Reliability of Dynamic Simulation to reproduce plant dynamics

Repsol – Inprocess

Manel Serra (Inprocess), JoseMaria Ferrer (Inprocess), Jose Garcia Vega (Repsol Tarragona Refinery), Francisco Cifuentes (Repsol Refining APC) , Marta Yugo and Maria Luisa Suarez (Repsol Technology Center)

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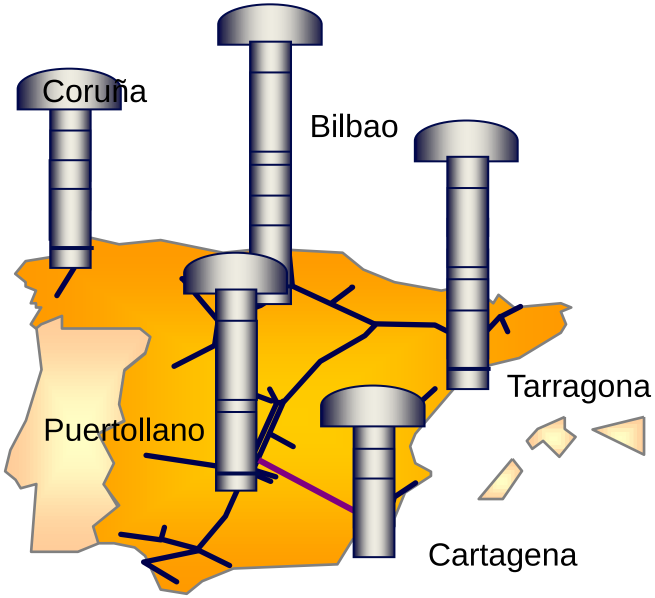
Repsol Presentation

- Integrated company: upstream, downstream, petrochemicals, gas
- Repsol downstream activities regionally based in Europe and South-America.
- Repsol has 6 refineries, 5 in Spain and 1 in Peru
- It is the refining leader in Iberia and the third LPG company in the world.
- Spanish refineries process 0.9 million bbl/day



Agenda

- Simulation: What is, Why and How good
- Case Study: Double C3Splitter
- Ideas for Future

What is Process Simulation

From time to time someone tells me:

“ I don´t believe in process simulation”

Well… that´s like saying:

“ I don´t believe in the Bernoulli equation”

Simulation is not a question of believing or not believing

Process simulation is only a macro-compilation of physics, chemistry and thermodynamics laws smartly coded in an interactive computer application.

Just a megaprocesscalculator.

1600 1700 1800 1900 2000

Chemistry, Mathematics, Physics

1614: Napier Logarithms
1637: Descartes Cartesian geo
1662: Boyle´s Gas Law
1665: Calculus (Leibniz)
1669: Newton´s Method
1680: Algebraic logic Leibniz
1687: Newton´s Motion and Cooling

1738: Bernoulli´s Law
1760: Lambert´s Law
1768: Euler´s Method
1785: Coulomb´s Law
1785: Laplace´s transform
1787: Charles´s Gas Law
1791: Richter´s reaction Law

1801: Dalton´s Law Partial P.
1802: Henri´s Gas Law
1808: Gay-Lussac´s Law
1811: Avogadro´s Gas Law
1822: Fourier´s Heat Law
1823: F.T. Calculus (Cauchy)
1829: Graham´s Effusion Law
1831: Faraday´s Electrolysis
1840: Hess´s Enthalpy Law
1840: Poiseuille´s Flow Law
1850: Clausius´s Law Thermo.
1851: Stoke´s Viscosity Law
1852: Beer´s Absortion Law
1854: Boolean Algebra
1855: Fick´s Diffusion Laws
1864: Kopp´s Heat Cap. Law
1866: Maxwell´s Gas Viscosity
1869: Mendeleyev´s Periodic
1871: Coppet´s Freezing Point
1871: Boltzmann´s Distribut. L
1873: EO Van der Waals
1882: Raoult´s Vapor Pressure
1885: van´t Hoff´s Osmotic Pr.
1893: Sutherland´s Gas Visco.

1900: Planck´s Raditon Law
1908: Grüneisen´s Thermal L.
1913: Heisenberg principle
1923: Pauli´s Exclusion prin.
1925: Fermi-Dirac distribution
1949: EO Redlich-Kwong
1972: EO Soave R-K
1976: EO Peng-Robinson
1999: EO Elliot-Suresh-Donoh.

This science has been there long time ago, but we are the first generation of people who has in our hands software tools and desktop computers capable to simulate dynamically entire process units.

Most of their applications are still in the early stages

Computers

1200: Abacus
1621: Slide Rule
1673: Leibniz's Step Reckoner

1700

1801: Punched Cards
1822:Mechanical Computer (Babbage)
1879: Cash Register (Ritty)

1930: Mechanical calculator
1934: Differential Analyzer
1939: Turing decrypter
1st Generation
1946: ENIAC
1952: IBM 701
2nd Gen.: transistor
1959: IBM 1401
3rd Gen.: integrated circuit
1964: IBM System/360
4th Gen.: Microprocessor
1971: Intel 4004
1977: VAX-11/780
1978: Intel 8086
1980: Sinclair ZX80
1982: Intel 80286, 1985: Intel 80386, 1989: Intel 80486
1993. Intel Pentium
2006. Intel Core line
2010. Intel Core i3,i5,i7

Why Dynamic Simulation

- Consolidated (blue)
- Exploring (orange)

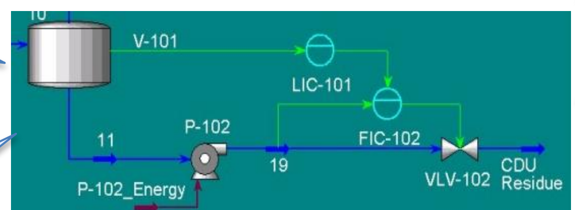
1. Equipment sizing and process layout verification:
- Compression systems
- Pipeline networks

2.- Flare Load calculation and PSV sizing
- Design/revamp flare networks

3.- Emergency System verification and HAZOP studies support
- HIPPS studies
- Cause & Effect matrixes

4.- Design control layout
- Scenarios analysis
- Perturbation rejection
- Control loops selection

Dynamic Model



5.- Prototyping MPC
- Obtain MPC models
- Study non-linearities
- Test/Tune MPC controller

6.- Develop virtual sensors
- Online Analyzers backup
- Fault diagnostic
- Look-ahead sensors

7.- DCS checkout
- DCS FAT with virtual plant
- Operating procedure test

8.- Operator Training System(OTS)
- Operator Training
- Emergency scenarios
- Knowledge base system

How good are the models

Well… plants are built based in steady-state models (they should be good enough)

But when moving to Dynamics, how good are they?

If the plant is being built there is no way to know it. You have to trust in the tool and the experience of the modeler

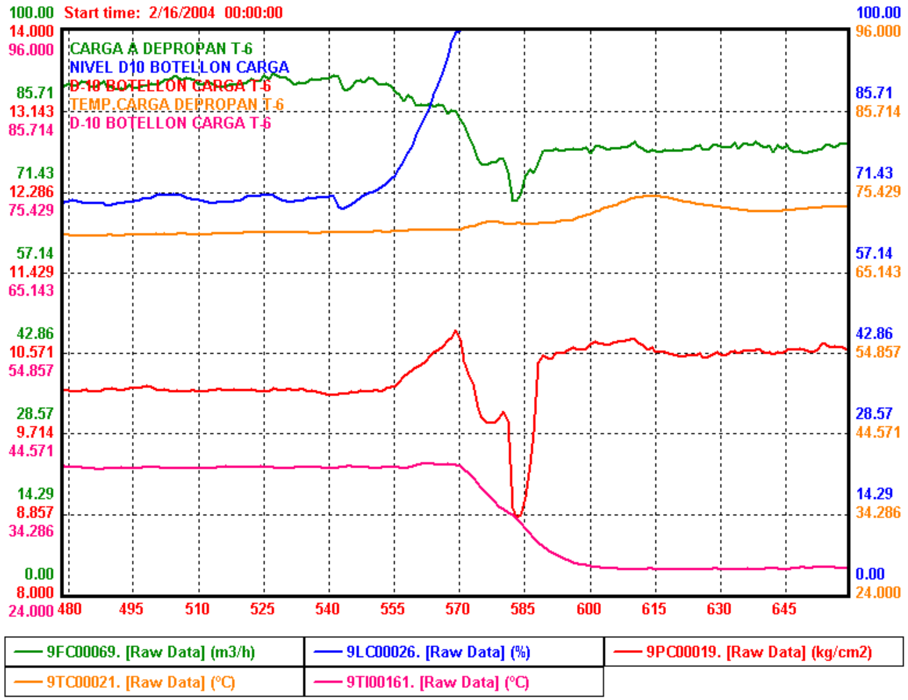
If the plant is available there are three methods:

1. Compare responses of single moves
2. Compare DMCplus models (plant vs. model)
3. Feed historical data into the model (presented here)

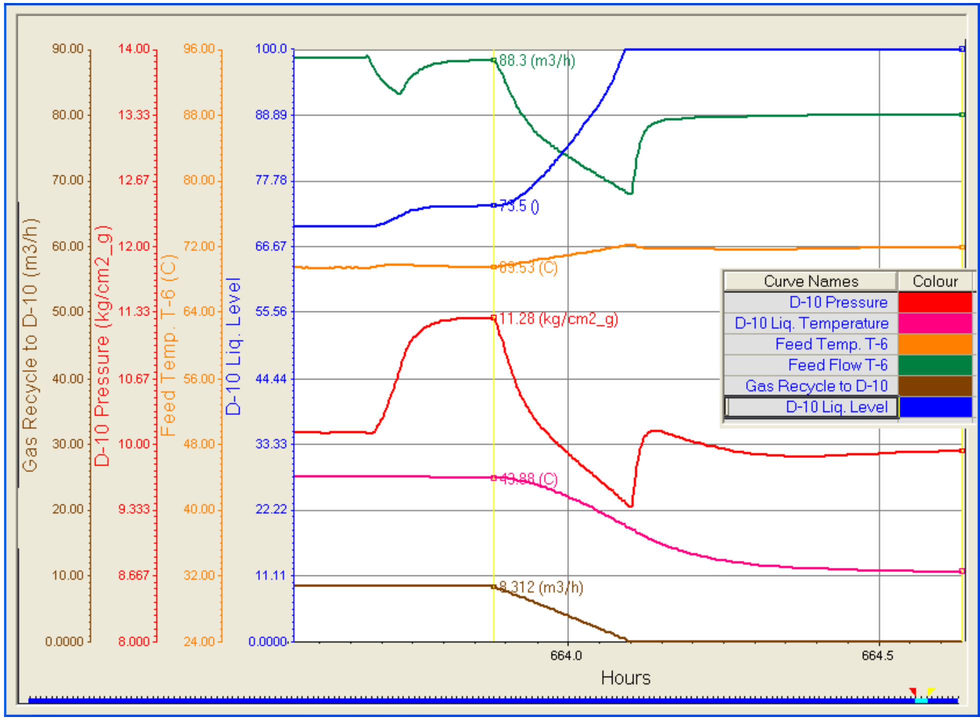
Method 1: Single moves

Shown in a debutanizer in AspenTech ACO UGM 2005 Barcelona

Real Plant



HYSYS Dynamics

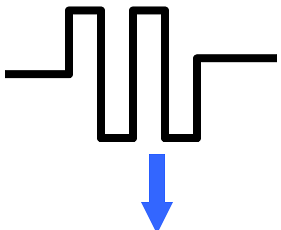


Reference: www.aspentech.com/publication_files/HP0906_Gonzalez_PDF.pdf

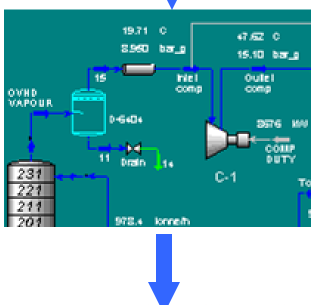
Method 2: DMCplus models

Shown in a C3 Splitter in AspenTech UGM 2008 Berlin (APC track)

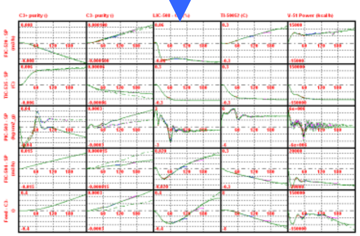
STEP-TEST



Dynamic Model

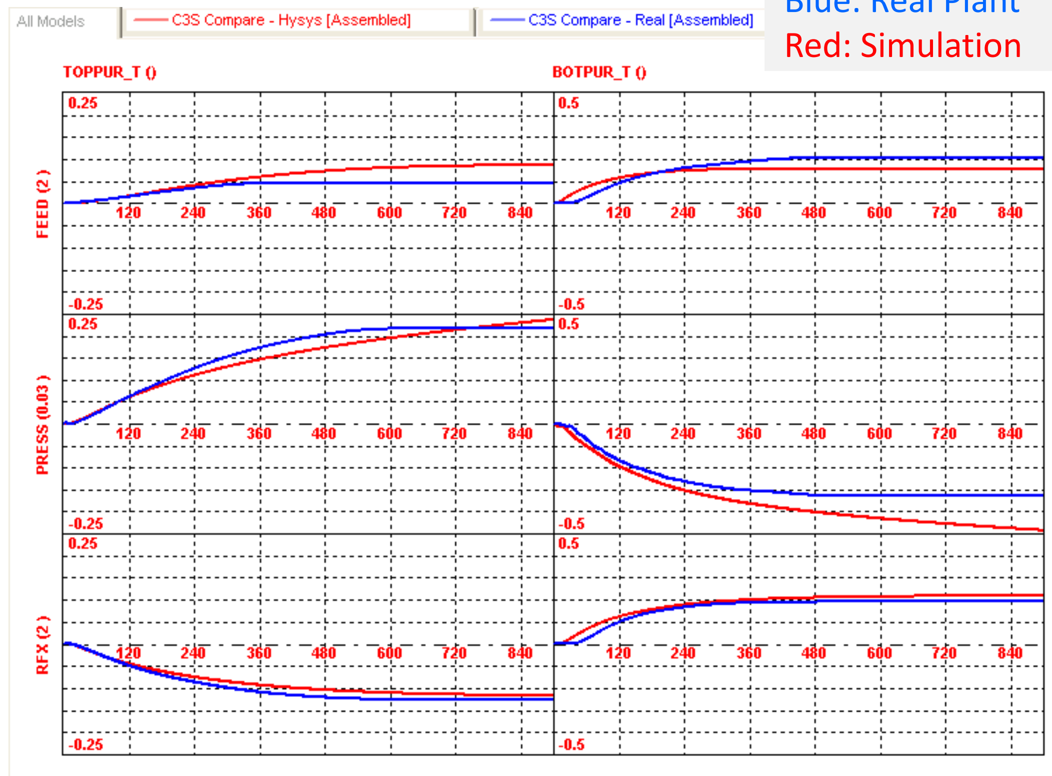


DMCplus Model



Blue: Real Plant

Red: Simulation



Other References:

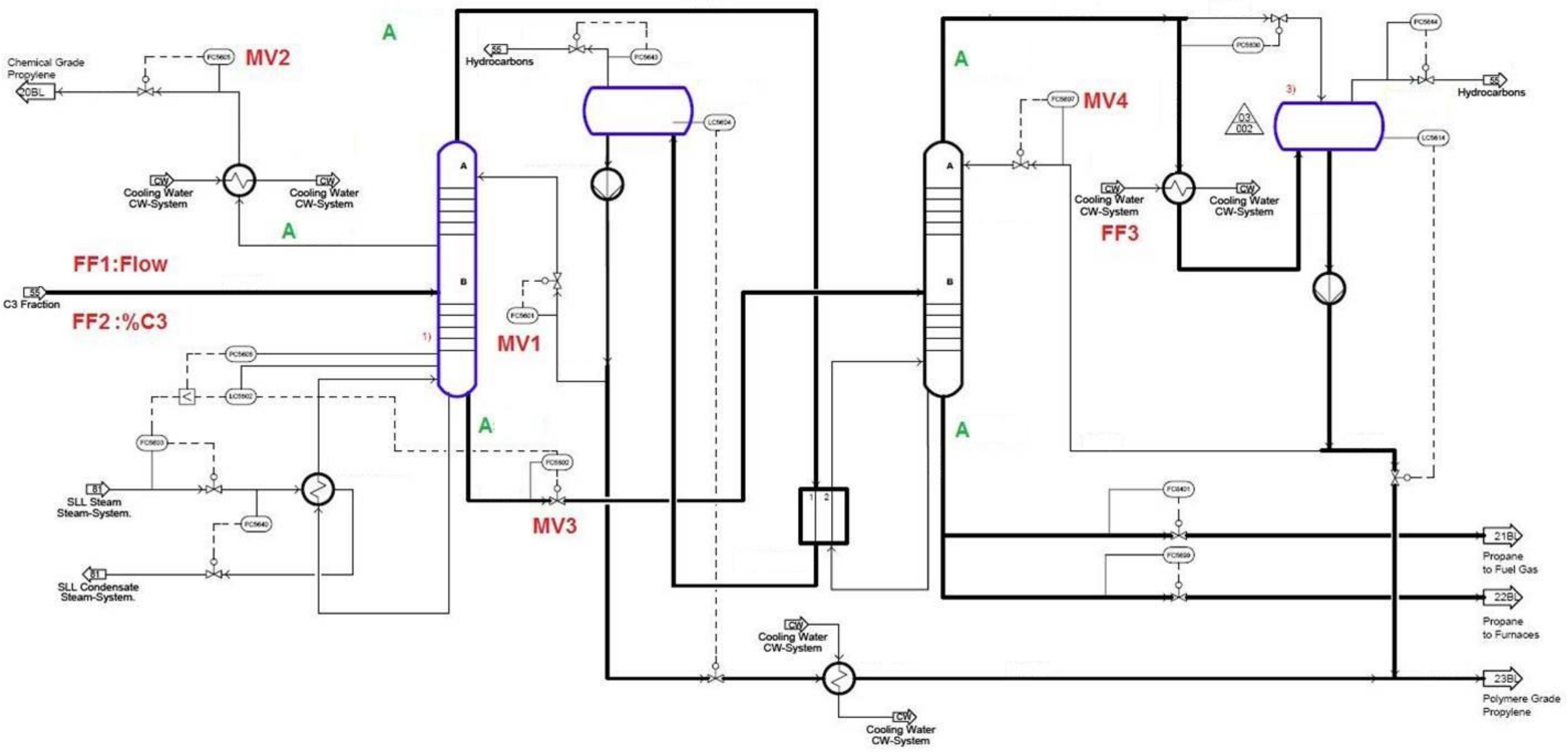
1. www.aspentech.com/publication_files/Hydrocarbon_Engineering_Nov_2004.pdf
2. www.aspentech.com/workarea/downloadasset.aspx?id=6442451960

Double C3 splitter polymer grade

1st column: 189 trays, lateral extraction chemical grade

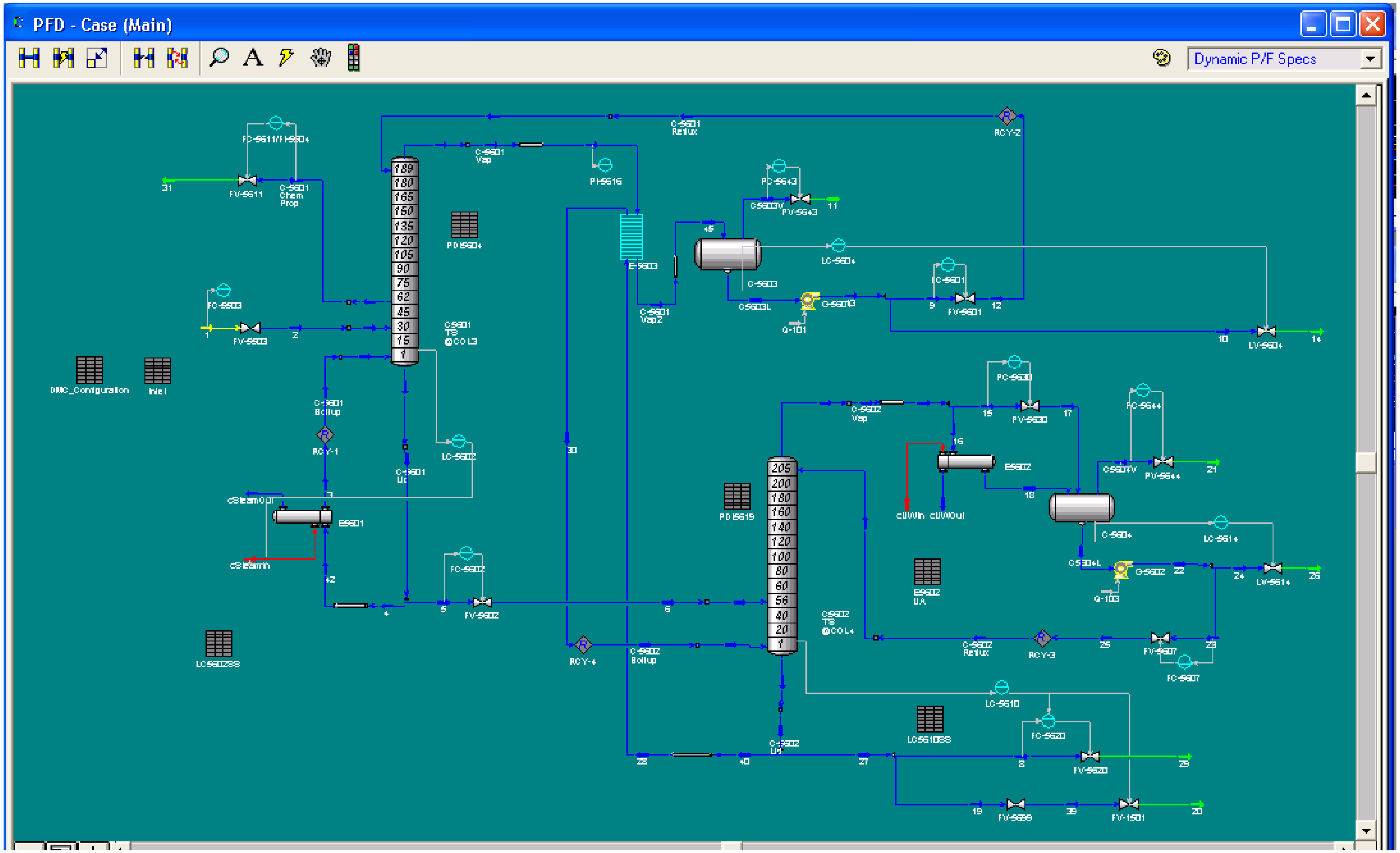
2nd column: 205 trays, reboiler is condenser of 1st column

Challenging to control: very long settling times, heat interaction, external disturbances and intrinsic non-linearity

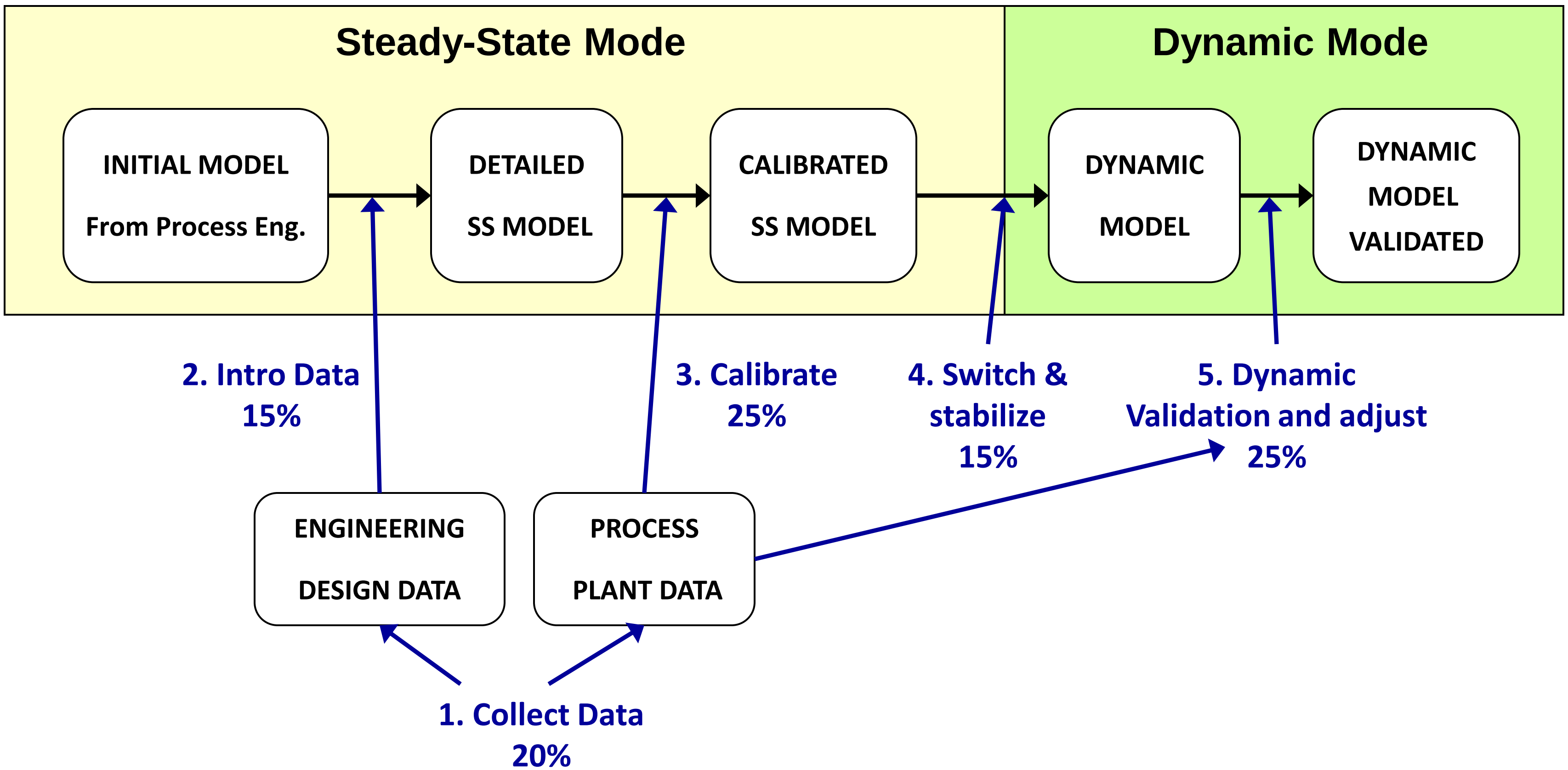


HYSYS Dynamics model

A HYSYS Dynamics model integrated with a DMCplus controller was developed in order to analyze unit interactions and dynamics, change basic regulatory controllers, generate HYSYS based DMC model and train engineers on their use.



Model Building steps

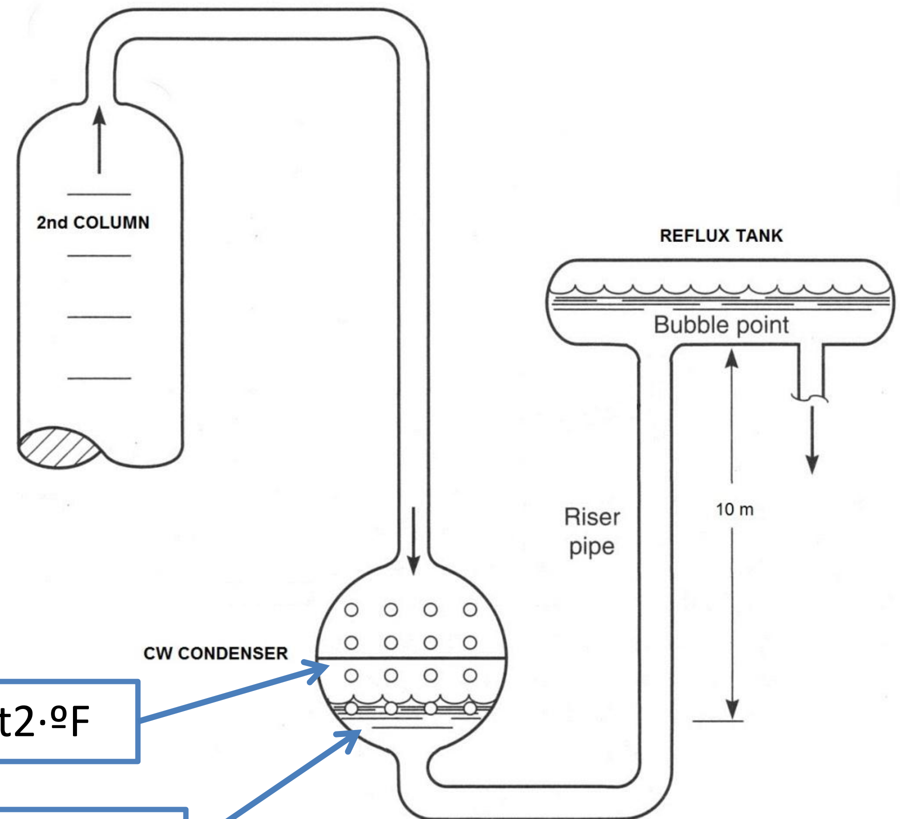


Percentages are efforts required for the model building

Self regulated top pressure

The liquid level in the shell depends on the differential pressure between top and reflux tank.

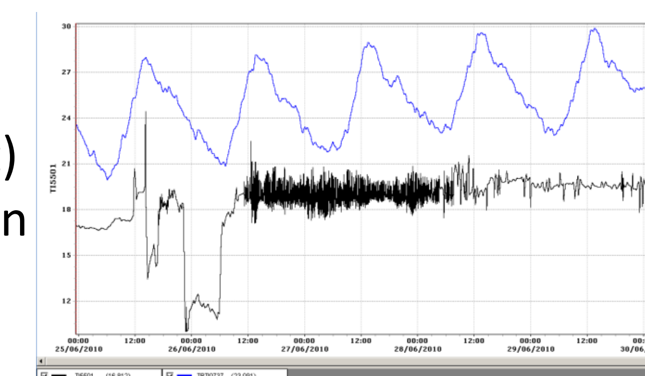
Heat transfer coefficient (U) of the 2nd column condenser fully depends on the liquid level in the shell side.



U Condensing Zone: 400 – 1000 Btu/h·ft2·ºF

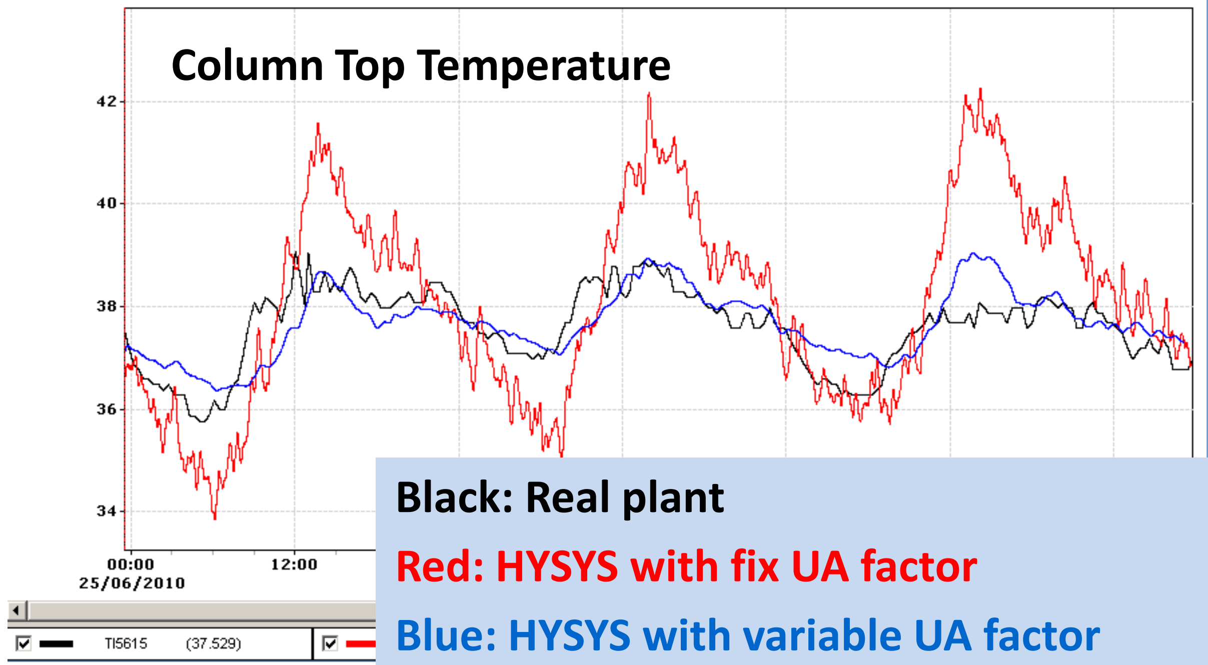
U Subcooling Zone: 10 – 30 Btu/h·ft2·ºF

Changes in the Cooling Water temperature (day/night) affects to the condenser duty and hence to the column top pressure and condenser shell liquid level.

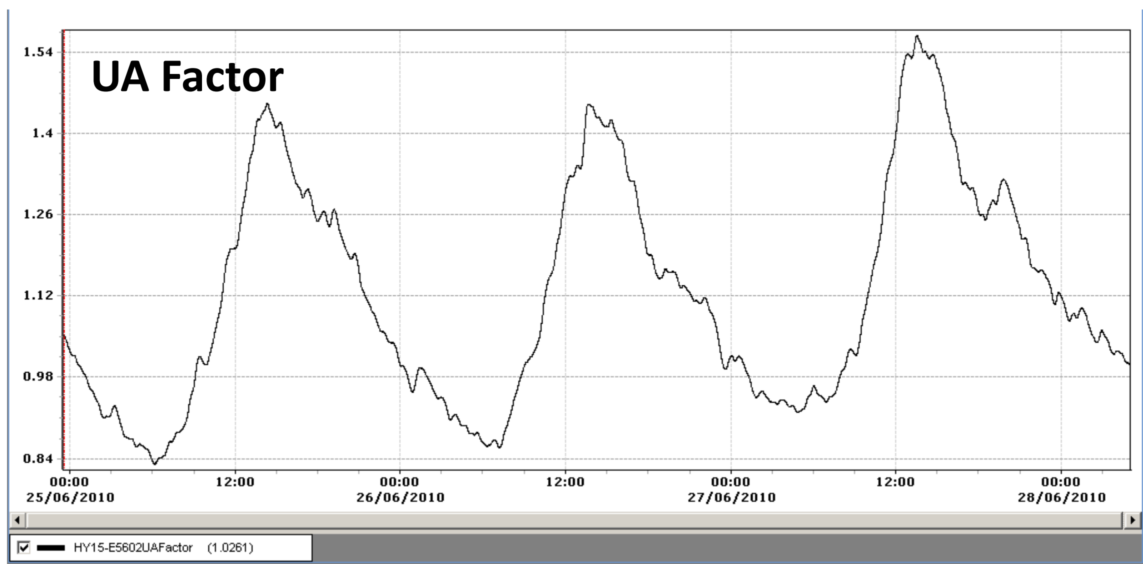


CW Condenser in HYSYS

The Shell&Tube exchanger of HYSYS Dynamics doesn´t consider the effect of shell liquid variations in the heat transfer coefficient.



Therefore a calculated variable UA factor has been introduced in the specified UA of the exchanger. It is a correlation based in pressures and design UAs.



CW Condensers

It was historically believed that these 6 CW Condensers worked at full capacity all the time with most of the tubes exposed to the hydrocarbons gas.

The HYSYS Dynamics model with a variable UA factor was fitting better with plant data, revealing that **condensers work partially inundated**.

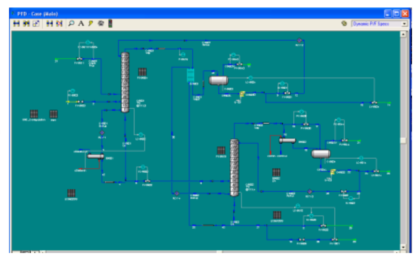
This was effectively verified by the 2-3 Deg C difference between the low shell zone (subcooled) and the high shell zone (equilibrium).

Validation Method 3:

For 5-days validation period, all the events that occurred in the real plant are synchronically (1 min) introduced into the dynamic model (DMCplus actions, measured disturbances, operators actions) in order to compare the variables calculated by the dynamic model with those obtained from the real plant.

INPUT DATA :
Reflux1 (MV1)
Side-draw (MV2)
Bottom Flow (MV3)
Reflux2 (MV4)
Feed Flow (FF1)
%C3 Feed (FF2)
CW Temp. (FF3)
Feed Temp.
Steam Temp.
LC´s SP

Excel Macro

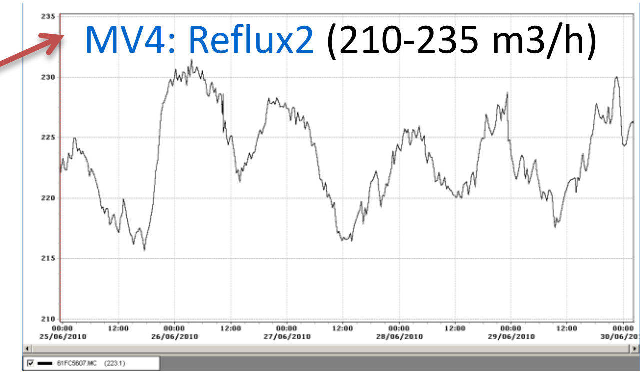


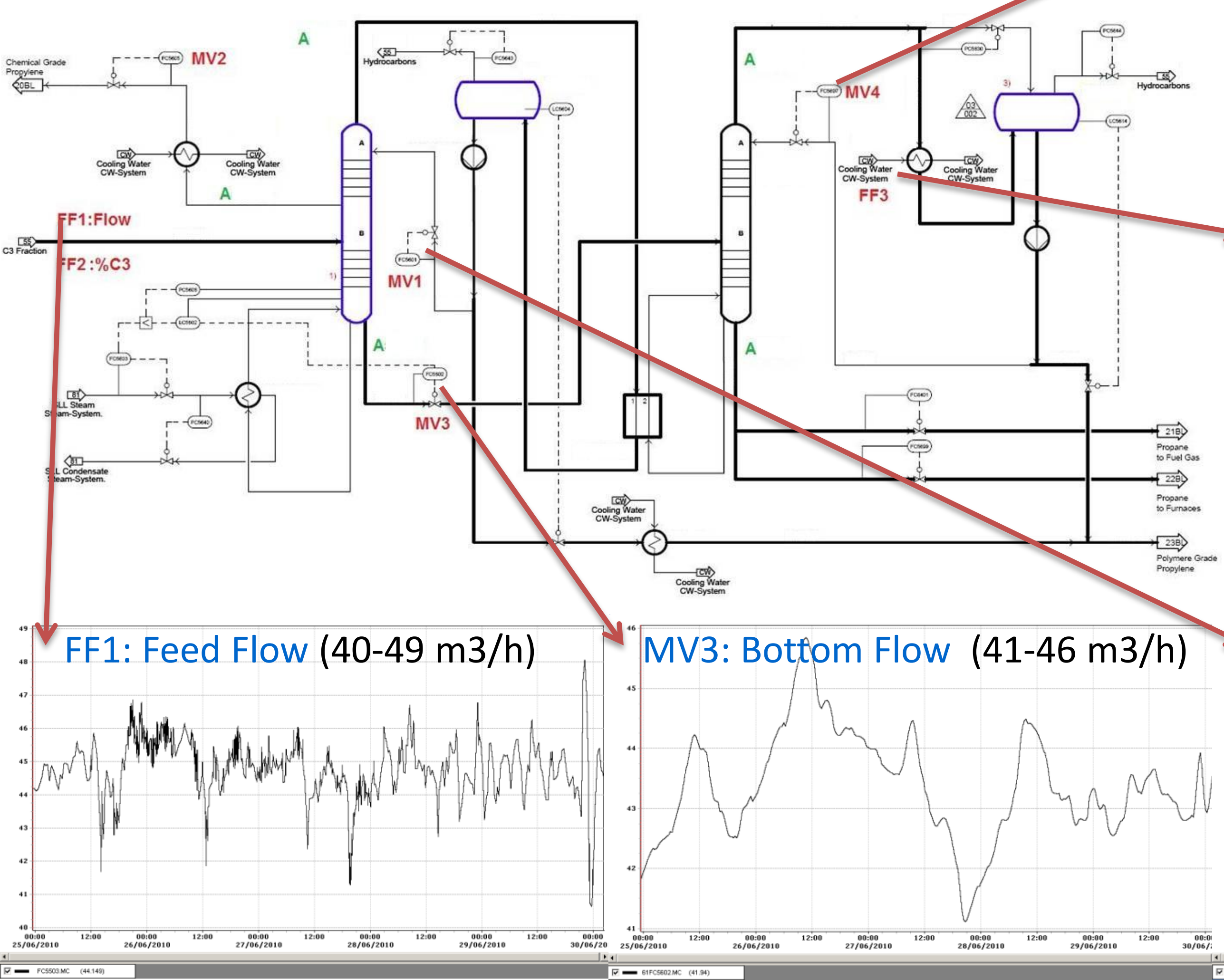
OUTPUT DATA :
All compositions
Temperatures
Pressures
Product flows
etc

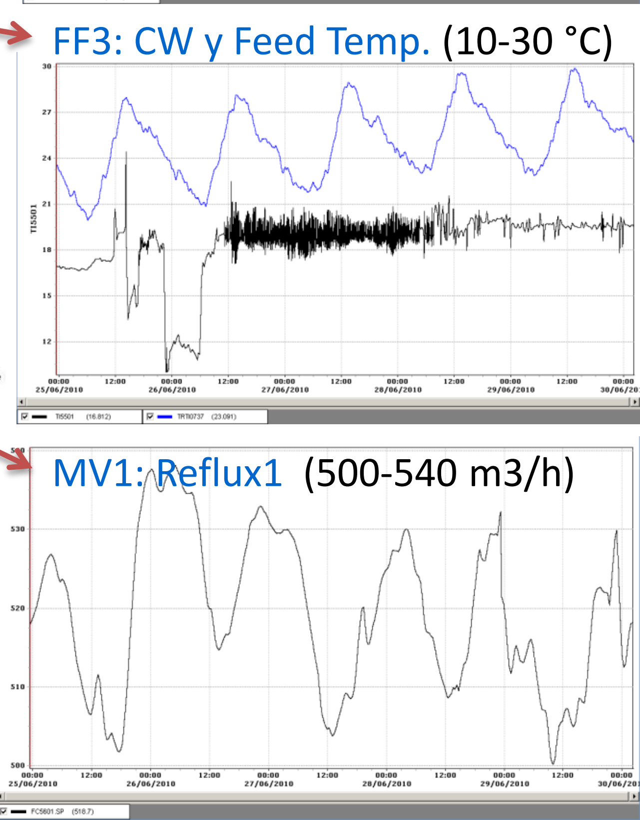
This type of validation is only useful if the main disturbances in the real plant are measured, as in the event of there being strong disturbances which go unmeasured they cannot be introduced into the simulation model, with the result that the responses may well be different

Some input variables

The DMCplus actions and disturbances were introducing significant changes to the unit

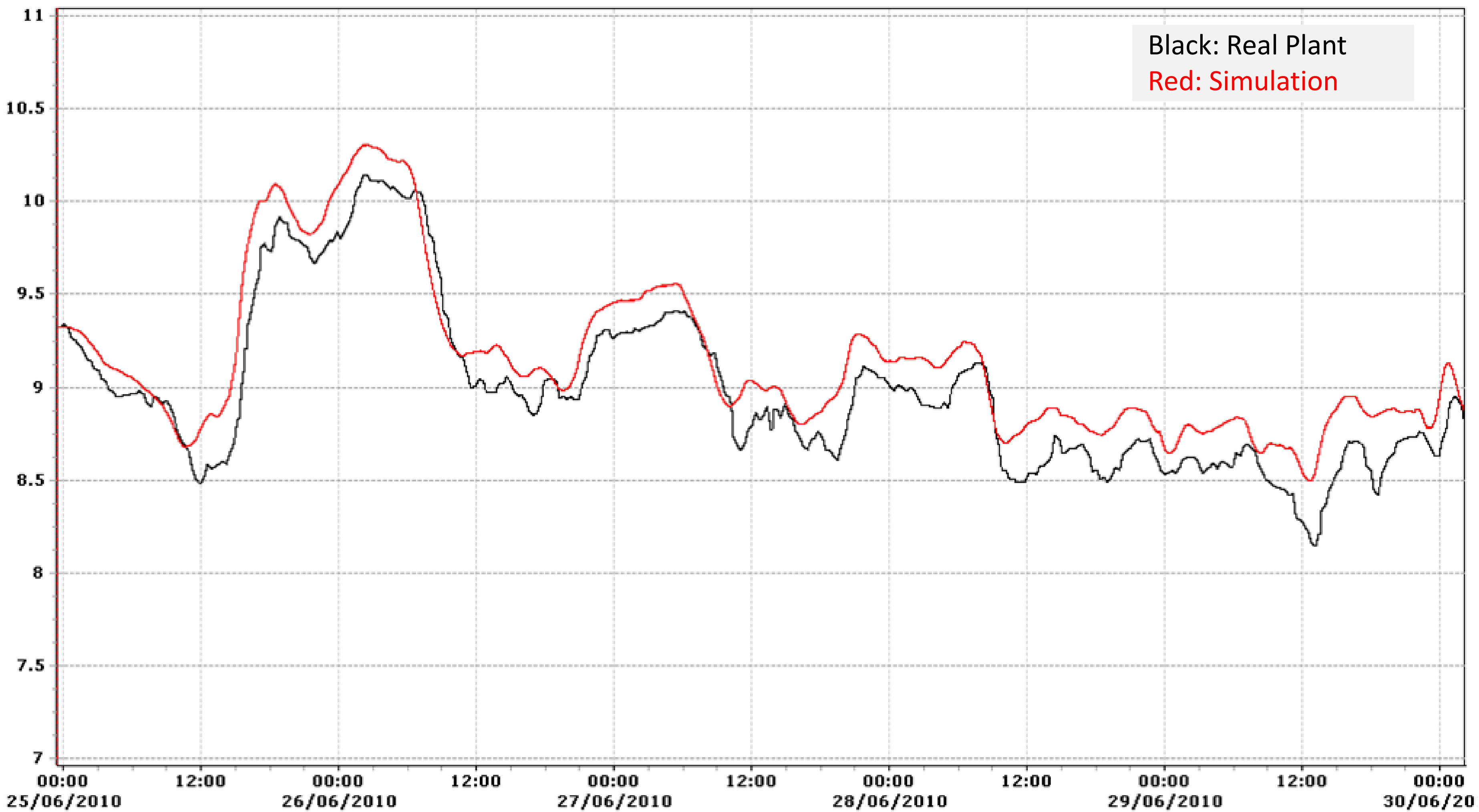






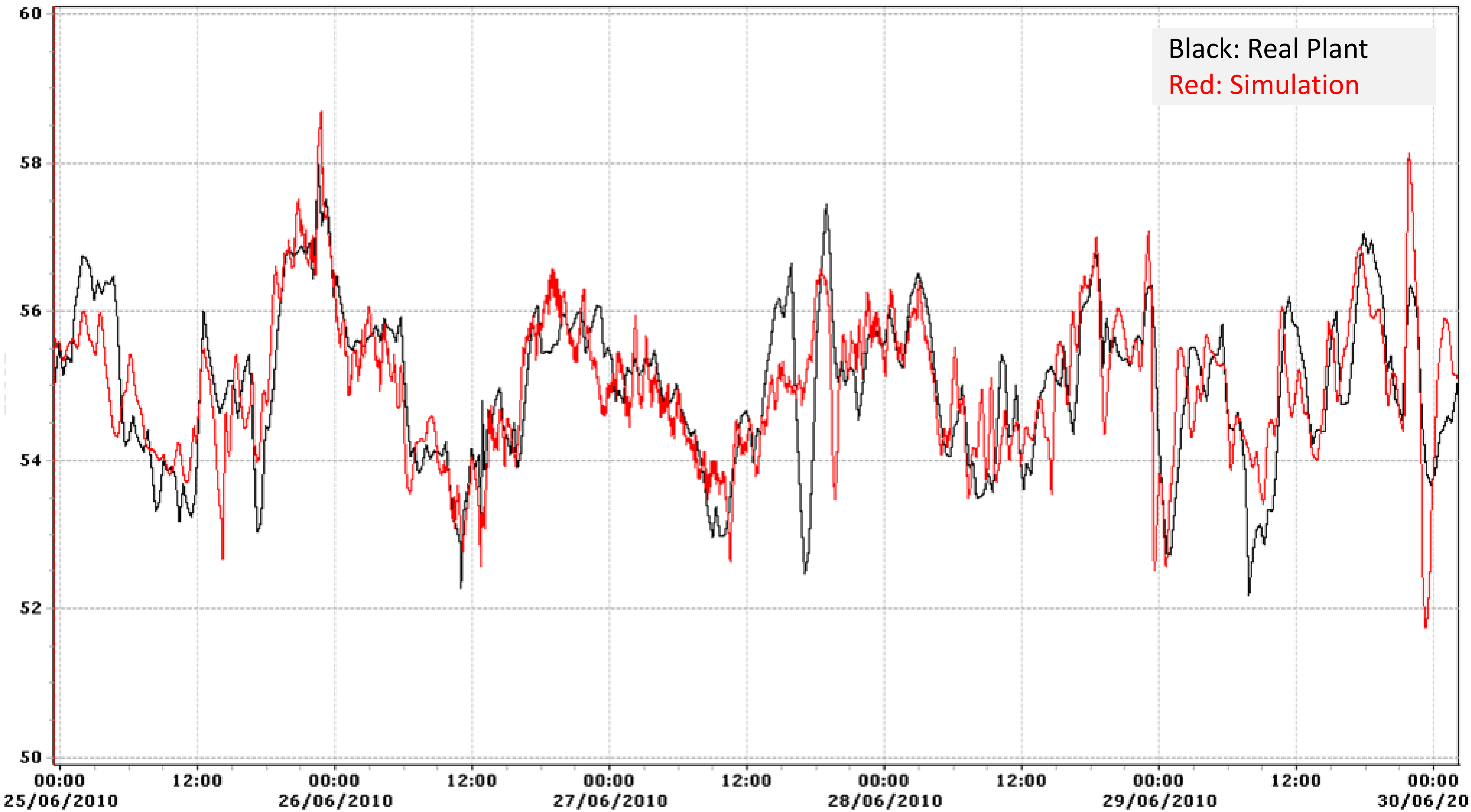
Validation (Method 3)

1st Column Bottom Quality % (C3= in C3)



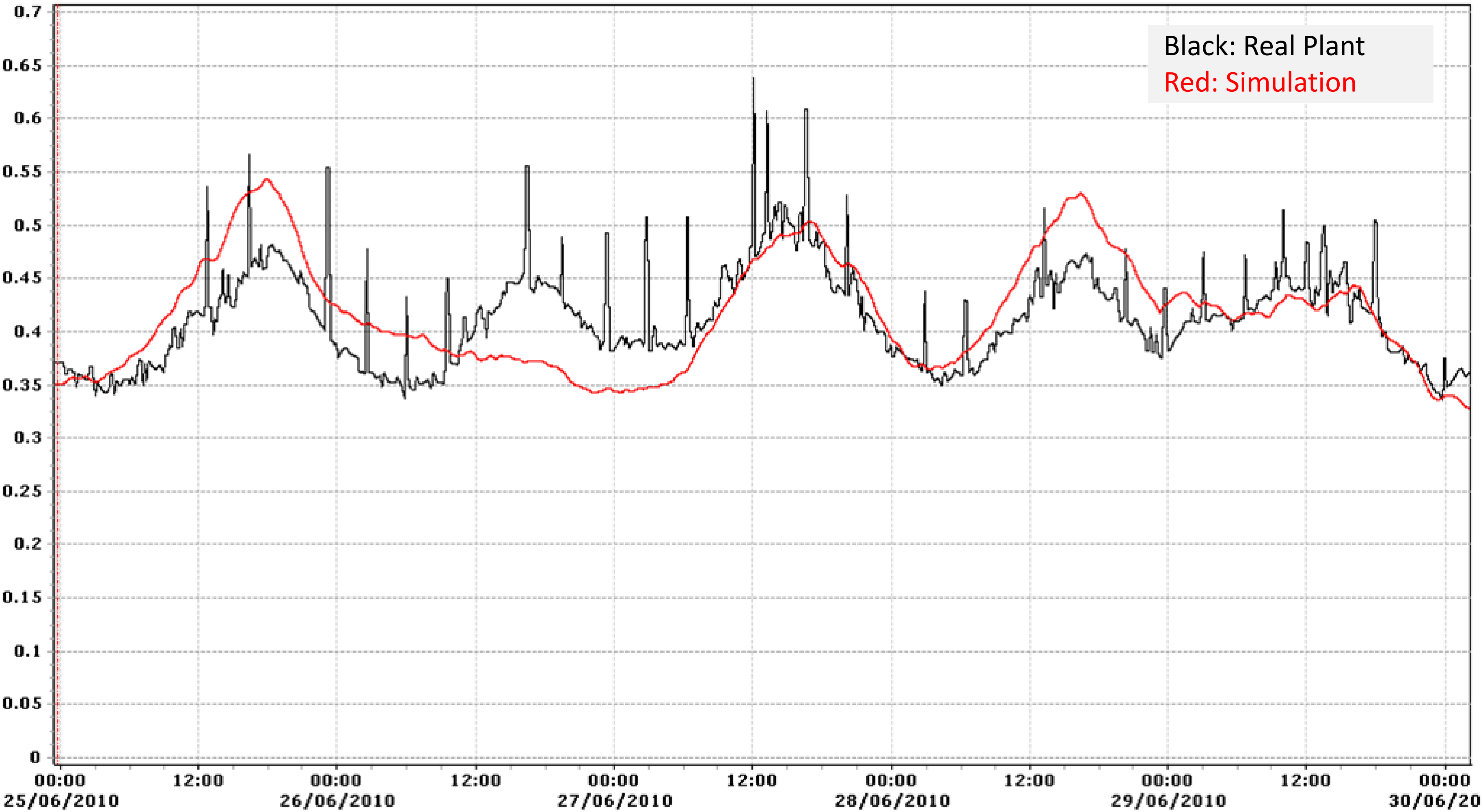
Validation (Method 3)

1st Column Bottom Level (%)



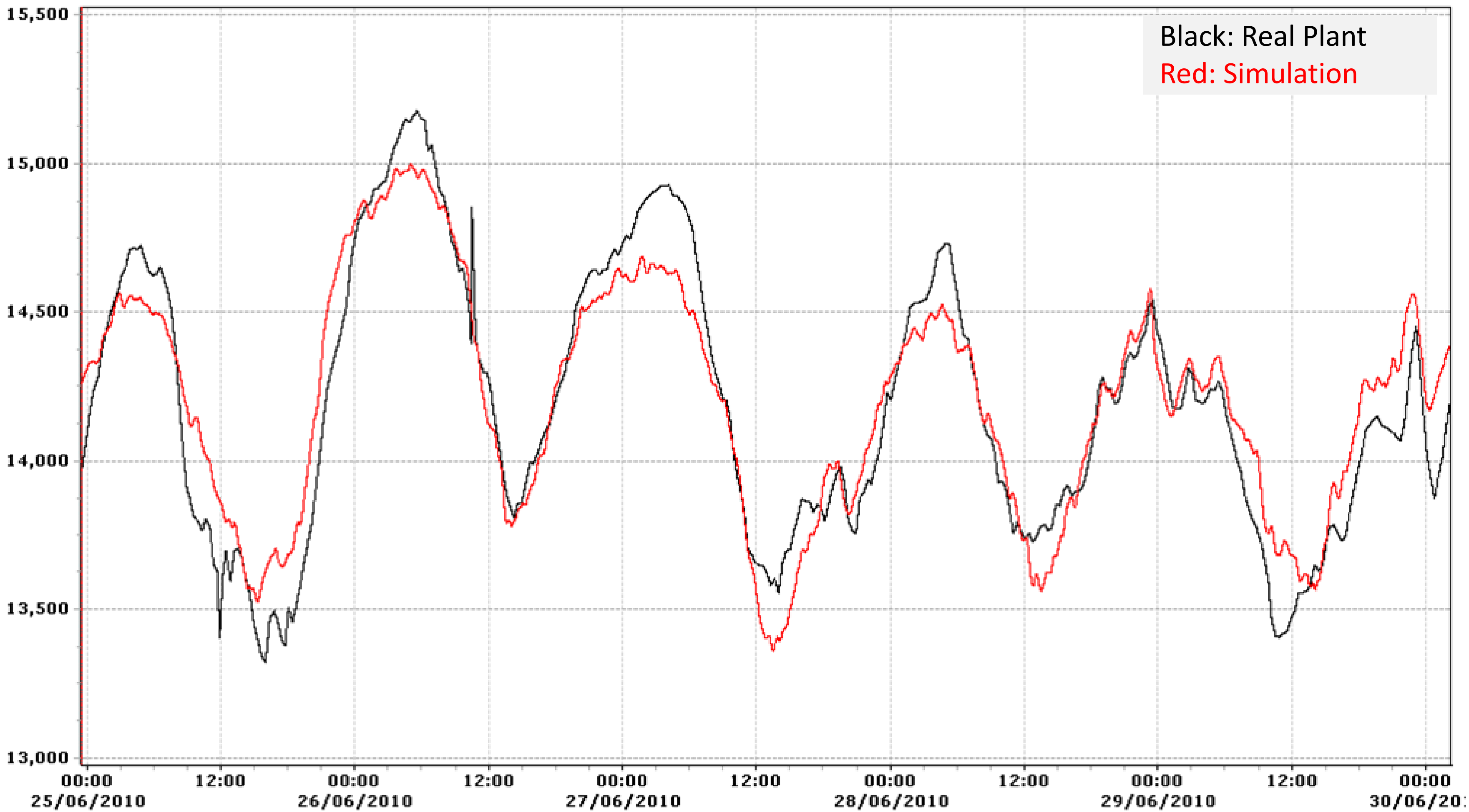
Validation (Method 3)

2nd Column Top Quality % (C3 in C3=). Scale: 0 to 0.7%



Validation (Method 3)

2nd Column Differential Pressure (mbar)



Ideas for Future: Virtual Sensor

- Steady-state online models need a reconciliation step in order to close Heat & Material balances of imbalanced real plants.
- Dynamic online models would **not need this reconciliation** step, but a proper input variable selection and some self adapted parameters (fouling, efficiencies, etc). Not an obvious task.
- Dynamic online models could provide virtual sensors for compositions, using them as backups of online analyzers which frequently require costly maintenance.
- With online dynamic models, the number and location of the instruments can be revisited, helping to reduce the instrumentation CAPEX.

Ideas for Future: Fault Detection

- What happen if an online dynamic model suddenly diverge from some plant data?

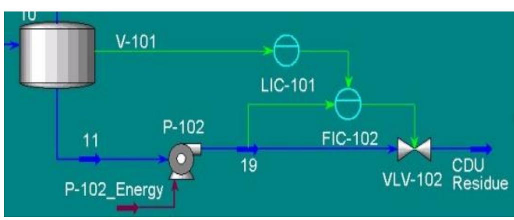
REAL PLANT

INSTRUMENTATION

PLANT REAL TIME DATABASE

INPUT VARIABLES

DYNAMIC MODEL ONLINE



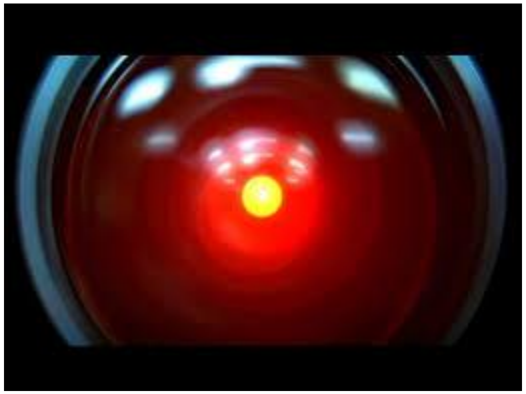
OPC data

The reason can be:

1) Wrong modeling approach
2) Instrument Fail
3) Equipment Fail/Constraint

Fortunately physical laws don´t lie !

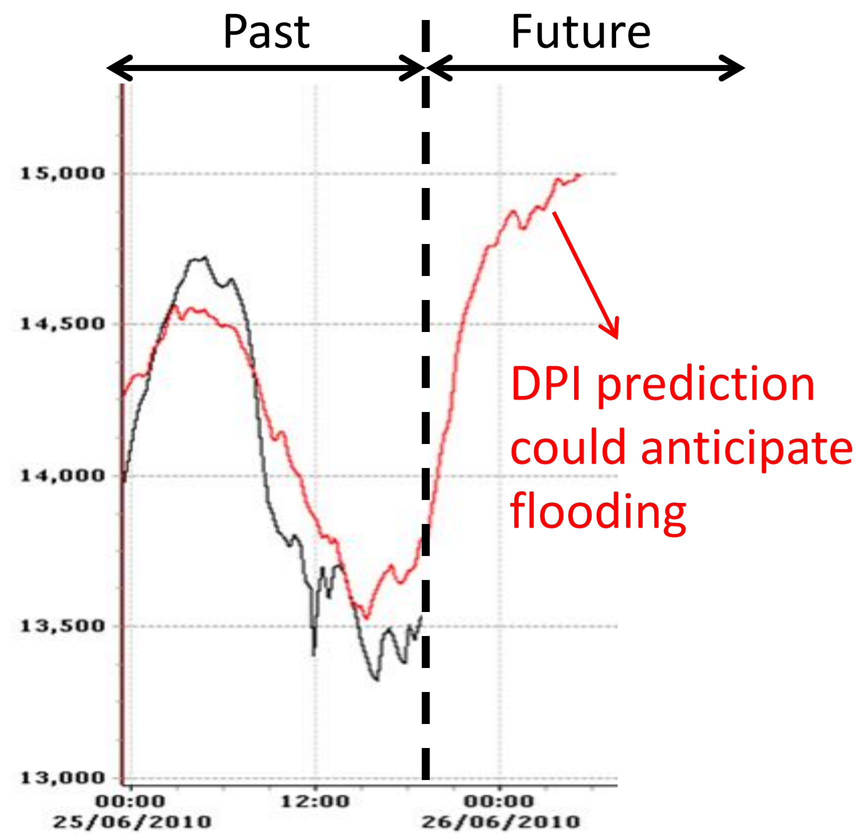
Ideas for Future: Look-ahead



Who does say this?:

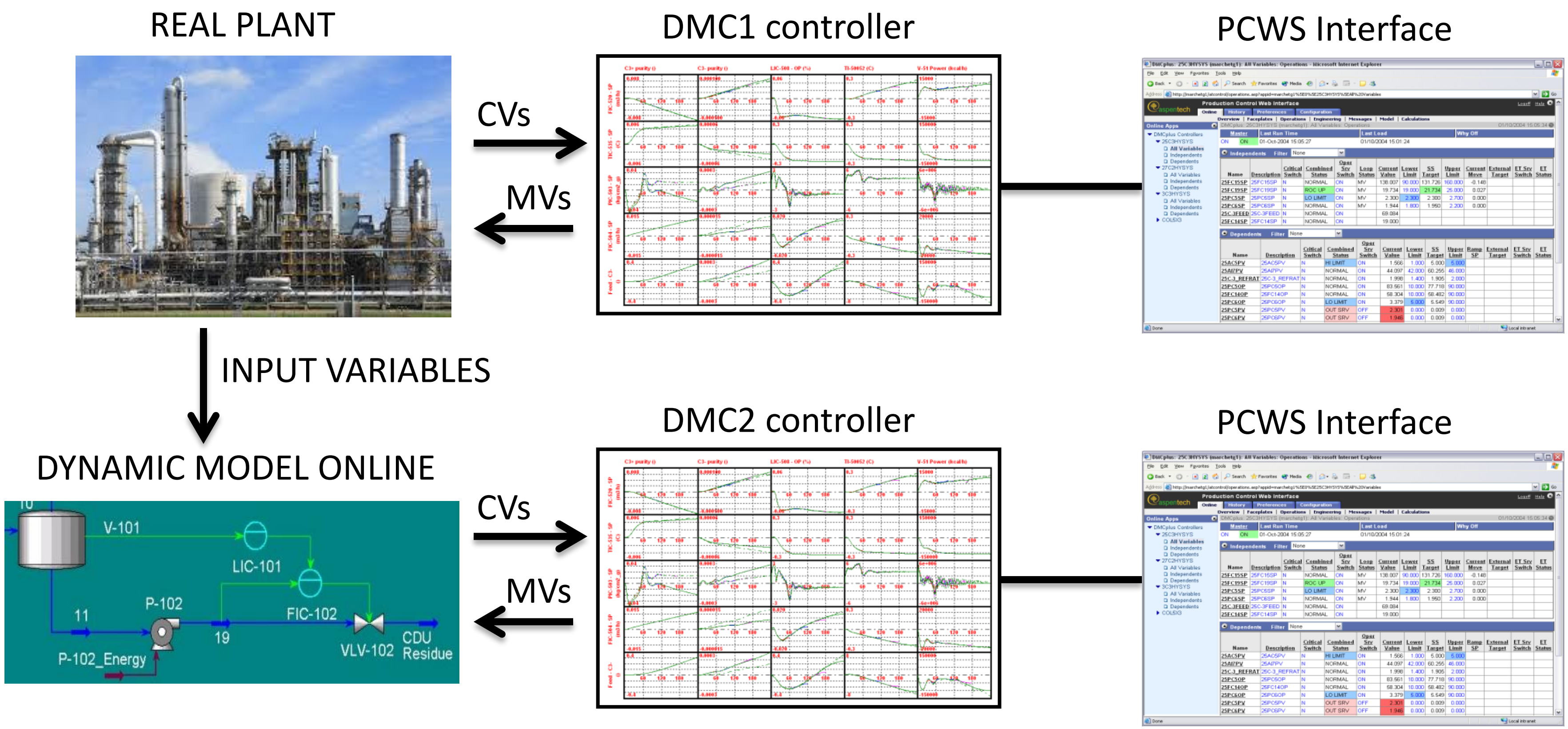
"I've just picked up a fault in the AE-35 unit. It's going to go a hundred percent failure within 72 hours."

- Online dynamic models can run faster than realtime providing predictions of critical variables
- Realtime look-ahead trends can be combined with plant trending application.



Ideas for Future: APC

- Look-ahead dynamic model could calculate rigorous CVs predictions, which could replace DMC predictions
- It could be also used as a test bed for DMC tuning



Conclusions

- When the thermodynamic package represent well the components and the main disturbances into the unit are measured, HYSYS Dynamics models can reproduce plant dynamics with acceptable precision and validation method 3 can be used.
- Exploiting the value of such models is still an issue
- Specific education on simulation for non-process engineers is required (Dynamic Simulation for Control Engineers course)
- Some HYSYS Dynamics improvements would be desirable