The Vattenfall – Air Products Oxyfuel CO_2 Compression and Purification Pilot Plant at Schwarze Pumpe – Initial Results

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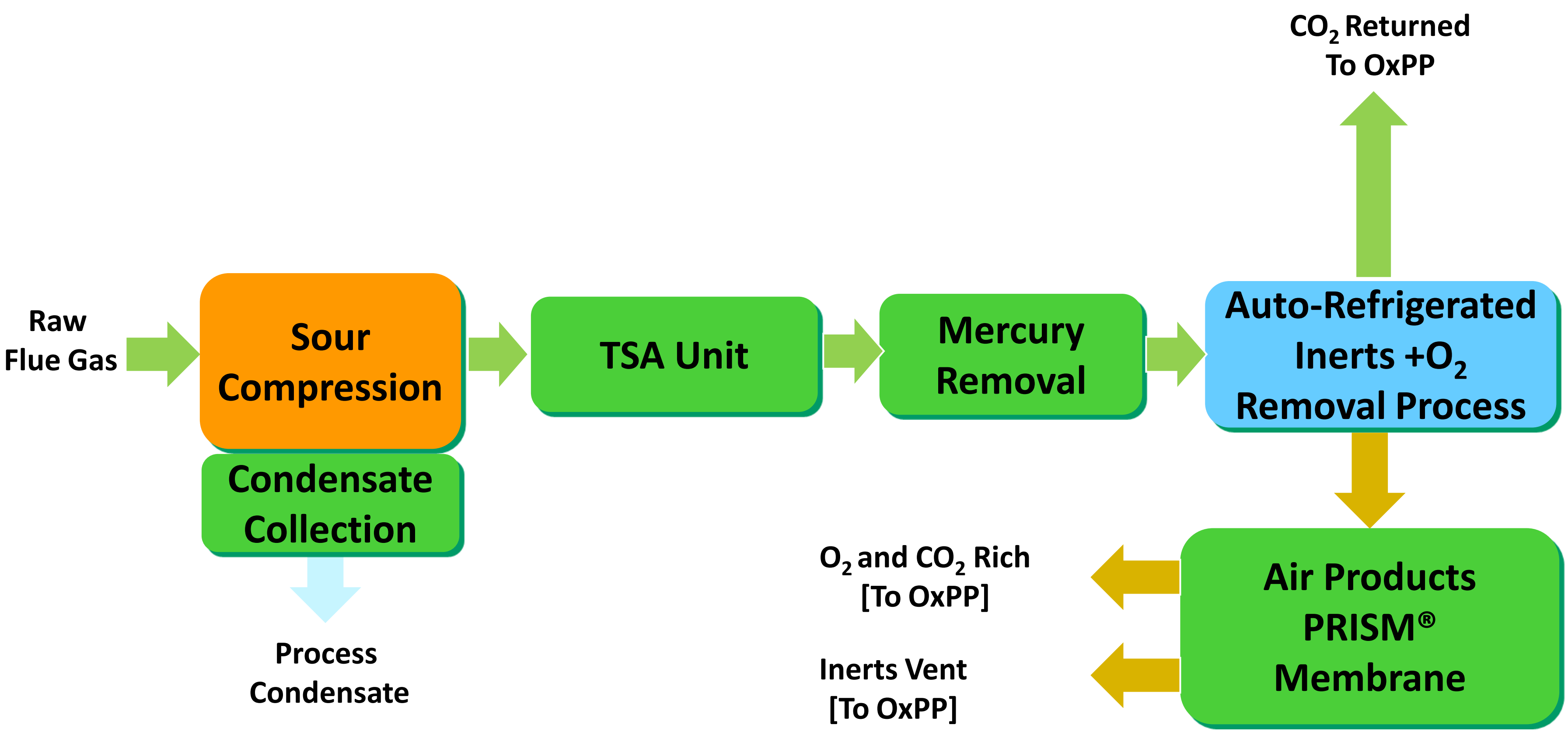
Oxyfuel Combustion Conference 2

AIR PRODUCTS

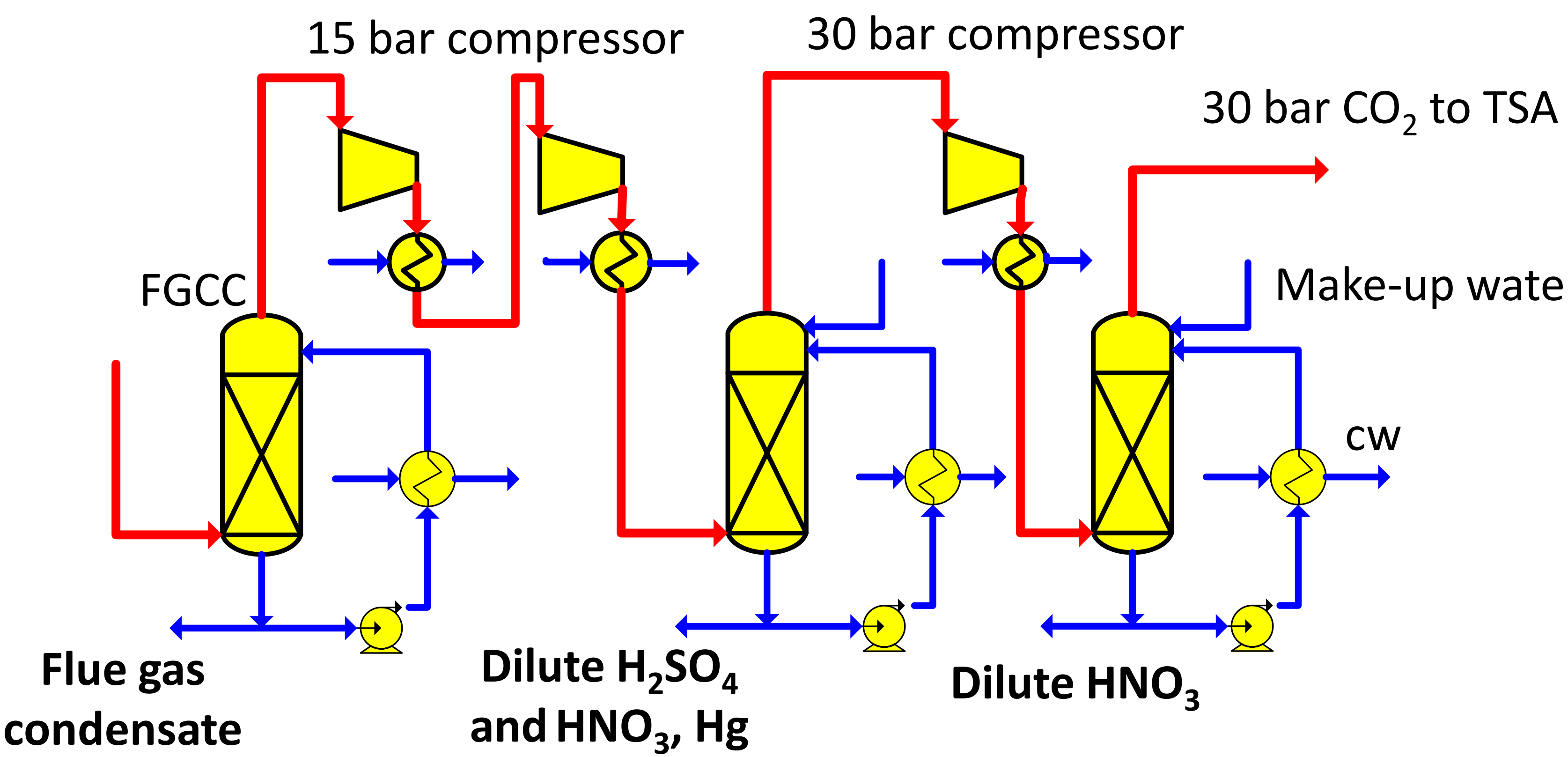
The Vattenfall – Air Products Oxyfuel CPU Pilot Plant

- Review results from first few weeks of running
- Demonstrate how results show sour compression works
- Discuss the importance of understanding gas phase analysis and the effects of corrosion
- Share our experiences of running the auto-refrigerated inerts + O_2 removal process

Air Products' CO_2 Purification Unit (CPU) Pilot Plant at Vattenfall's Schwarze Pumpe OxPP



Sour Compression: Removal of SO_2 & NO_x



Flue Gas Cooler Condenser

- Some SO_2 removal seen
- Only minor amounts of nitrates and nitrites found in the liquid phase
  - i.e. No NOx removal
- Removes all Chlorides (HCl) and all particulates

Compression to 15 bar before 1st Column

- NOx only (No SO_2)
  - NOx removal during compression
  - NO converted to NO_2
- NOx and SO_2
  - SO_2 removal during compression
  - Less NO_2 seen, confirming NO_2 that is formed reacts with SO_2 as expected

Control of condensate formation during compression

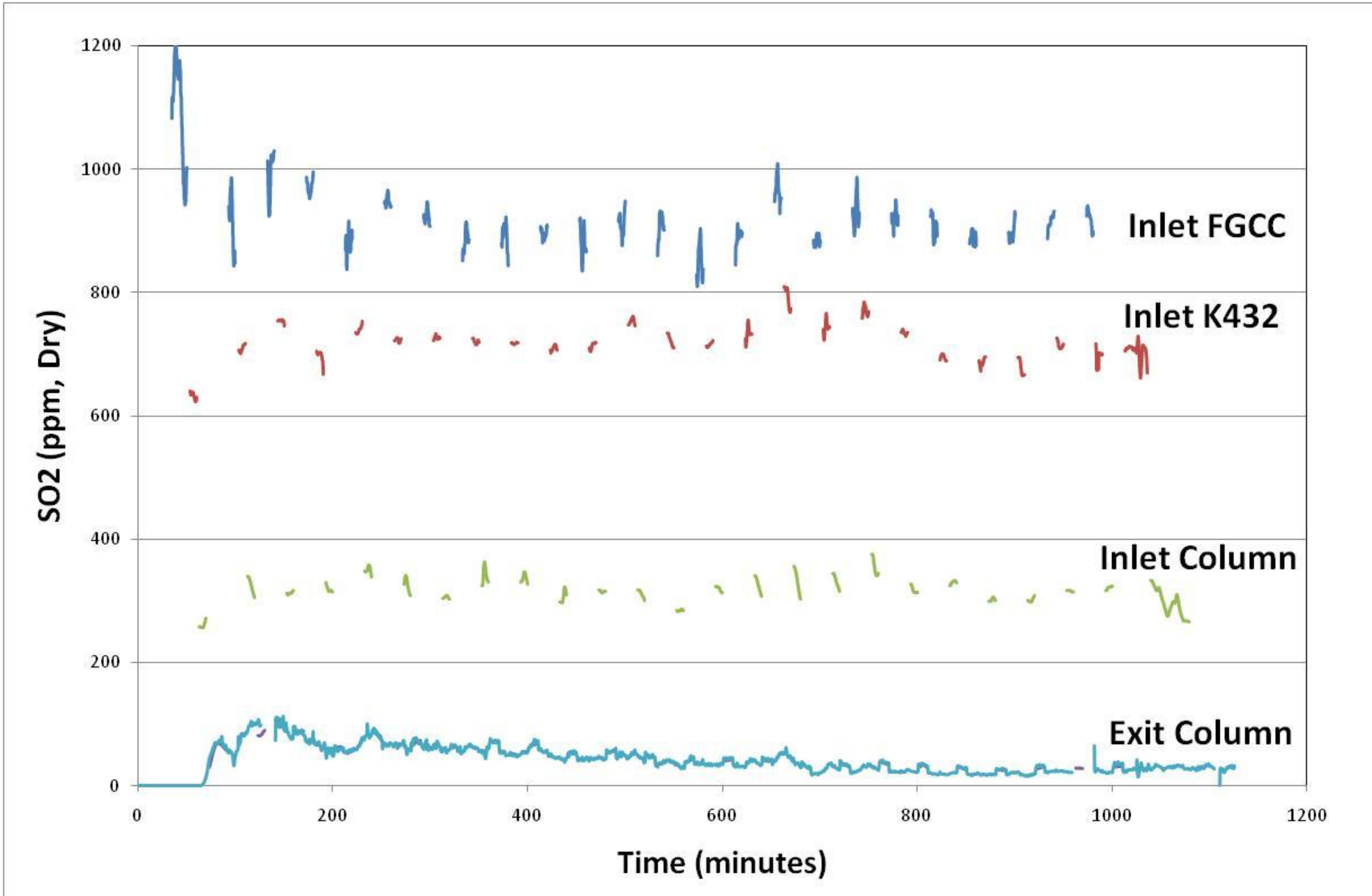
- Need to control where condensate forms
- Temperature – Pressure – composition profile needs to be understood to prevent condensation, as acids will form
- First set of diaphragm compressor valves incorrectly specified with incompatible material
  - Mode of operation caused condensation, hence acid formation
  - Not all stainless steels are equal!

And what happens when the correct valve material is selected:

15 bar column

- NOx only (No SO_2)
  - Almost complete NOx removal – 30 bar column polished off the rest
- NOx and intermediate levels of SO_2, taken from up and downstream FGD
  - ~90% NOx removal
  - ~90% SOx removal
- NOx and high levels of SO_2, taken from upstream of the FGD
  - Only preliminary results at the moment at 2500 ppm SO_2 (dry) from a short test just before shutting down for the OxPP burner changeout
  - Results are very encouraging but need verifying when the plant restarts
  - Will be presented when we have more data

50/50 Flue Gas Mix From Before and After OxPP FGD



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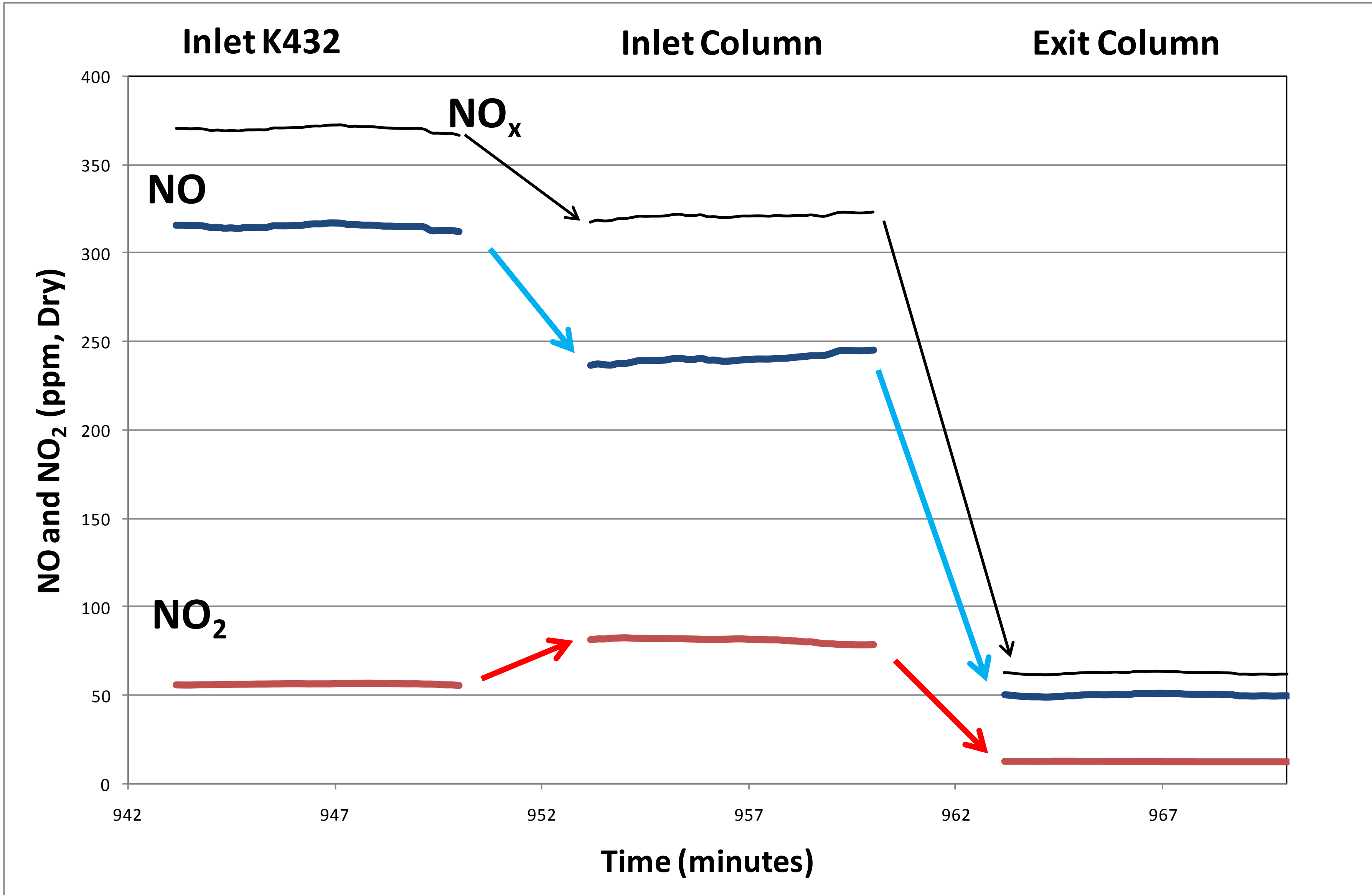
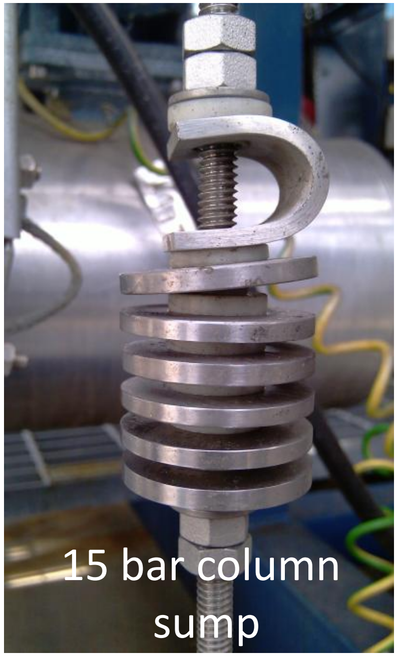


Liquid and Gas Phase Analysis

- Liquid analysis for nitrate/ite, sulphate/ite
- SO_2, NO, NO_2 analysis of wet flue gas streams is difficult
  - ACPP and OxPP both using new type of analyser from SICK Maihak
    - Calibration is complex and unique to each analyser
    - Multi-dimensional calibration curve to compensate for NO_2, H_2O, CO_2 (etc) cross interference
  - Results cross-checked with Teledyne and Rosemount analysers where possible
- Very easy to believe analysers – more difficult to cross check and verify
  - But critical to the success of this project
- Also seen N_2O in certain conditions
  - Need more work to understand N_2O formation

Corrosion Coupon Racks

- To help understand materials of construction and the effects of the acids on these materials, corrosion coupon racks were used
- Most coupons just as "shiny" as they were when they were new
- However, as expected, we have seen attack on corrosion coupons that are in the chloride containing part of the system.
  - which is why we have made the dirty end of the FGCC out of fibreglass.


15 bar column sump

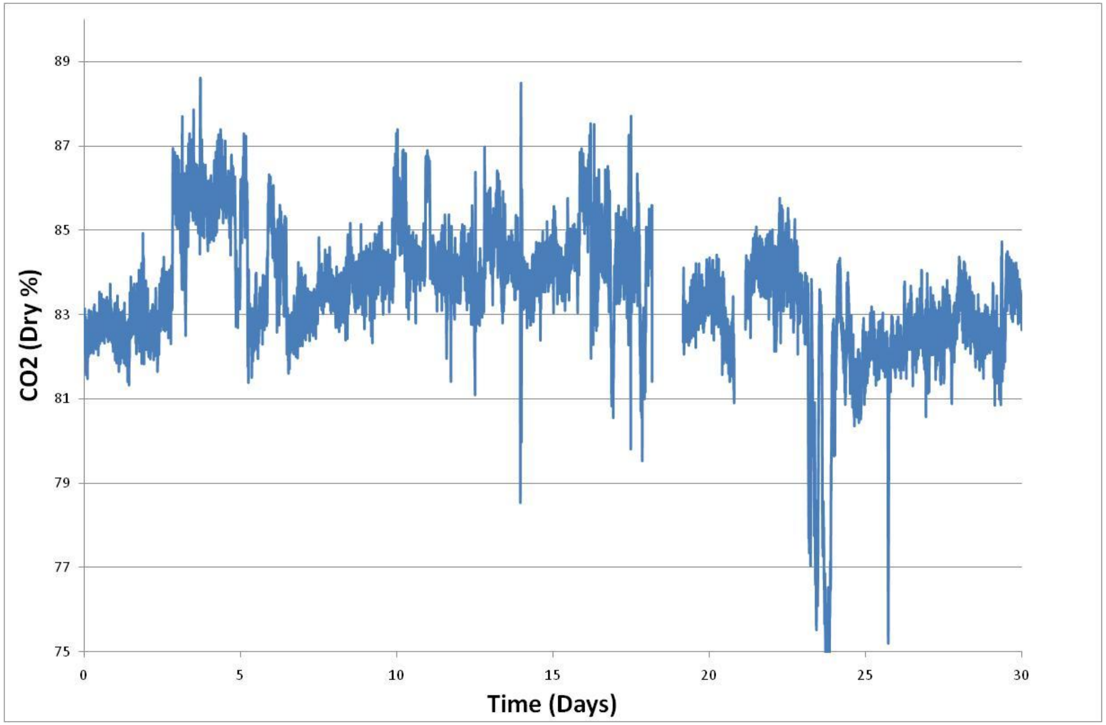

FGCC sump

Auto-refrigerated Inerts removal process

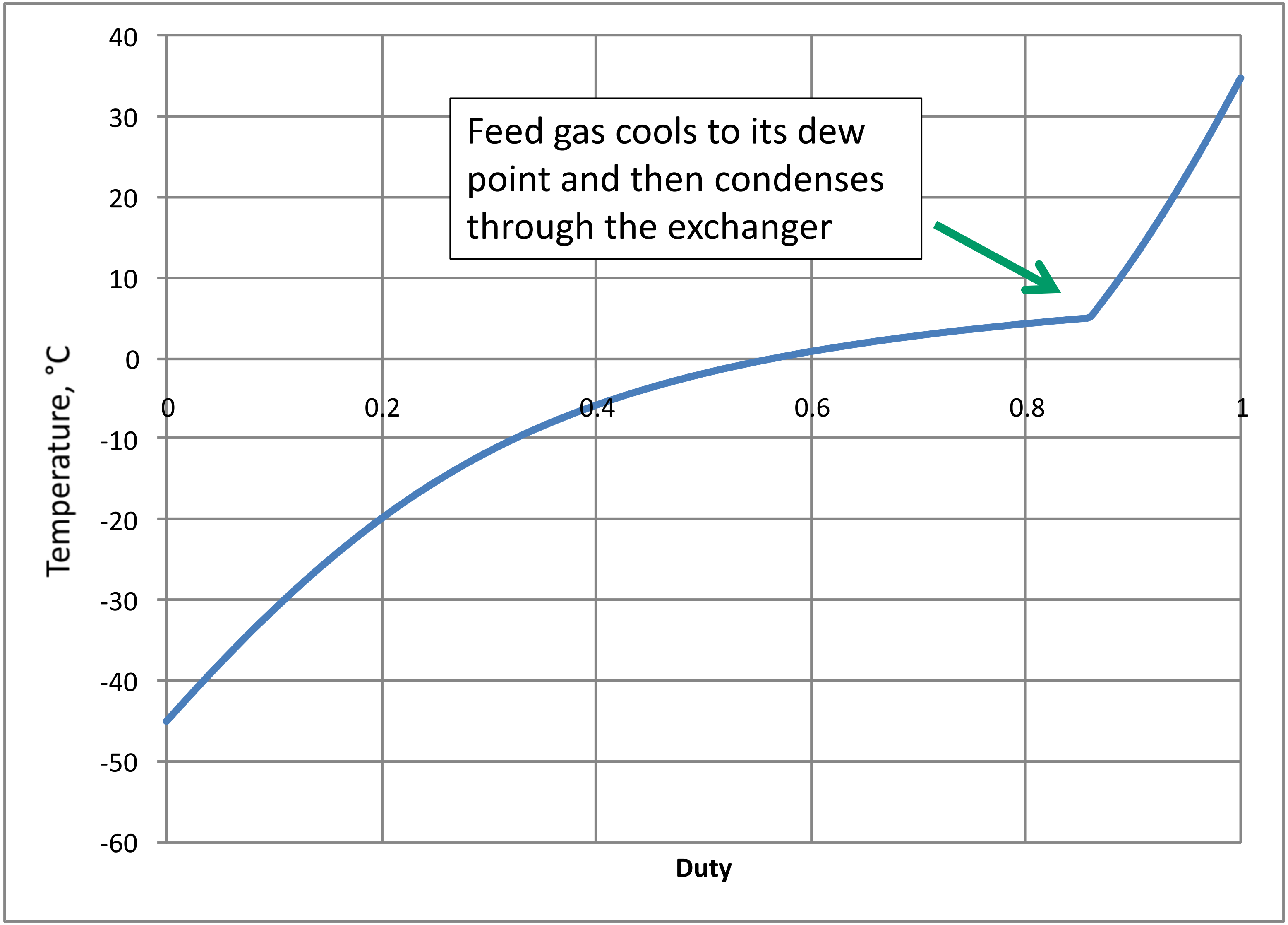
- This is the cold end of the system including the heat exchanger and distillation stripping column
  - Removes N_2/Ar/O_2 from the CO_2
  - Optional distillation column for high purity CO_2
- Process is auto-refrigerated – an integrated, efficient process that uses the CO_2 product as the refrigerant

Feed composition variation

- Variations in flue gas composition from the OxPP
  - Normally 81-87% CO_2
  - But spikes to 89% and drops to 75%
- This variation affects the performance of the inerts removal process
- Understanding the effect on the heat exchanger cooling curve will allow better control, for better performance and higher CO_2 recovery



Cooling Curve Low Purity Mode



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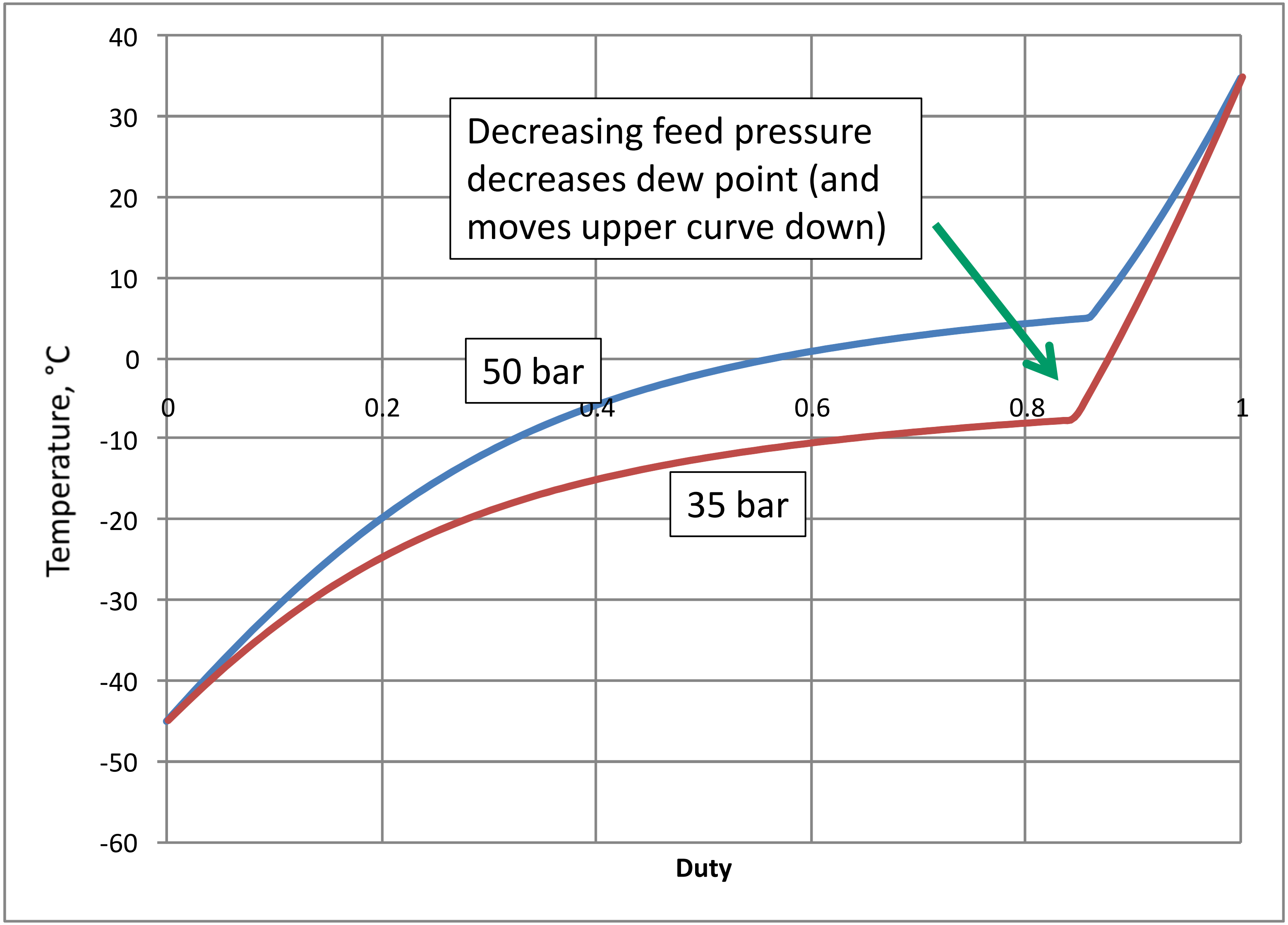

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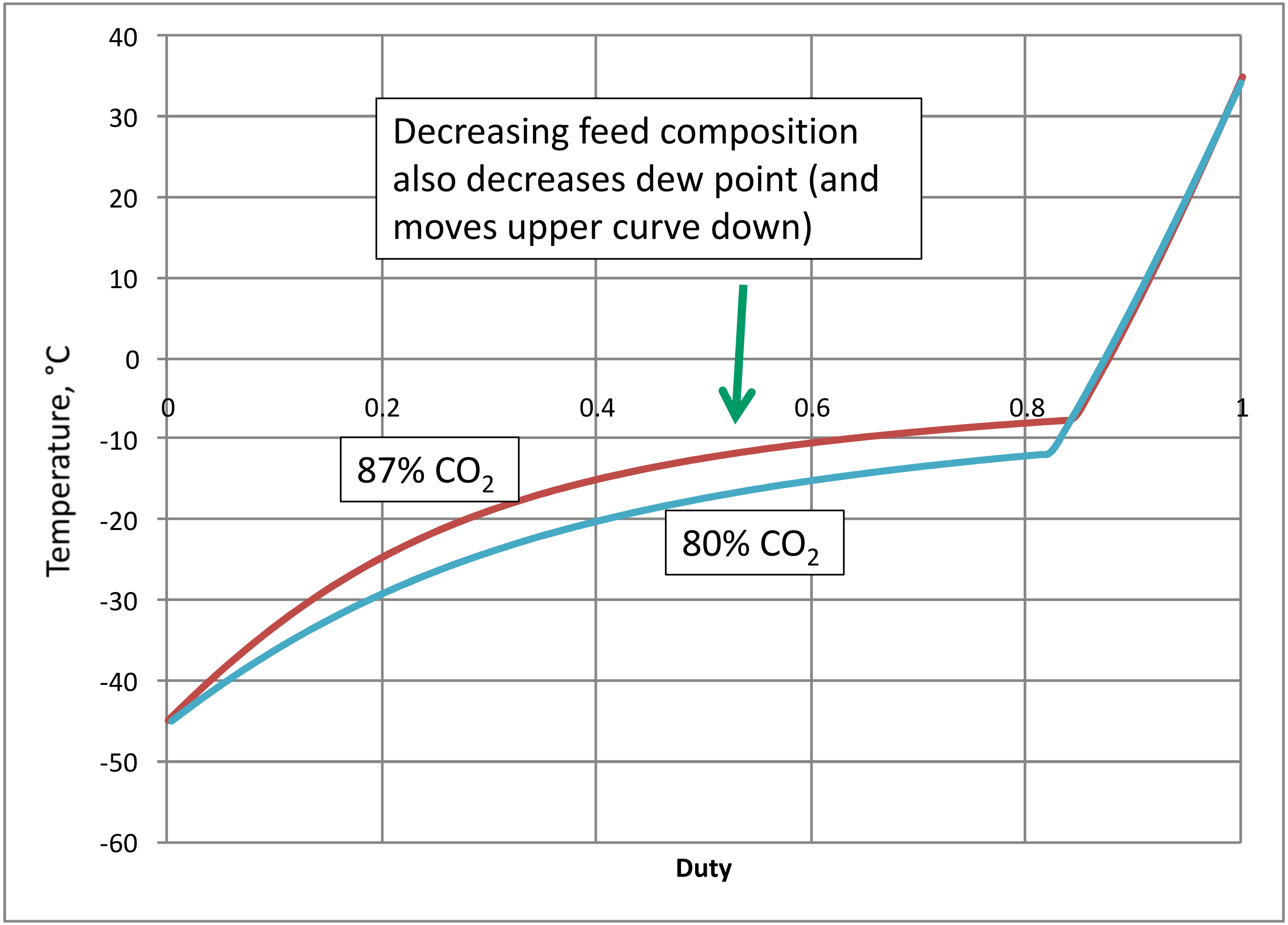

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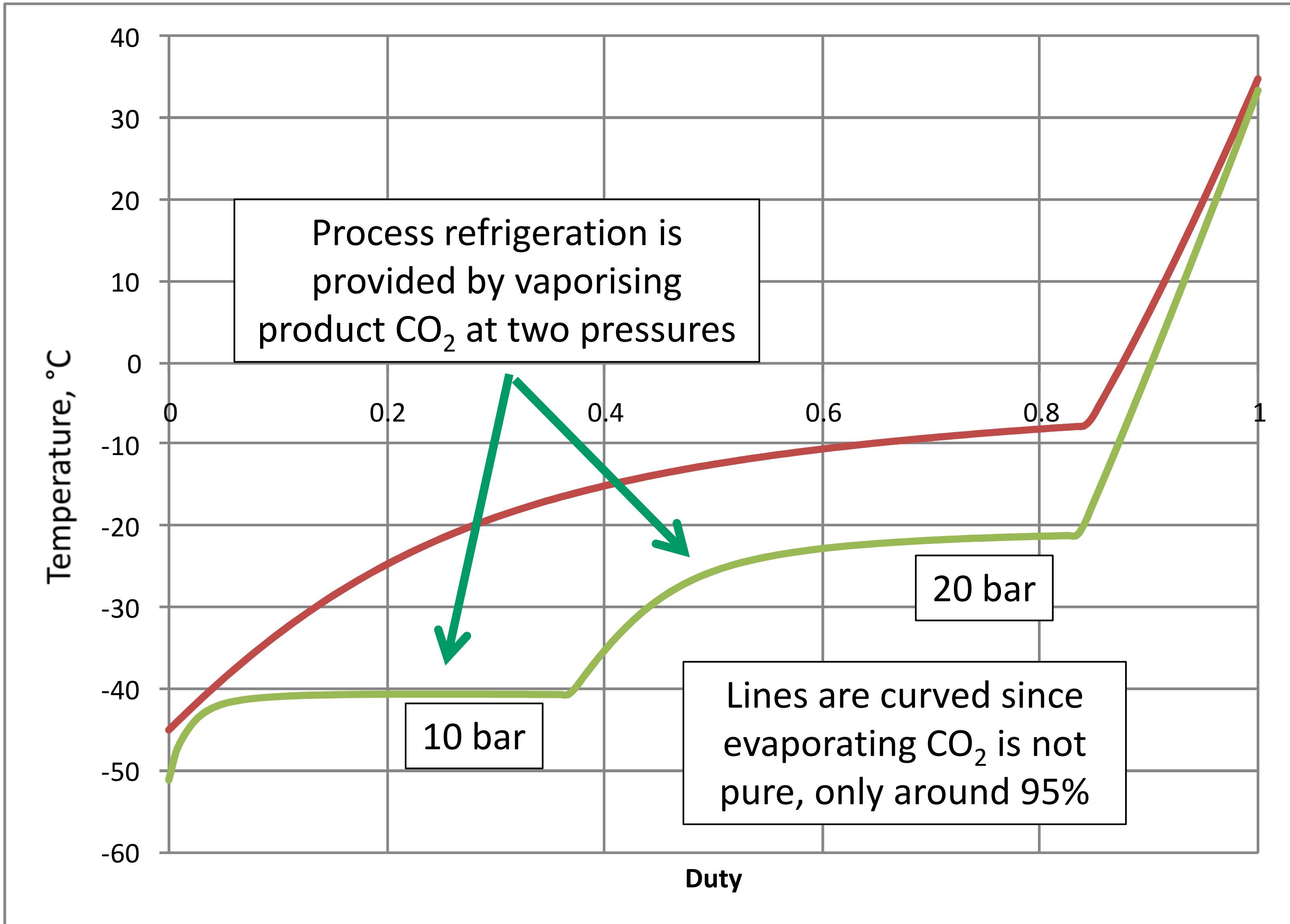

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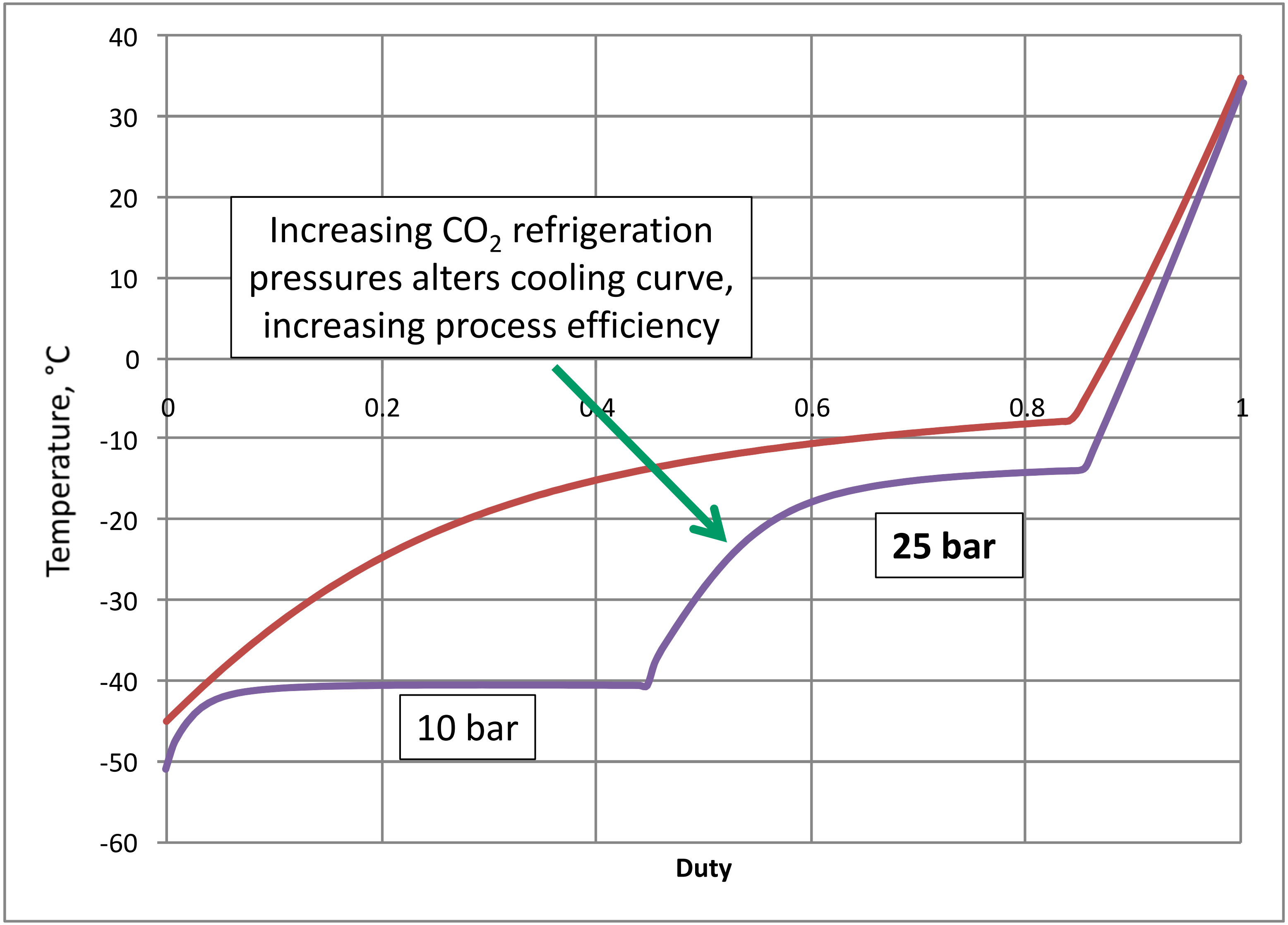

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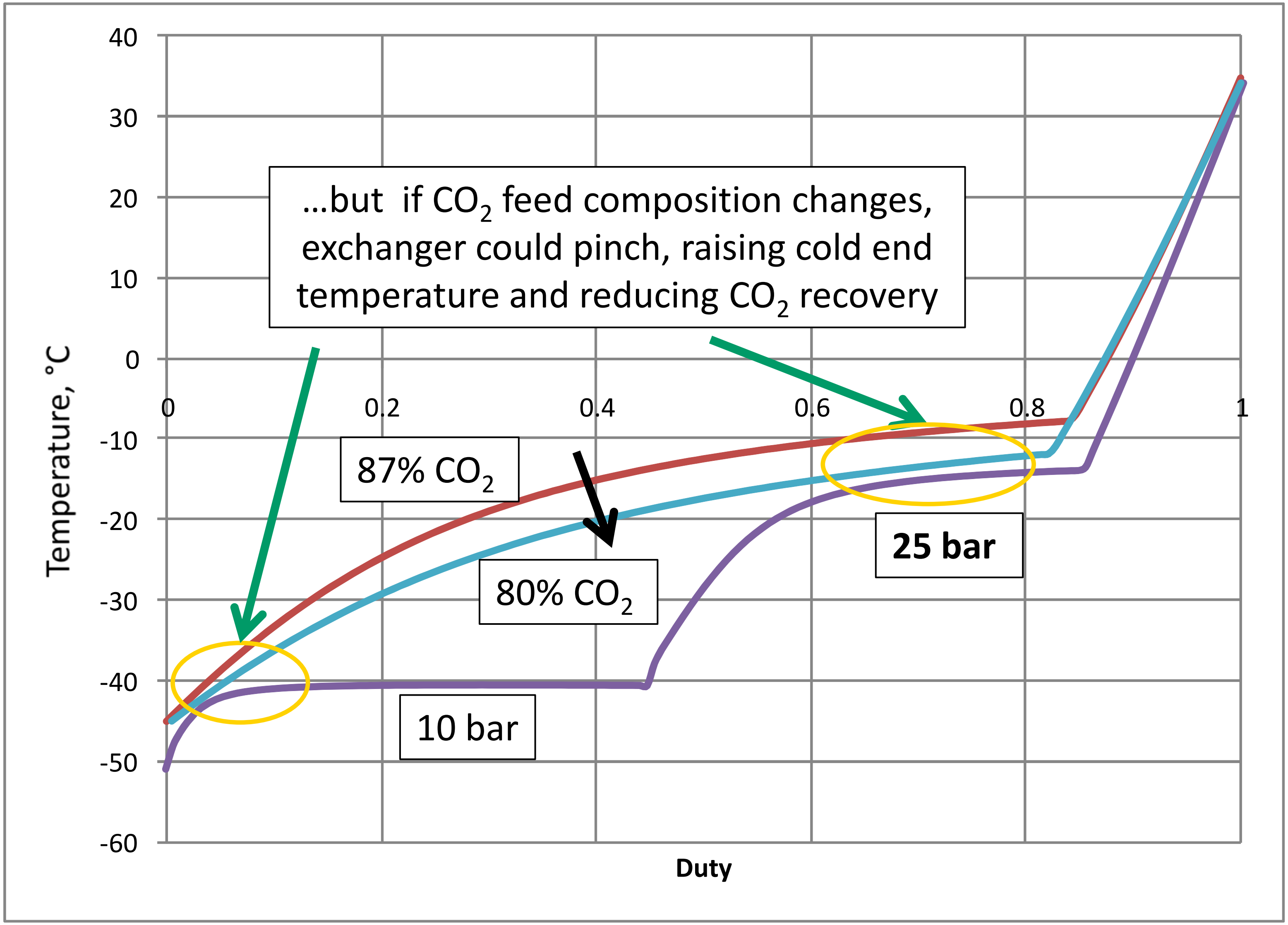
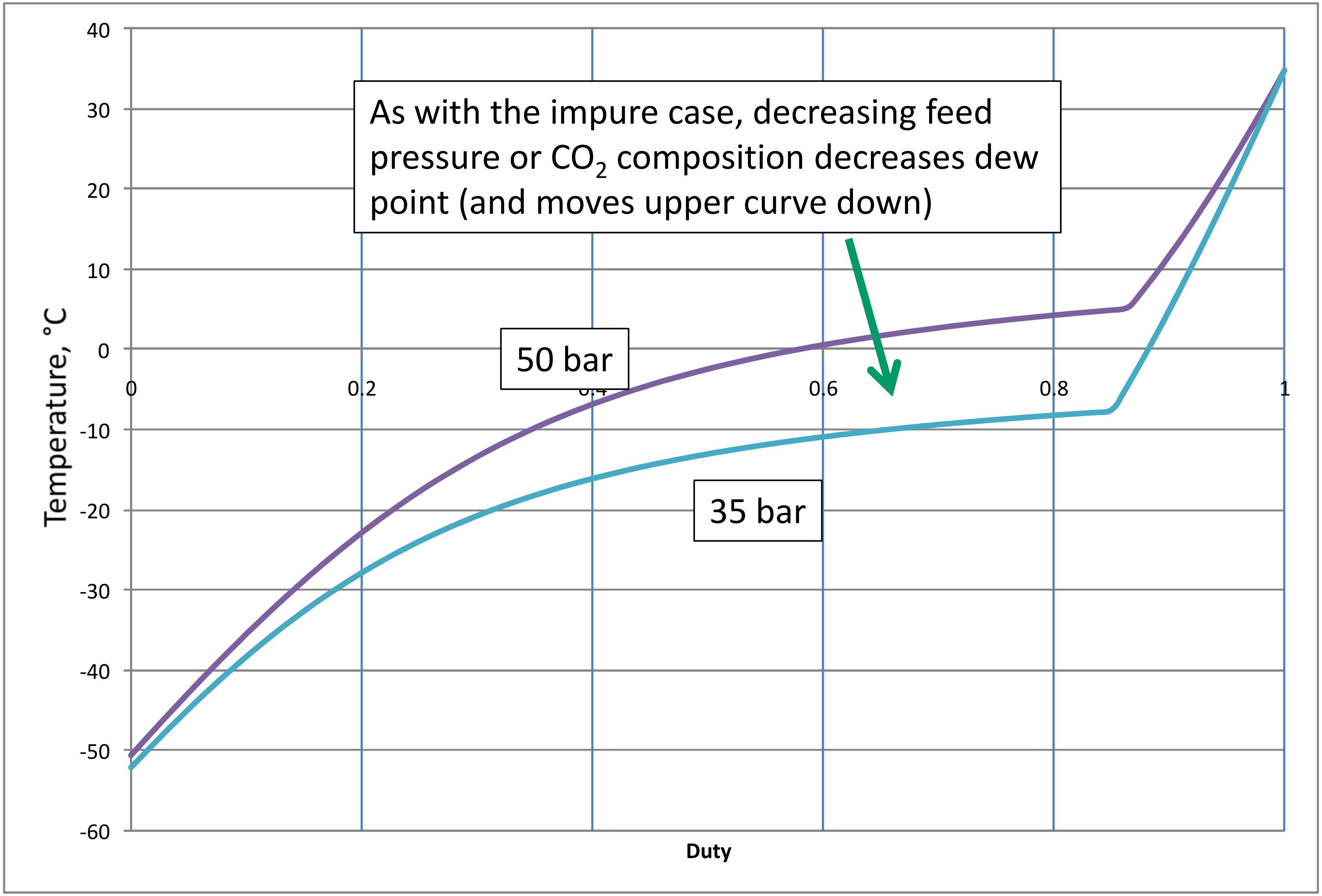


Cooling Curve – Pure CO_2



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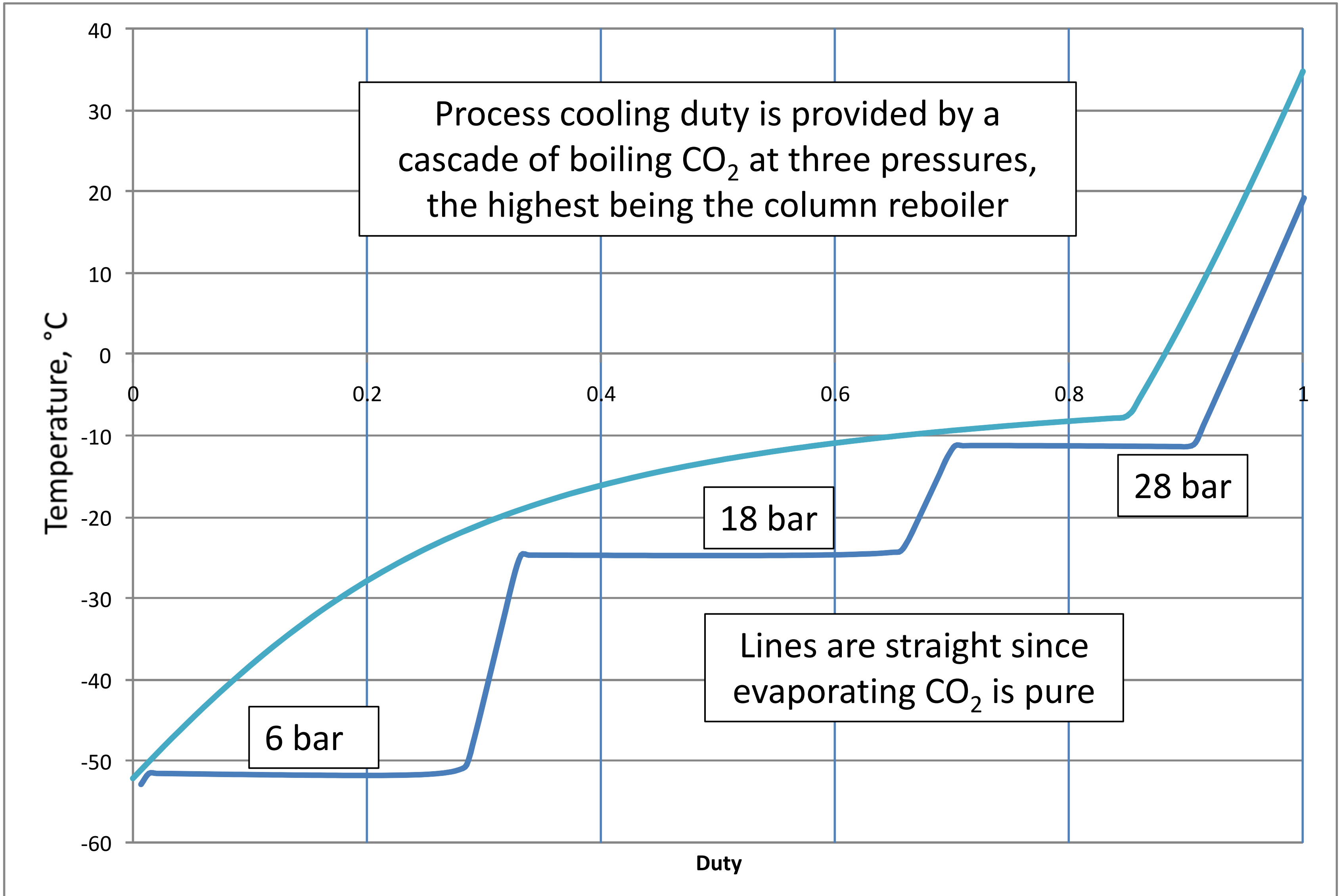

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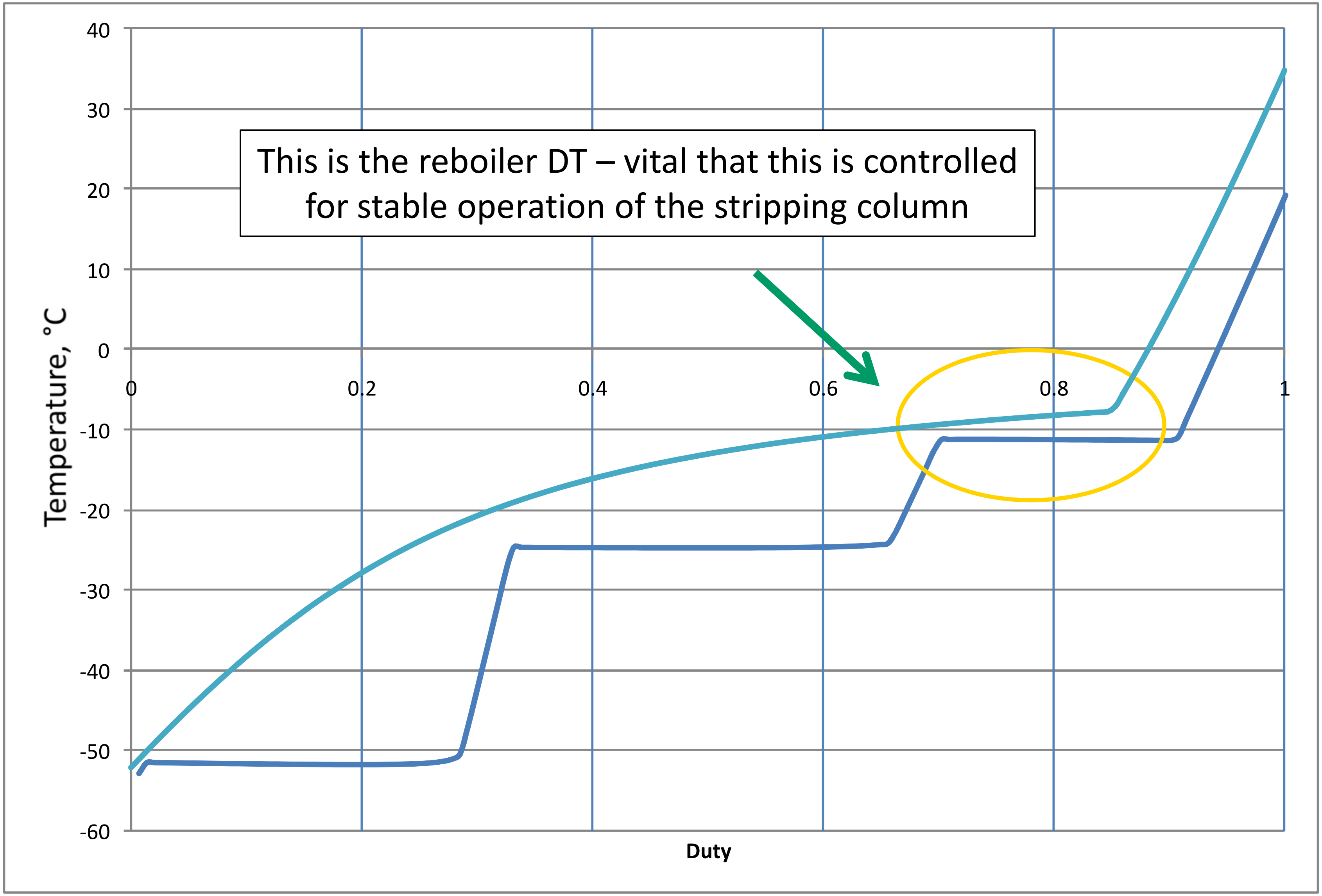

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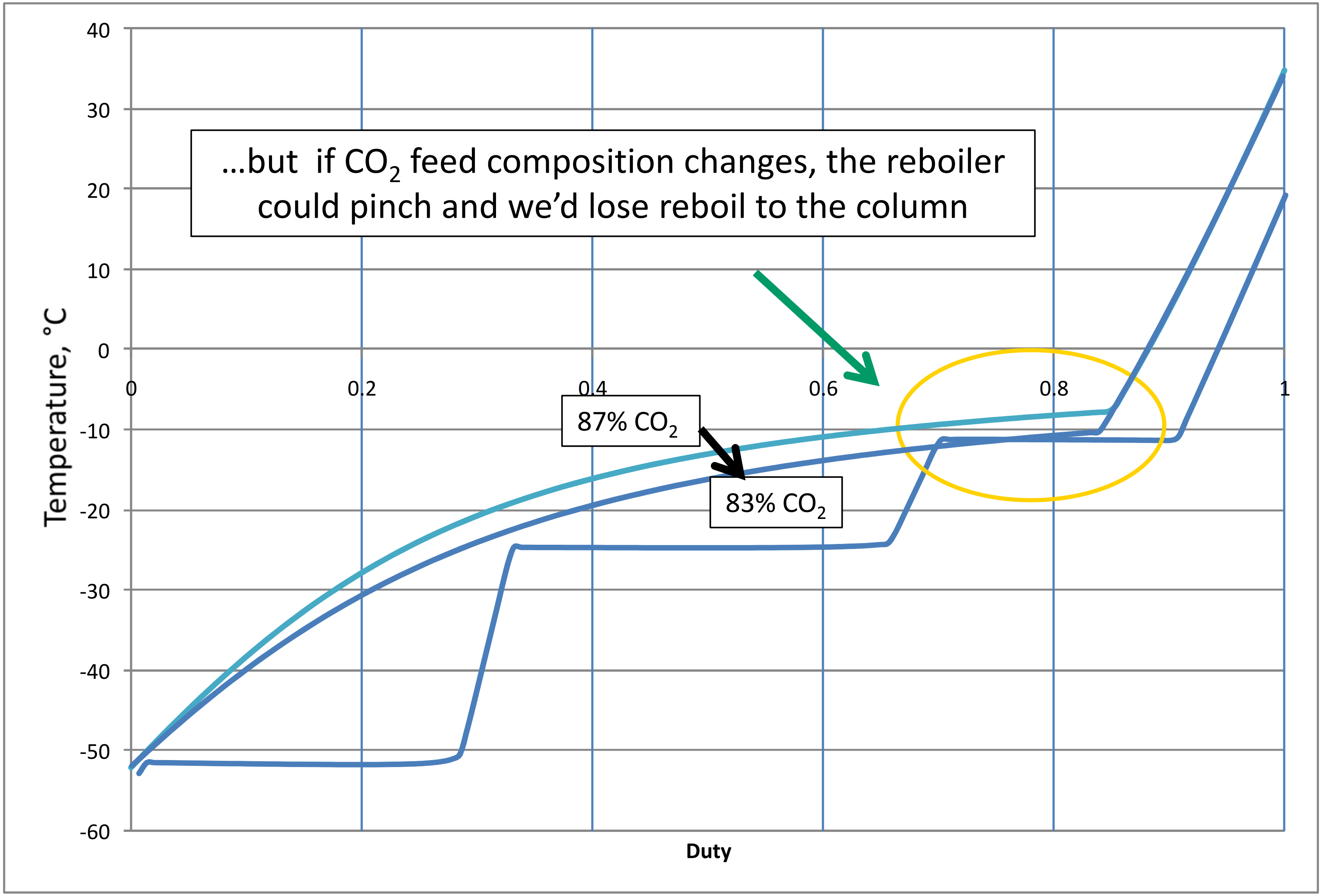

Operation of the inerts removal system

- Disturbances from feed composition variation need to be expected and mitigated
- Feed cooling curve can be influenced by the condensing pressure
- LP CO_2, MP CO_2 and reboiler pressures control heat exchanger performance
- Pressures need to be controlled to maintain the exchanger temperature profile
- Reboiler DT needs particular attention – can't be too wide nor too narrow
- Solution we are adopting is to feed forward the operating pressures from the feed CO_2 composition

Compromises made for the pilot plant

- We do pilot plants to learn and make compromises in the design for many reason, particularly due to the small size of the plant
  - Not practical to use the same equipment that would be used in a full scale plant
- Compressors
  - Due to the required flowrate we couldn't use the turbo-machinery that would be used on demonstration plants
  - Needed to avoid machinery that would affect the sour compression chemistry, such as water-flooded screw compressors
  - Selected diaphragm compressors – not ideal for this application but chosen because of the flow range required
- Inerts removal system
  - To simplify the system a cycle was chosen that included feed compression
  - Reboiler integrated into the main exchanger
  - Small size of equipment increases the effect of heat leak

Conclusions

- First demonstration of Sour Compression in representative equipment
  - Although only limited running so far, results are very encouraging and support the Sour Compression theory
- First demonstration of auto-refrigerated inerts removal
  - Running of the inerts removal process challenging due to the variation of the feed composition and its affect on the heat exchanger cooling curve
  - Understanding this behaviour now means we can set the control system to respond correctly
- Learned many lesson relevant to full scale plant design and operation
  - Operation under realistic conditions
  - Materials of construction
  - Analysis of wet flue gas

- Testing to restart in the Autumn, once OxPP restarts with new burner



Thank you

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