Dynamic Simulation for APC projects

A case study on a Reformate Splitter with side draw

Dr Sebastien OSTA – TOTAL

Jose Maria FERRER – Inprocess

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TOTAL

Introduction

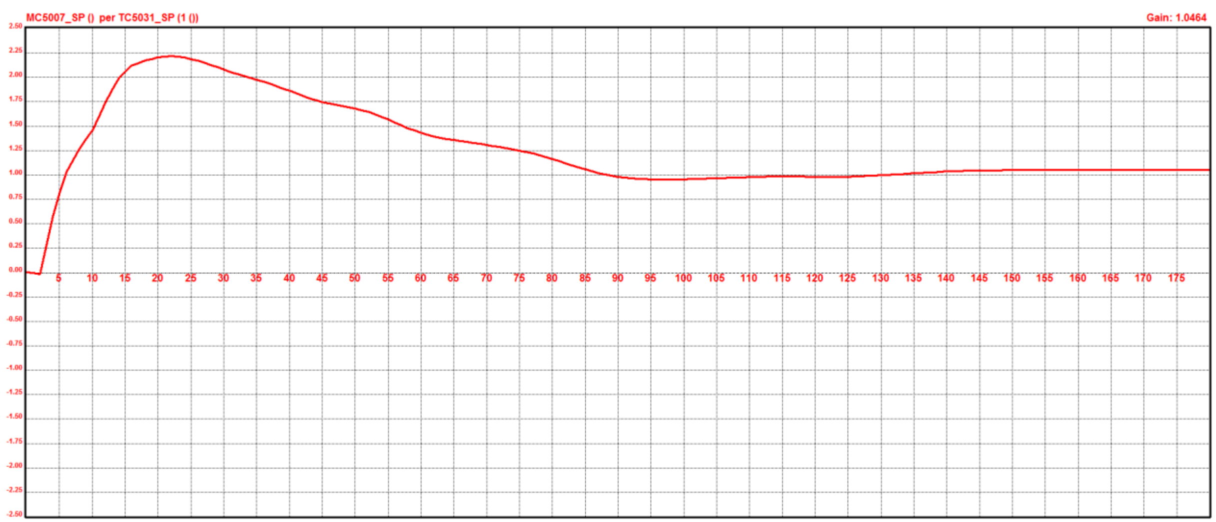
- Steady-state simulation is used traditionally for engineering design, process analysis and troubleshooting, performance monitoring and real-time optimization
- Dynamic simulation is used traditionally for process control studies, operability studies, safety and HAZOP studies and operator training simulators
- Dynamic simulation could possibly be used to assist Advanced Process Control engineers with speeding up the deployment of some APC projects, as well as enhancing the quality of the linear models embedded within the multivariable predictive control applications
- This presentation shows the current status and the preliminary results of a dynamic simulation project applied to the Reformate Splitter at TOTAL La Mede refinery

Agenda

- Vocabulary and Objectives
- Building the Dynamic Simulation
- Exploring the Steady-State Simulation
- Exploring the Dynamic Simulation
- Results

Vocabulary

- **APC** stands for Advanced Process Control – In this case APC refers to Multi-Variable Predictive Control, with the use of **linear models**
- An APC model is the **dynamic** function representing the effect of the change of an independent variable (called here **MV**, i.e. Manipulated Variable) to a dependent variable (called here **CV**, i.e. Controlled Variable)
- As an example, increasing a column tray temperature by 1°C causes the overhead product flow to increase by an extra 1.0464 T/h (i.e. “the **model gain**”), reaching **steady-state** after approximately 150 minutes

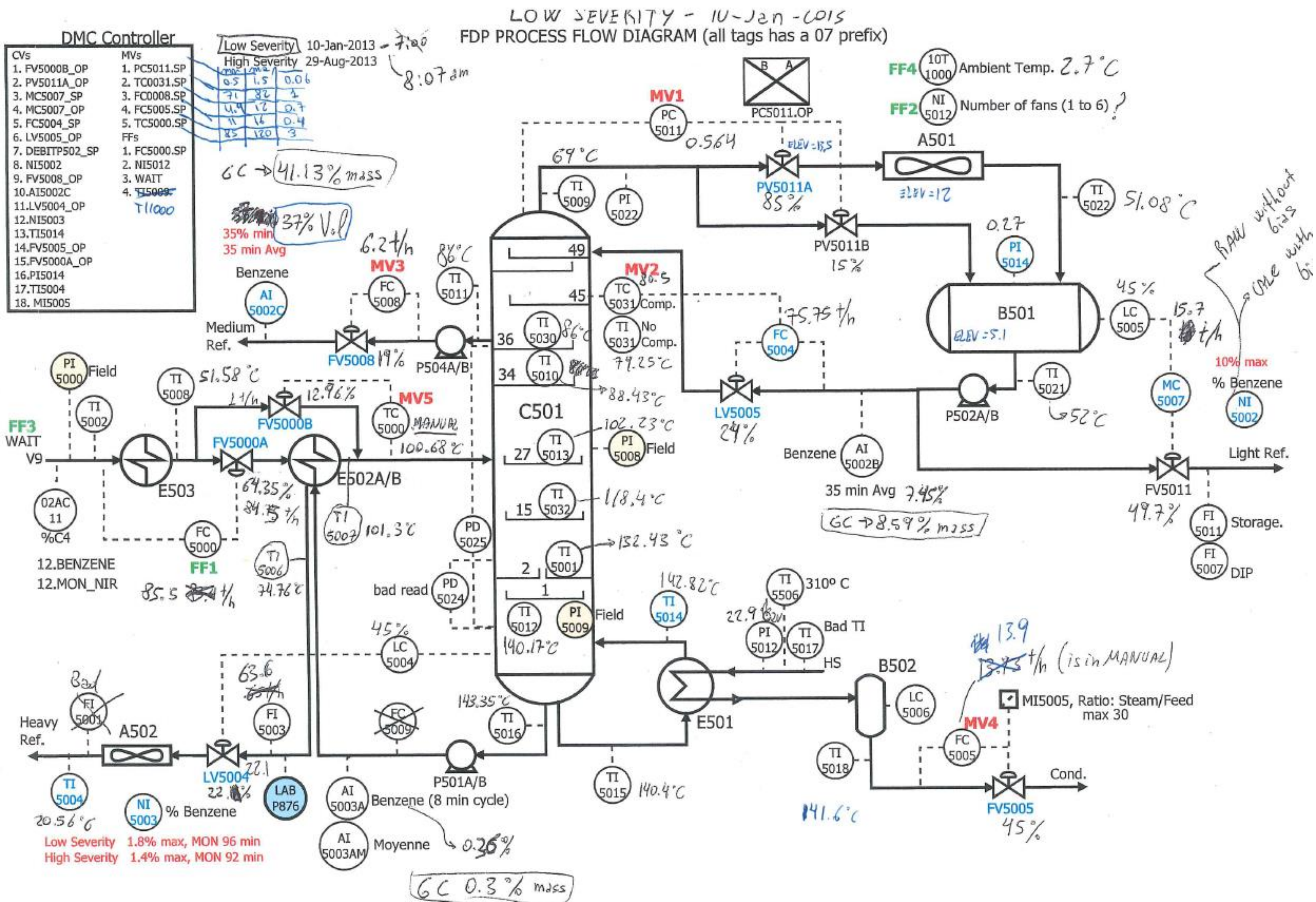


Project Objectives

- Contract a 3rd party, the company Inprocess (specialized in simulation) to build a Dynamic Simulation of TOTAL La Mede Reformer Fractionation Column
- Validate the Dynamic Simulation using online data and check the prediction of benzene concentration in the 3 product streams
- Run step-testing within the Dynamic Simulation, exploring a wide range of operating domains, e.g.:
  - High/Low Reformer severity
  - High/Low Benzene concentration in bottom's
  - High/Low throughput
- Build linear APC models from simulated step-tests data
- Define a strategy to account for non-linearities in the process, e.g.:
  - Swap between several linear models depending upon process conditions
  - Use a single APC model with gain adaptation depending upon process conditions
- Re-commission the APC controller and check the results

BUILDING THE DYNAMIC SIMULATION

Reformer Fractionator

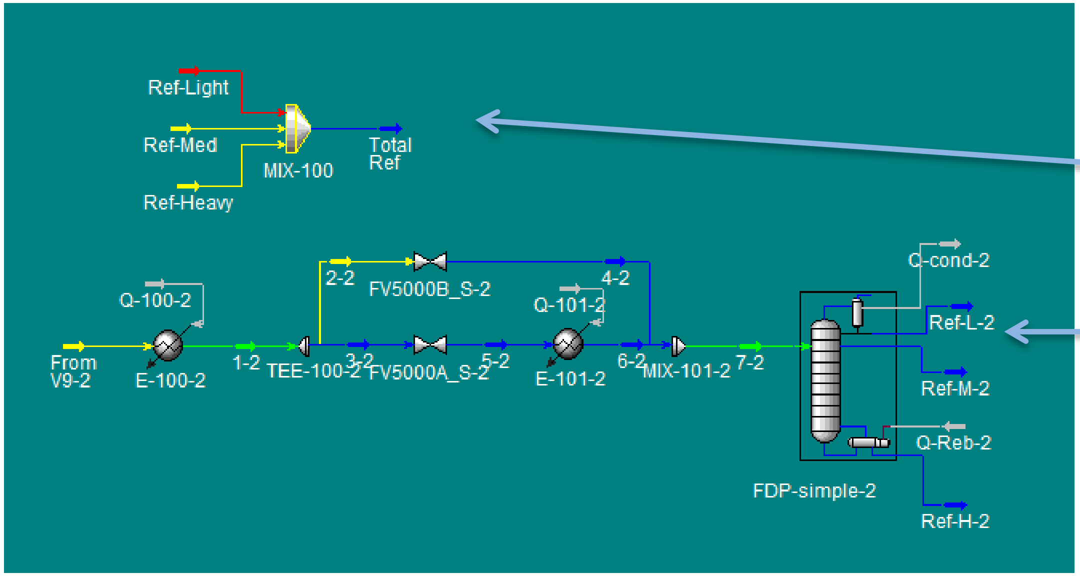


Plant Data

- TOTAL supplied Inprocess with all process data, including:
  - PFD's, P&ID's
  - Vessels, exchangers, air coolers
  - Pumps, column, piping
  - Valves and instruments
  - Process description and test-runs
  - PID controllers and tuning
  - Process and lab data
  - DCS calculations and inferentials equations
- Inprocess' project methodology is to condense all necessary information in a few Excel spreadsheets
  - Component list (101 chemical compounds)
  - Equipment data
  - Tag list, including PID tuning

Steady-State Simulation

- Inprocess first builds the steady-state simulation in Aspen HYSYS
  - Tuned on an agreed test-run (here 2 simulations were made available, for high and low severity conditions on the reformer)
  - This allows to initialize later the dynamic simulation
  - This also allows to run case studies (explained later)

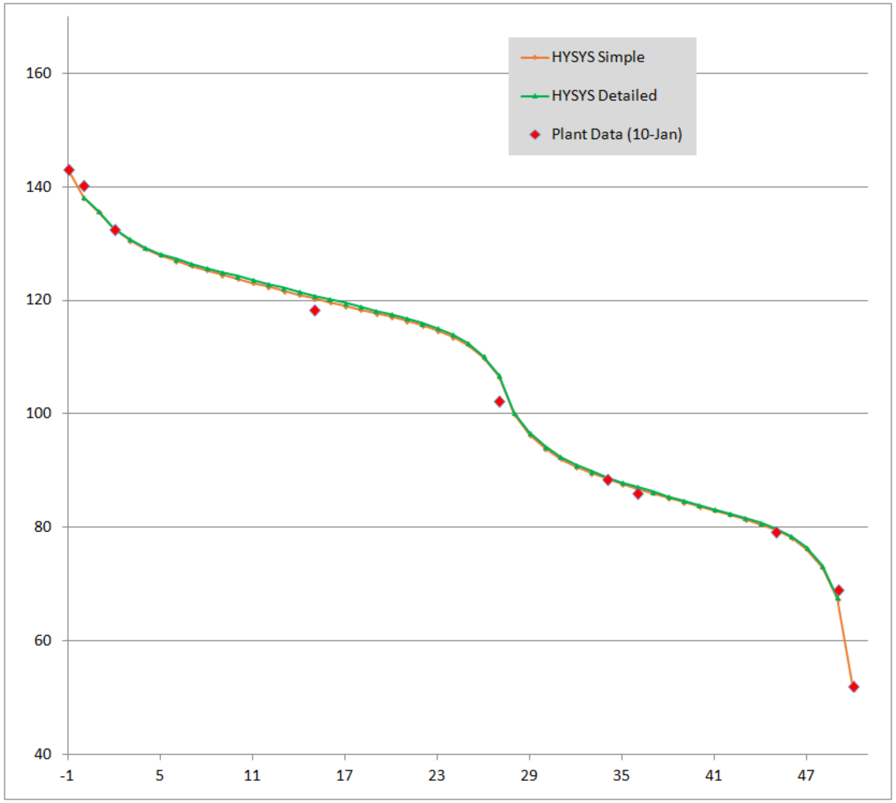


Mixer to recalculate feed composition from products GC

Uses HYSYS standard distillation column object

Validation of the SS Simulation

- The main validation criteria for the steady-state simulation is the comparison of the simulated and actual temperature profiles for the test-run data. Obtaining a similar temperature profile ensures that simulated composition along the column will match with plant data

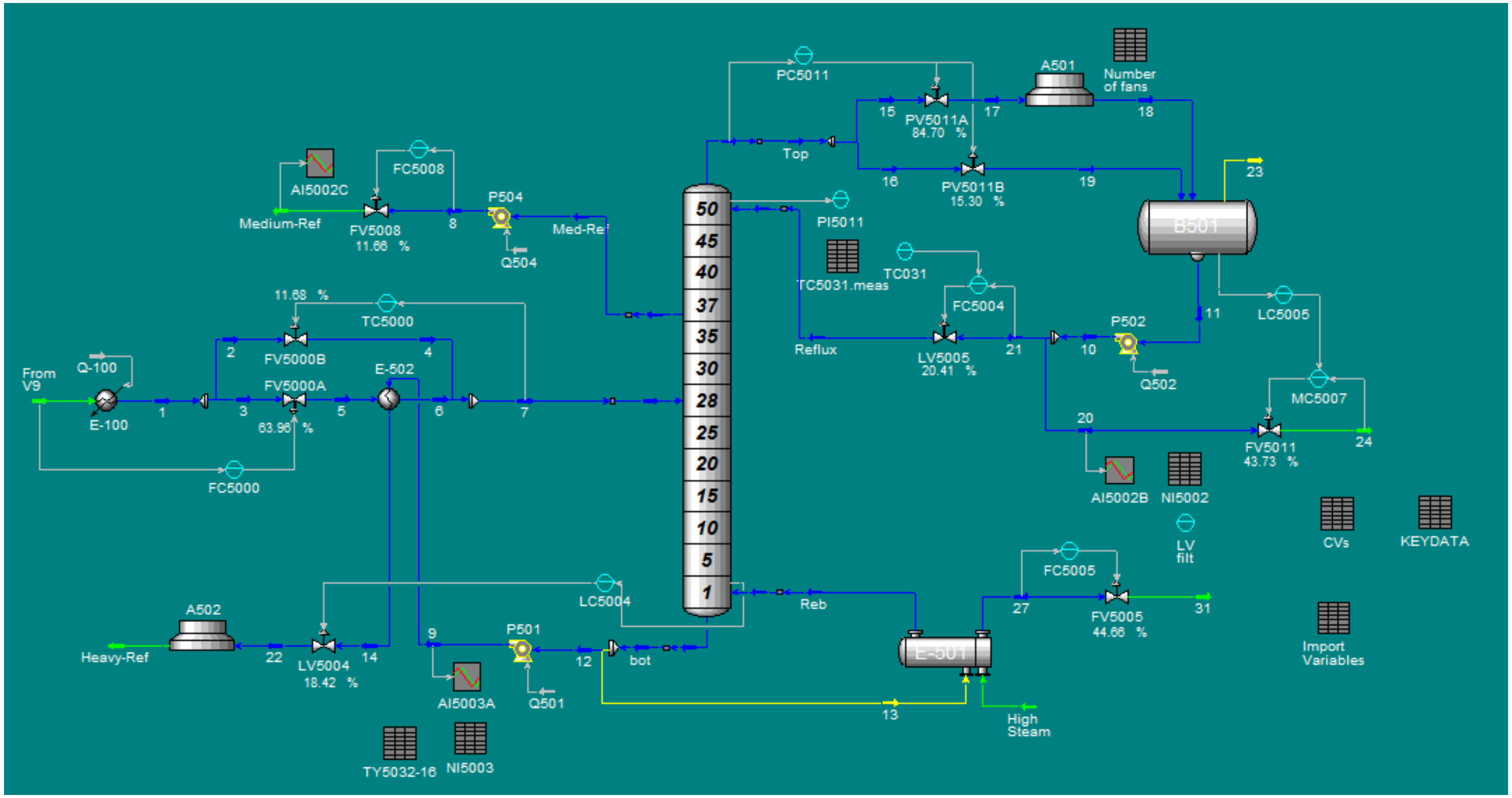


Temperature profiles (Y axis) for the low severity case, as a function of tray number (X axis)

→ The simulated temperature profile matches well the plant data

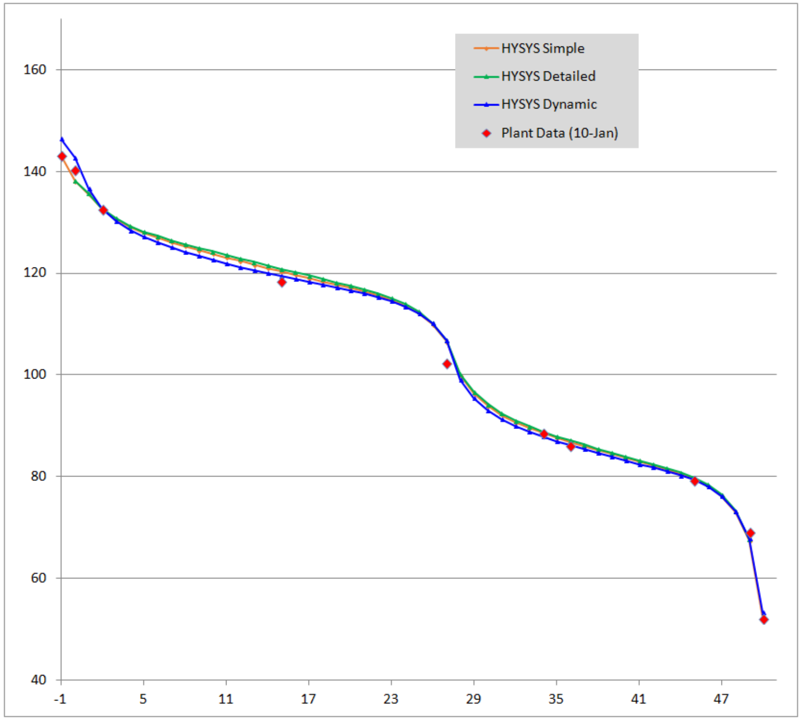
Dynamic Simulation

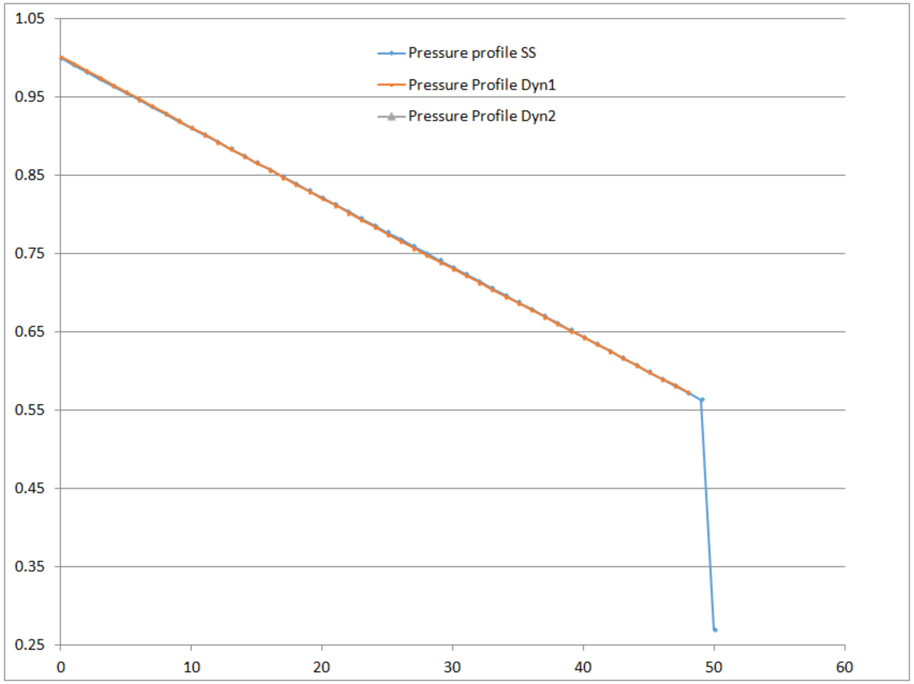
- Inprocess reproduces the plant as-is during the test-run
  - With all equipment characteristics
  - With all valves, control loops and specific PID algorithms (here Foxboro)
  - With inferential calculations (inferential = virtual quality estimator)



Validation of the Dyn Simulation

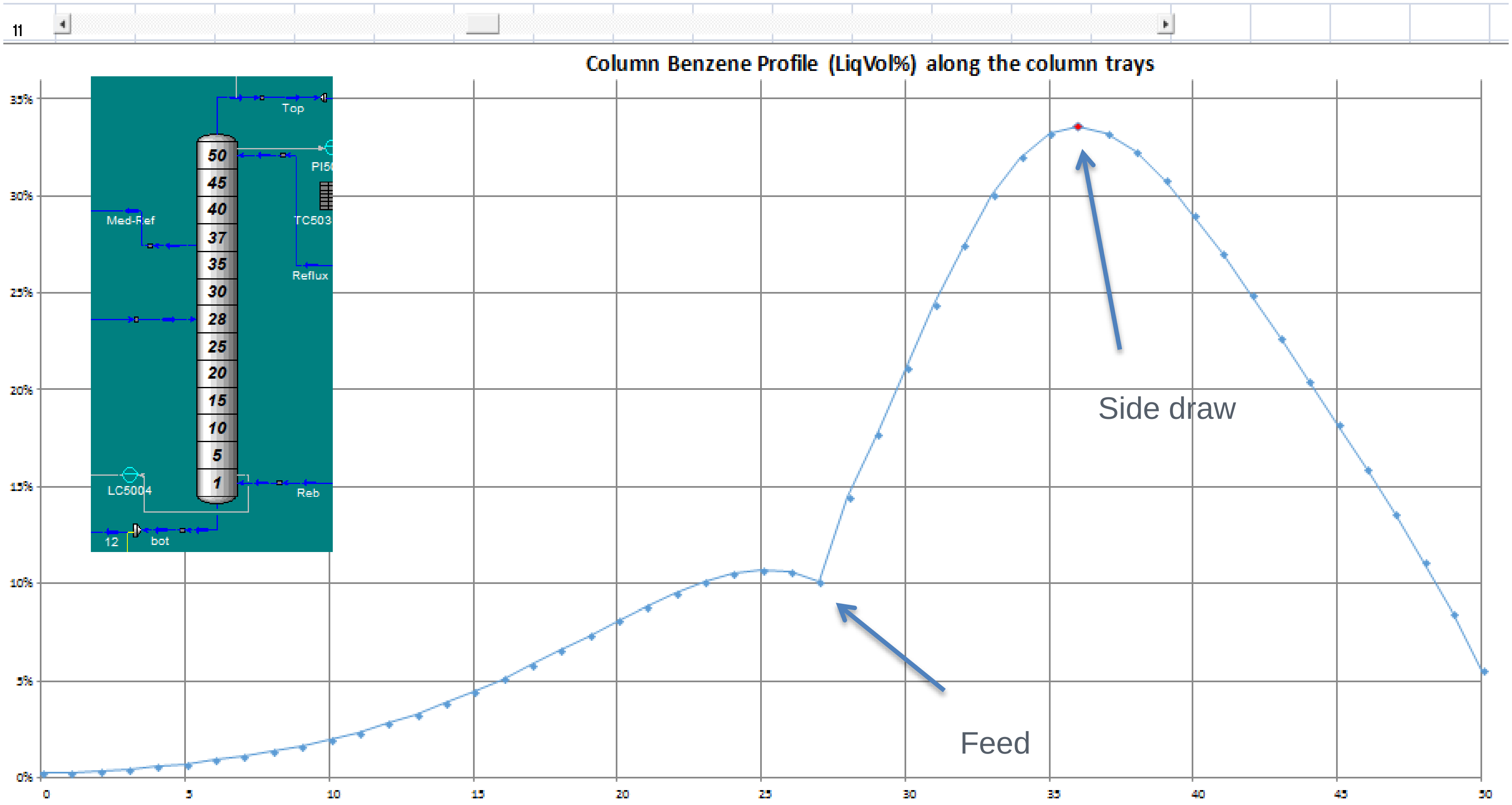
- The main validation criteria for the dynamic simulation are:
  - The comparison of the simulated and actual temperature and pressure profiles for the test-run data
  - The reason for potential differences between the simulated steady-state and dynamic profiles comes mainly from the difference in algorithms used to solve the problem, as well as extra parameters in the dynamic simulation such as the elevation of equipments





EXPLORING THE STEADY-STATE SIMULATION

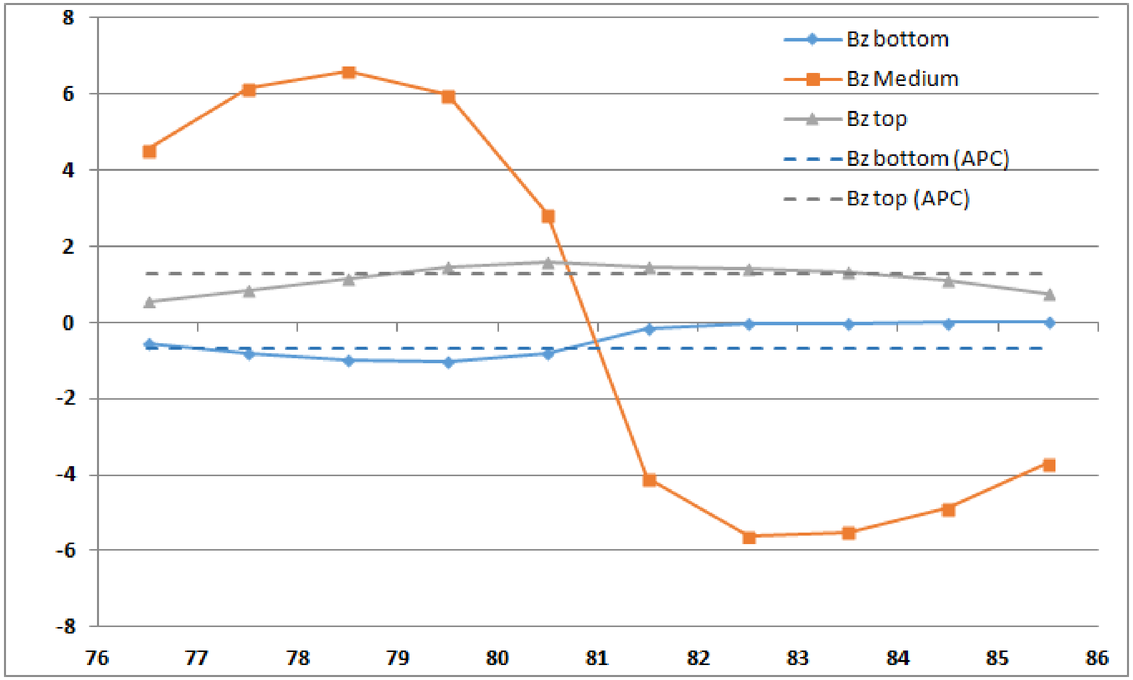
Understanding the Process



Microsoft Office Excel Worksheet

Question #1

1. What are the steady-state gains, obtained from the steady-state simulation, between the APC MV's and benzene concentration in overhead (Bz top), side draw (Bz Medium) and bottom (Bz bottom) products ? How do these gains compare with the gains found from actual step-tests data ?



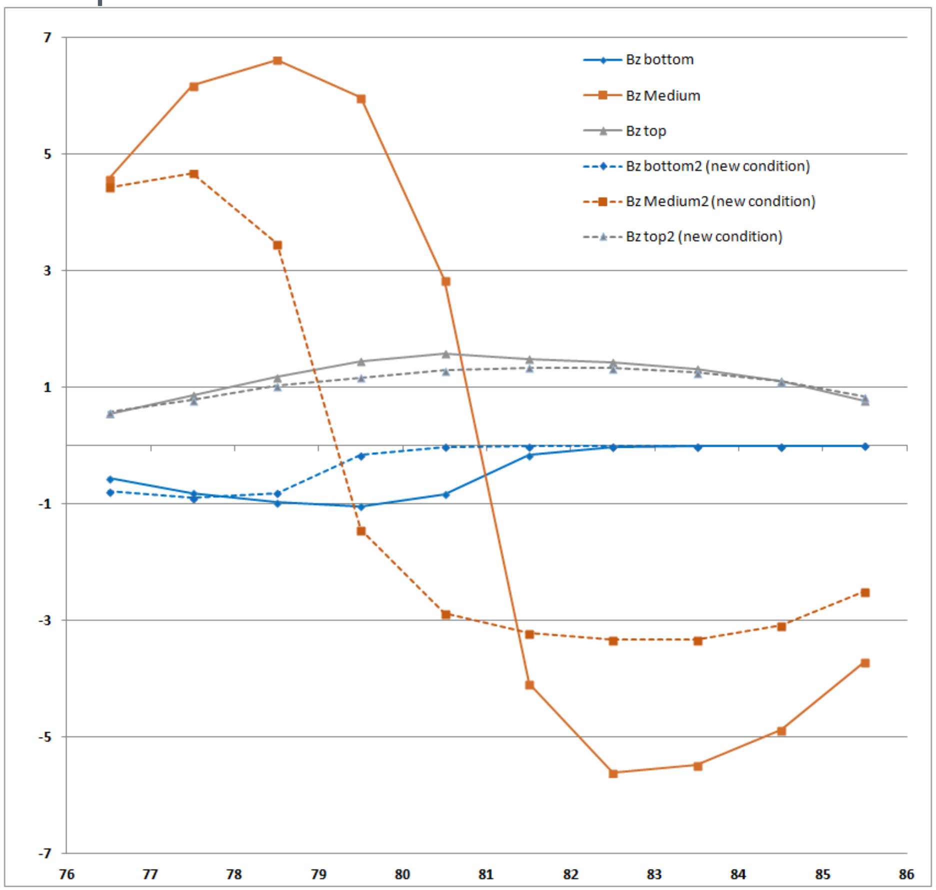
The dotted lines represent the APC gain of the tray#45 temperature to Bz top (+1.29) and to Bz bottom (-0.67), computed from actual step-tests data

→ Strong non-linear effect of temperature to benzene in the side draw, with change in sign

Evolution of the gain of the tray#45 temperature to benzene concentration (%LiqVol), as this temperature increases from 76 to 86°C

Question #2

2. How do MV's starting point influence the steady-state gains ? In other words, are the previous gain functions valid across the entire range of process conditions ?

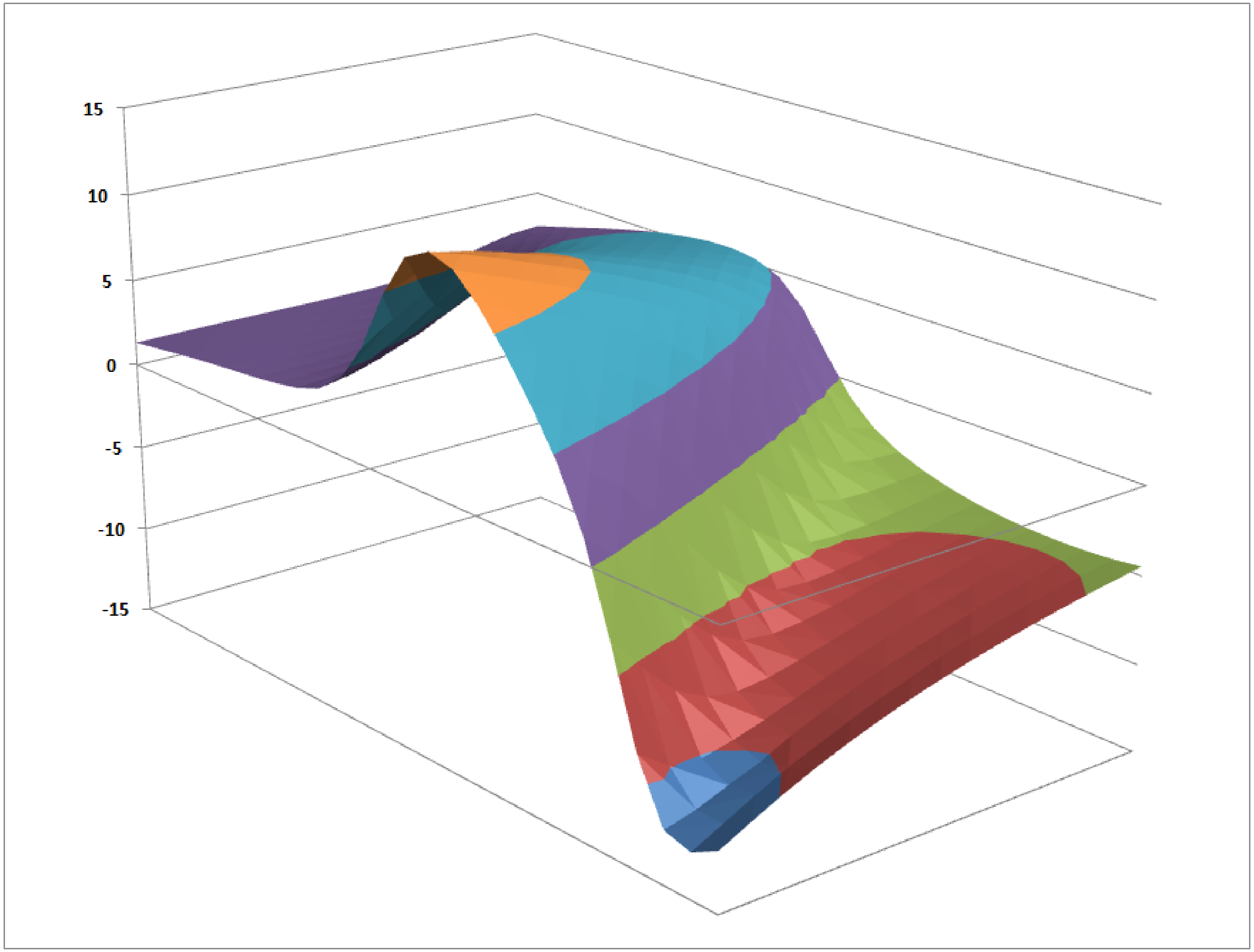


Evolution of the gain of the tray#45 temperature to benzene concentration (%LiqVol), as the temperature increases from 76 to 86°C, with influence of side draw flow

With the same ovhd pressure, the same reboiler duty, the same feed temperature and flow, the side draw flow is increased from 6.2 T/h (base case) to 9.2 T/h (new condition)

→ The gain function of tray#45 temperature to benzene in side draw (Bz Medium) changes significantly, and more importantly, the curve shifts along the temperature axis

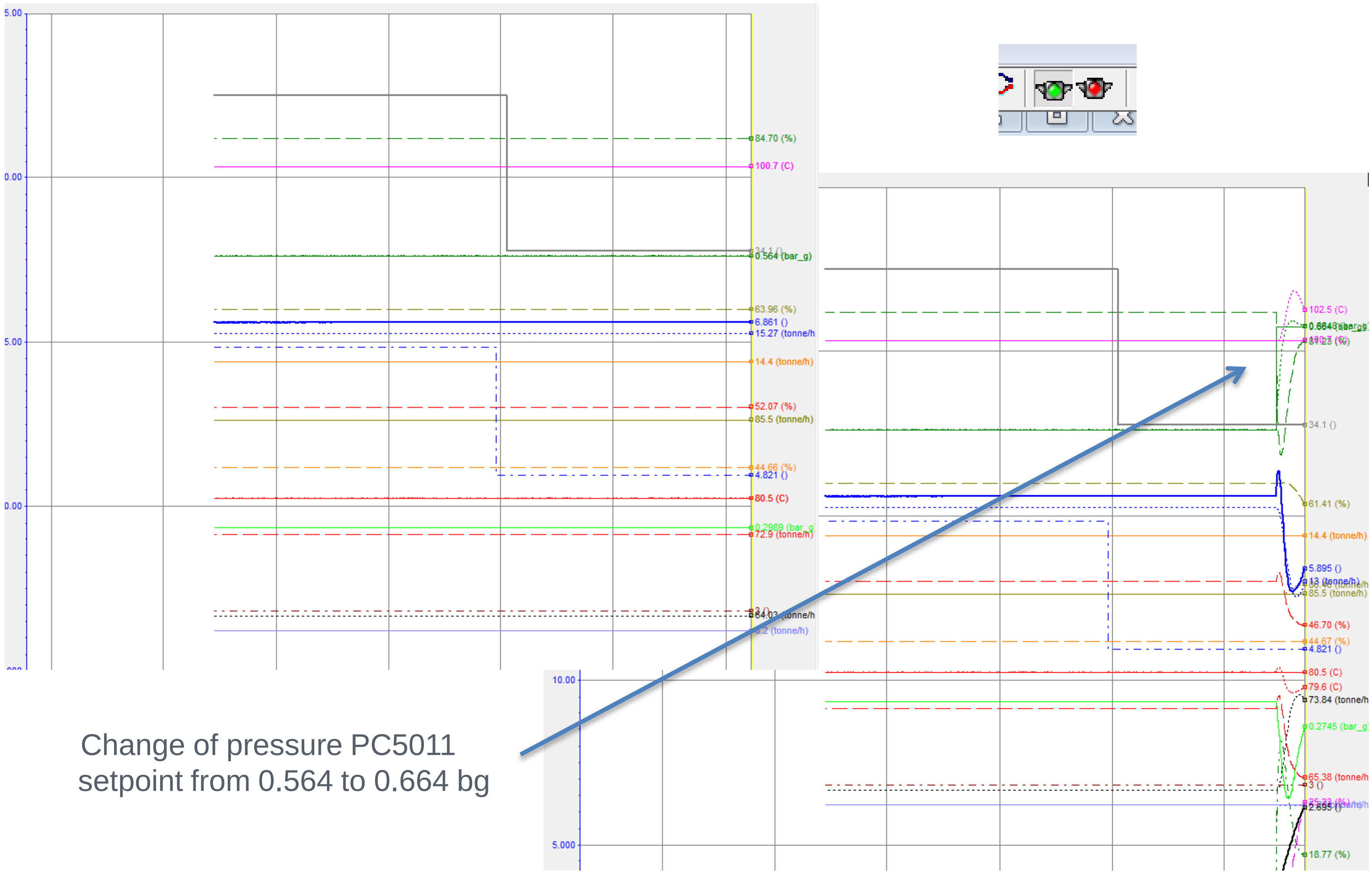
Question #2 – Con't



Another representation of the gain of the tray#45 temperature to the benzene concentration in the side draw, as the temperature varies from 71 to 83°C, and the side draw flow varies from 5 to 12 T/h

EXPLORING THE DYNAMIC SIMULATION

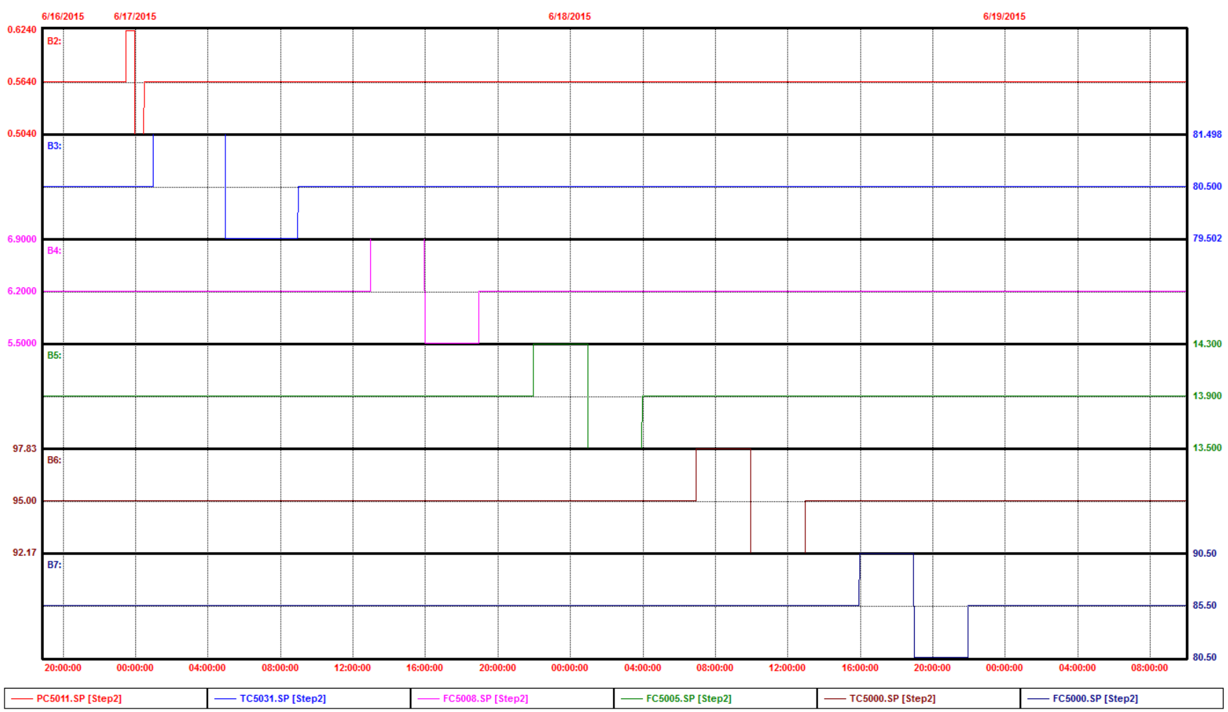
Running the Dyn Simulation



Change of pressure PC5011 setpoint from 0.564 to 0.664 bg

Question #3

3. How do the gains computed from step-tests data generated by the dynamic simulation, compare with the gains obtained from actual step-tests performed on the plant ?



Automated step-tests in the dynamic simulation

This simulation runs ~ 9 times faster than real time on a standard laptop

→ Step-tests took approximately 4 hours

→ But we didn't explore (yet) the entire envelope of process conditions

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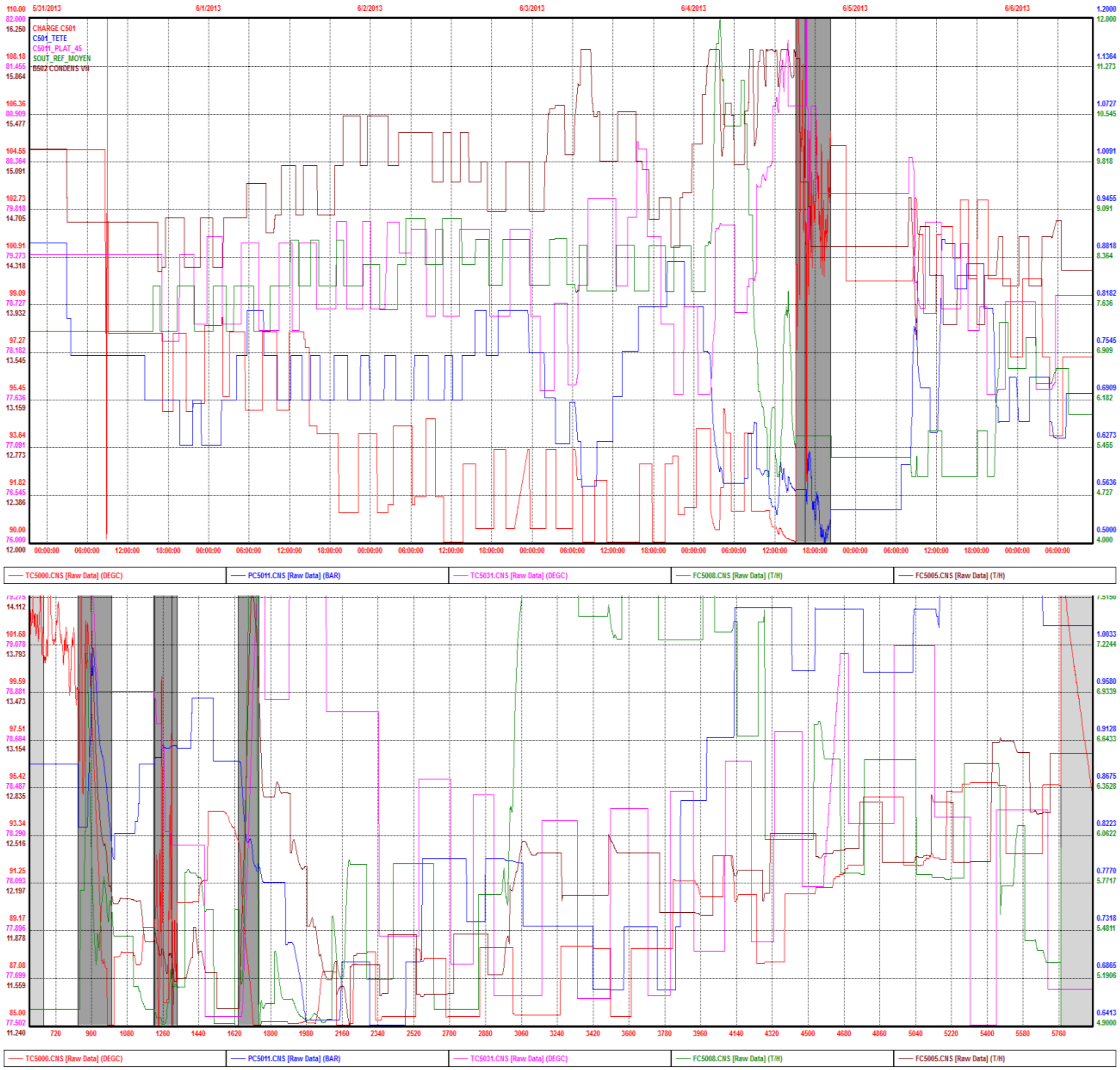
Question #3 – Con't

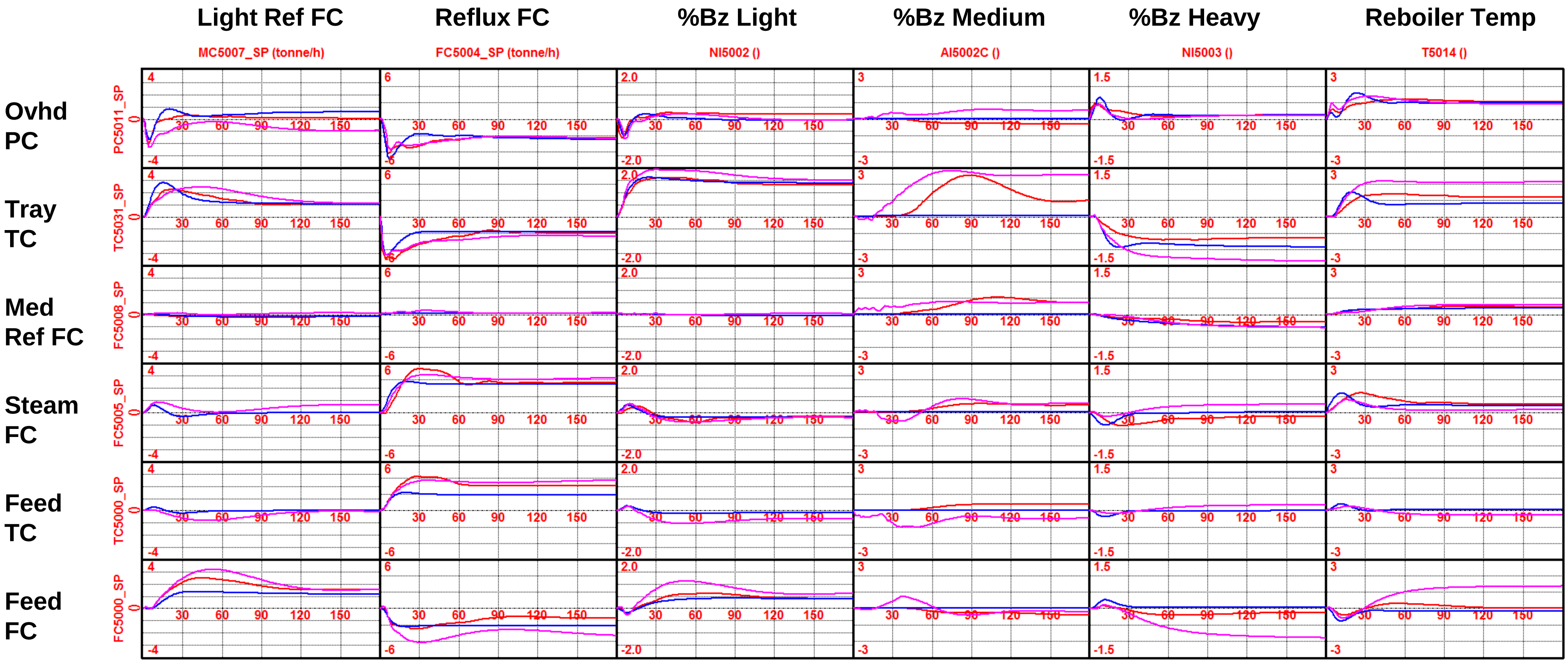


Actual step-tests on the plant

Step-tests took approximately 6 days in 2013, when the plant was running mostly at high severity

4 additional days in 2015 for revamping the APC models, with the plant running low severity, which is now the usual mode of operation

Question #3 – Con’t



Comparison of APC models obtained from

Actual plant data (2013) **Dynamic simulation data** **Actual plant data (2015)**

→ Models are quite close, for both the dynamic shape and the steady-state gain

→ Differences observed for %Bz Medium are expected due to the non-linear behavior

→ Some differences also in the dynamic response of the reboiler

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PROJECT RESULTS

Results

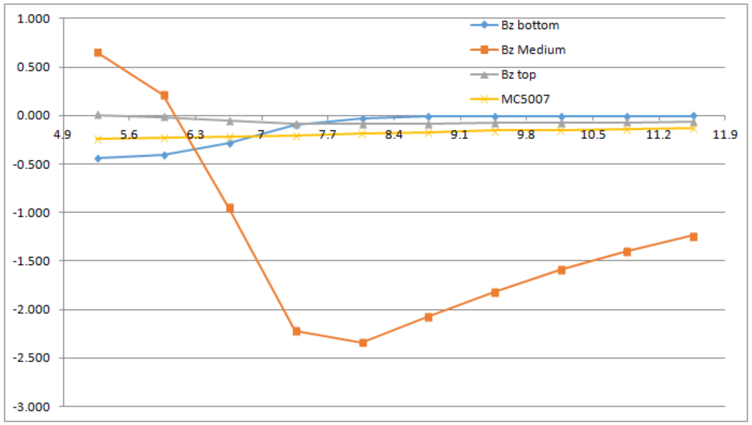
- Confirmed benefits of using Simulation for APC purpose
  - Running quickly multiple case studies, with varying operating parameters on the plant
  - Gaining deep understanding of the process
  - Finding APC-type steady-state gains between MV's and CV's, with the possibility to highlight non-linear behaviors
  - Determining Pressure Compensated Temperature parameters for improved basic control at the plant
  - Generating high quality data for building inferentials
  - Helping with designing APC controller structure
- Revealed benefits from using Dynamic Simulation for APC purpose
  - Performing step-tests like on the real plant but significantly faster
  - Building an APC model that can be used as a 'seed model' for constrained automatic step-testing
- Immediate benefit for TOTAL La Mede was to improve the inferential for benzene concentration in the bottom product
- More benefits are to come once all available data is fully exploited

Thank You

Any Question ?

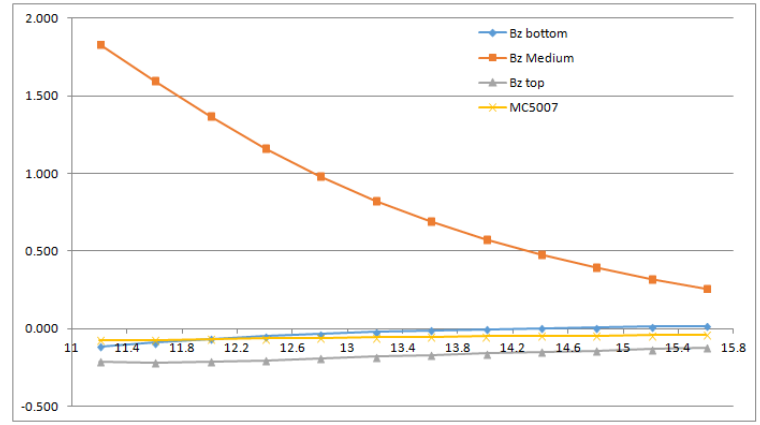
BACK-UP SLIDES

Q #1 – MV Gains



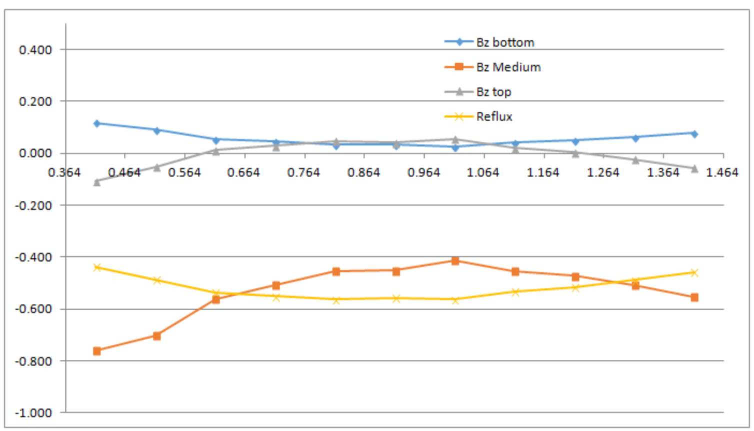
Gain of side draw FC5008

APC gain to Bz top 0, to Bz medium variable and to Bz bottom -0.24



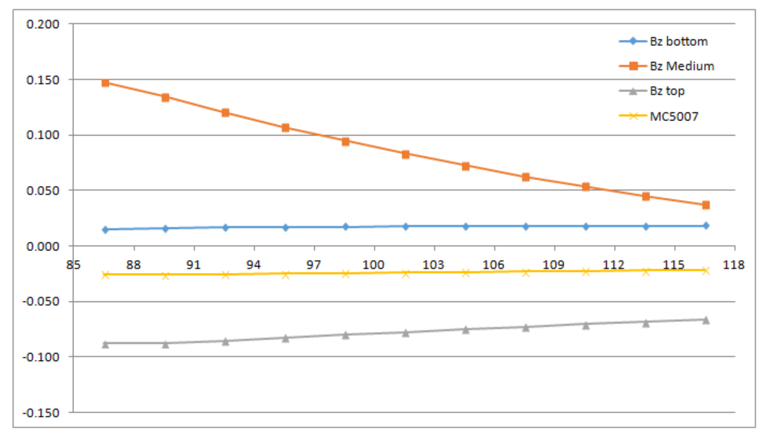
Gain of steam flow FC5005

APC gain to Bz top -0.17, to Bz medium +0.43 and to Bz bottom -0.14



Gain of pressure PC5011

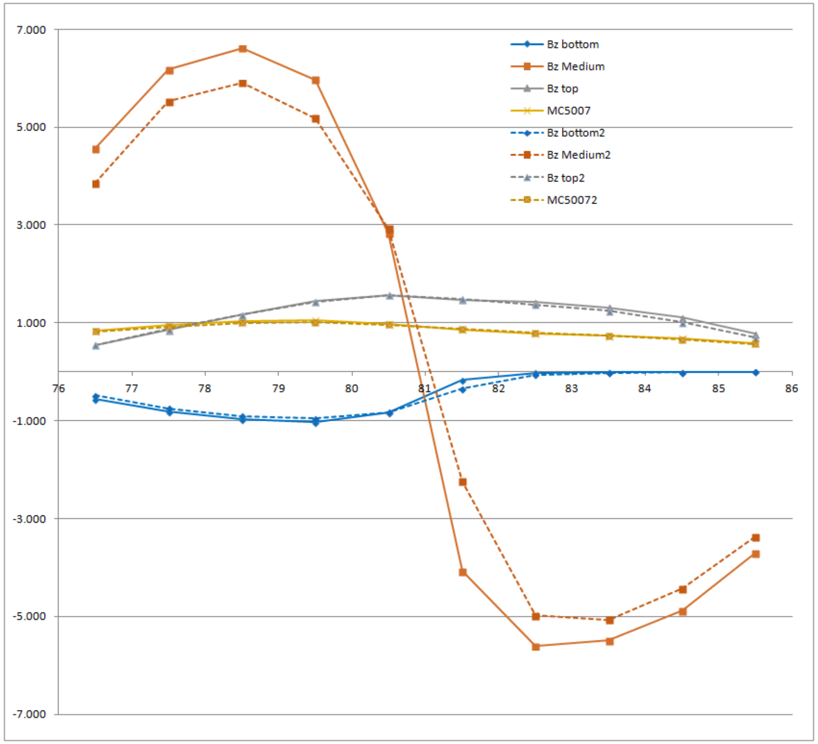
APC gain to Bz top +0.18, to Bz medium -0.33 and to Bz bottom +0.11



Gain of feed temp TC5000

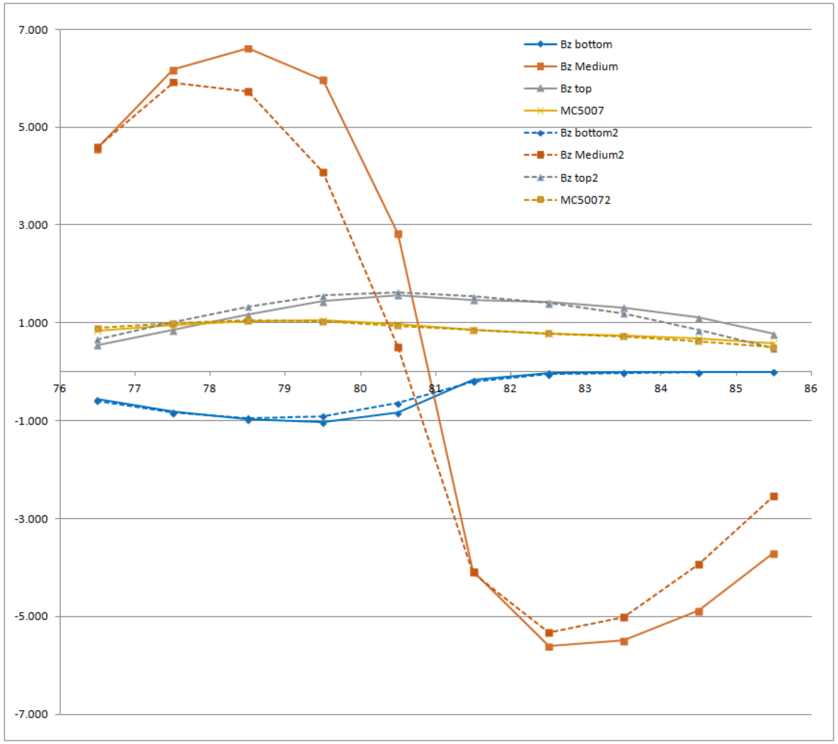
APC gain to Bz top 0, to Bz medium +0.36 and to Bz bottom 0

Q #2 – Influence of other MV's



Influence of pressure PC5011 to gains from tray temp TC5031

1.164 bg vs 0.564 (base case)

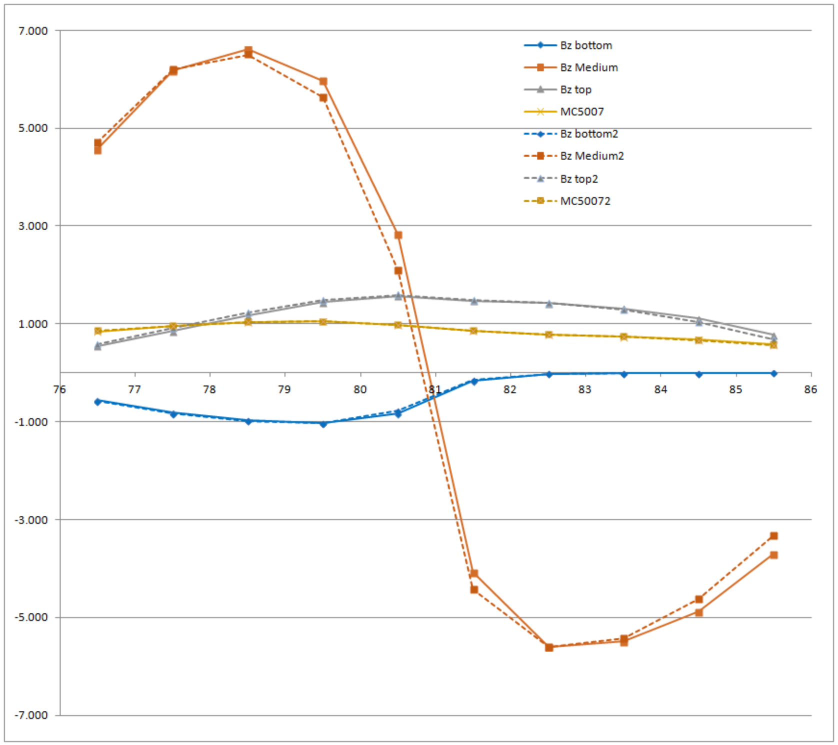


Influence of steam flow FC5005 to gains from tray temp TC5031

8900 KW instead of 10300 KW (base case)

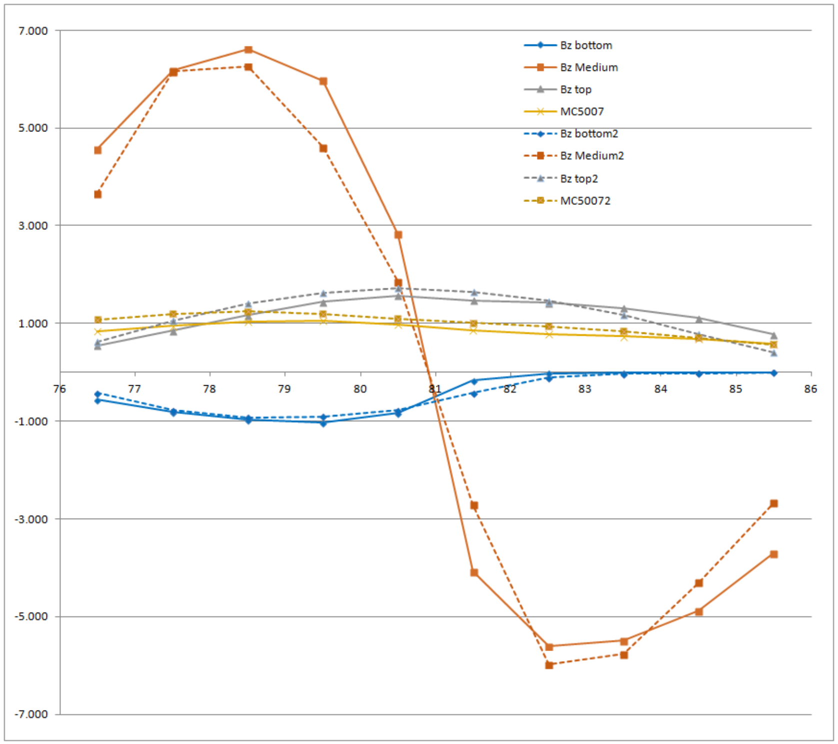
Equivalent to a change in steam flow of 2 T/h

Q #2 – Influence of other MV's – Con't



Influence of feed temp TC5000 to gains from tray temp TC5031

90.7°C vs 100.7°C (base case)



Influence of feed flow FC5000 to gains from tray temp TC5031

100.5 T/h instead of 85.5 T/h (base case)