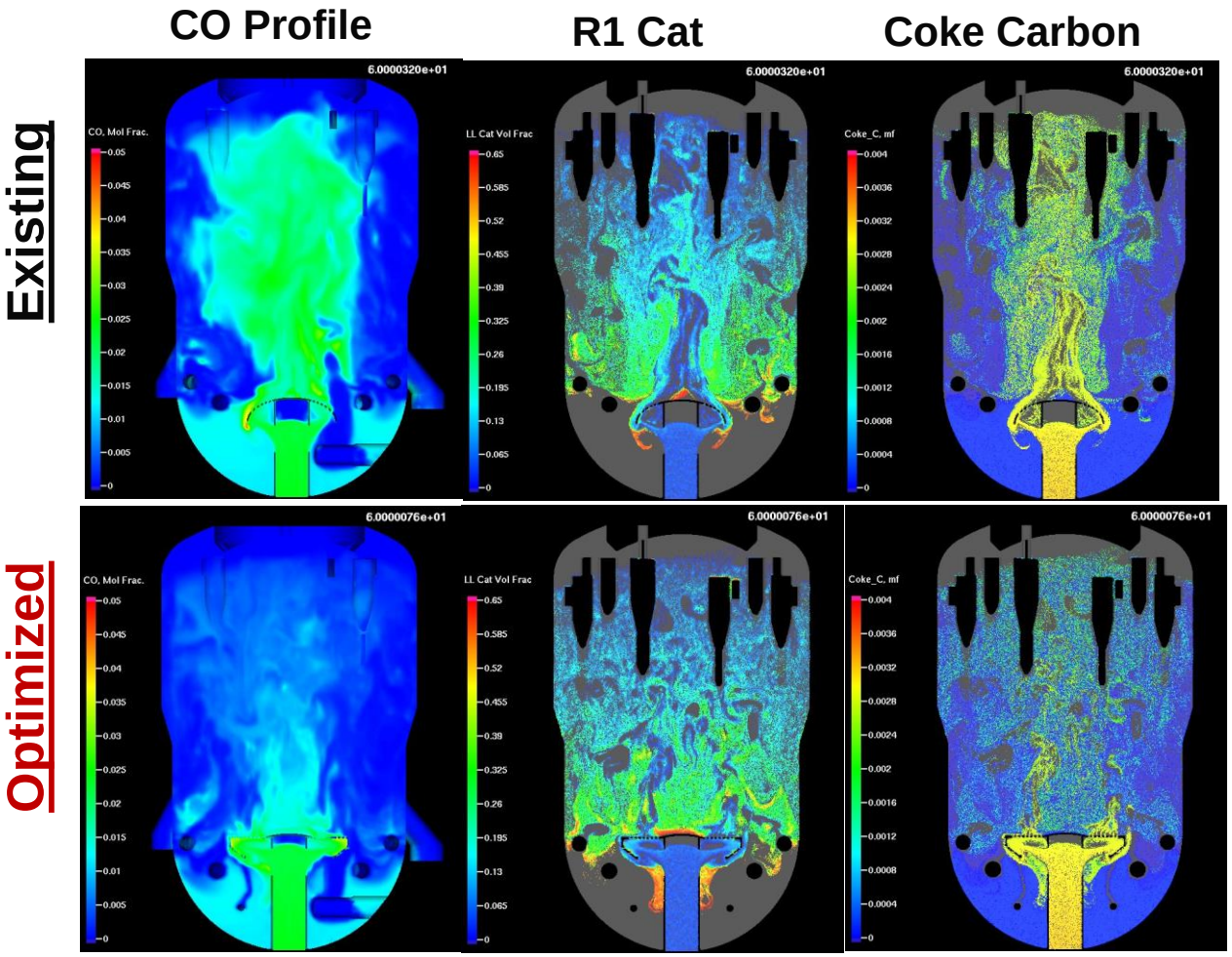




Modeling Results

Optimized configuration

- Improved regenerator performance with mushroom distributor with branch arms
- Improved coverage and coke carbon distribution
- Uniformity, CO, and coke profiles indicate better mixing and more efficient combustion
- Temperature profile does not show reduced afterburn, rather indicates more carbon burn
  - Equivalent carbon burn case could be considered for comparison



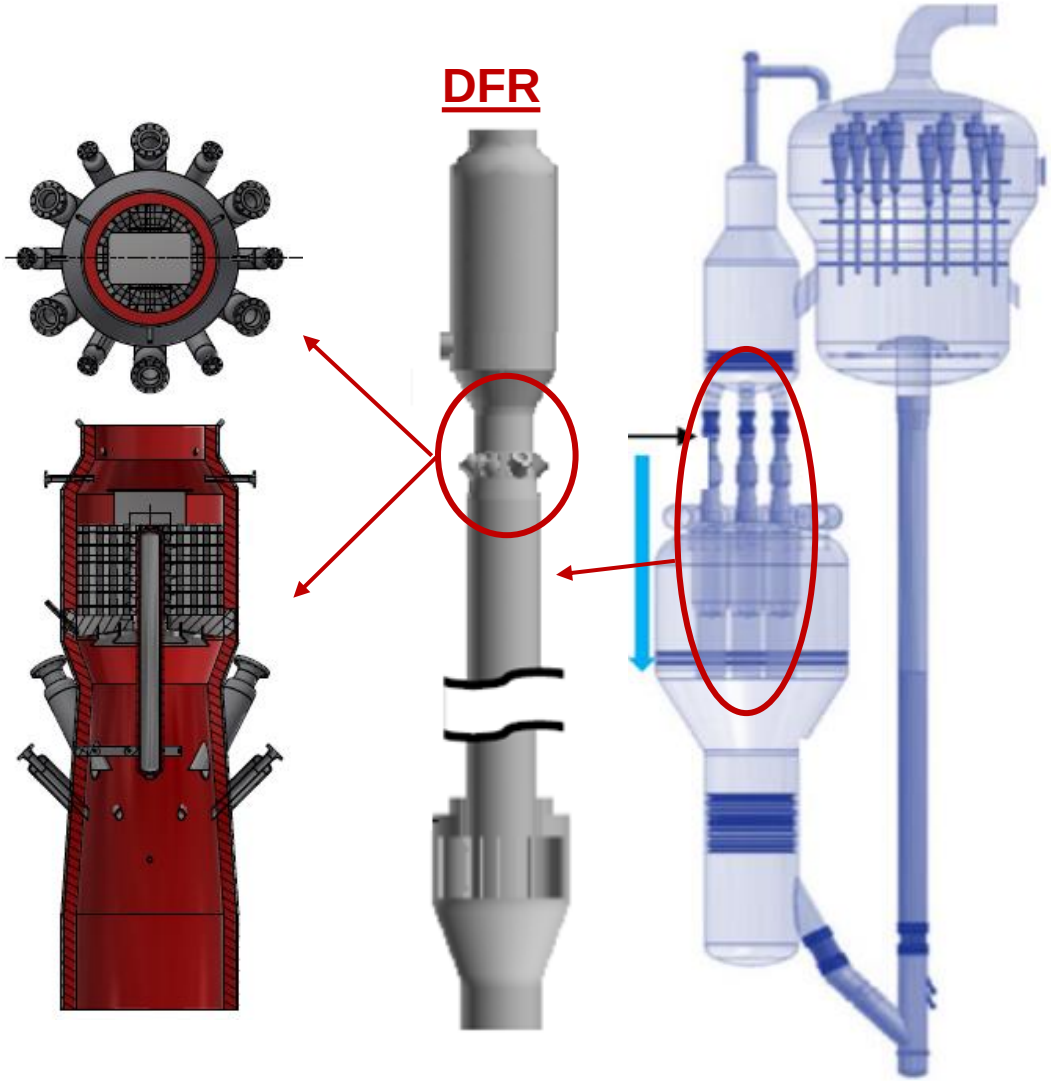
Example #4

HS-FCC DFR Feed Zone Optimization

Background

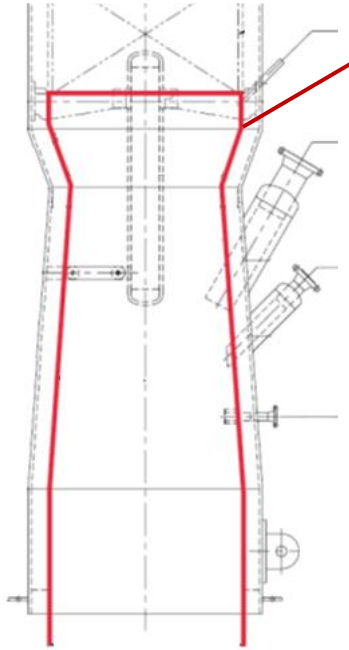
- **Unique FCC reactor configuration**
  - Down-flow reaction (DFR) system eliminates back-mixing
  - High catalyst/oil, high temperature
  - Short contact time, high selectivity
  - C3= yields 15-20wt%

- **Collaboration with CPFD to improve DFR performance**
  - Use BarracudaVR VLS feature for CFD modeling
    - Inject “particles” of liquid feed
    - Examine feed + cat mixing and feed vaporization
    - Assess initial design of commercial unit
    - Simulate improvements



DownFlow Reactor “DFR” Model

Modeling Domain

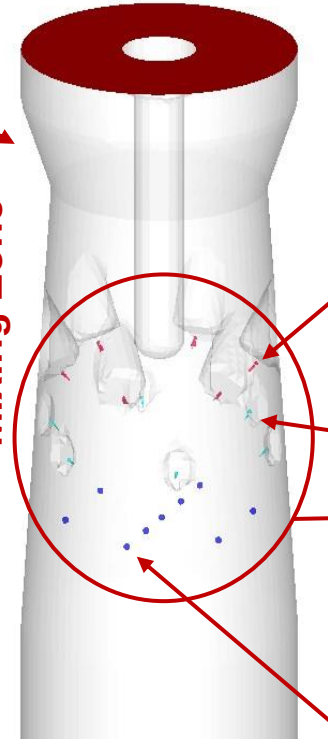


CFD Model

Outlet Pressure BC

Flow BC
Regen Cat To DFR

Feed + Catalyst Mixing Zone



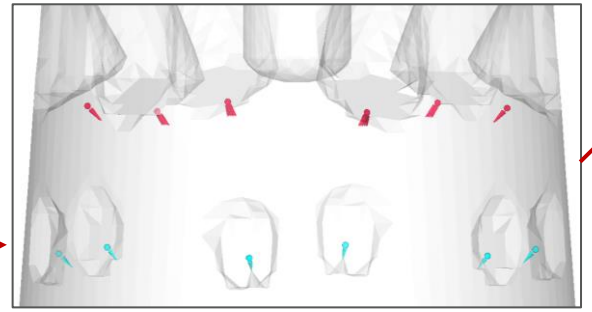
Feed Nozzles

Steam Nozzles

Transient Data Points

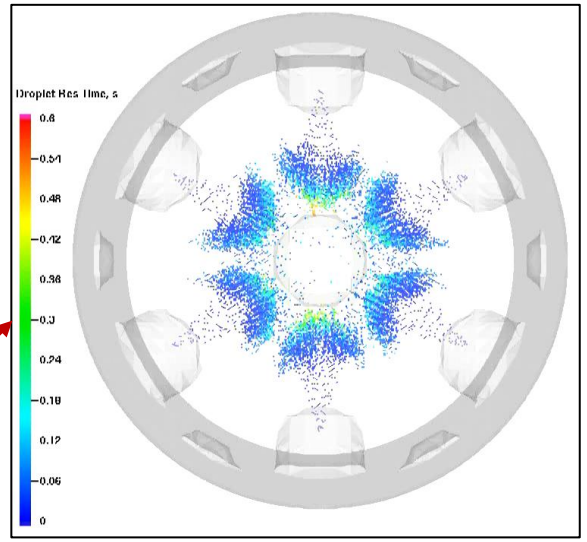
Feed Injection BC’s

- Discrete points for each feed nozzle in flat fan pattern
- “Particles” of liquid feed input through each point
- Spray angle, volume flux distribution, and droplet size distribution match injector cold flow experimental data



Steam Injection BC’s

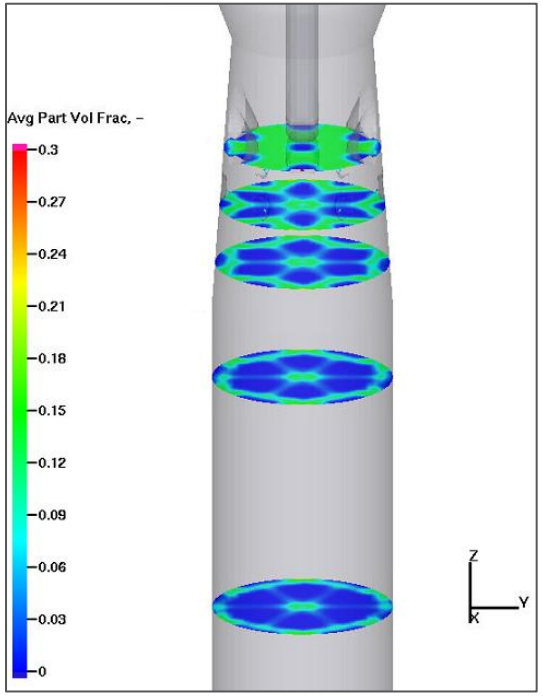
Single point injection for each steam nozzle



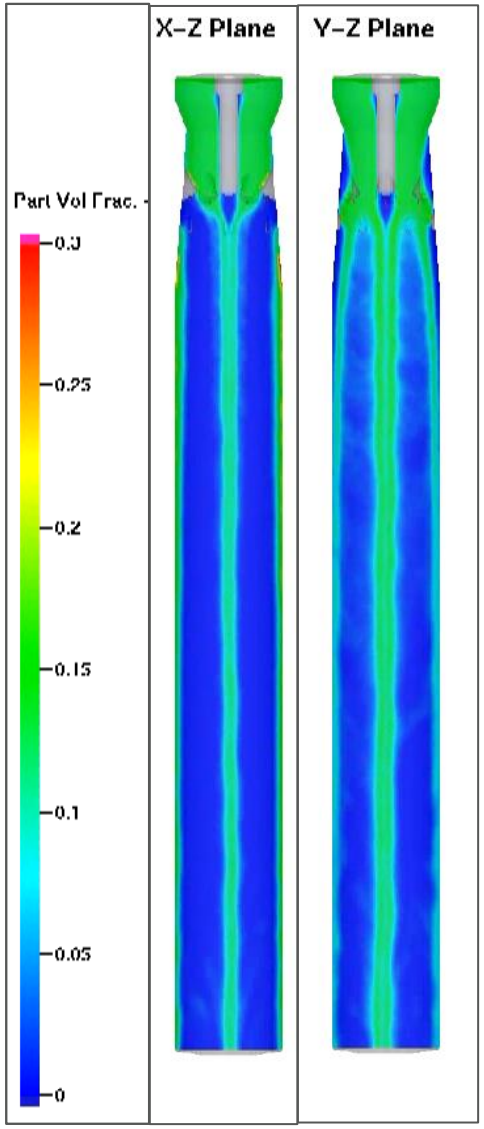
Base DFR Performance

- **CFD Observations**
  - Catalyst bypassing between feed nozzles
  - Central core of catalyst in center
    - Insufficient feed penetration
  - Minimal lateral mixing in down flow

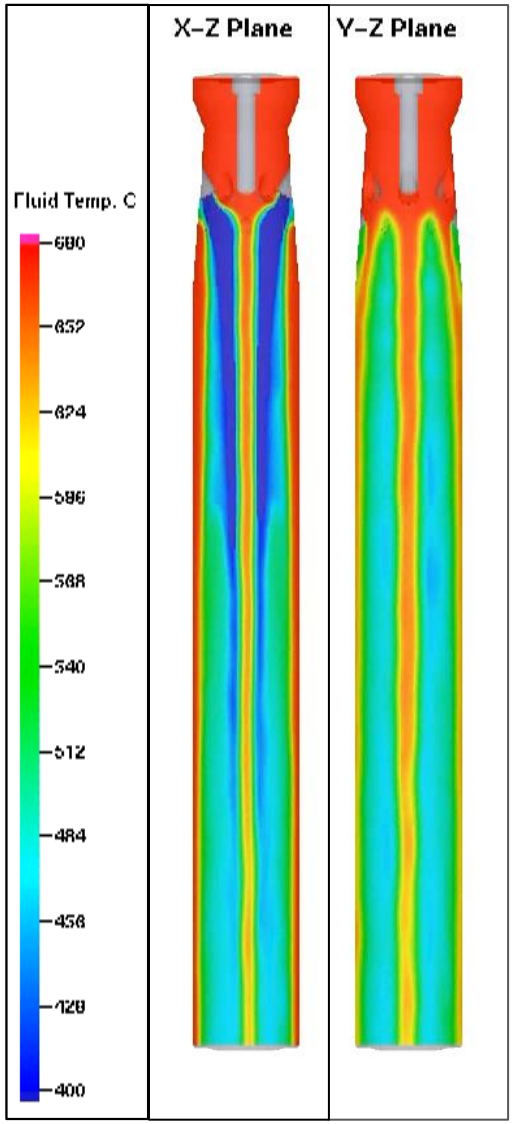
Time Average Particle Volume Fraction



Particle Volume Fraction

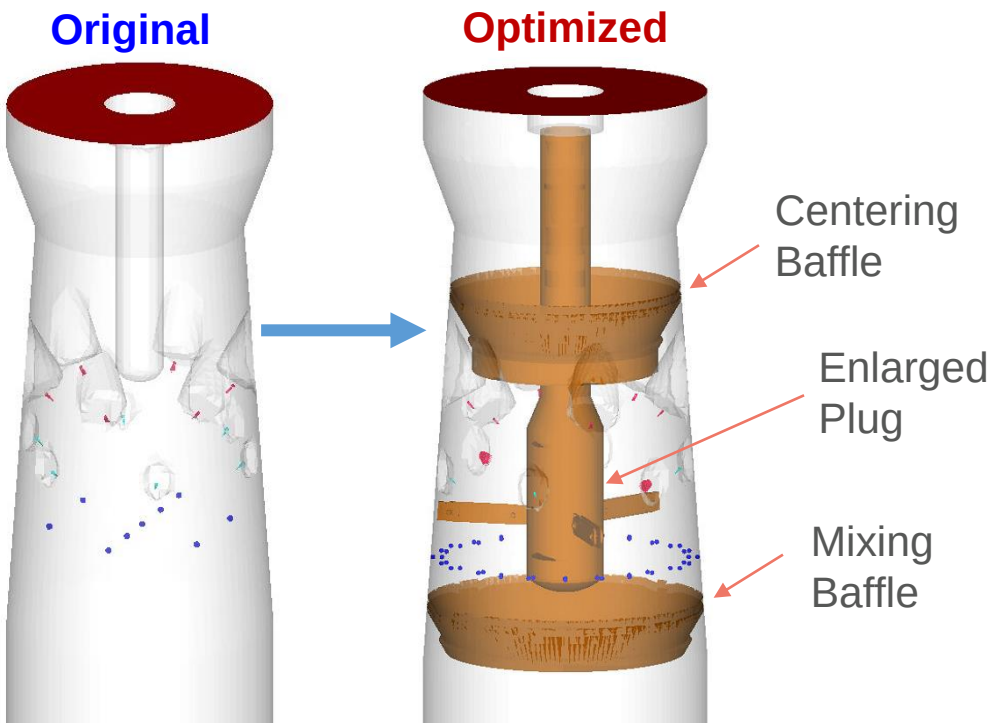


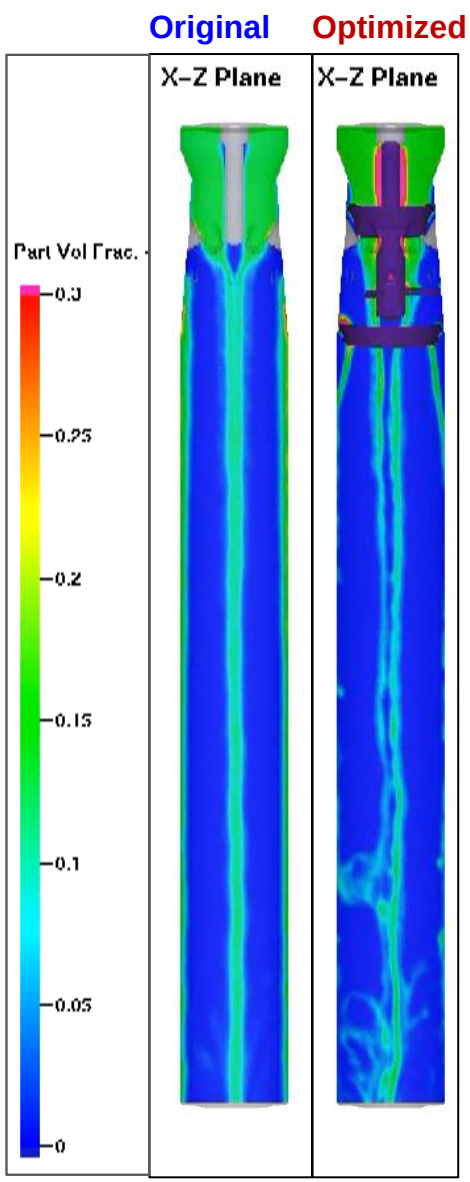
Fluid Temperature

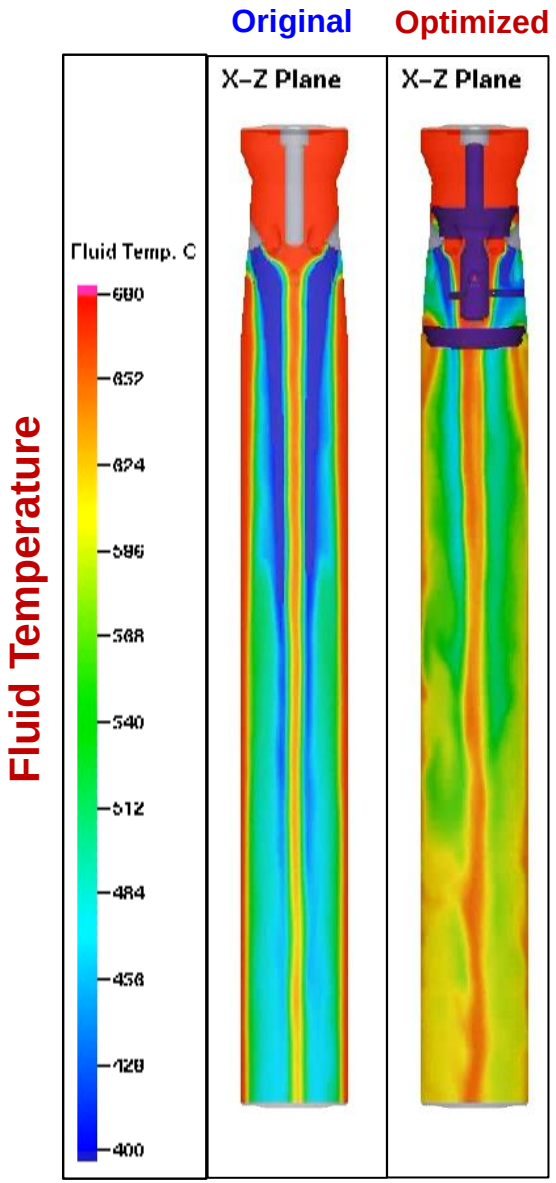


DFR Modifications Using CFD

- **Design enhancements/modifications**
  - Centering baffle
  - Enlarged plug
  - Mixing baffle



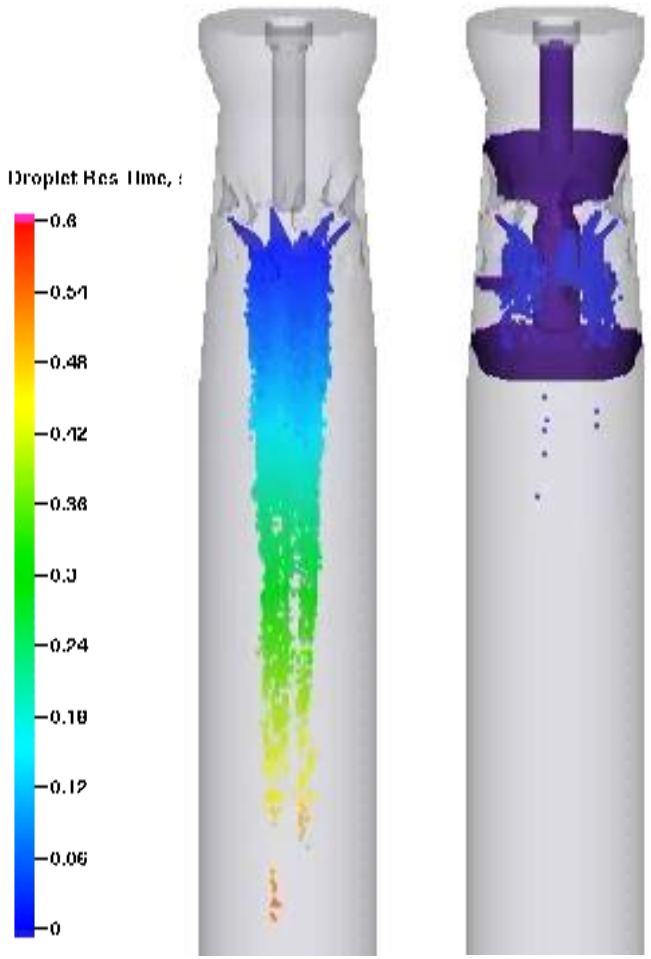




Optimized DFR Performance Comparison

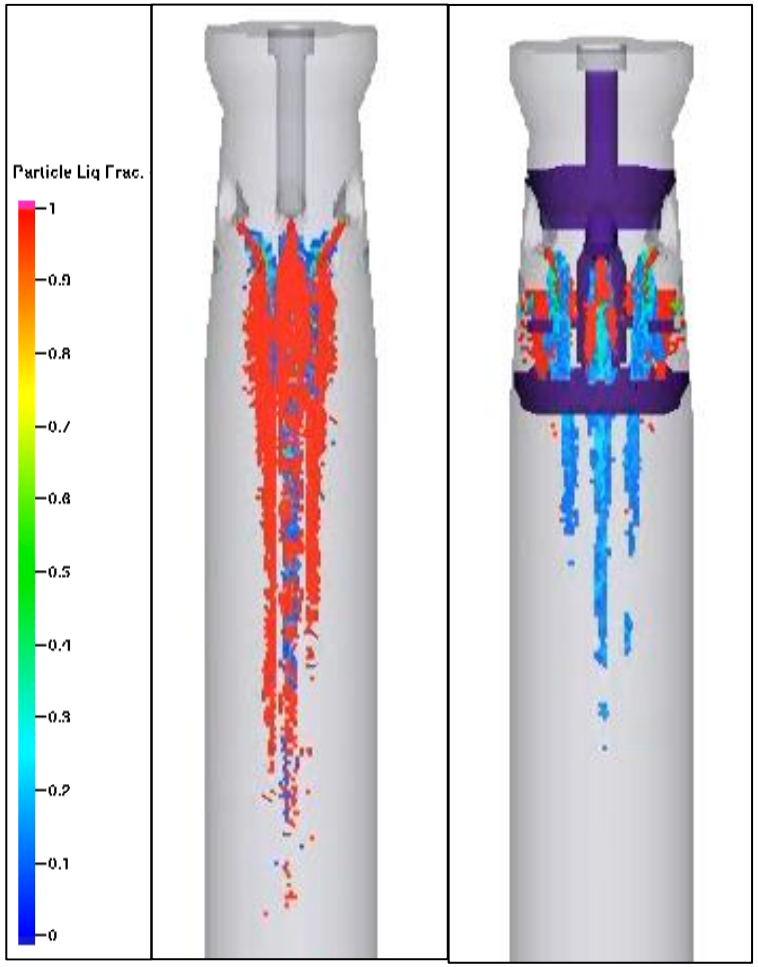
Original **Optimized**

Feed Droplet Residence Time



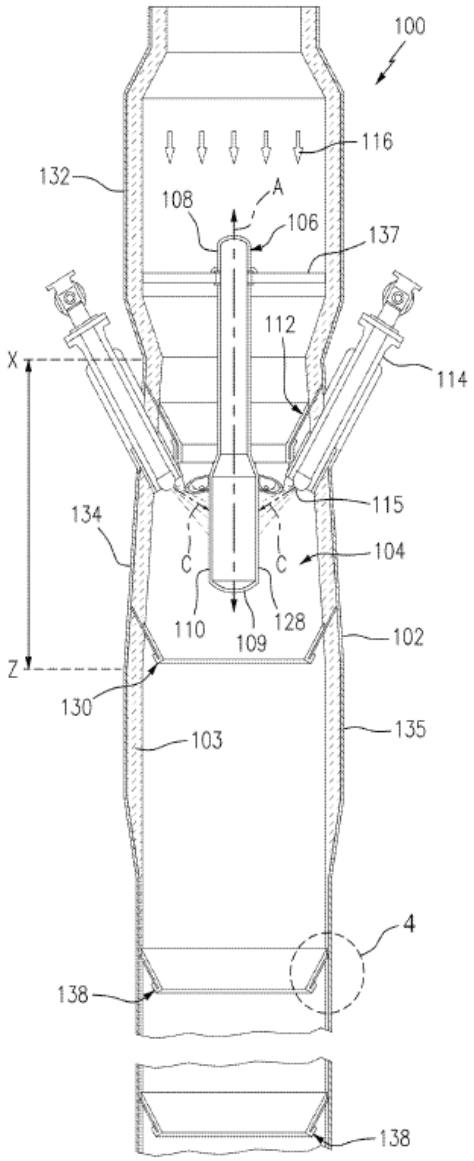
Original **Optimized**

Liquid Fraction



DFR Modeling Outcome

- VLS feature in BarracudaVR provided insight into downflow reactor hydrodynamics and feed vaporization
- CFD model assisted in developing an optimized design
- Successful implementation in commercial unit
  - Increased conversion, higher light olefin yields, reduced slurry and dry gas
  - Improved radial temperature distribution (effective cat/oil ratio)
- Patent granted for the innovation
  - US 11,235,301 B1



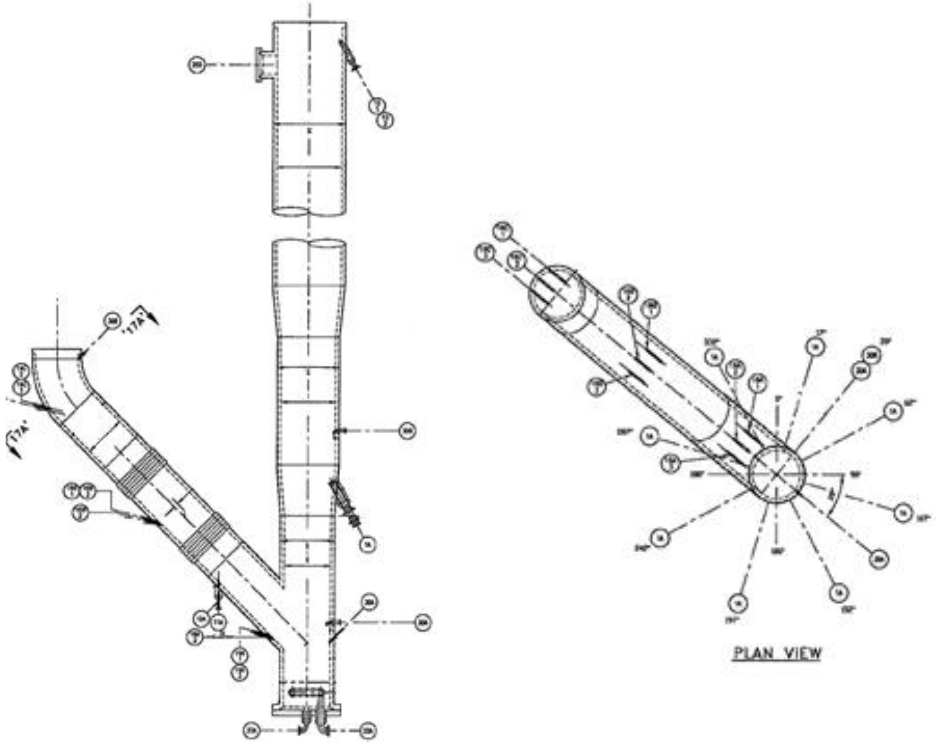
Example #5

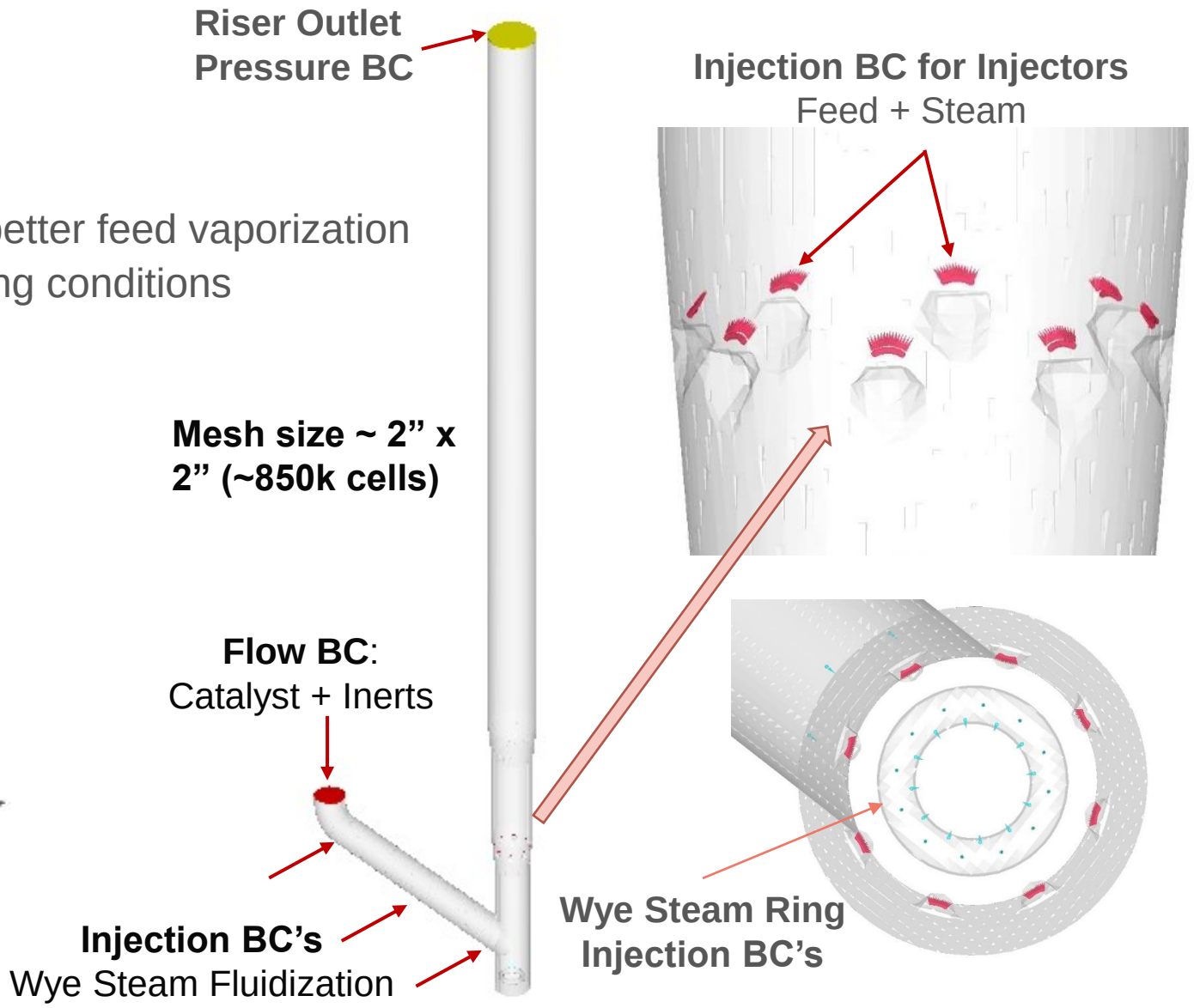
FCC riser modeling and design optimization

Riser Model Setup

Objective

- Improve mixing of feed and catalyst in riser for better feed vaporization
- Use CFD w/VLS for screening concepts/operating conditions

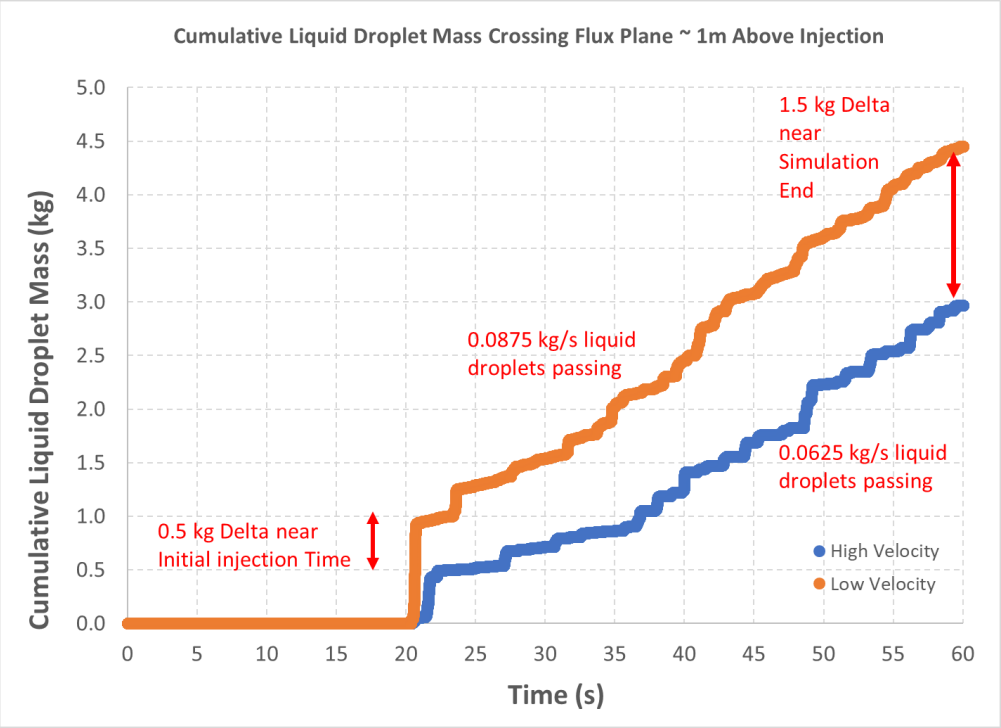




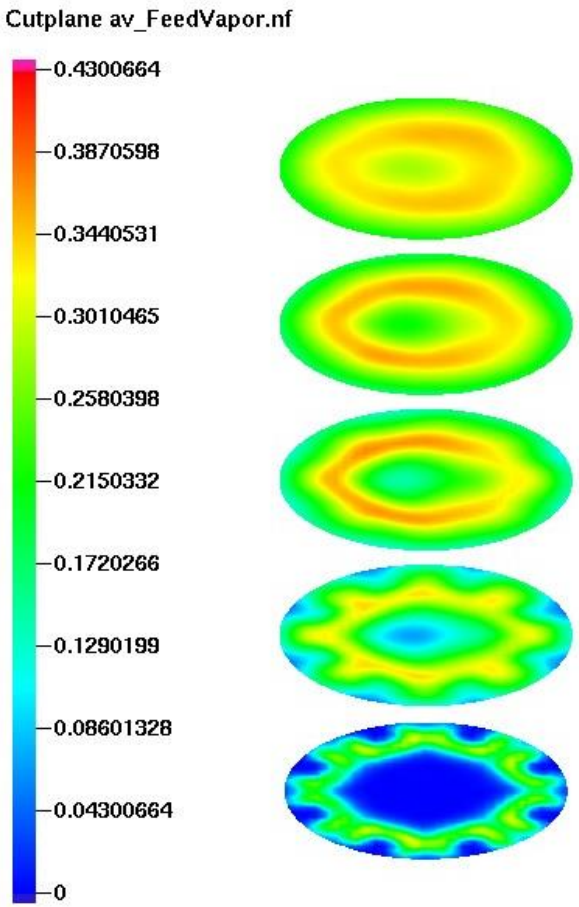
FCC riser modeling

Comparison of operating conditions

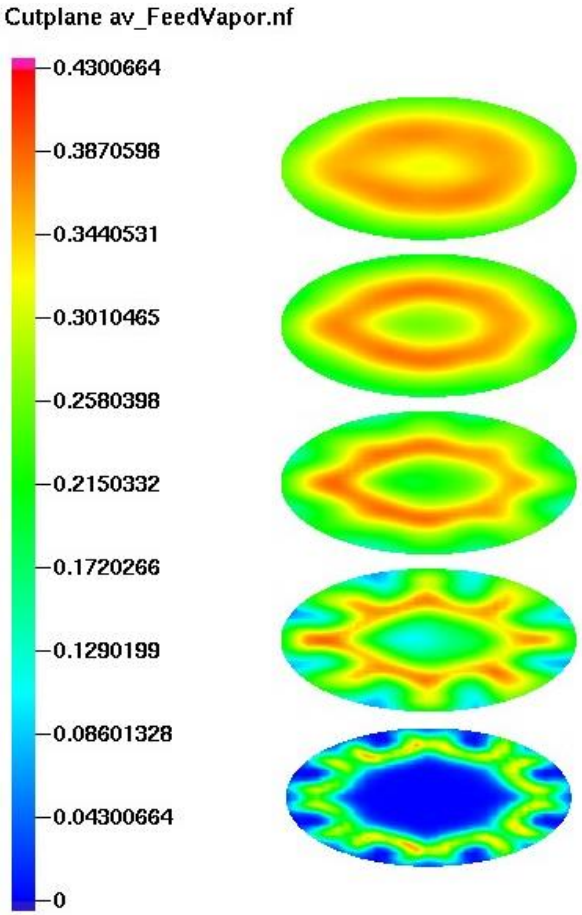
- Test effect of feed injection velocity
- 220 fps vs. 100 fps



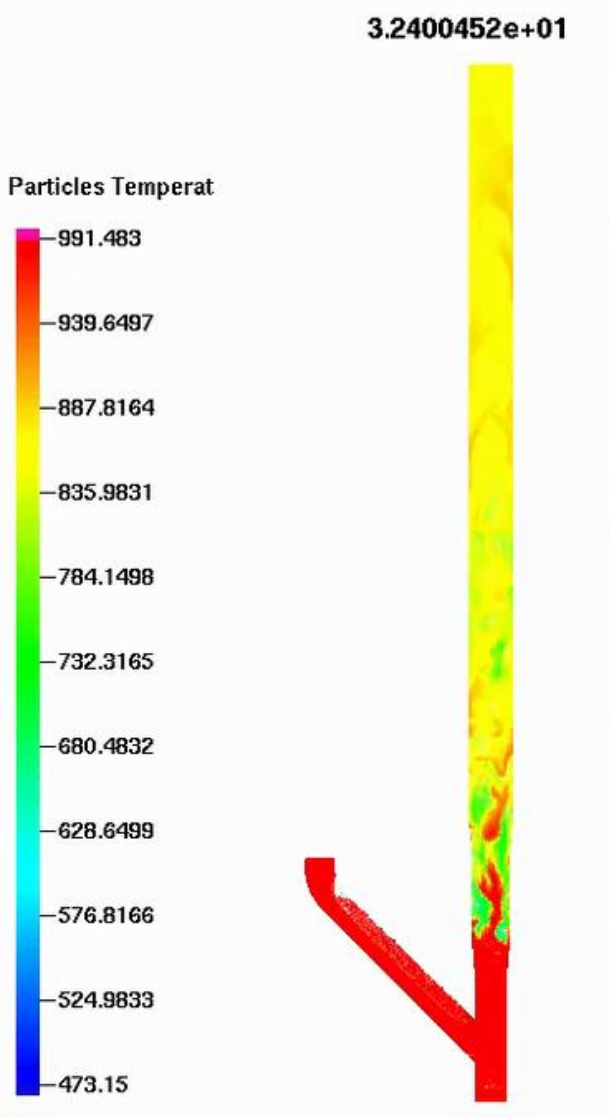
Low Injection Velocity

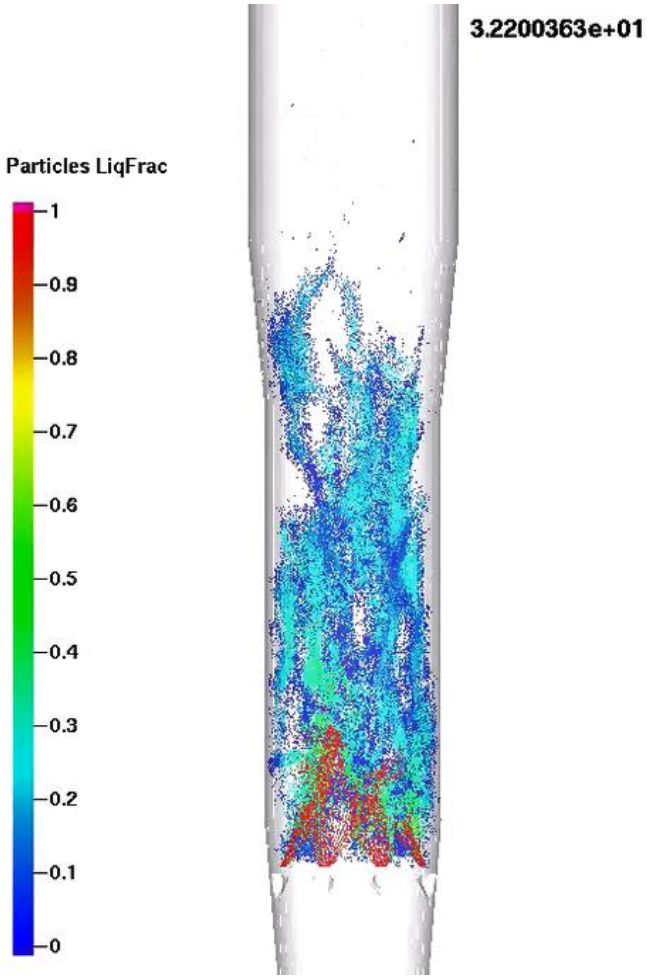


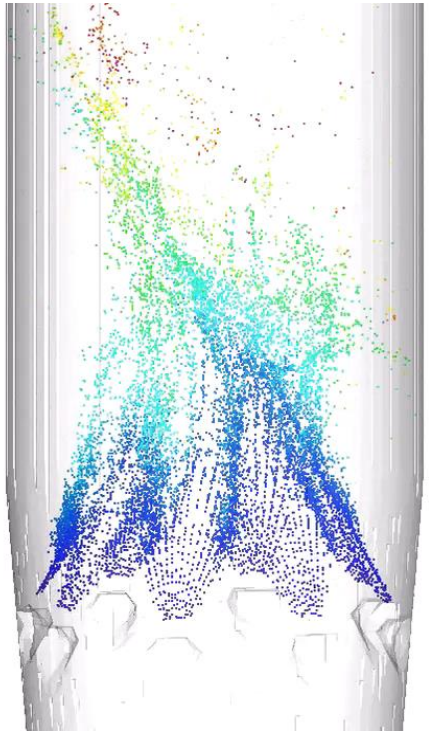
High Injection Velocity



Riser Modeling







Riser Modeling

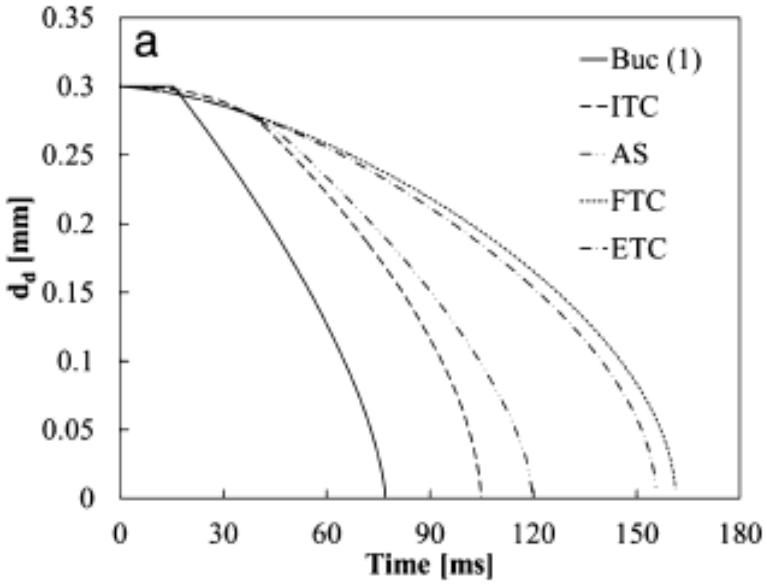
Feed “Droplet” Residence Time

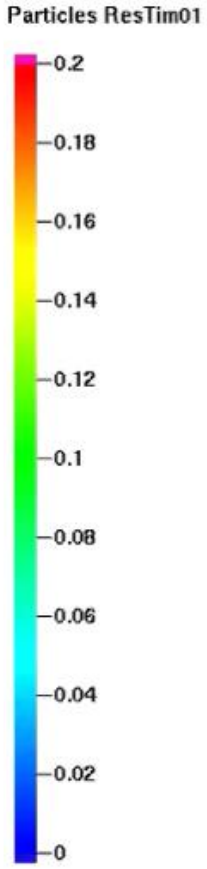
- Most feed droplets “disappear” between approximately 50 and 150 ms
- Reasonable comparison to literature values:

Comparison of vaporization models for feed droplet in fluid catalytic cracking risers

Tuyen T.B. Nguyen[a,b], Subhasish Mitra[a], Vishnu Pareek[c], J.B. Joshi[d], G. Evans[a,]*

[a] *Discipline of Chemical Engineering, School of Engineering, University of Newcastle, NSW 2308, Australia*
[b] *Danang University of Science and Technology – The University of Danang, 54 Nguyen Luong Bang, Danang, Viet Nam*
[c] *Department of Chemical Engineering, Curtin University, Perth, WA 6102, Australia*
[d] *Institute of Chemical Technology, Mumbai 400019, India*



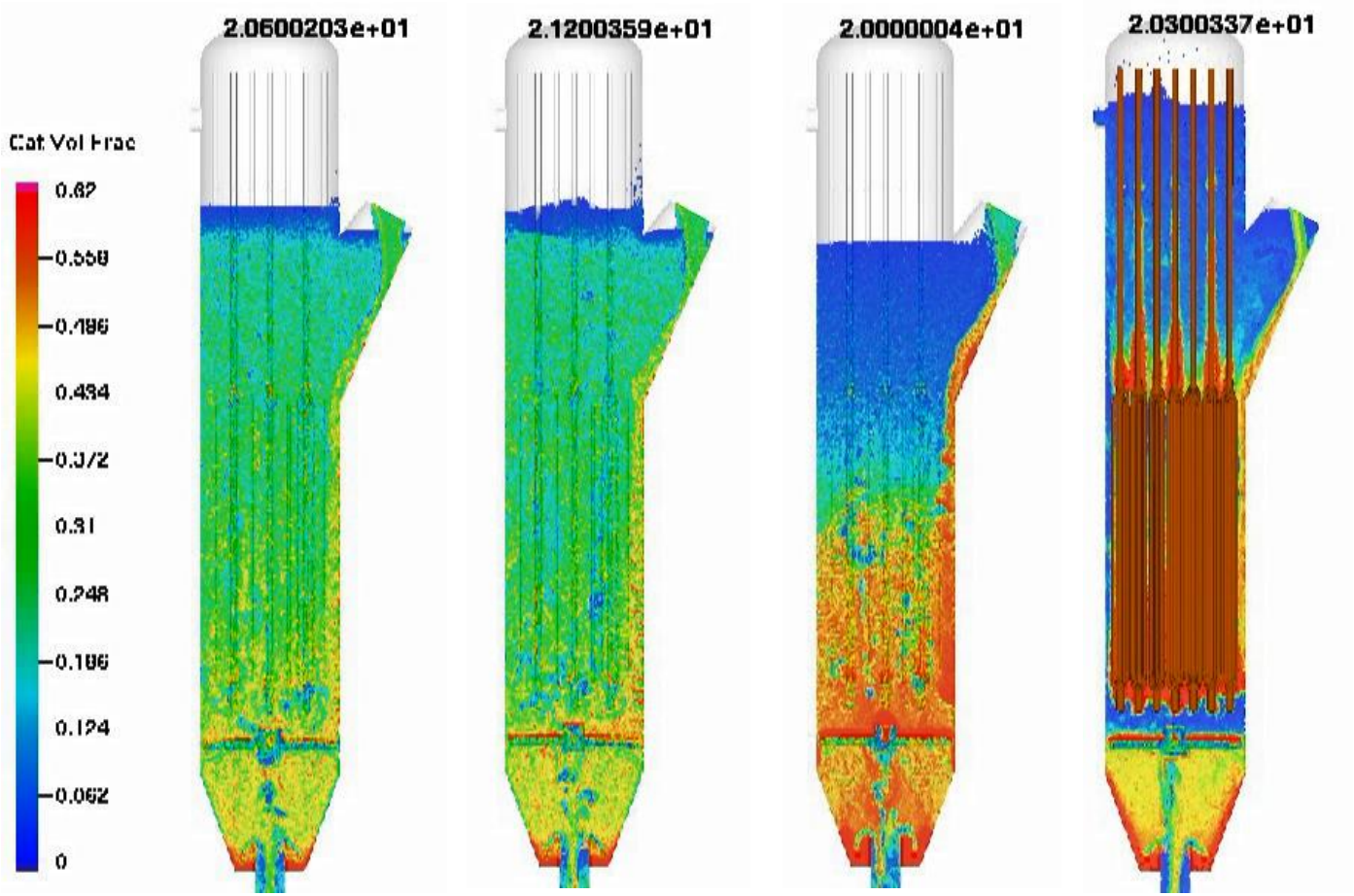


Modeling Challenges

Modeling Catalyst Cooler

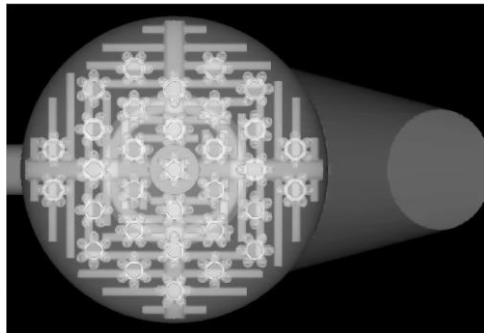
Modeling Catalyst Cooler Tube Bundle

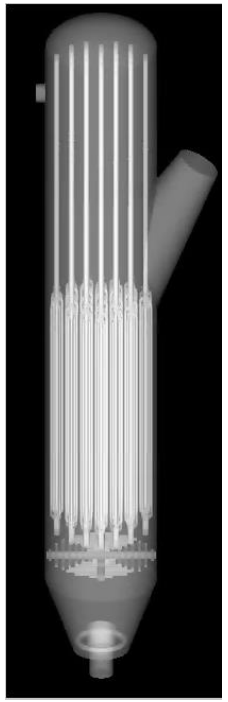
7 Million Cells & 32 million Particles

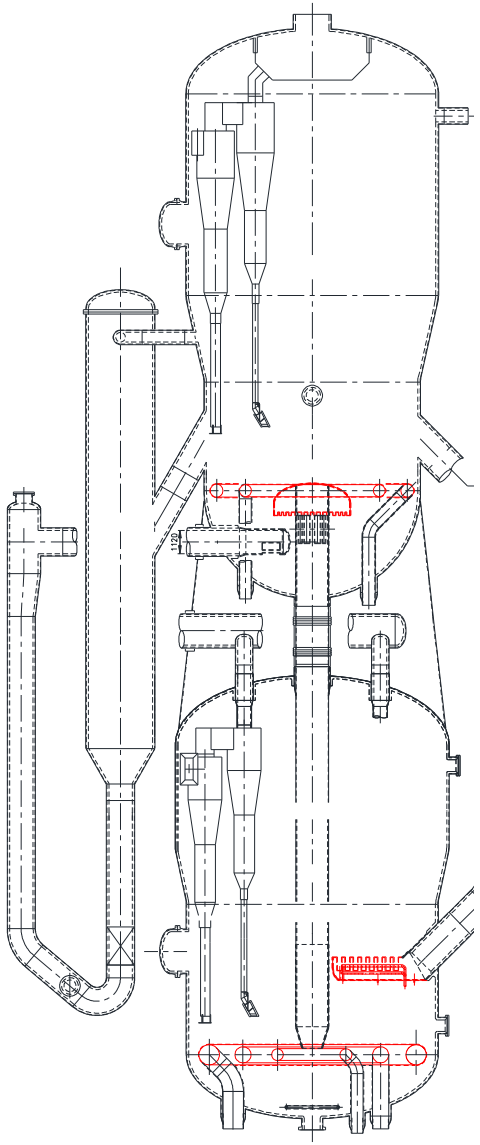


CFD Unable to resolve hydrodynamics correctly

Cat Cooler with 200 Tubes







Summary

- **Technip Energies is actively using computational modeling to improve FCC features**
  - Improve existing designs, develop new design and build IP
  - Provide validations and design improvements and helps in troubleshooting
  - Screen new concepts as part of R&D
  - Bring confidence in implemented solution
  - Several success examples in commercial application

- **BarracudaVR VLS feature is useful in evaluating feed mixing / vaporization in riser/downer**
  - Successfully implemented in design optimization and troubleshooting industrial unit

- **CFD qualitative results frequently guide engineering in the right direction**
  - Can also perform well quantitatively, but needs some caution

Thank you