Chevron Pascagoula FCC regenerator optimization via modeling

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The presentation intent is to share an example of how advanced modeling can be used in the pursuit of a lower carbon future.

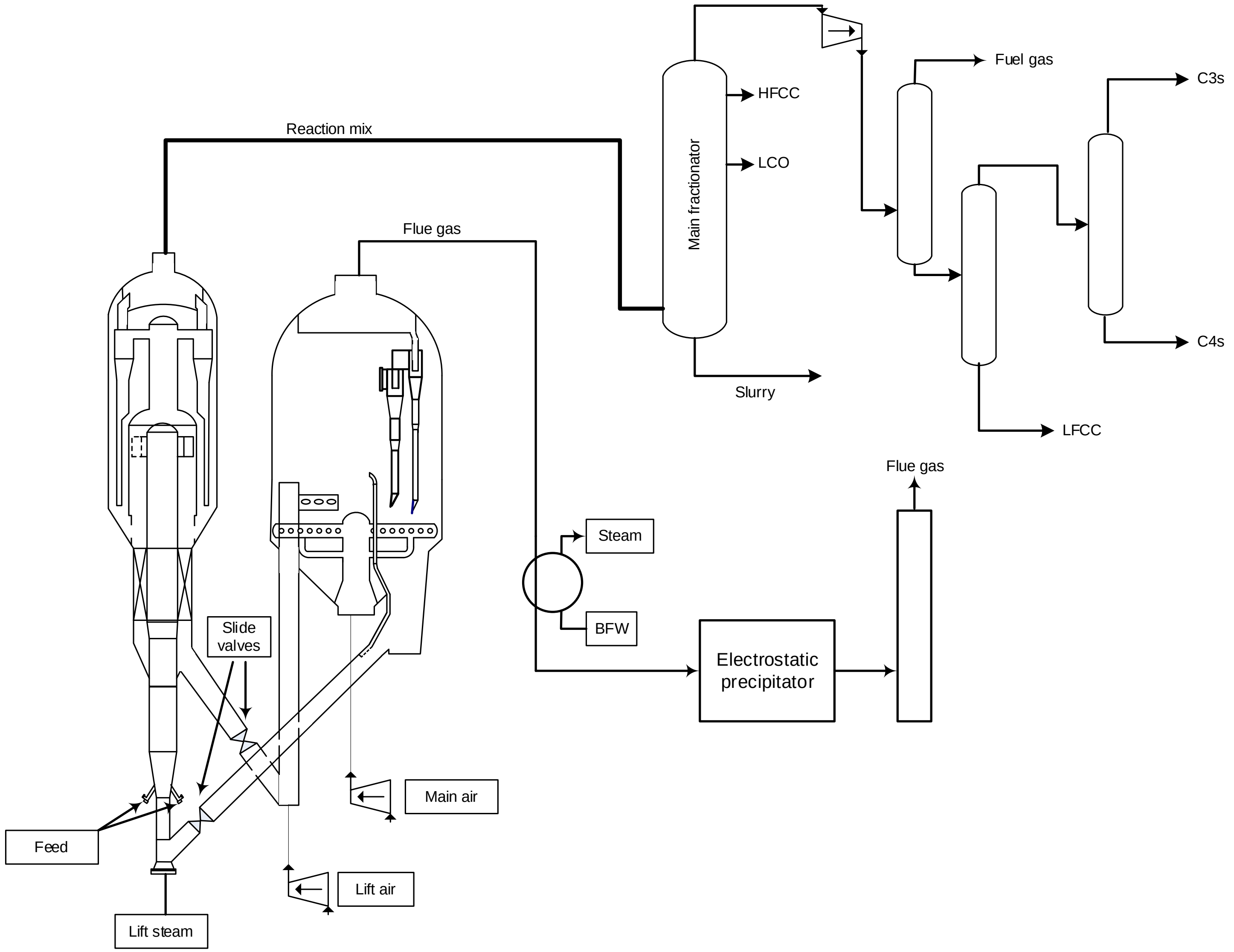
Pascagoula FCC background

Pascagoula refinery built in 1963 on the coast of Mississippi

Original FCC construction, Exxon Model IV - 66 mbd (36 mbpd fresh feed)

1991 upgraded to slide valve control with new RX and main frac

2006 regen/RX revamped to 80 mbd – limit reached at 88.7 mbd



Pascagoula FCCU turnaround goals

Improved environmental performance

- Better mixing of spent catalyst and air
- Lower CO, afterburn, combustion promotor use

Reduce catalyst losses

- Lower average losses and carryover events
- Rearrange regen diplegs to eliminate miter bends
- Retain fines and improve catalyst circulation and stability

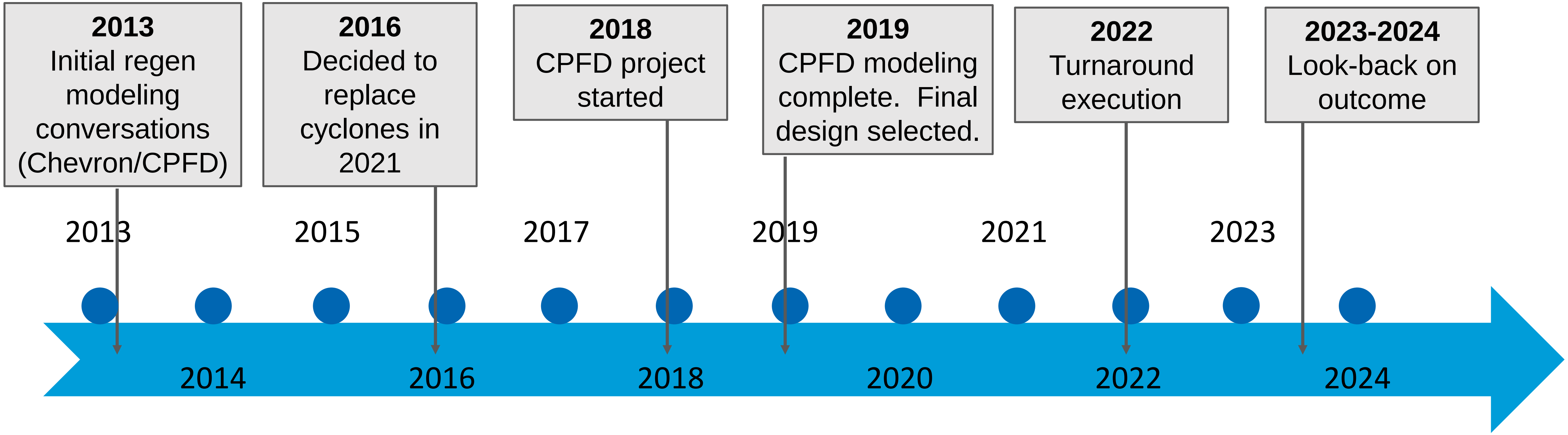
Improve reliability

- Extend cyclone life (lower erosion, more uniform loading)

Minimize risk of changes

- “Don’t fix what’s not broken.”
- Virtual testing of changes and sensitivities

Timeline



2013
Initial regen modeling conversations (Chevron/CPFD)

2016
Decided to replace cyclones in 2021

2018
CPFD project started

2019
CPFD modeling complete. Final design selected.

2022
Turnaround execution

2023-2024
Look-back on outcome

What's different today?

- Simulation speed: GPU & multi-GPU
- Simulation resolution and complexity
- Proliferation of FCCU simulation
- More suitable model features (BC connectors, particle exit BC, empirical models, etc.)

What's the same today

- Turnaround planning cycles
- Coordination with multiple stakeholders
- Importance of risk reduction

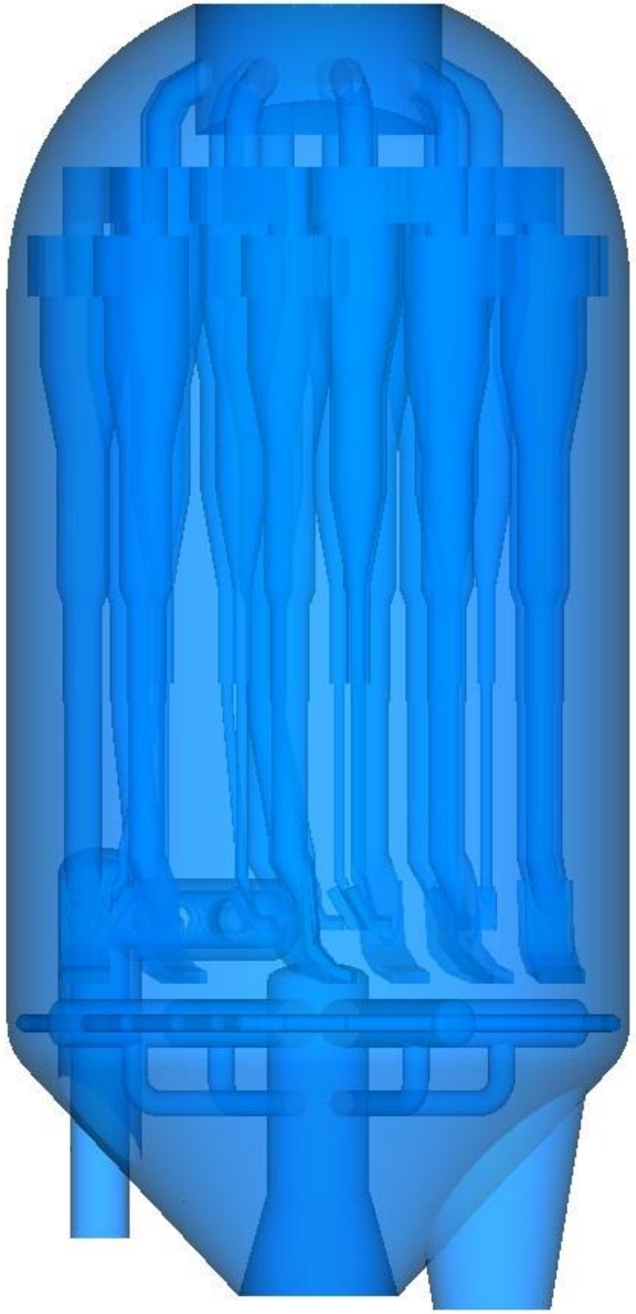
Model domain

The regenerator model included:

- Cyclones
- Spent catalyst distributor (SCD)
- Air distributor
- Regenerated catalyst standpipe (RCSP)

Smaller components treated via subgrid baffles or boundary conditions

- RCSP burp tube
- Torch oil nozzles
- Fluffing air ring
- Catalyst withdrawal pipe



Computational model details

Operating conditions taken from refinery process data

- DCS data
- ECat PSD
- Material and energy balance

Barracuda Virtual Reactor was used to simulate the fluidization, heat transfer and chemical reactions to obtain transient and time-averaged results.

$$\mathrm{C\ (s)} + \mathrm{O_2} \xrightarrow{r_1} \mathrm{CO_2}$$

$$\mathrm{C\ (s)} + \frac{1}{2}\mathrm{O_2} \xrightarrow{r_2} \mathrm{CO}$$

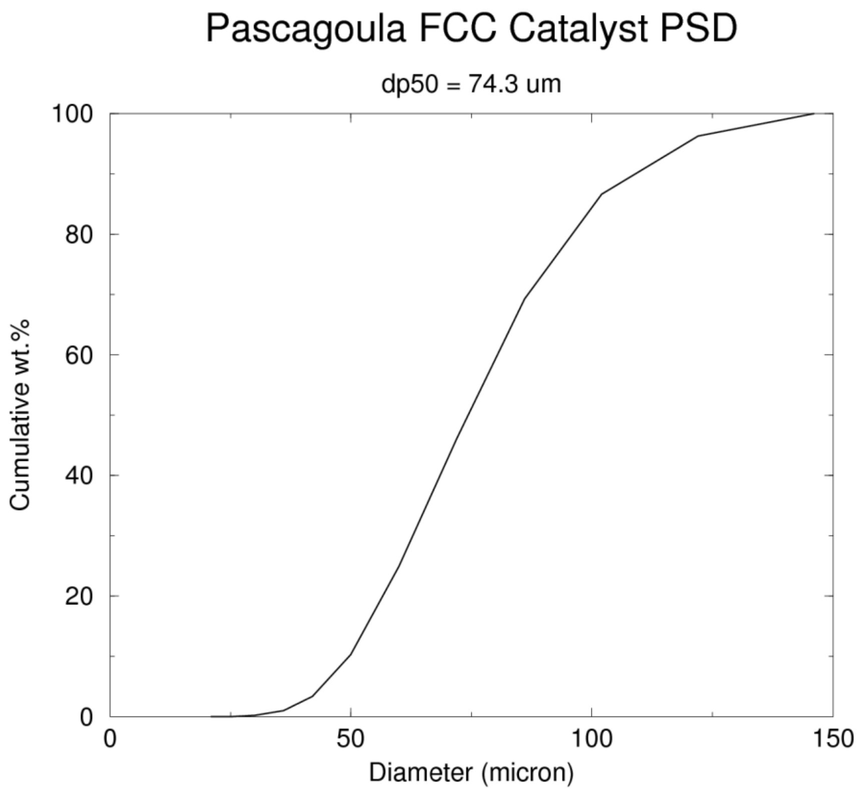
$$\mathrm{H\ (s)} + \frac{1}{4}\mathrm{O_2} \xrightarrow{r_3} \frac{1}{2}\mathrm{H_2O}$$

$$\mathrm{CO} + \frac{1}{2}\mathrm{O_2} \xrightarrow{r_4} \mathrm{CO_2}$$

(homogeneous)

$$\mathrm{CO} + \frac{1}{2}\mathrm{O_2} \xrightarrow{r_5} \mathrm{CO_2}$$

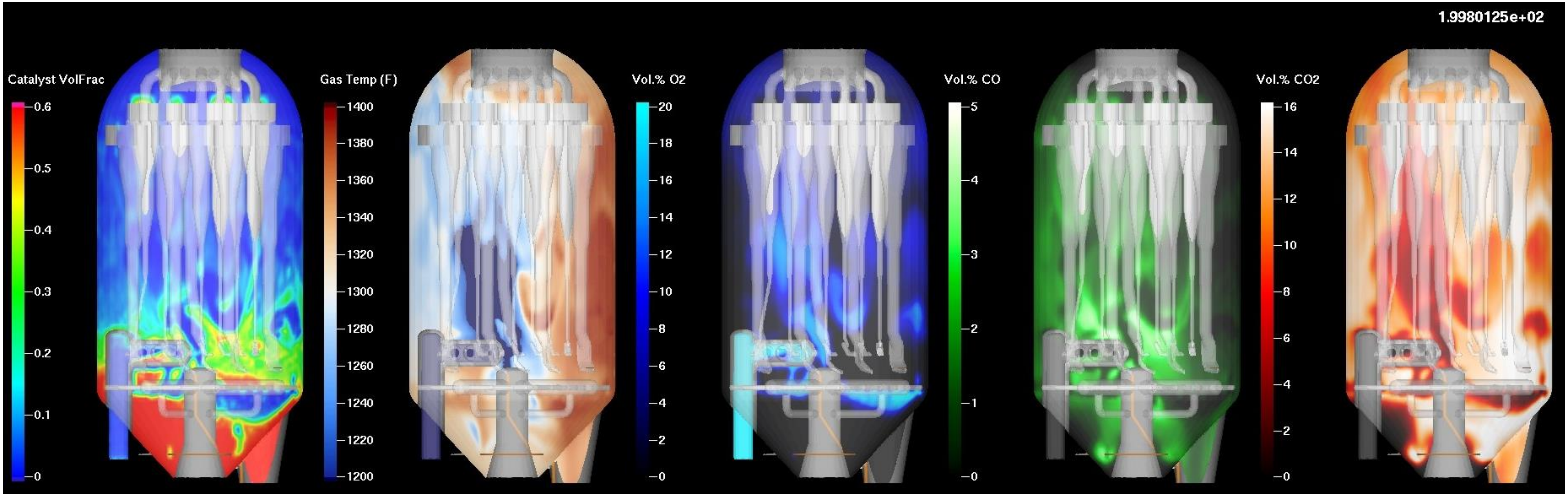
(heterogeneous, with combustion promotor)



Sources:

Arbel, A et al. (1995) Dynamics and Control of Fluidized Catalytic Crackers. 1. Modeling of the Current Generation of FCC's. *Ind. Eng. Chem. Res.* 34: 1228-1243
Weisz, P. and Goodwin, R. (1966). Combustion of Carbonaceous Deposits within Porous Catalyst Particles. II. Intrinsic Burning Rate. *Journal of Catalysis* 6:227-236
Weisz, P. (1966) Combustion of Carbonaceous Deposits within Porous Catalyst Particles. III. The CO2/CO Product Ratio. *Journal of Catalysis* 6:425-430

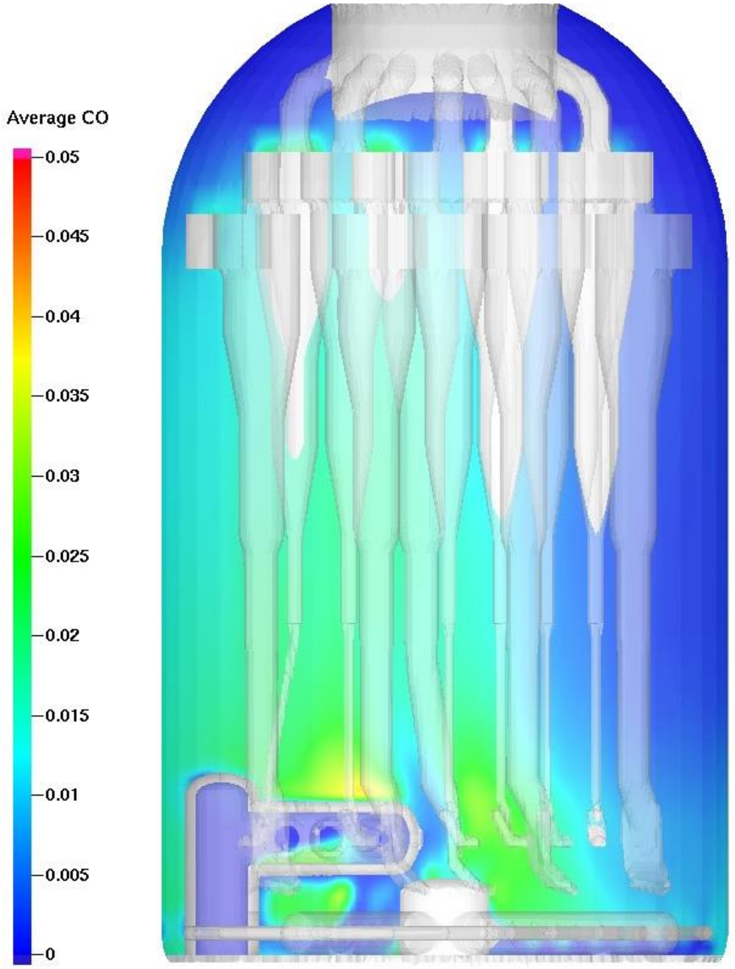
Baseline behavior



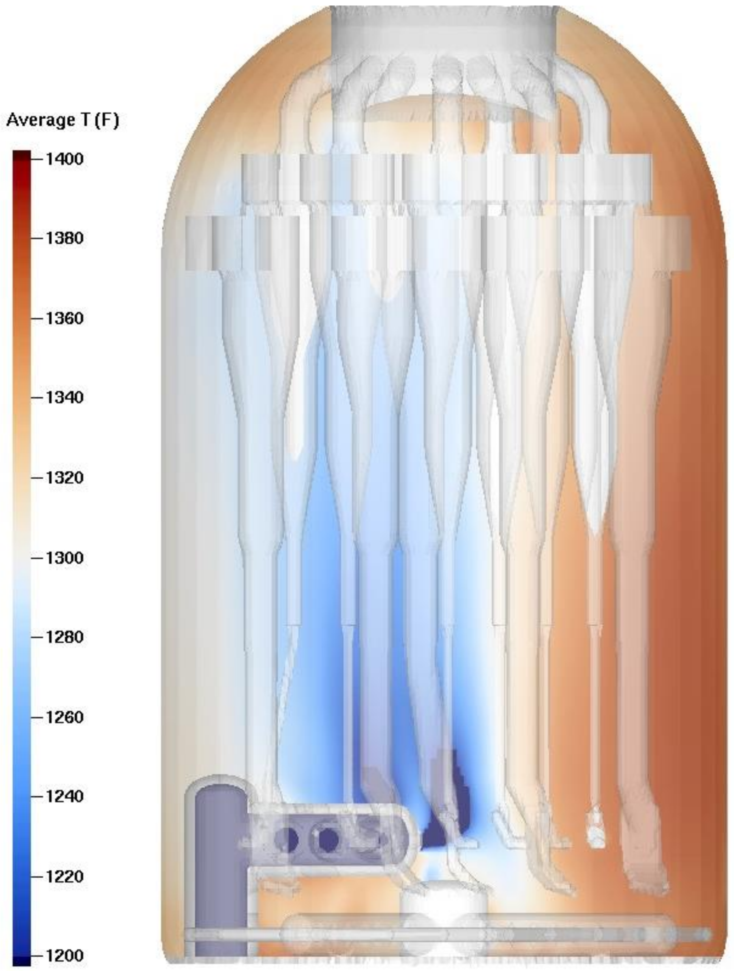
Chevron

Baseline details

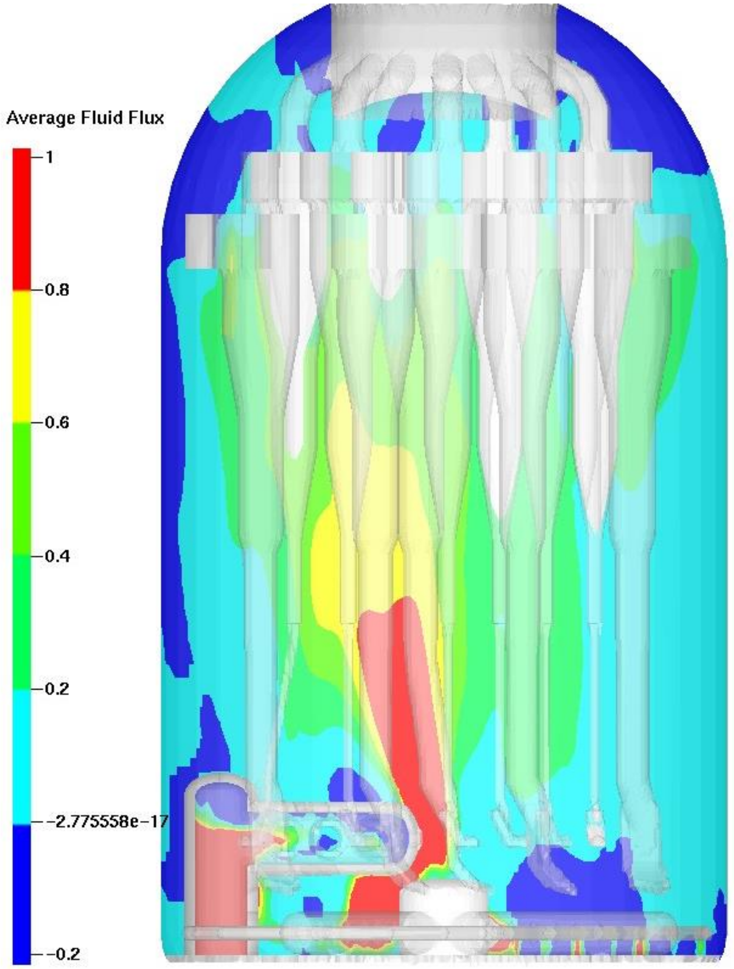
Carbon monoxide



Temperature



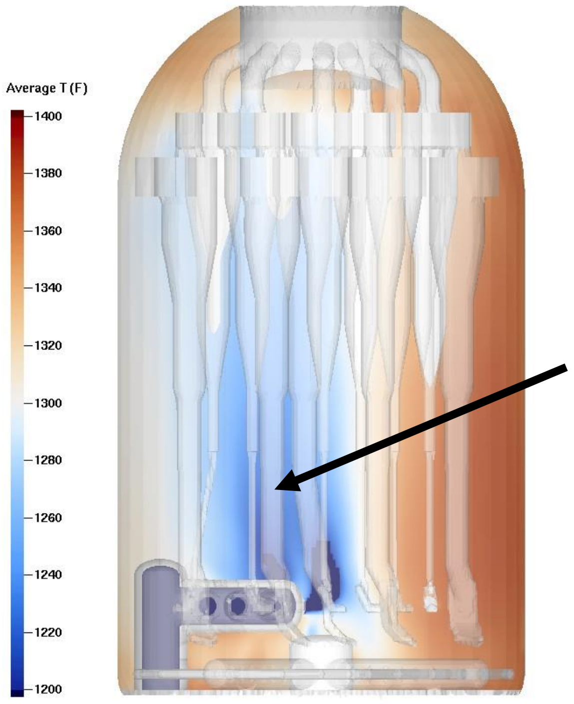
Vertical gas flux



Why non-uniform?

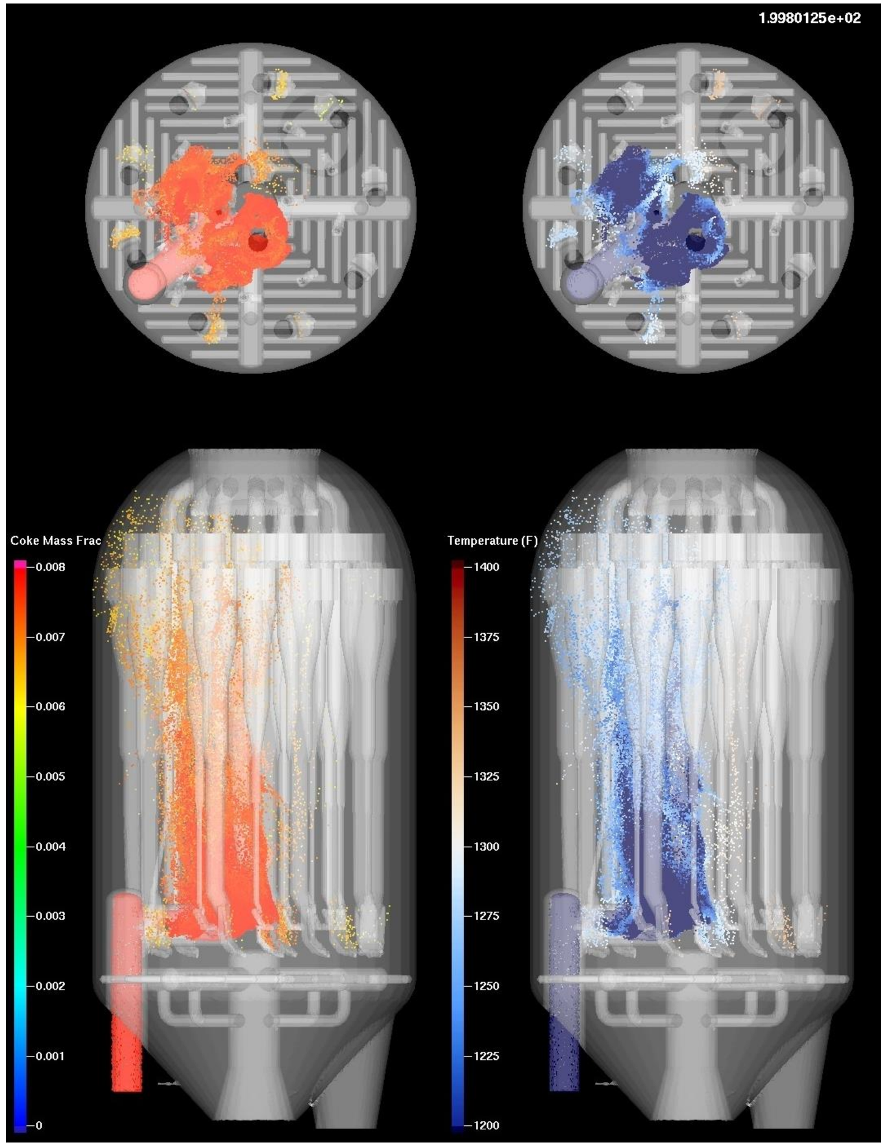
Only spent catalyst with a residence time less than 5 seconds is shown in the video:

- Colored by coke mass fraction on left
- Colored by particle temperature on right



The cooler spent catalyst is swept out of the dense bed by the strong gas stream.

Some time is required for the spent catalyst to heat up and combust, resulting in the cooler region.

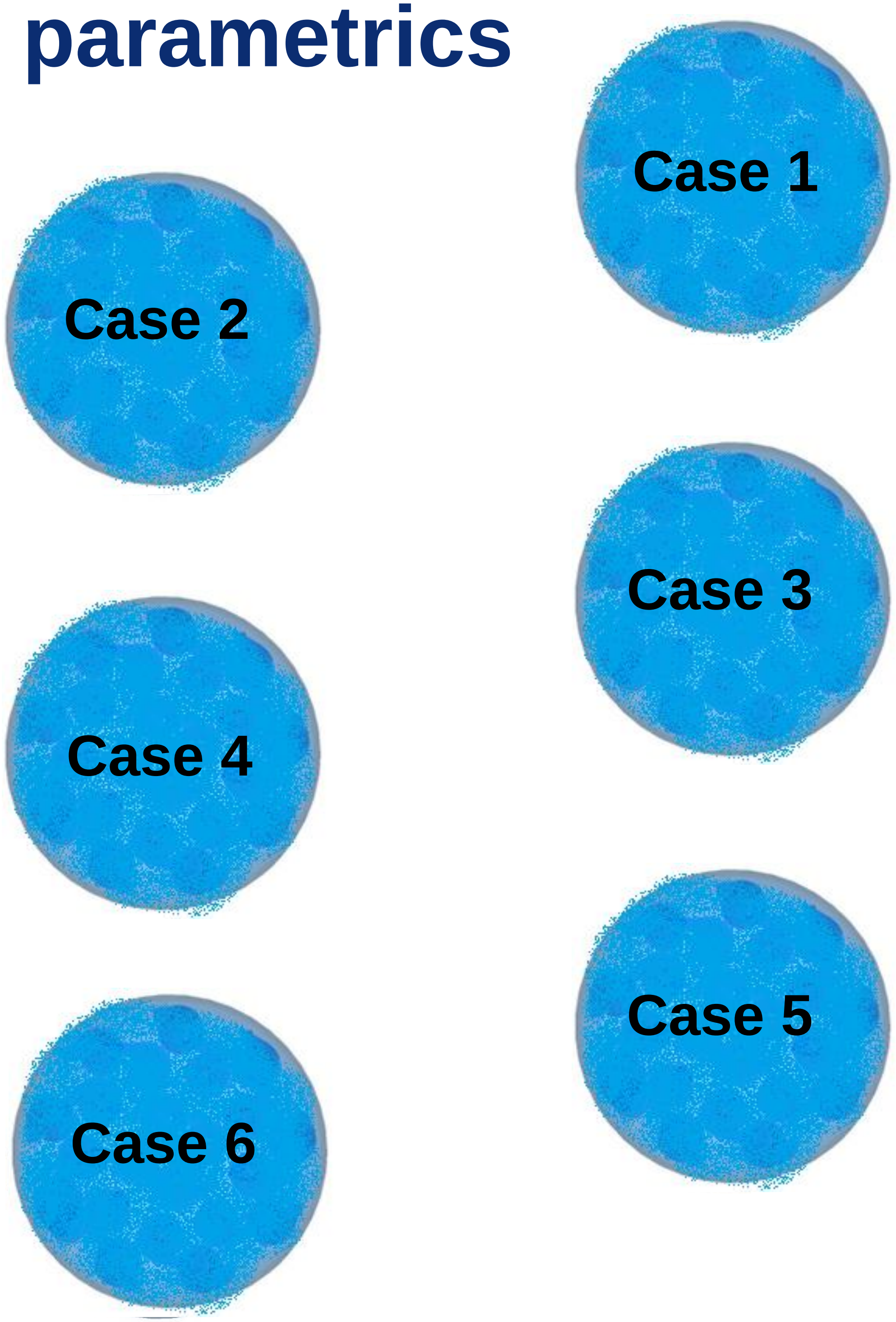


Cyclone geometries and parametrics

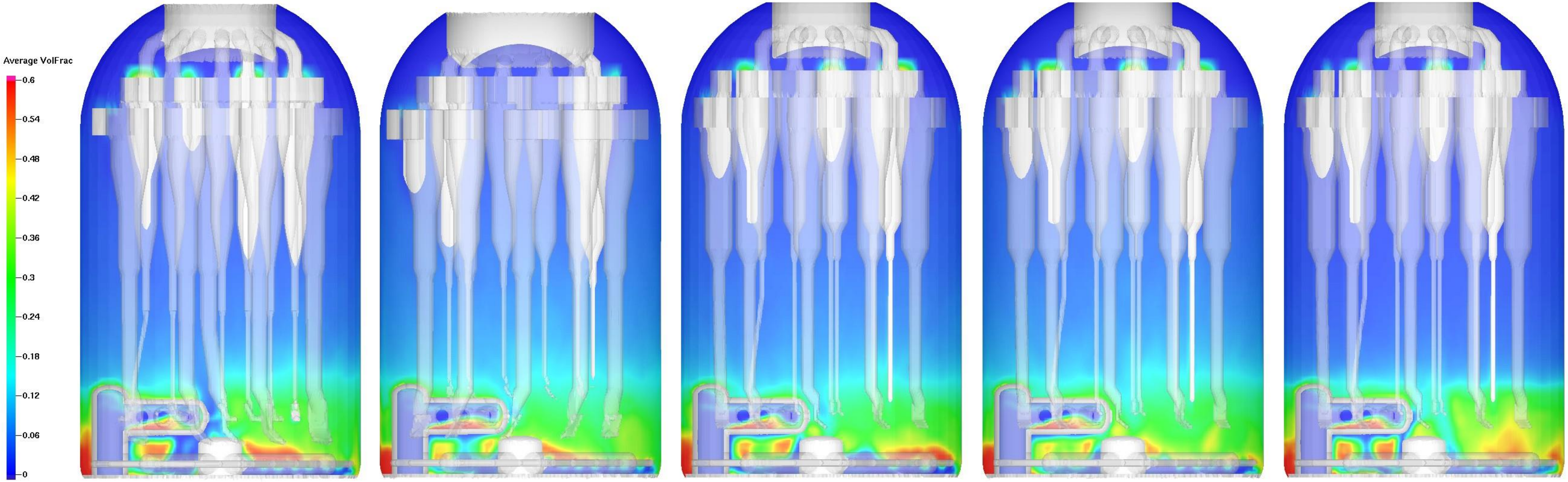
Virtual testing was used to explore changes to design and operating conditions.

- Case 1: Base case (two center cyclones)
- Case 2: No center cyclones
- Case 3: One center pair
- Case 4: No center cyclones + SCD change
- Case 5: One center pair + 2/3 turndown
- Case 6: One center pair + plugged nozzles (multiple plugging options considered)

50+ years of hardware simulations in 18 months

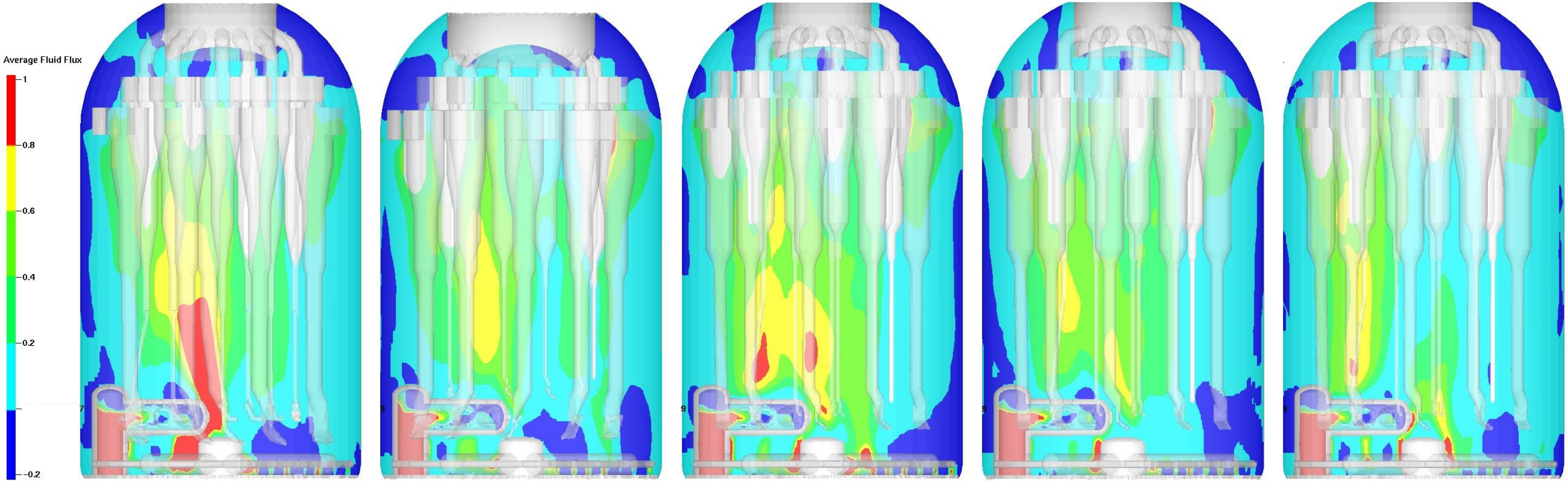


Time-averaged catalyst volume fraction



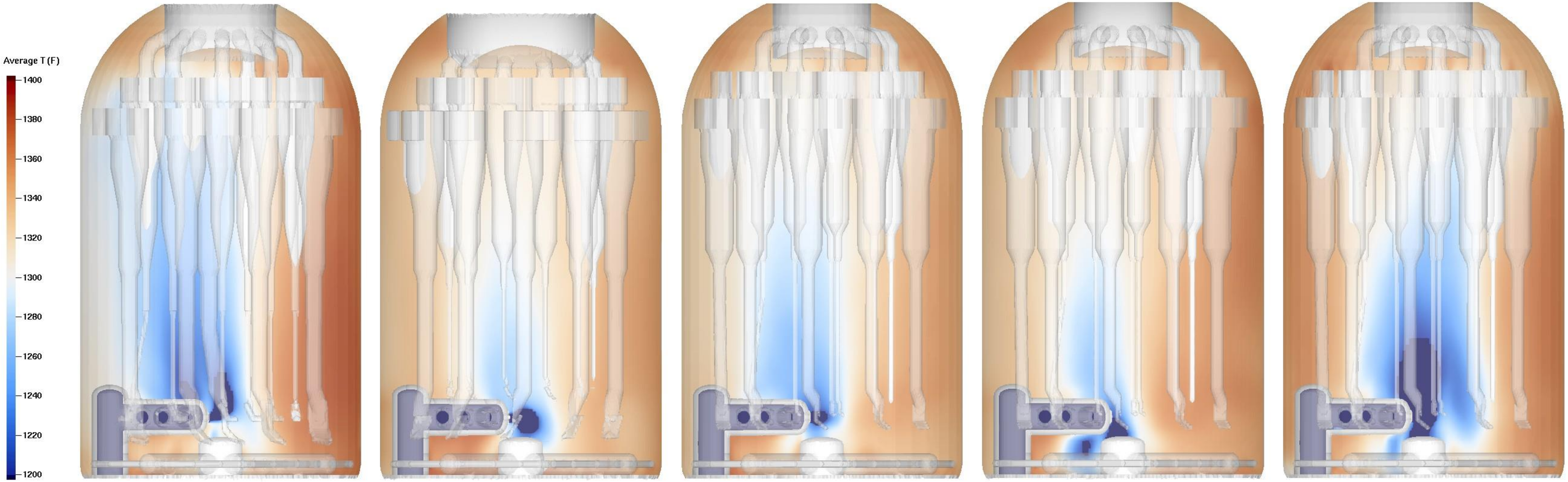
Case 1 **Case 2** **Case 3** **Case 4** **Case 5**

Time-averaged gas flux



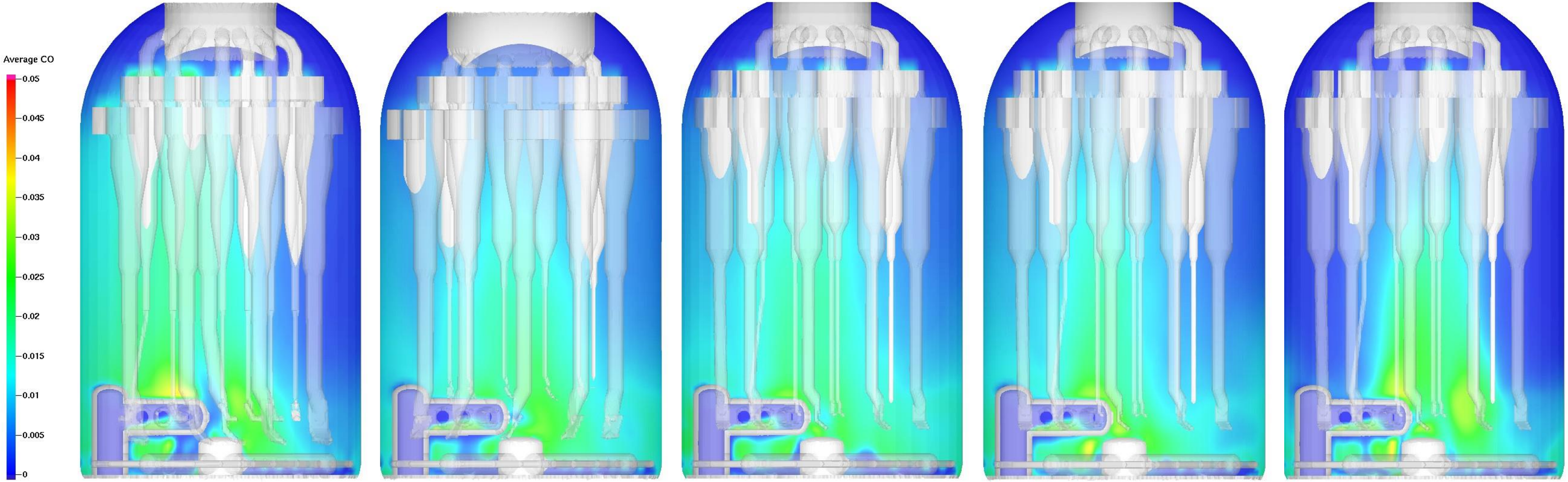
Case 1 **Case 2** **Case 3** **Case 4** **Case 5**

Time-averaged temperature



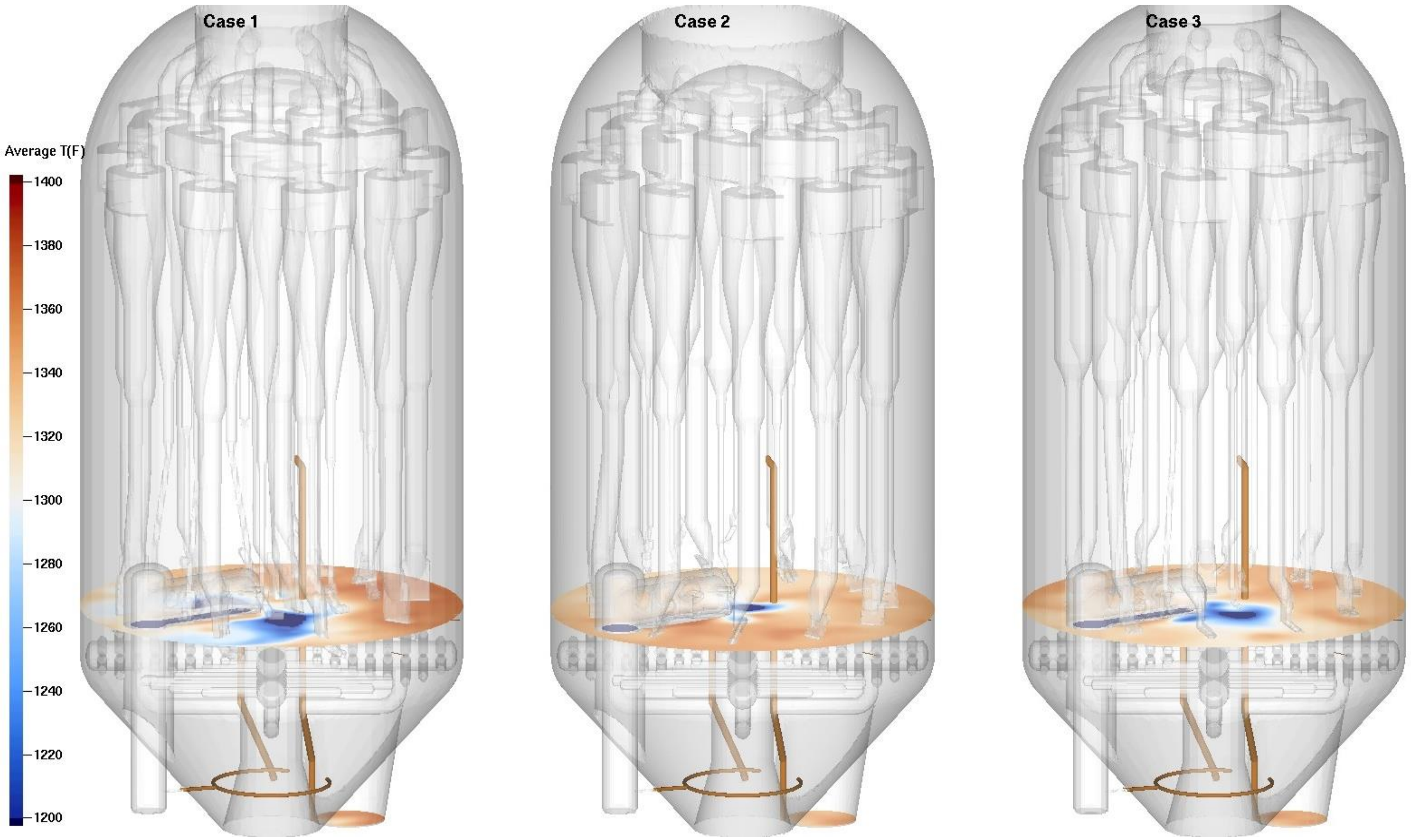
Case 1 **Case 2** **Case 3** **Case 4** **Case 5**

Time-averaged CO

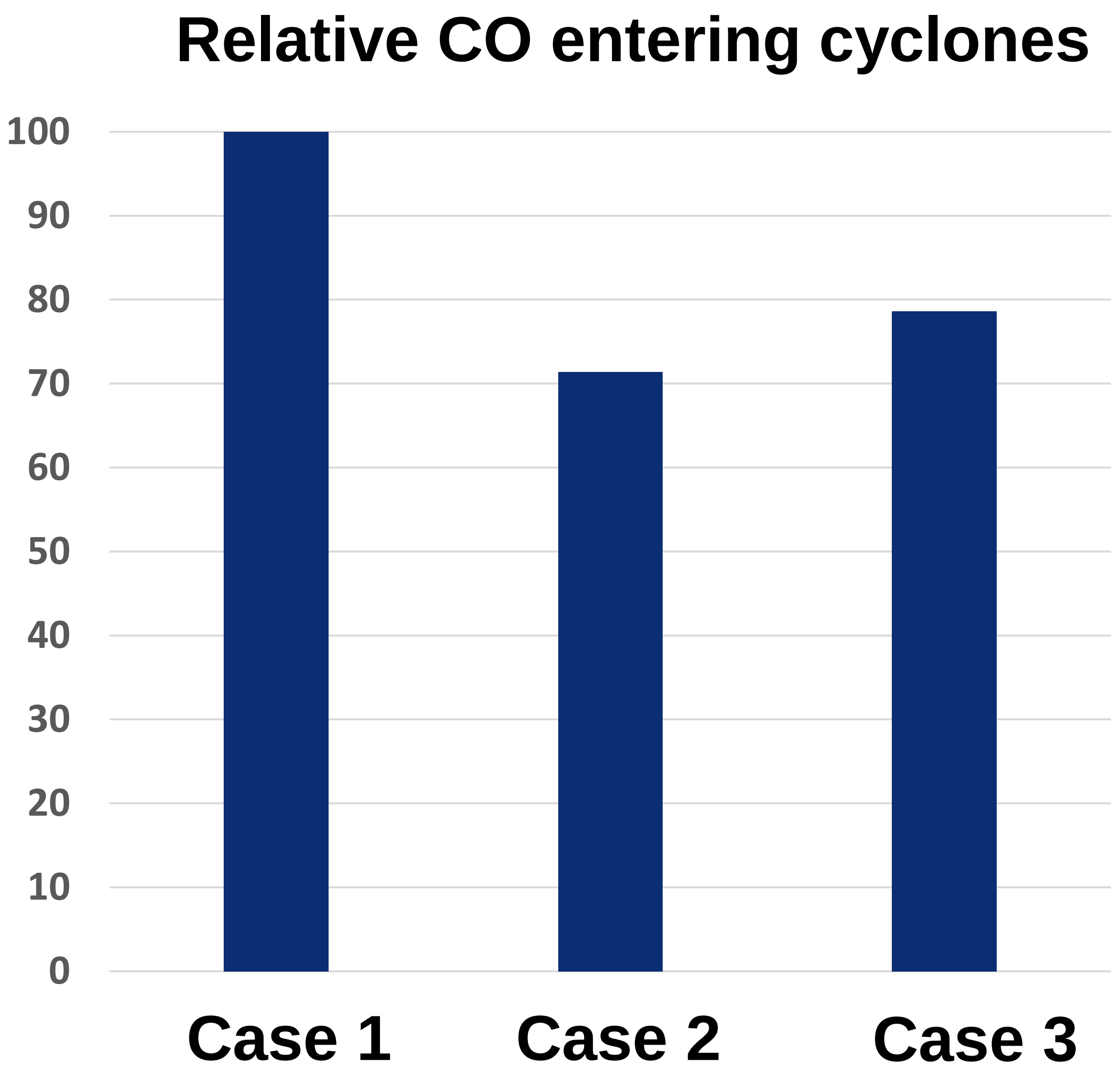


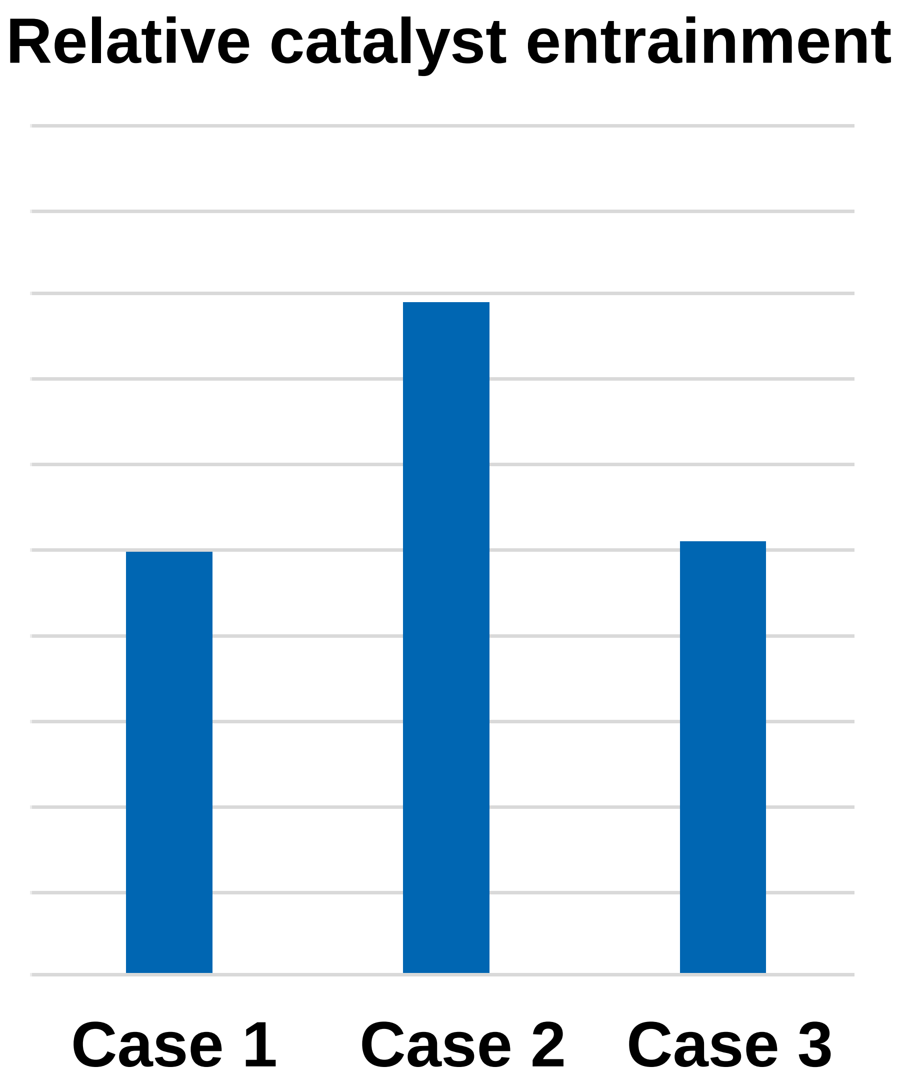
Case 1 Case 2 Case 3 Case 4 Case 5

Analysis of 3D behavior



Quantitative analysis on primary objectives





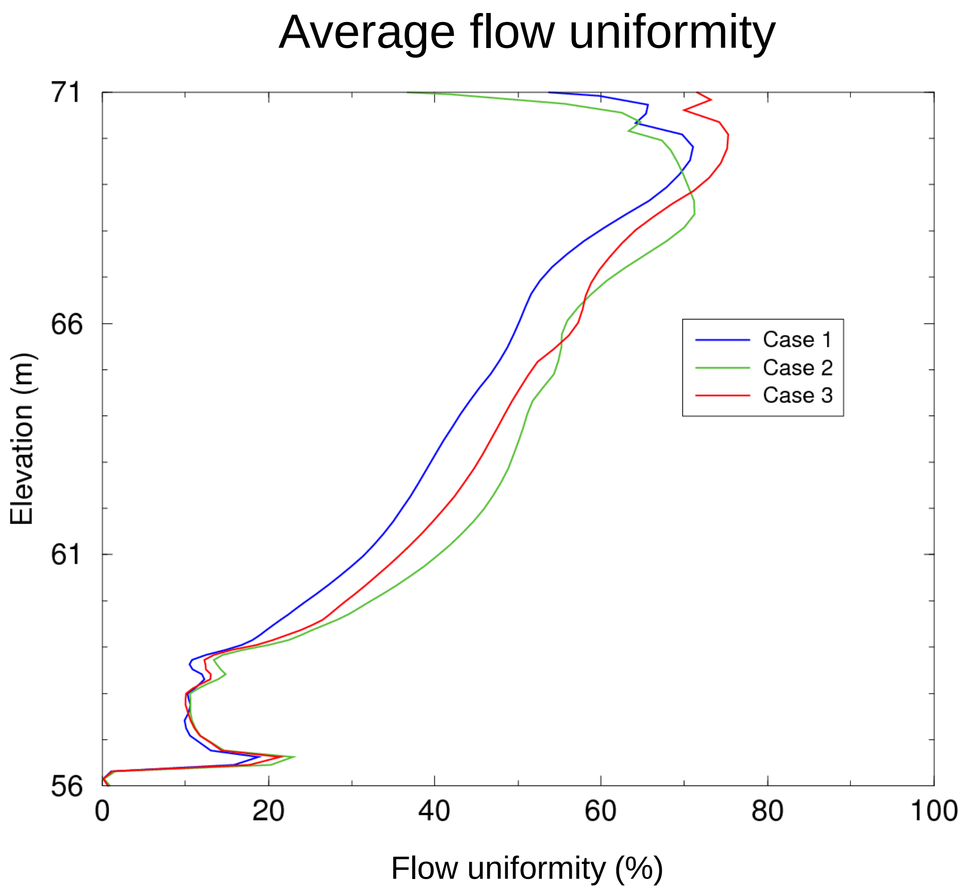
Other considerations

Flow uniformity was assessed

- Both cyclone configurations showed better utilization of the overall regenerator cross-section
- Simple metric to estimate impact on NOx (higher uniformity -> lower NOx)

Other assessments included:

- Detailed hydrodynamic, thermal and gas species analysis
- Erosion
- Spent catalyst mixing
- Coke on regenerated catalyst
- Catalyst loading and entrained PSD by cyclone
- Impact of various nozzle plugging patterns



For more on flow uniformity see:
AFPM AM-16-15 by Fletcher, R., Clark, S., Parker, J., and Blaser, P.

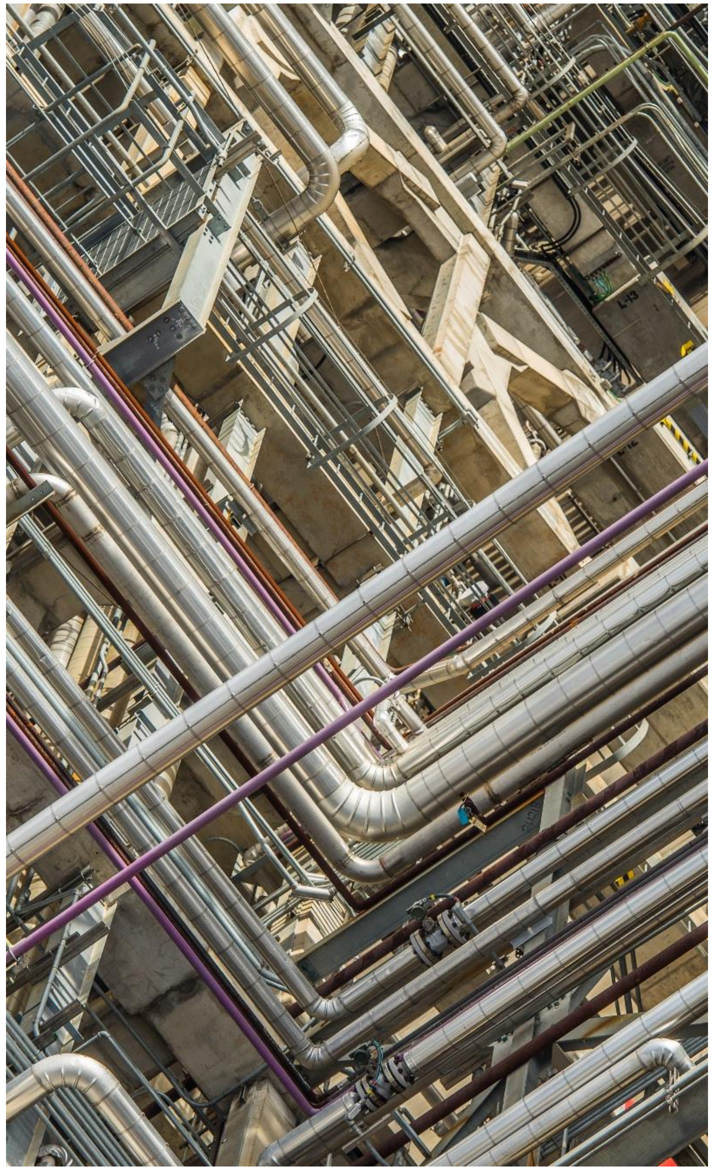
Turnaround implementation and results

A modified Case 3 was implemented during the 2022 turnaround.

- Added 2 feet to overall height
- Final design based on input from simulation results, refinery engineers, corporate engineers, cyclone vendors, PSRI

After turnaround, results were analyzed including:

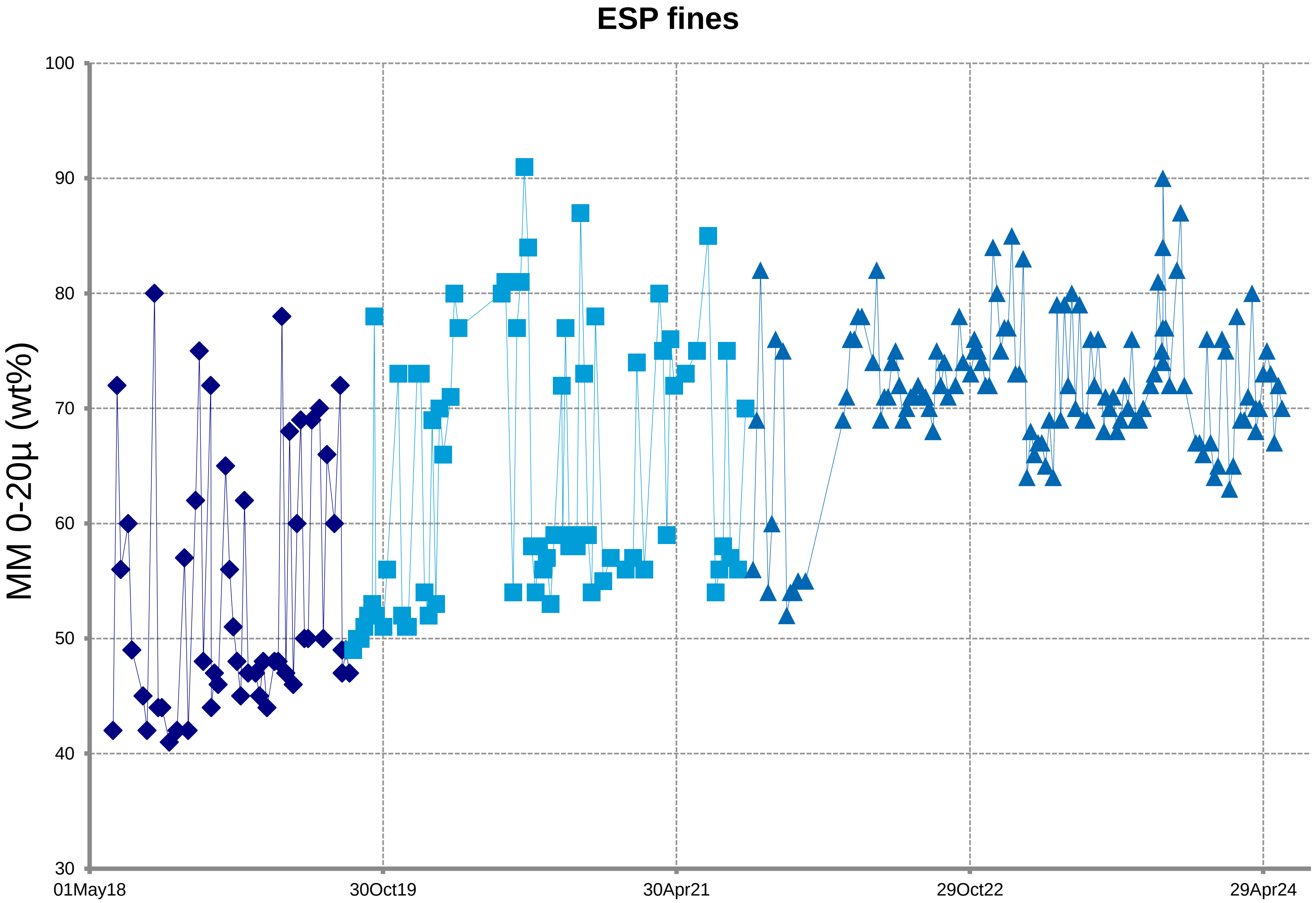
- ESP APS and fines
- ECat fines
- Fresh catalyst addition
- Slurry data
- Environmental performance



Results: ESP-captured fines before/after analysis

ESP-captured, 0-20 micron fines shown

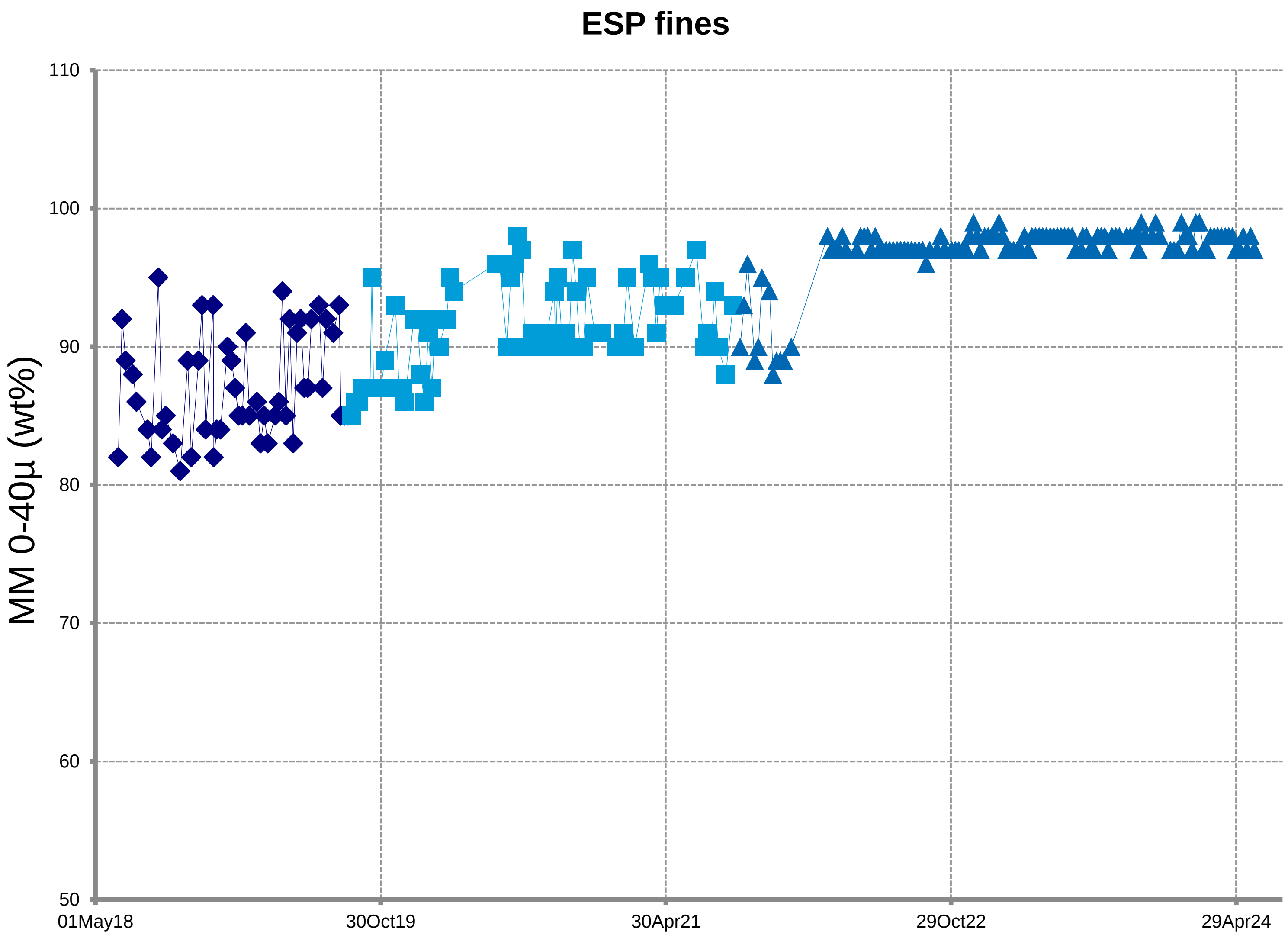
- Increased from 65% to 75%
- Less variation (±30 to ±20 microns)
- Cyclones doing a better job of capturing and returning larger particles



Results: ESP-captured fines before/after analysis

ESP-captured, 0-40 micron fines shown

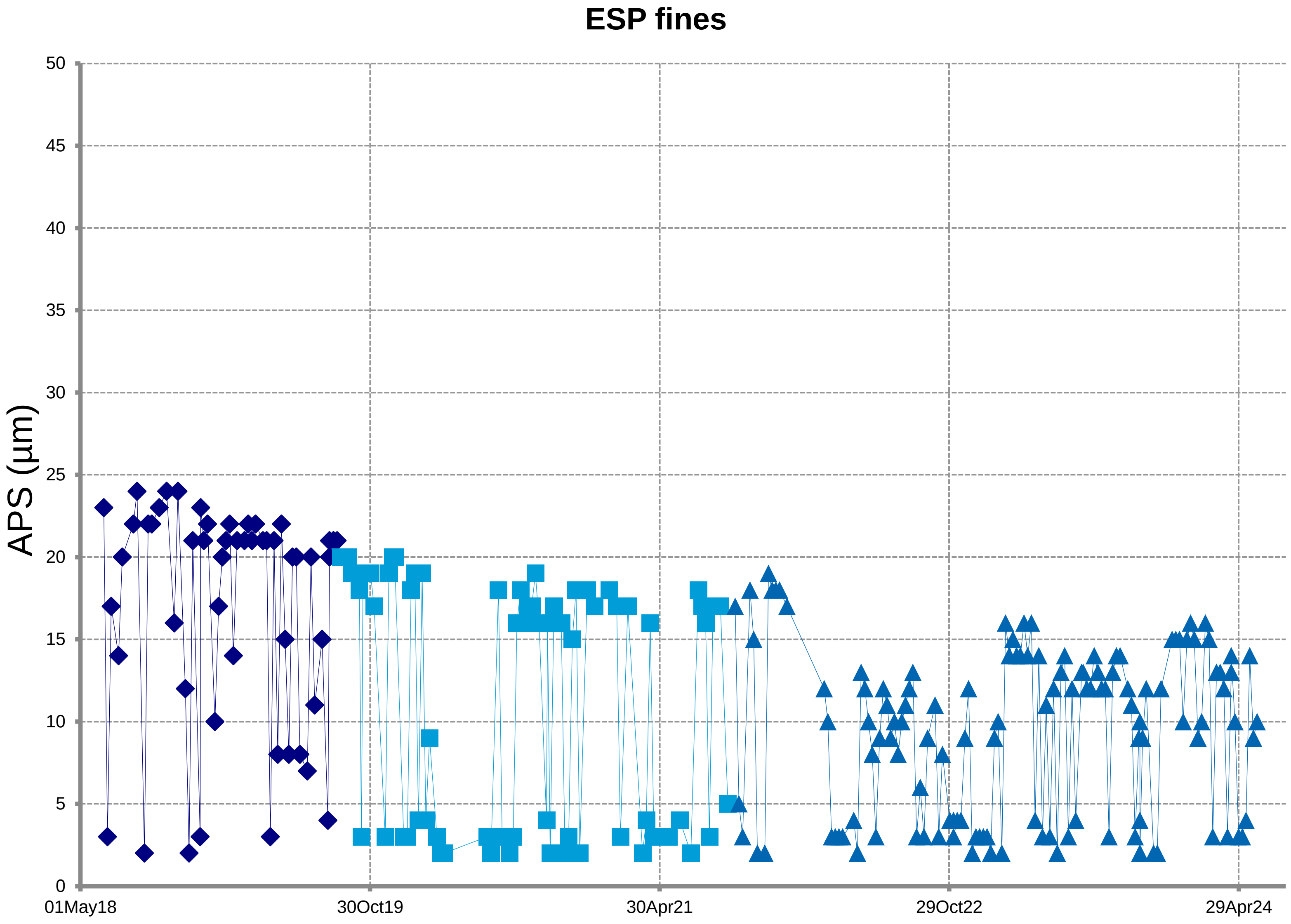
- Increased from 92% to 98%
- Less variation (±10 to ±3 microns)
- Only fines make it to the ESP now



Results: ESP-captured APS before/after analysis

ESP-captured APS

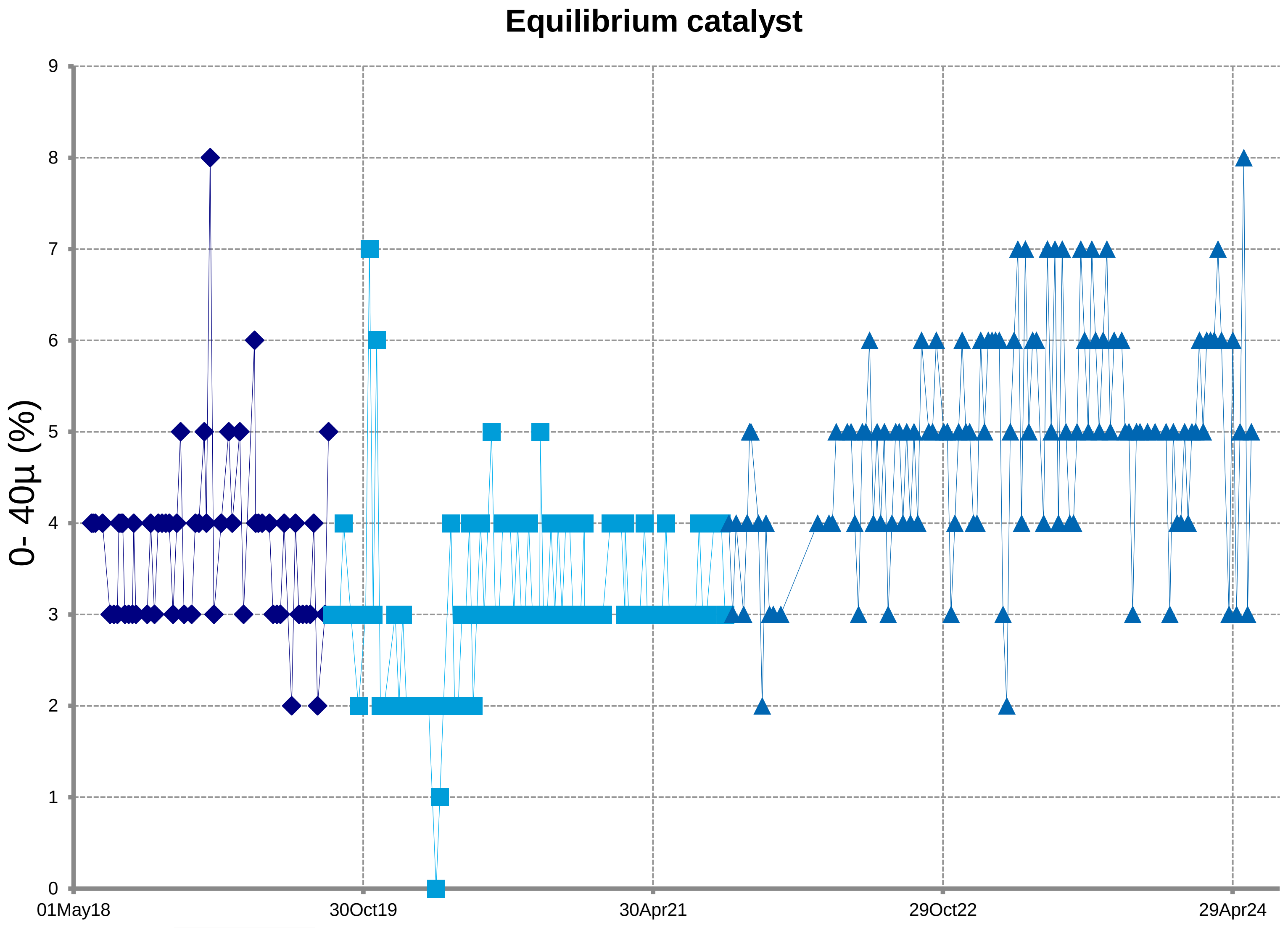
- Decreased from 17 to 12 microns
- Less variation (top end decreased from 20 to 17 microns)
- More of the larger catalyst is being returned to the regen



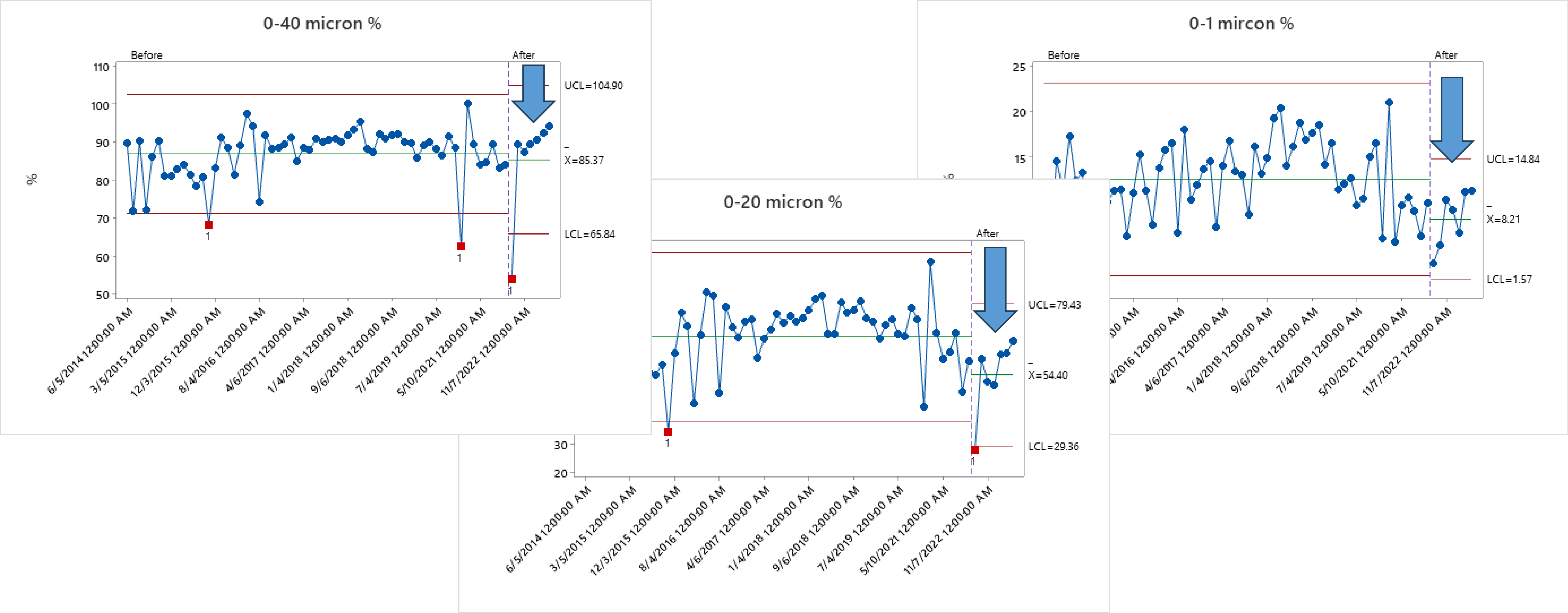
Results: ECat fines before/after analysis

ECat fines shown

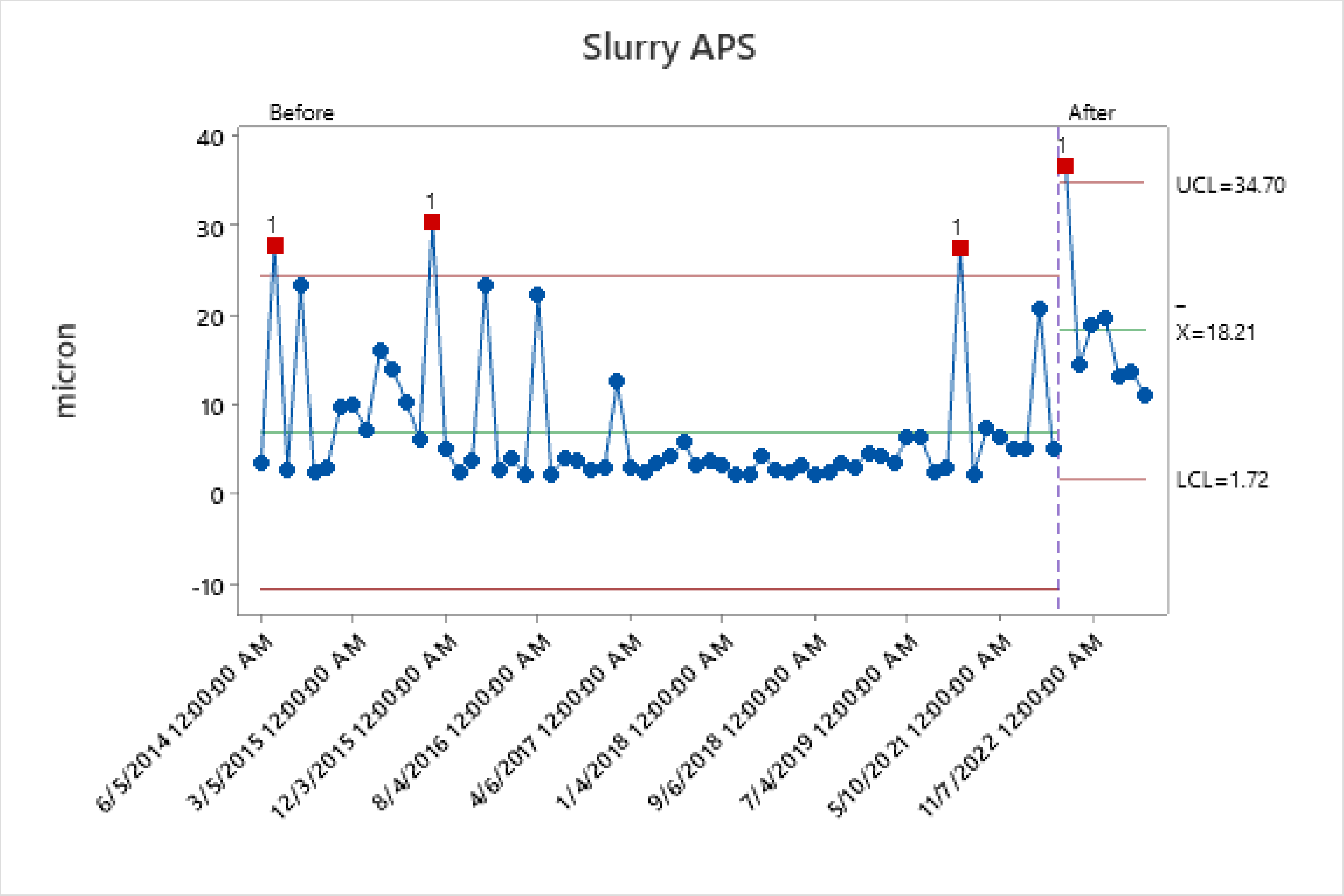
- Increased retention of fines in the FCCU (from ~3% to 5%)
- Positively impacts fluidization and circulation
- Unit is typically circulation constrained, so increased circulation stability correlates with better yields and overall economics



Slurry fines before/after analysis



Slurry fines before/after analysis



Results: before/after catalyst balance (tons/day)

Increased cat addition due to catalyst change

Reactor side cat losses increased

Regen cat losses decreased

Total cat losses decreased

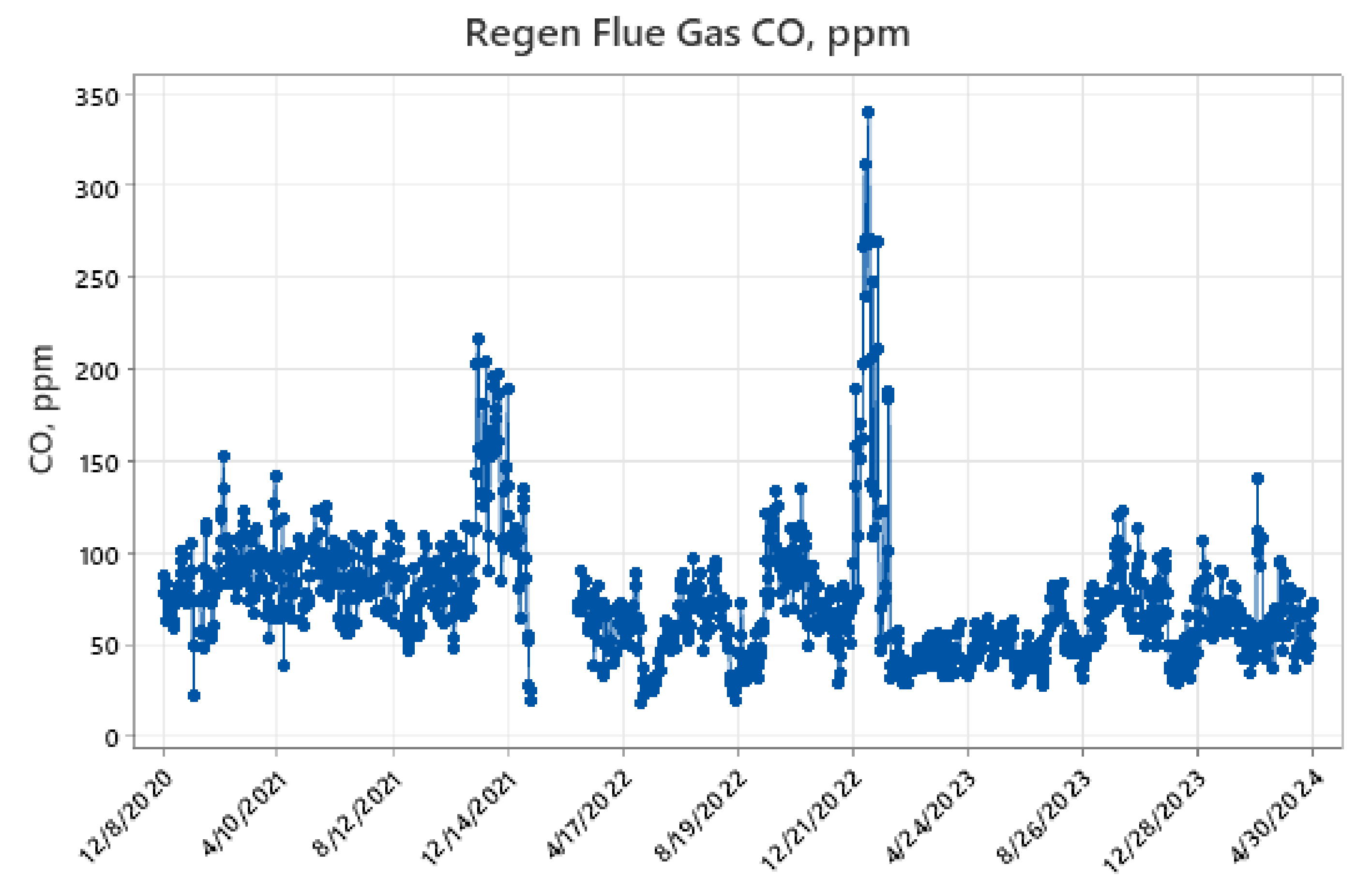
Results: before/after catalyst balance summary

	Before	After	Delta
Fresh cat addition, tpd	6.0	7.2	**+1.2**
RX cat losses, tpd	0.4	0.7	**+ 0.3**
Regen cat losses, tpd	2.6	1.8	**-0.8**
Total cat losses, tpd	3.0	2.5	**-0.5**

Results: CO before/after

CO impact

- 24-hr average CO decreased ~28%
- 24-hr average
  - 92 ppm before
  - 65 ppm after



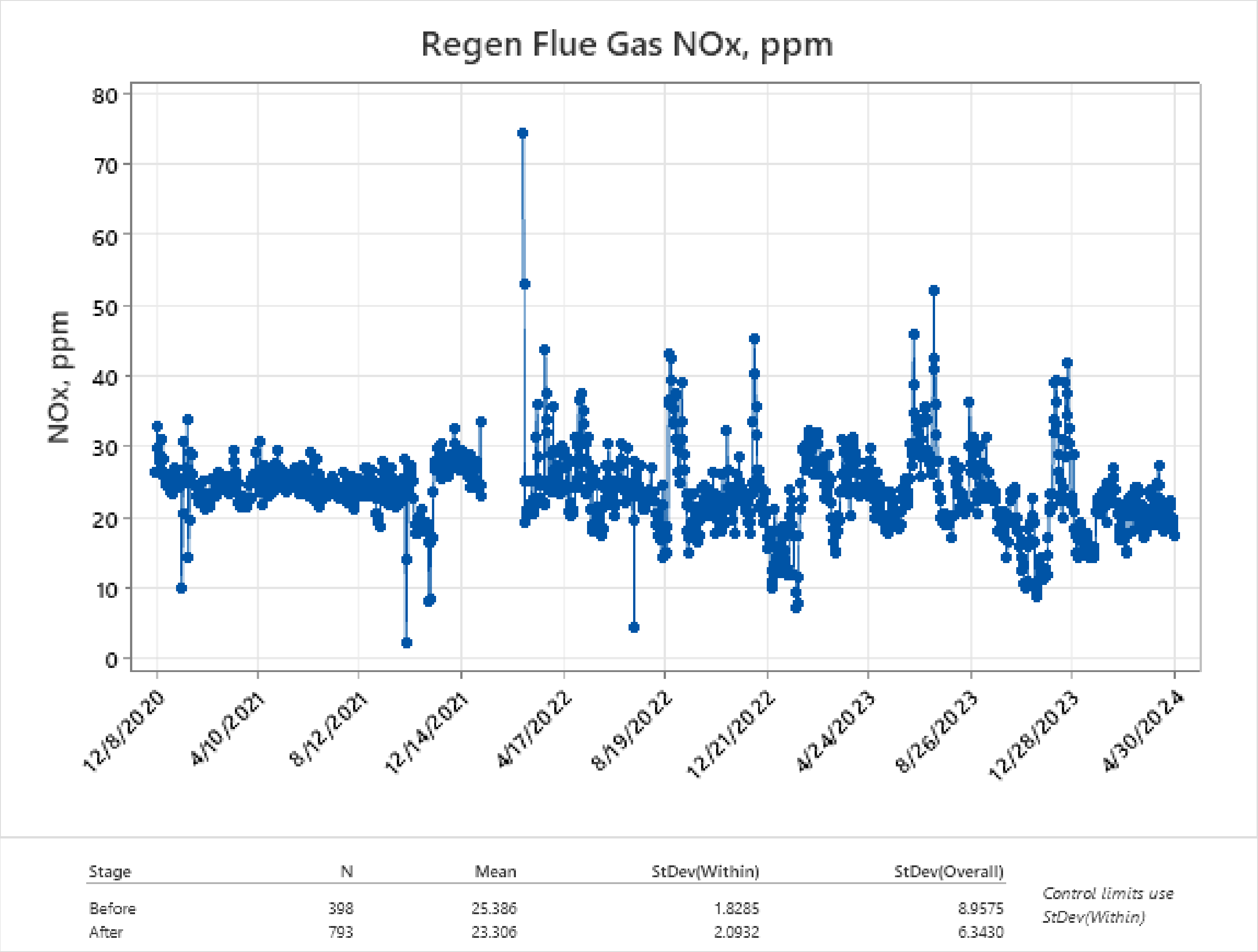
Stage	N	Mean	StDev(Within)	StDev(Overall)
Before	398	91.882	11.803	28.549
After	793	65.435	9.2828	33.896

Control limits use StDev(Within)

Results: NOx before/after

NOx shown

- Changes did not adversely impact NOx
- Variation increased
- 24-hr Average
    - 25 ppm before
    - 23 ppm after



Stage	N	Mean	StDev(Within)	StDev(Overall)
Before	398	25.386	1.8285	8.9575
After	793	23.306	2.0932	6.3430

Control limits use StDev(Within)

Conclusions

Barracuda Virtual Reactor was used for virtual testing of potential regenerator changes before implementation

- Minimized turnaround risk
- Explored many more options than were possible otherwise

Changes were implemented during the 2022 turnaround resulting in:

- Same or improved environmental performance
- Reduced catalyst losses
- Same or improved catalyst circulation stability
- Expected extension in cyclone life (to be verified during future turnarounds)

Thank you and questions

The speakers wish to acknowledge the work of John Pendergrass, who performed much of the CPFD modeling work presented herein.