Pilot-scale CFP Commissioning: *Creative Problem Solving and Lessons Learned*

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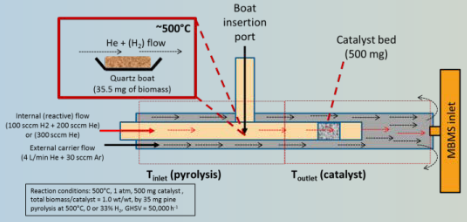
Staged Multi-Scale Evaluation Improves Research Efficiency

Microscale Reactor

Schematic of reaction system (MBMS horizontal reactor)



Catalyst: 1g

Biomass: 25 mg/run

Uses/Purpose:

- Rapid catalyst screening
- Preliminary product analysis (no condensed oil)
- Batch experiments
- Mechanistic insight

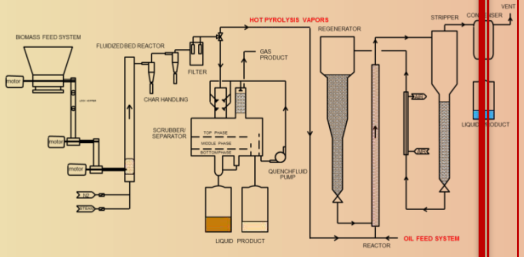
Laboratory Scale Fluid/ Fixed Bed Reactor

500g

0.5 kg/h

- Catalyst evaluation with continuous biomass feed
- Assess operating conditions
- Full product/yield analysis
- Extended time on stream
- Fixed/Fluidized bed (not representative of riser)

DCR (Small Pilot Scale)



2kg

3 kg/h

- Process evaluation / integration with industrially-relevant riser
- Assess operating conditions compared to lab-scale
- Co-processing of biomass and petroleum feeds (liq. and gas)

R-Cubed (Pilot Scale)

100kg

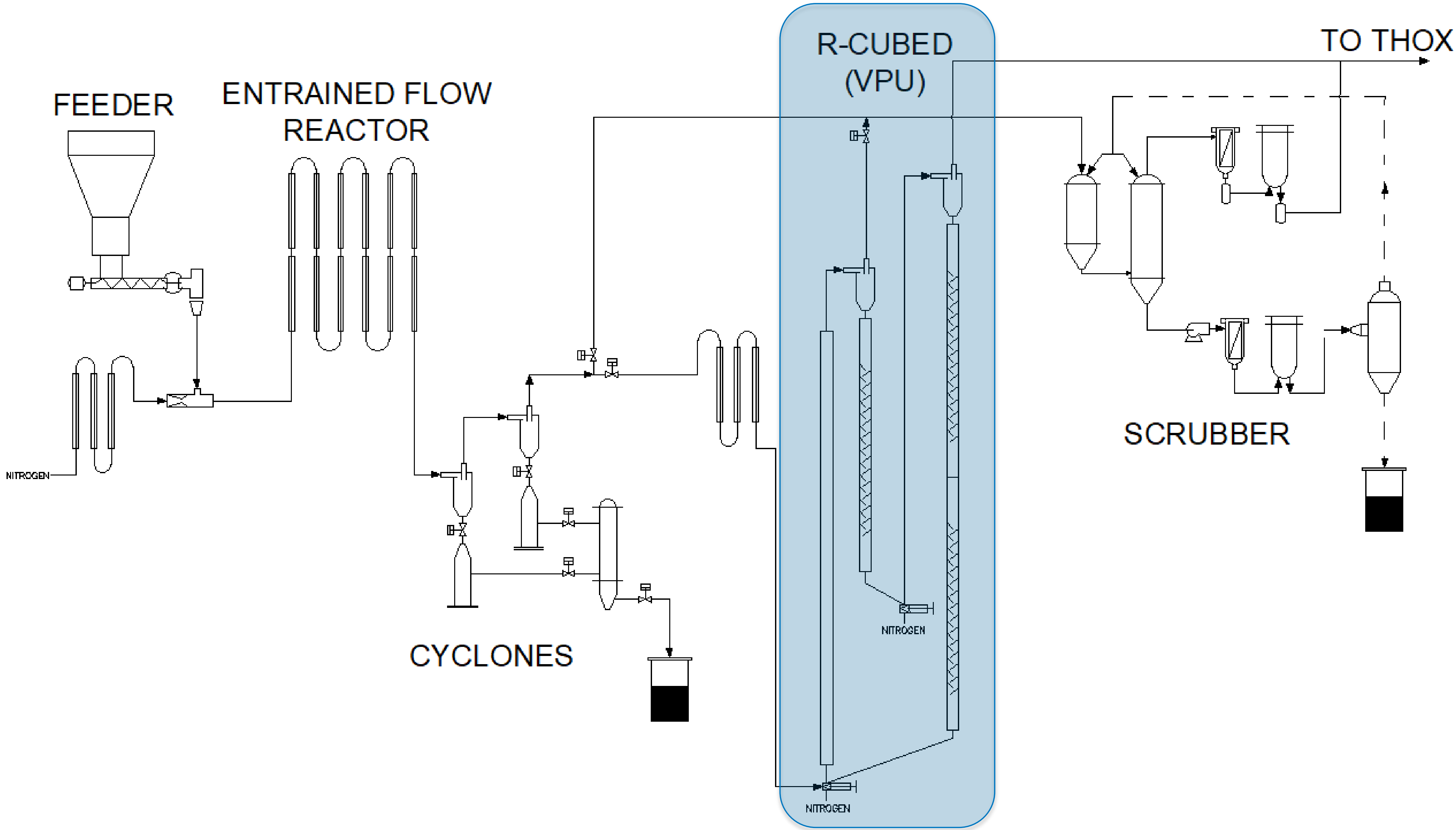
20 kg/h

- Evaluation of process operability / uptime
- Identification & assessment of scale-up challenges & impacts
- Generate significant product quantities

Process and catalyst evaluation at multiple scales:

- Improves research efficiency, thus reducing cost
- Provides data that is directly transferrable to industry partners
- Allows for a tiered catalyst and process development approach

TCPDU Process Flow Diagram



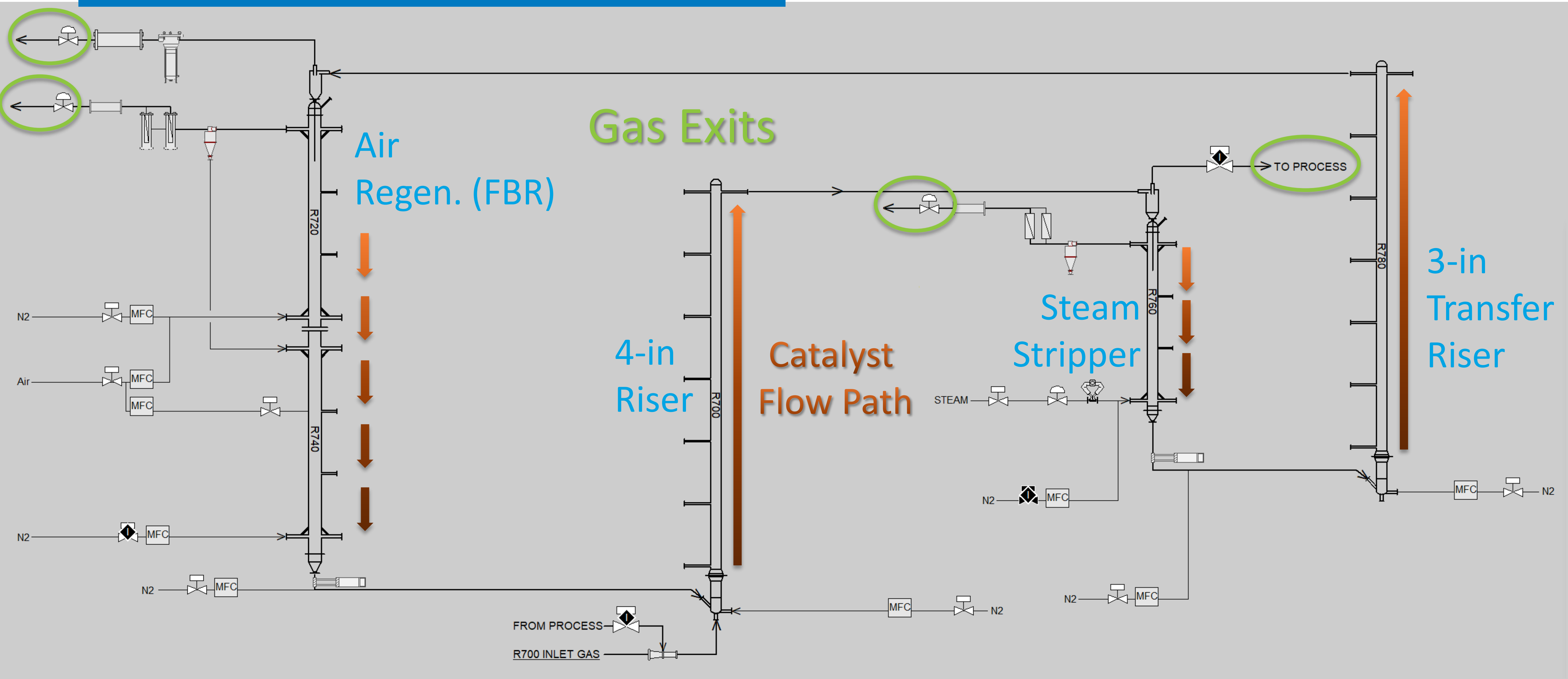
Challenges / Creative Problem Solving

- Design Constraints
- Measuring & controlling catalyst flow rate
- Pressure & level control
- Plugging in exit lines
- Air regeneration – complete coke combustion for catalyst efficiency

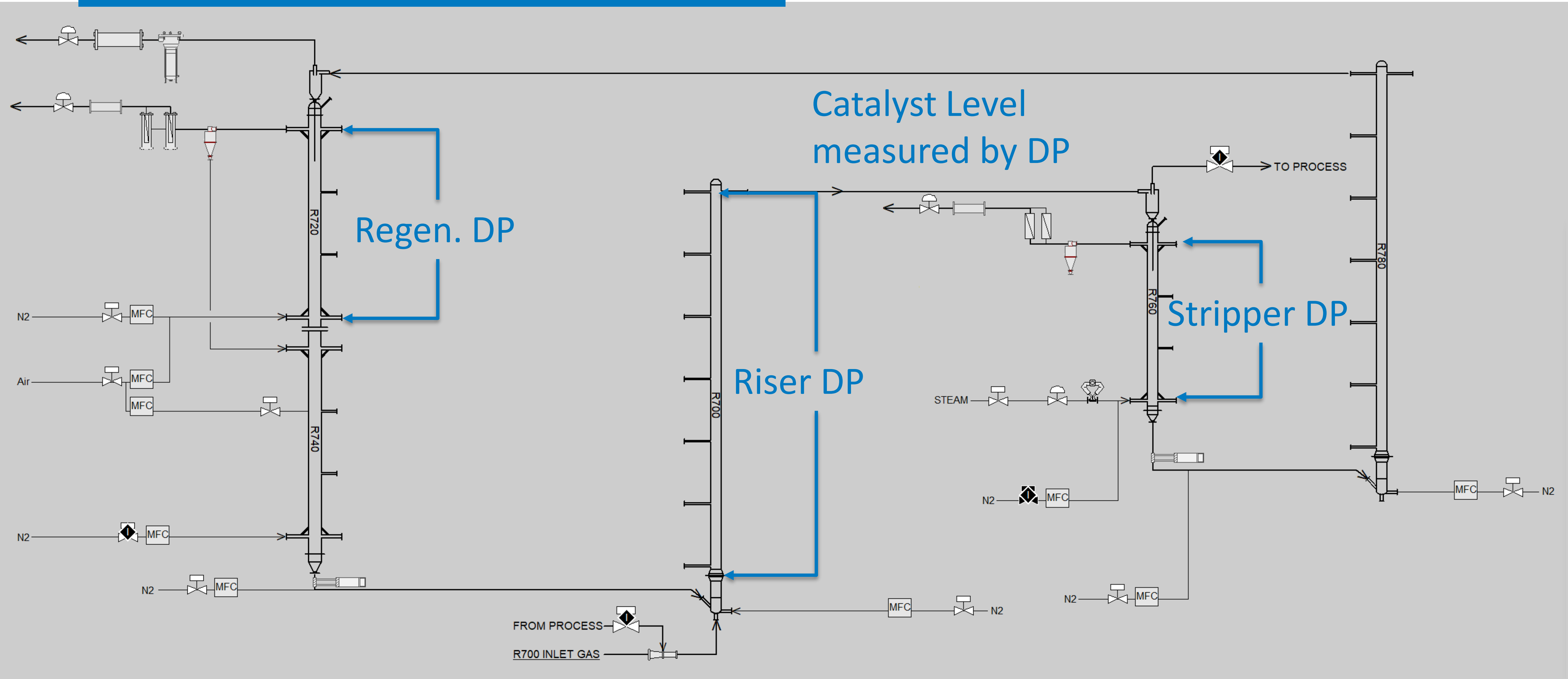
Design Constraints

- Must have built-in flexibility
- Ceiling height limit
  - Must account for thermal expansion
- Floor loading limit (Techlok flanges)
- BPVC: limited to 6-in. diameter pipe
- Highly fluidizable catalyst (Zeolite)

R^3 Process Flow Diagram

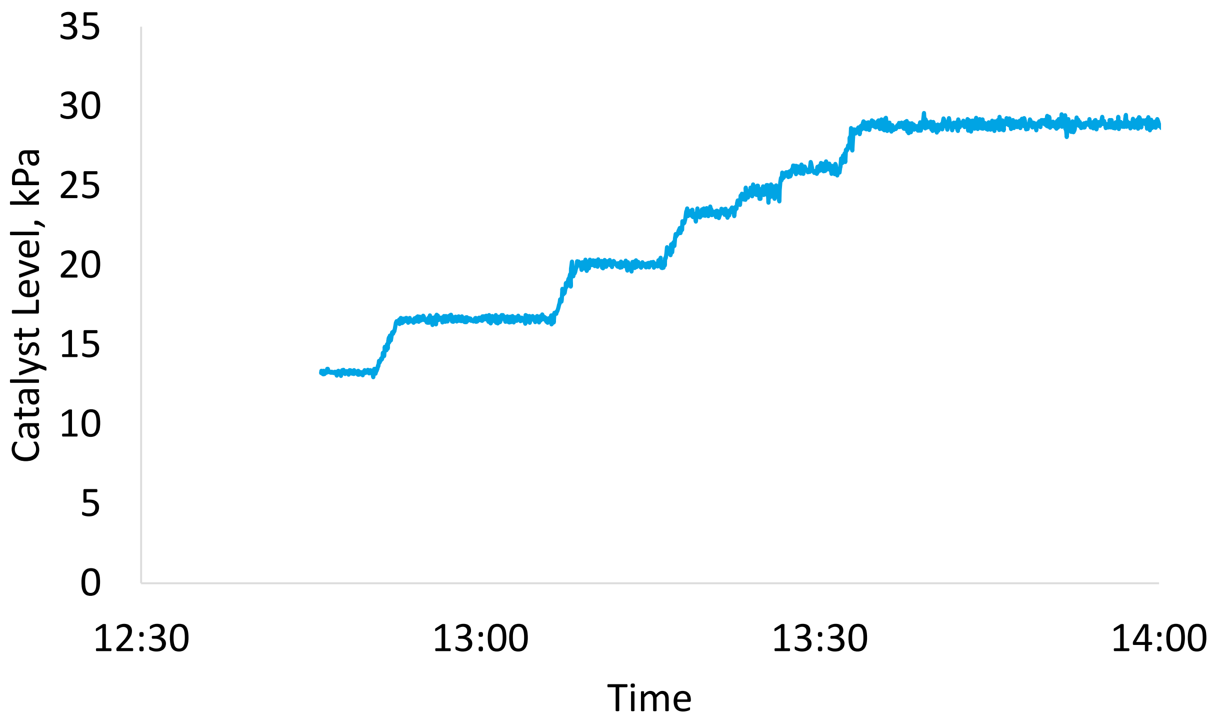


R^3 Process Flow Diagram



How to Measure Catalyst Mass Flow

- Loaded 5 kg shots of catalyst
- 1 kg = 0.64 kPa at 60 kPa



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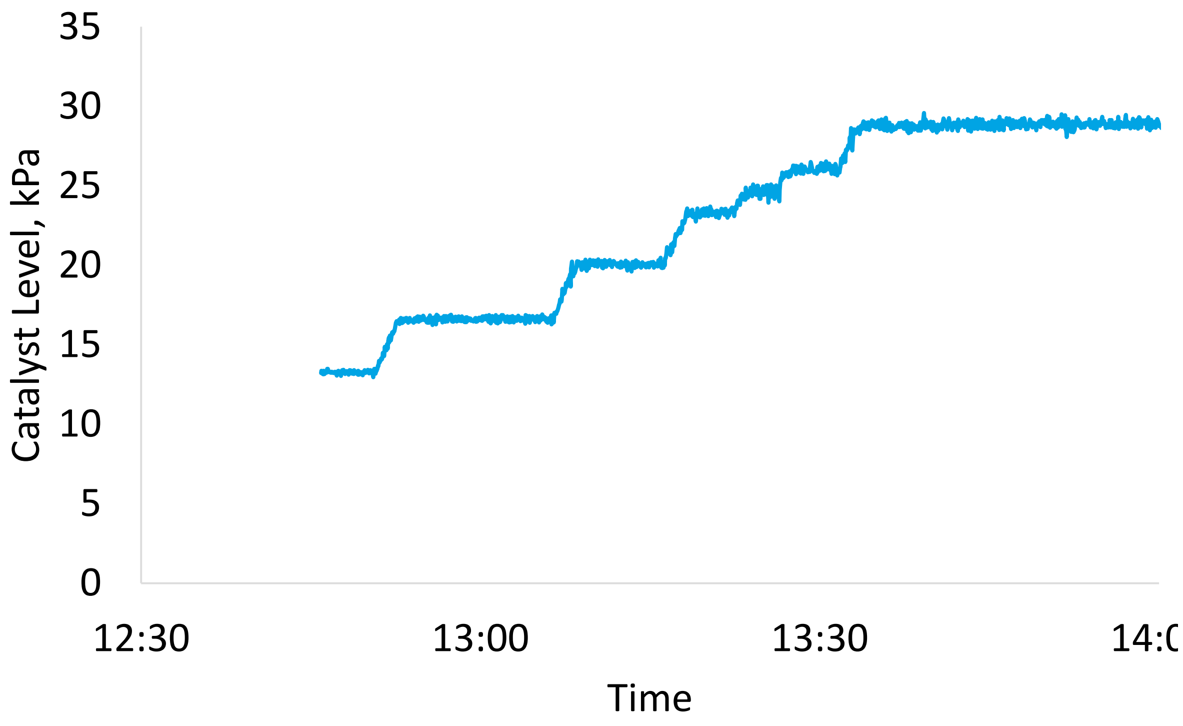
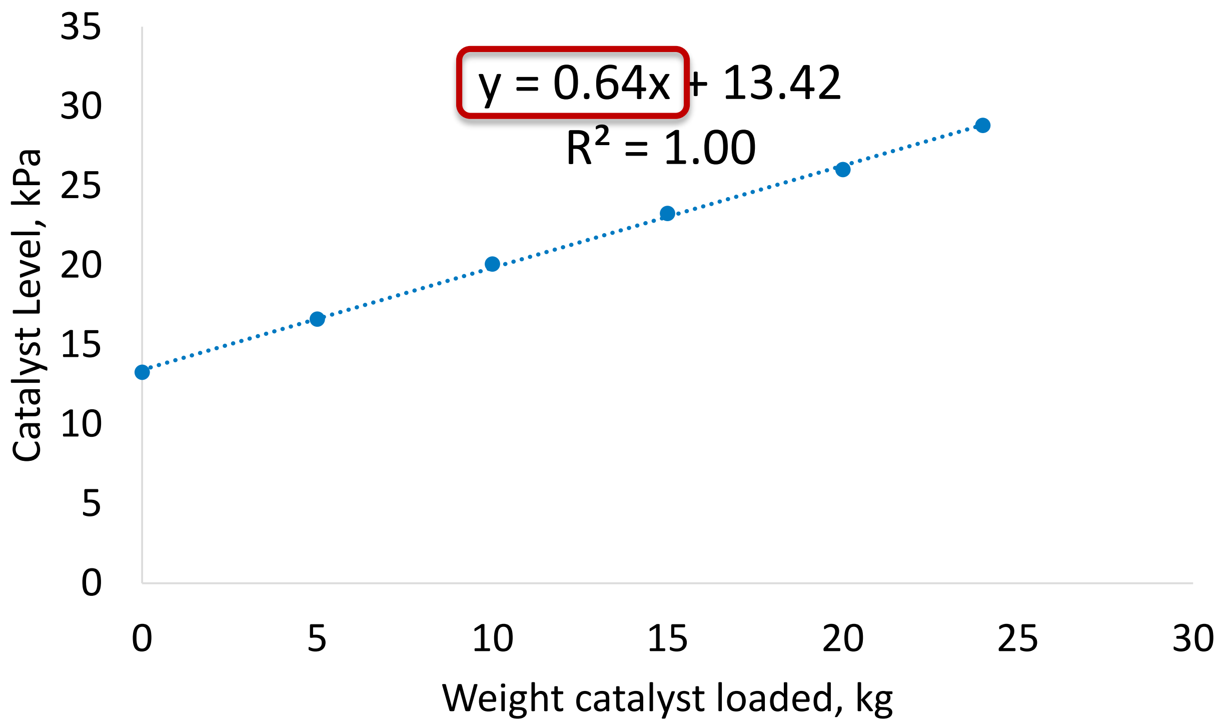
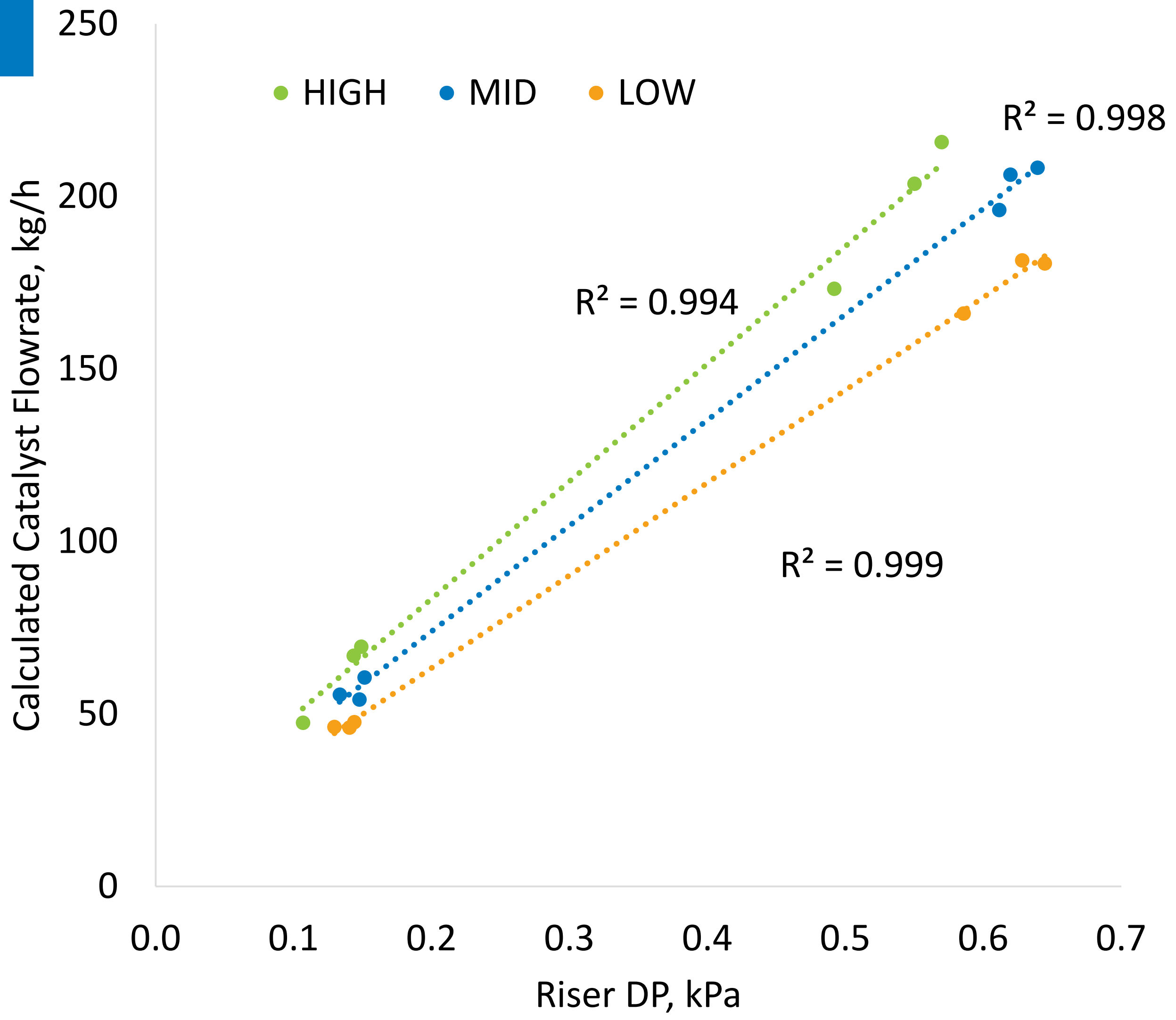




Catalyst mass flow required for kinetics

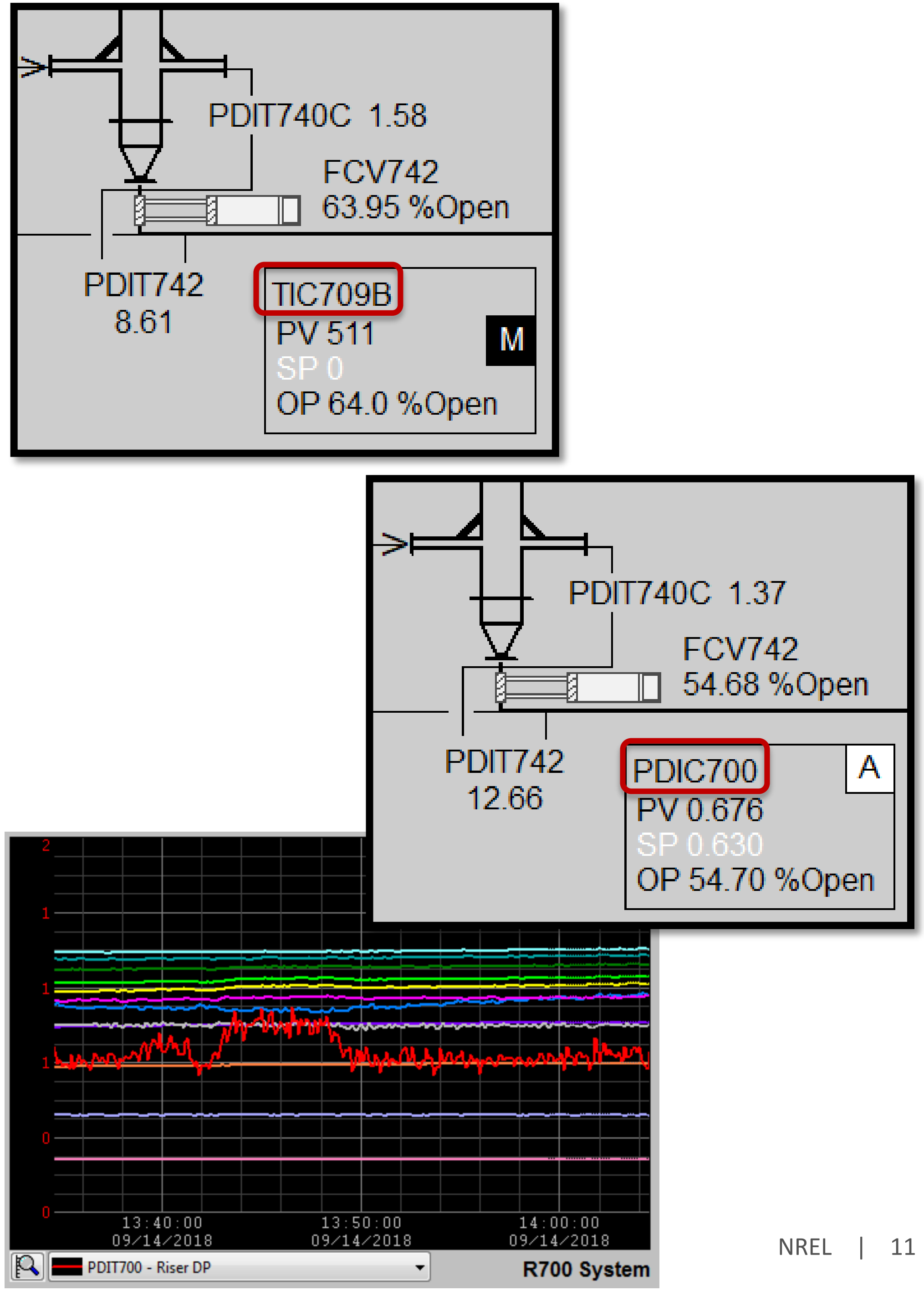
$$\dot{M} = (\Delta P_{start} - \Delta P_{end}) \times \frac{1\,kg}{0.64\,kPa} \times \frac{1}{\Delta t}$$

- Timed the transfer of catalyst from one FBR to other
- Simulated high/mid/low process gas flows with N_2

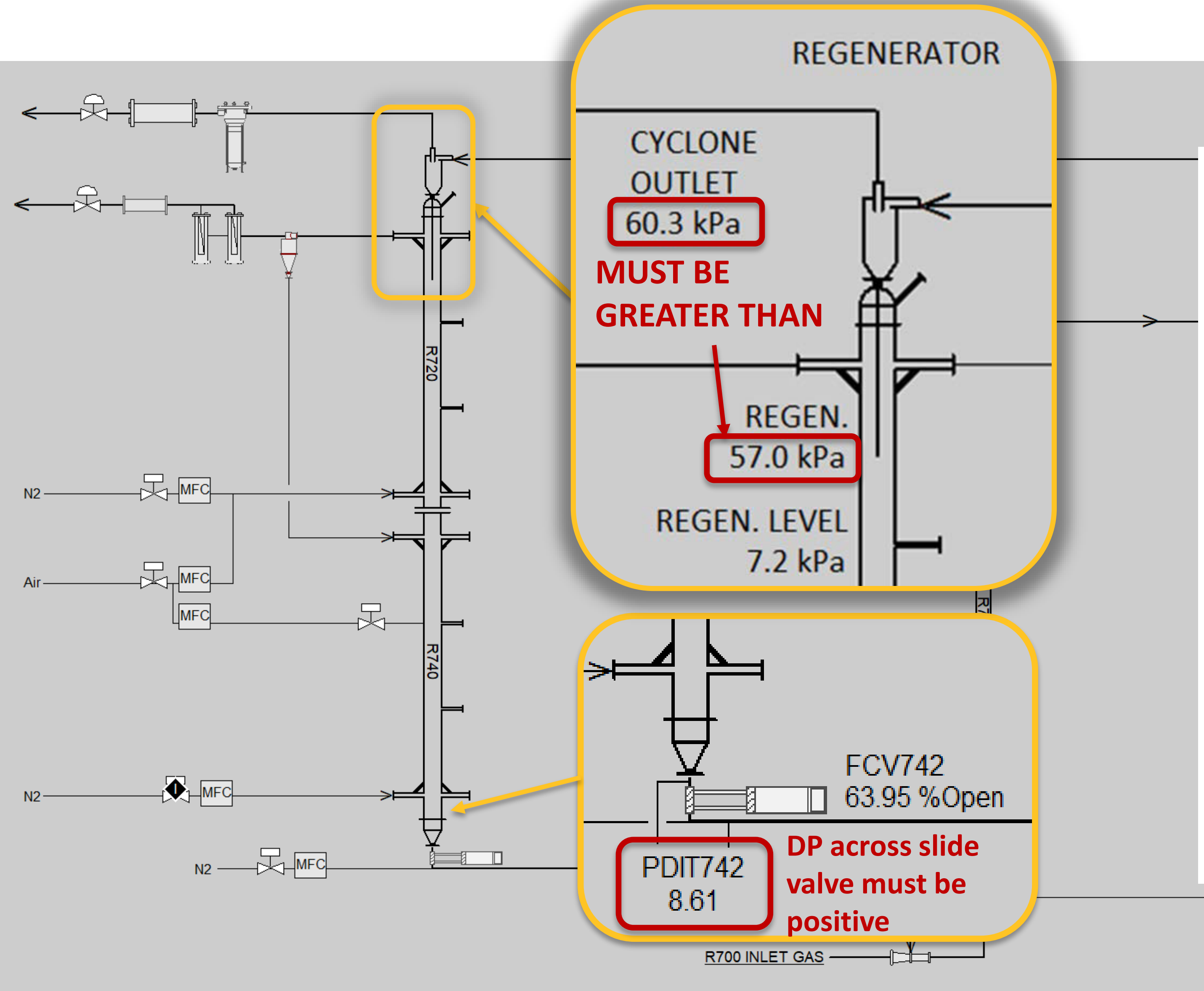


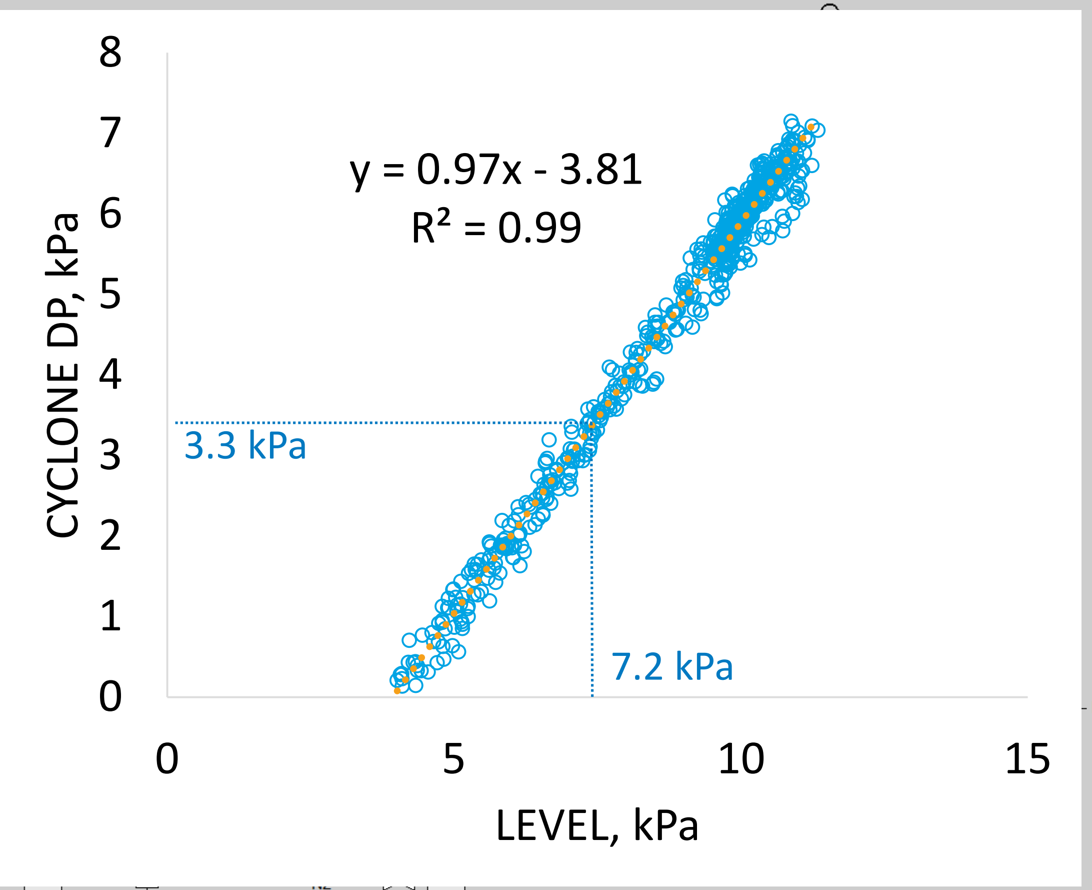
Controlling catalyst flow via slide valves

- First generation: temperature at Riser exit (TE709B) controlled catalyst flow
  - Difficult due to thermal mass of riser & external heaters (thermocouple not sensitive to catalyst flow)
- Next generation: keeps catalyst flowrate constant, as measured by DP across riser (PDIT700)



Pressure Control in Fluidized Beds (Regen/Stripper)





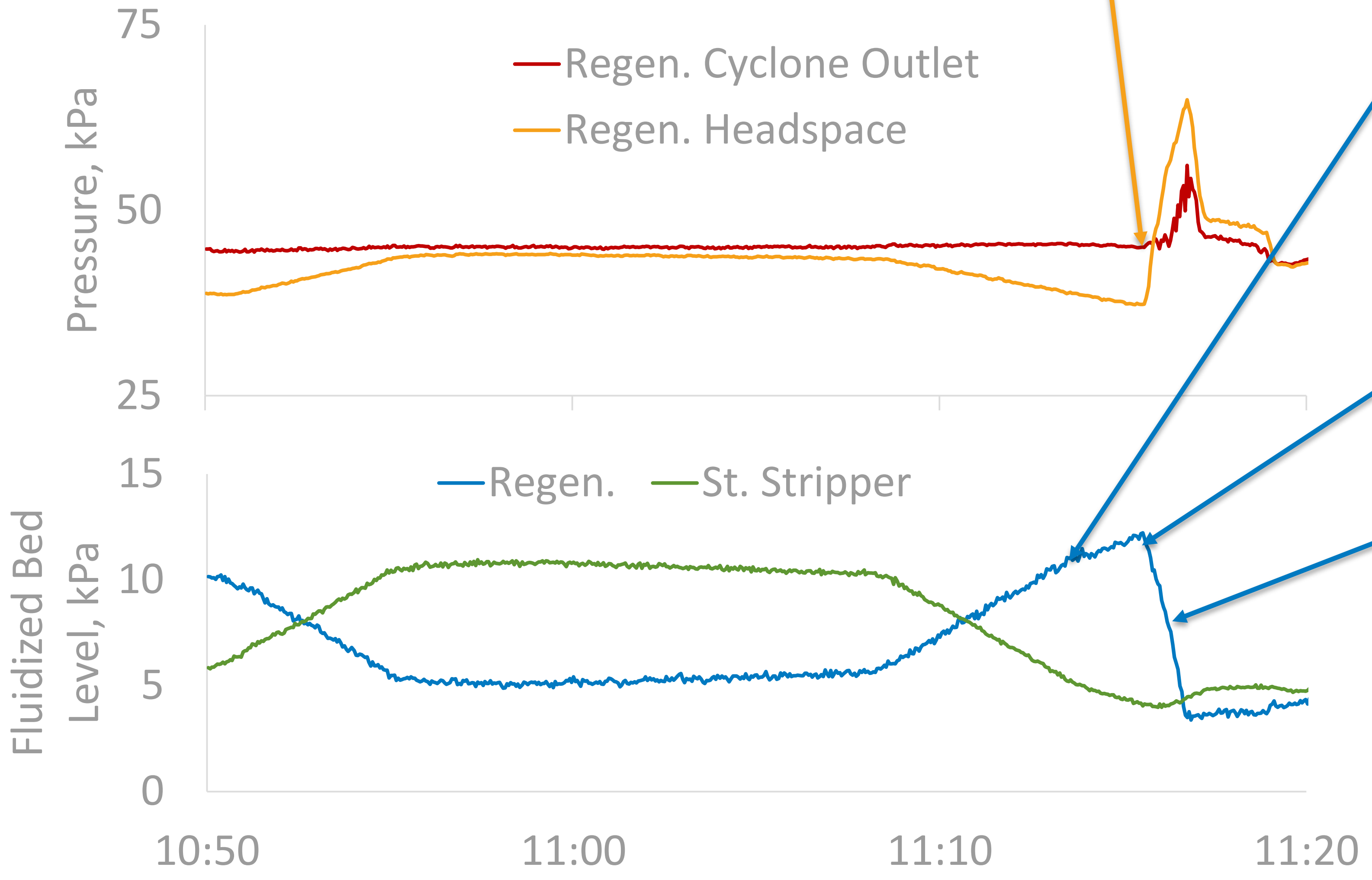
Level Control & Maximum Level in FBRs

DP across cyclone inverts

Regen. Level increases as Stripper Level decreases

Max level in Regenerator plugs Sidearm

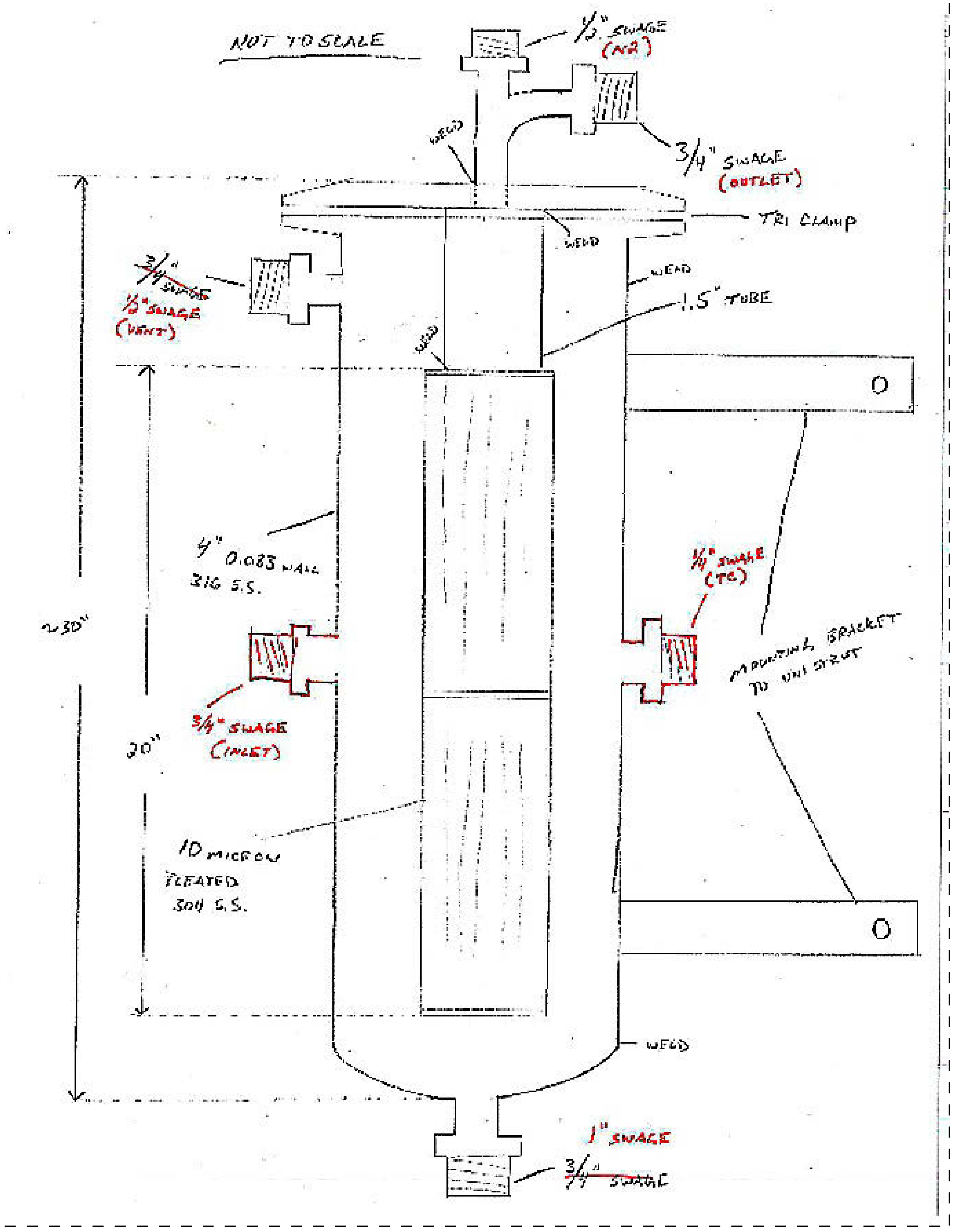
~13 kg of catalyst out cyclone gas exit

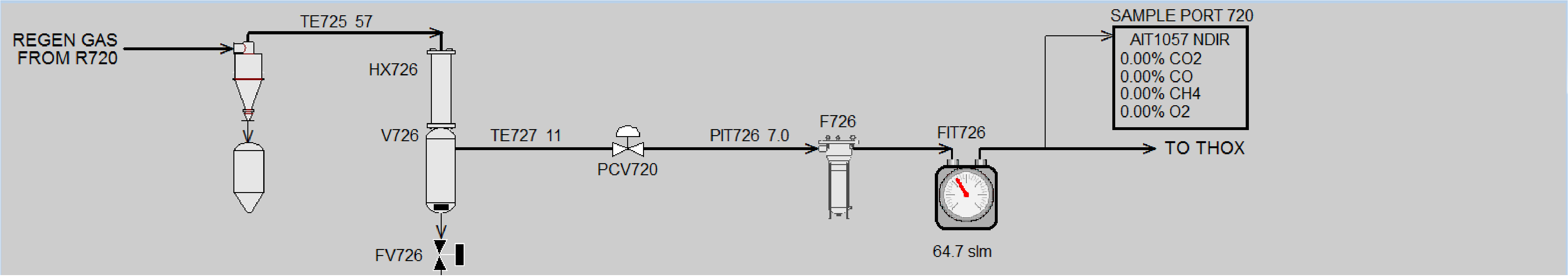


Hot Gas Filtration

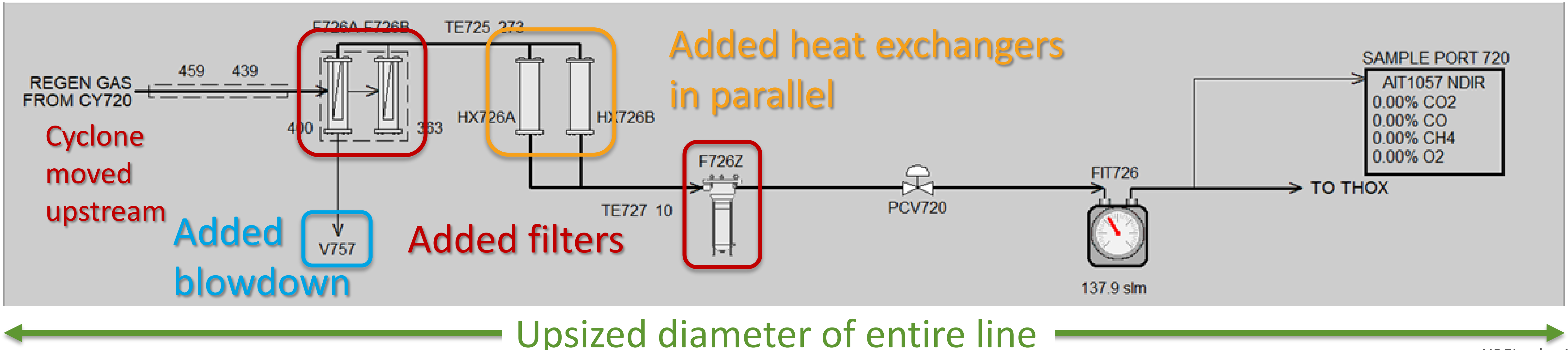
- Catalyst + water = Mud = Plugged Sidearms = Catalyst out
- Hot Catalyst + water vapor = ok
- Required on ALL exit streams

CRITICAL TO SUCCESS OF OPERATION



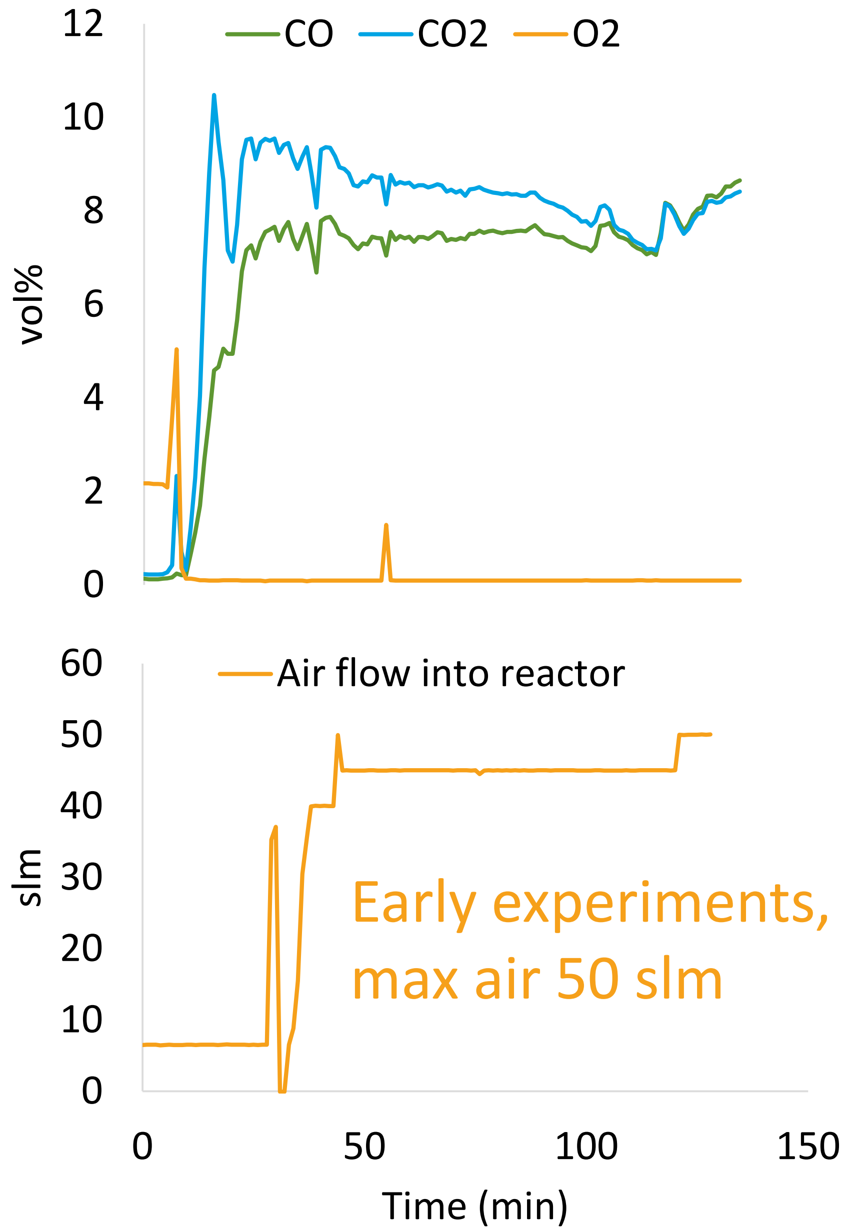


Upgraded exit lines to remove catalyst particles while hot

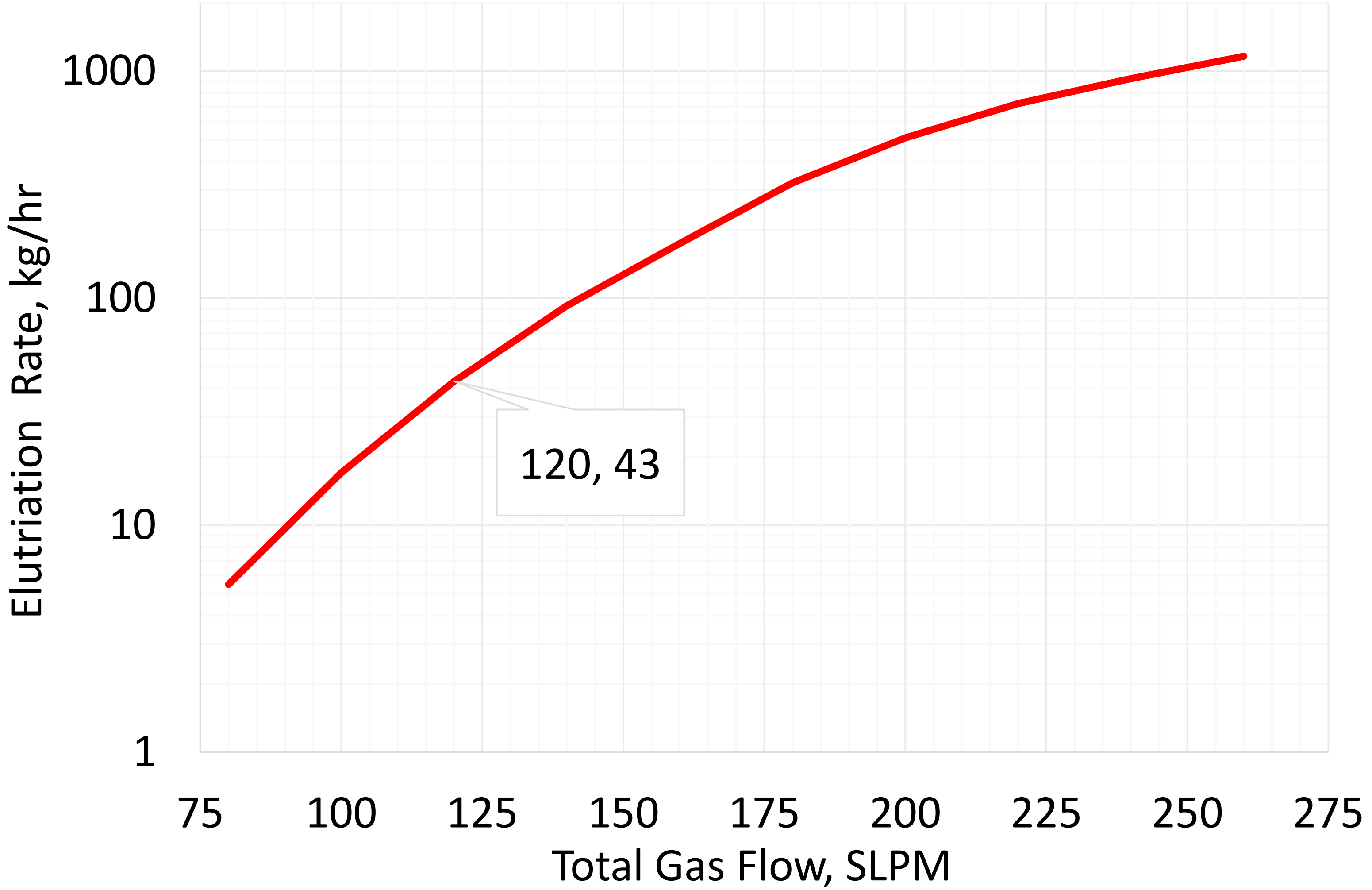


Insufficient Regen Air

- Initial Design: Coke loading estimated from *preliminary* results on Bench-scale FBR
- No O_2 measured on regen exit
- Limited by reactor geometry:
  - Exit line too small diameter
  - Too much carryover (elutriation) at higher air flow



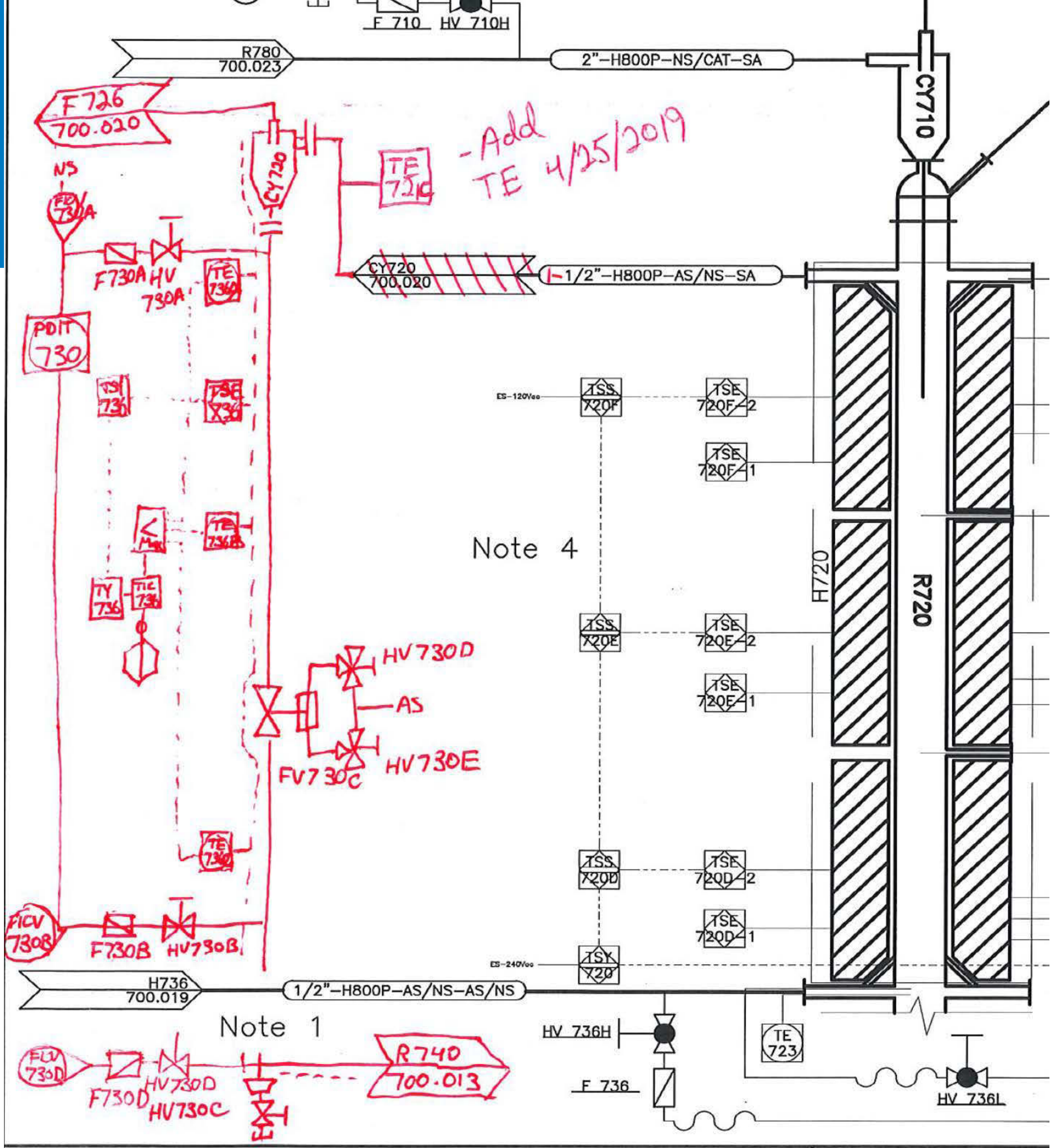
Elutriation of Catalyst at Increased Air Flow



Credit:
Bruce Adkins (ORNL)
(using PSRI models)

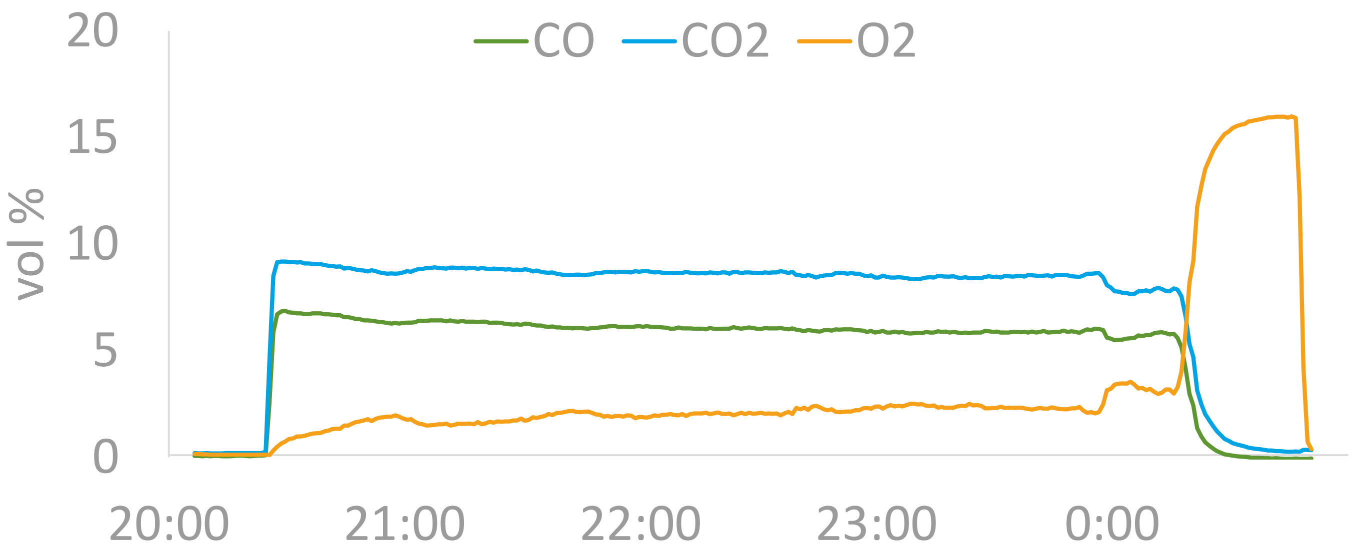
Add Cyclone Return into Regenerator

- Increased air flow carries over MUCH more catalyst
- Effectively increased Regen. diameter
- Installed cyclone to return catalyst into reactor
- Tricky design: must keep horizontal section of return pipe fluidized



Air Regeneration Results

Coke on Catalyst (%C by wt)	Insufficient Regen	Complete Regen
Post-stripper, after ~2 hours	0.94%	0.58%
Post-regen, after ~2 hours	0.66%	0.01%



Insufficient Regen

Complete Regen

Lessons Learned

Catalyst mass flow rate, which is critical for VPU kinetics,

- can be empirically determined by change in level in fluidized bed reactors,
- then correlated to differential pressure across Riser,
- *as long as gas flow rate stays constant*

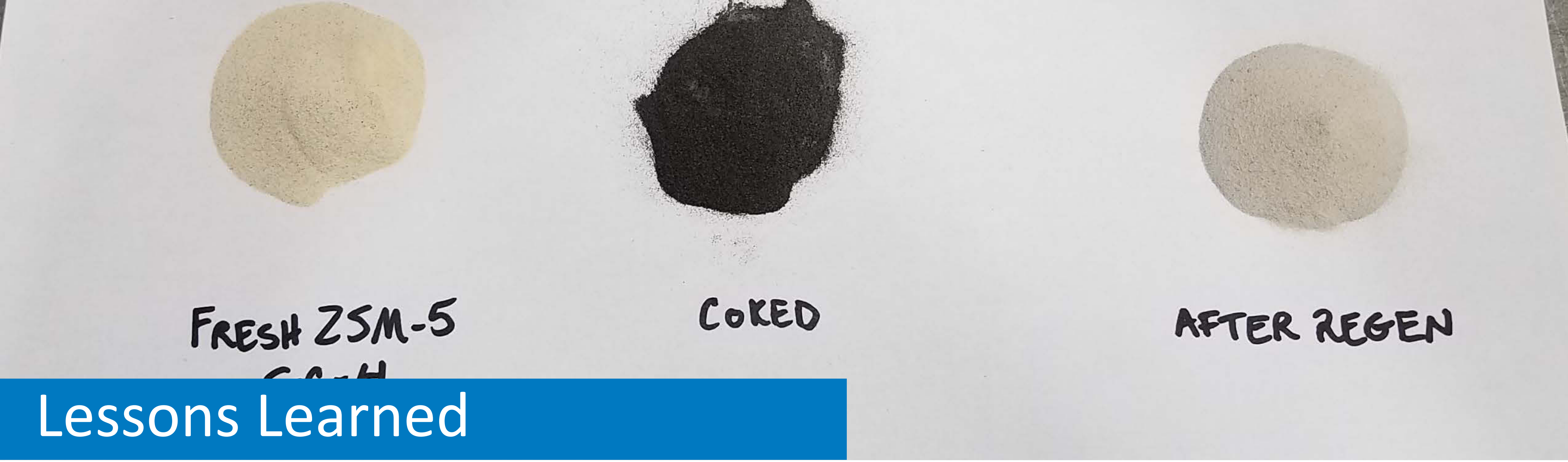
Lessons Learned

- Pressure in top of fluidized beds varies linearly with level of catalyst in bed
- D Pressure across Regen. cyclone must be positive
  - *Flowrate out sidearm must be greater than flow in, or pressure flips and catalyst empties*

Lessons Learned

DON'T PLUG SIDEARMS

- *Don't overflow fluidized beds*
- *Filter catalyst particles out while hot (mud plugs lines & is difficult to clean out)*



Lessons Learned

NEED PLENTY OF O_2 FOR REGENERATION

- High-risk to scale up using bench-scale data from dissimilar reactor system
- We mitigated catalyst elutriation out of Regen. by adding a cyclone
- Ideally, disengagement zone (freeboard) keeps catalyst in reactor
- Pure oxygen is dangerous & expensive, but plausible

Acknowledgements

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DOE Advanced Development & Optimization program (ADO)

10/9 @ 4pm Jessica Olstad (NREL)
Co-Processing Catalytic Fast Pyrolysis Oils with Vacuum Gas Oil in a Davison Circulating Riser – Upgrading Track

Questions?

www.nrel.gov

NREL/PR-5100-75187

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