4th Latinoamerican Refining Congress – November 17 to 20, 2015

Operational excellence
Simulation, optimization & control

Advanced Process Control from a Licensor's Point of View

1. Summary

Nowadays Advanced Process Control (APC) is recognized and commonly used to boost operational performance of process units in refineries. Deployment of APC system is often considered as the first building block of a larger refinery performance optimization system.

Although many companies are providing such applications, Process Licensor's solutions are typically the only ones unleashing the full benefits of an APC system.

Licensor strengths are:

- Perfect knowledge of process principals and unit behavior
- Accurate inferences for catalytic processes
- Unique APC strategies based on Licensor's expertise
- The right APC tools, to make full use of knowledge, inferences and strategies

The resulting benefits for customers are an APC application focusing on main key operating parameters leading to increased robustness, thanks to a reduced matrix size, and to easier maintenance. In addition, Process Licensor APC commissioning is very smooth and straight forward, hence tuning and step tests are often unnecessary.

Process Licensor APC solution will not only address performance of reaction sections (yield, product quality and catalyst run length) but it will also reduce energy consumption of all associated utilities.

2. Introduction and APC basics

2.1. Introduction

That paper is discussing strengths of a Process licensor APC solution, presenting some concrete applications examples:

- Chapter 3 is dealing with importance of having a perfect knowledge of process principals and unit behavior
- Chapter 4 is dealing with the importance of accurate inference in development of an APC
- Chapter 5 is focusing on aspects that are making Process Licensor APC unique
- And finally Chapter 6 is presenting briefly importance of having fit to purpose tools to setup, maintain and sustain an APC application

2.2. APC basis

Advanced Process Control (APC) offers solutions to safely stretch process units to their full capacity, generating substantial benefits thanks to significant yield increases and operating cost reductions.

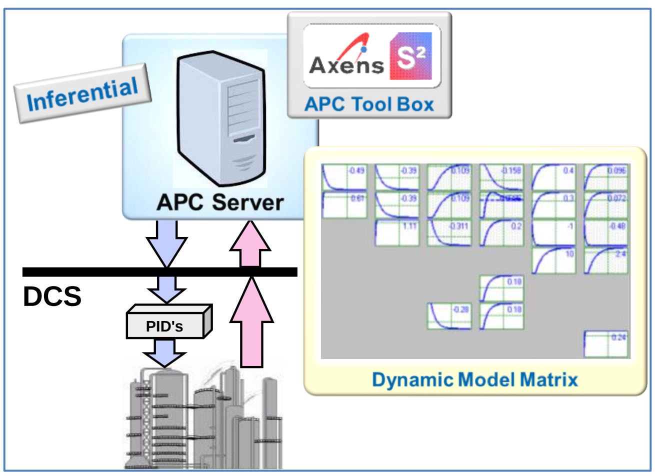


Figure 1: APC Overview : Plant / PID / DCS / APC

APC updates the setpoints of the DCS PID controllers every 1 to 20 minutes, using mainly:

- **Inferentials** to estimate unmeasured properties
- A **Dynamic Model Matrix** derived from plant step test data, to predict the future and optimize set points moves
- A **Tool-Box** to configure, perform and monitor all the calculations.

3. Process knowledge

Advantages of perfect knowledge of process principals and unit behavior are illustrated below with two examples:

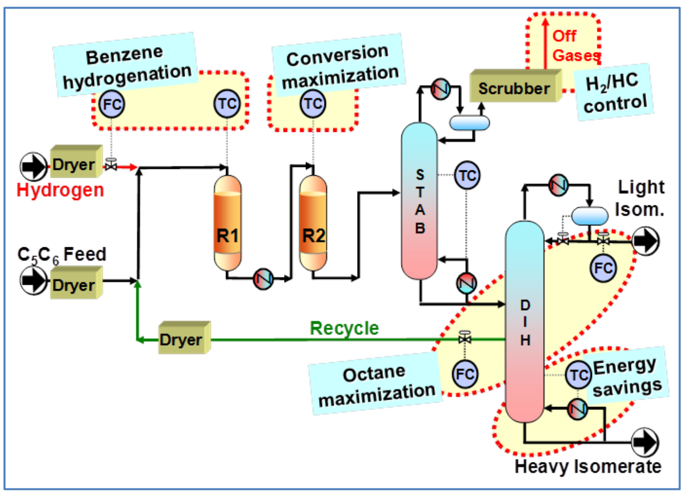
- Isomerization unit with DIH & Recycle
- Paraxylene adsorbtion (Axens ELUXYL process)

3.1. Octane Maximization in a C5-C6 Isomerization Unit with DIH

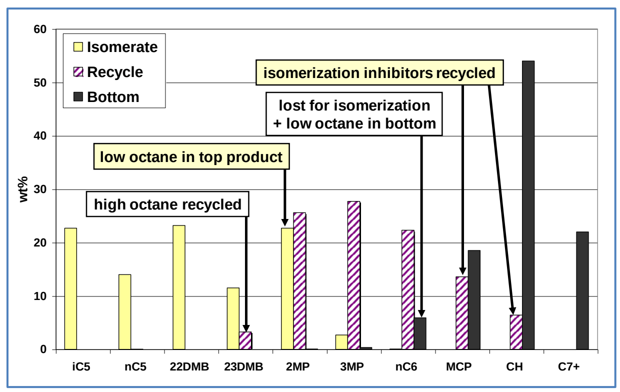
Based on the unit process operations and economic environment, the objectives for the Advanced Process Control are to safely, within the operating limits and product specifications, perform the following functions:

- Complete Benzene hydrogenation,
  to remove it from Isomerates (and from Gasoline pool)
- Reactor operation at optimal H2/HC ratio
- Conversion Maximization in the reactors
- **Mixed Isomerate Octane maximization**
- Energy savings in the DIH (and Stabilizer) reboilers

The best way to maximize Mixed Isomerate Octane choice is to optimize the composition of the Recycle, by reviewing the various species present in the DIH feed. It is not necessary to infer Octane value.



Process summary & Control Objectives

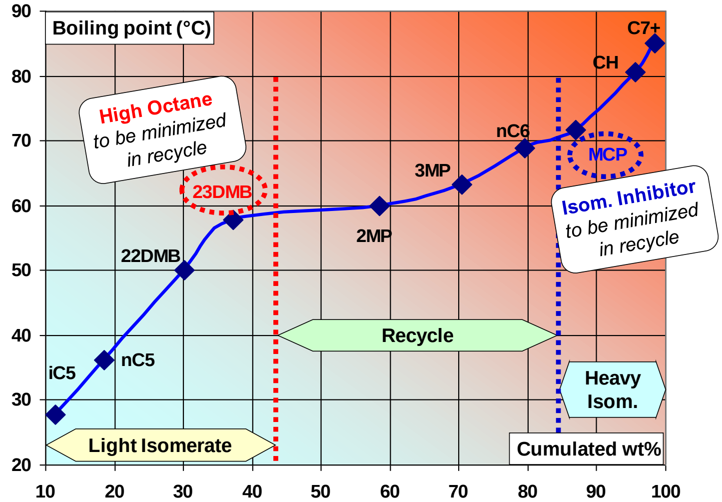


DIH Feed composition

APC will pay special attention to following components:

- 23DMB: high octane component, to be extracted at the top
  (to be minimized in the Recycle)
- 2MP: low octane component, to be recycled
- nC6: low octane component, to be recycled
- MCP: low octane component, to be extracted at the bottom
  (to be minimized in the Recycle)

Typically, DIH Feed TBP looks like this:

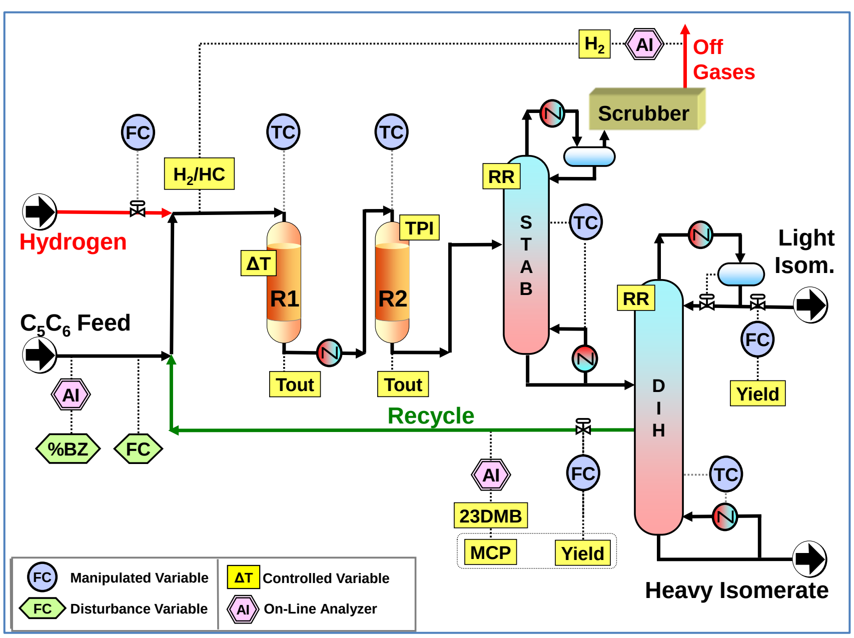


DIH Feed TBP curve – Cut points and yields

- Ligh Isomerate (LI) yield is calculated as 100 x ratio between LI flow and DIH feed flow.
  Recycle yield is calculated the same way, but a change in Recycle flow will also change the DIH feed flow.
- As far as the TBP curve (and the cutpoints) are not available on-line in real time, it is necessary to control the LI and Recycle yields, by manipulation of corresponding flows.
- A change in LI yield will change both 23DMB and MCP in the recycle.
- A change in Recycle Yield will change only MCP in the recycle.

Therefore:

- APC will control MCP & 23DMB in the Recycle at an optimized target,
  by manipulating recycle and LI yield.
- This strategy will directly guaranty the highest possible Octane, without having to infer it.



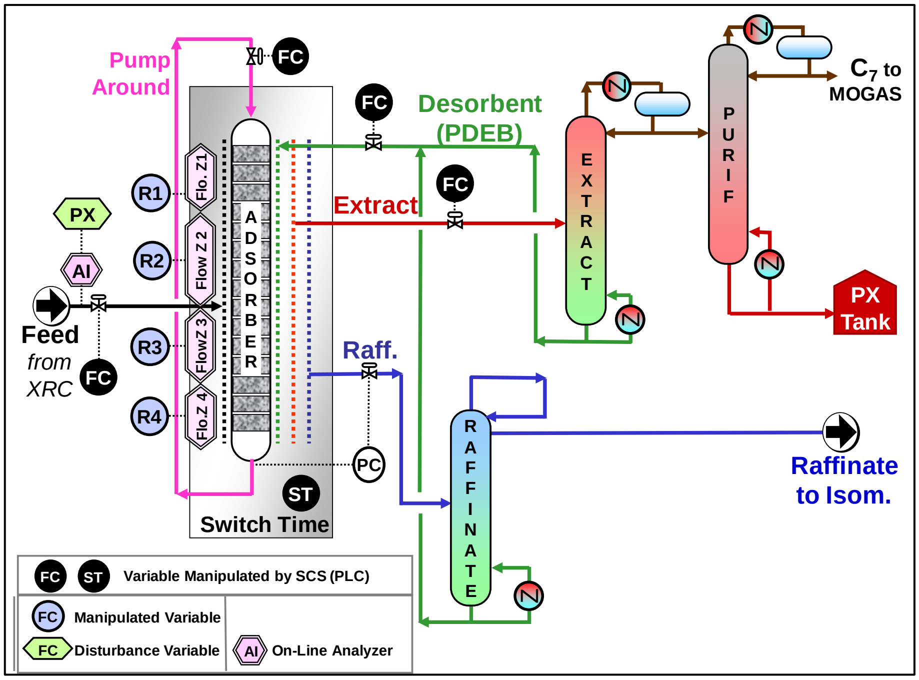
Summary of APC Control Strategy

3.2. ELUXYL: Adsoption profile control for PX optimization

The adsorber emulates a true counter-current moving bed adsorbion by changing cyclically the input and output streams location. This is why the controllers around the adsorber are manipulated by a Sequencial Control System (SCS) every cycling period.
The controllers manipulated by the SCS are:

- Feed Flow
- Pump-Around Flow
- Desorbant Flow
- Extract Flow

The maximization of PX yield and purity is achieved by tuning the zone flows and the switching time in order to modify the adsorption profile.
In order not to disturb the process the tuning is performed by small moves requiring a high level of experience. Adsorber stabilization after a tuning move requires 10 to 15 hours.
A Zone Flow, is the downstream liquid flow in the adsorber, in a specific zone; each zone flow is calculated from material balance around the adsorber.



SCS Tuning Move parameters and APC Adsorber MV's

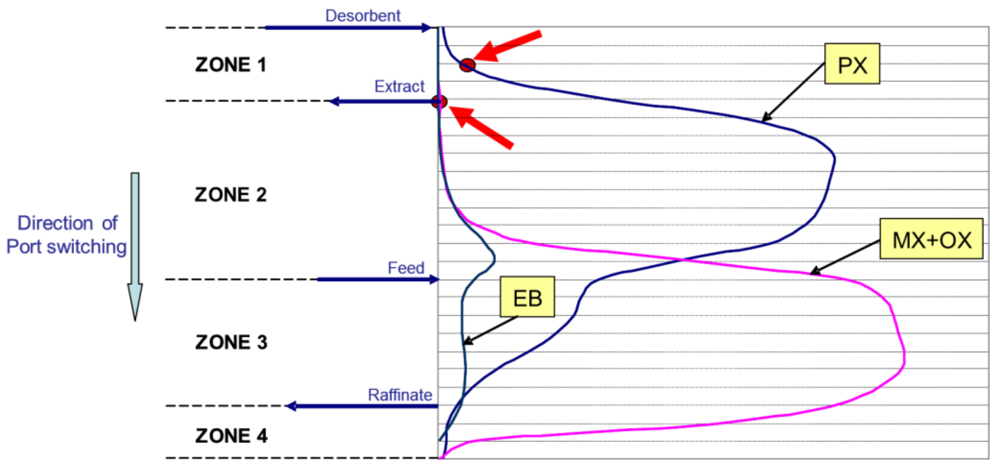
APC experts together with process experts established that to reflect the physical lows around counter-current moving bed, the best MV's for the APC are the 4 ratios "Zone_Flow / Adsorber_counter_current_flow".

The following controlled points were selected:

- PX in zone 1, to control PX content in extract.
  Calculated by SCS from Adsorption profile.
  Controlled at target by manipulation of R1, R3 and R4.

- EB in Extract, to prevent EB profile to move to the top, and to pollute extract.
  Calculated by SCS from Adsorption profile.
  Controlled below a maximum limit by manipulation of R2, R3 and R4.

It is to be noted that this APC strategy is patented.
The profile is available on-line, in real time from the SCS screens, and calculated from the data supplied by the RAMAN on-line analyser.

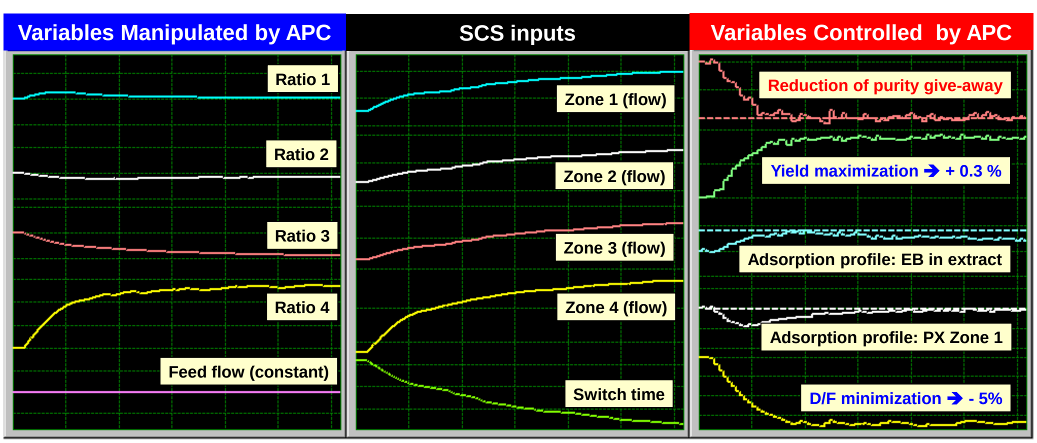


Adsorption profile from Raman on-line analyser

Figure below shows how the manipulation of the internal zone ratios by APC, generates new zone flows and new switching time for the SCS.

First objective is to control the adsorption profile:
- EB in extract is maintained below max limit,
- PX in Zone 1 is controlled at optimal target.

Second objective is to reduce the extract purity to the minimal limit, reducing give away.
The "room" created by purity minimization, allows APC to perform:
- D/F minimization, reducing column desorbent load, and consequently reboiler and pump duties,
- PX yield maximization, increasing production.



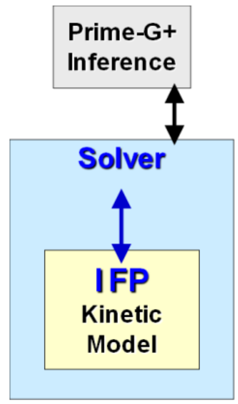
4. Accurate inferences

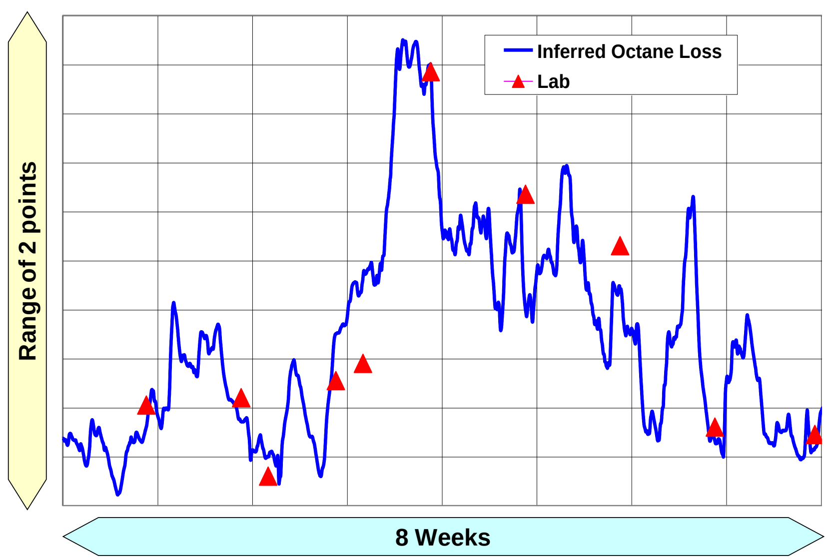
4.1. Octane Loss in Prime-G+™ HDS reactors

Axens Prime-G+™ process is the deep desulfurization process for FCC Naphtha. The reaction knowledge allows to build an accurate and reliable HDS inference using a mathematical solver calling the IFPEN rigorous kinetic model.

Several ways of calling the model are pre-configured, in order to satisfy the various use of the inference:

- Inverse Mode *for octane loss estimation*
    - Some reactor input data are unknown
    - Reactor output data are estimated
- Update Mode *for catalyst activity estimation*
    - All reactor input and output data are known
    - Catalyst activity is estimated
- Direct Mode *for what-if studies*
    - All reactor input data are known
    - Reactor output data are estimated





Example of accuracy of Octane Loss Predictions

The model inputs are:

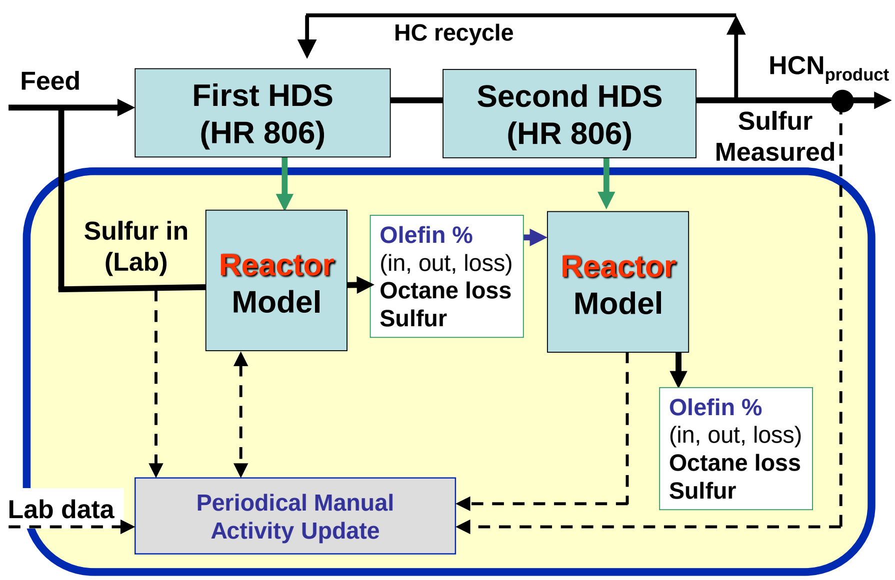
- Reactors inlet temperature
- Reactors outlet temperature
- Reactors pressure
- Hydrogen partial pressure (ppH_2)
- Space velocity
- Catalyst condition
  tuning parameter
- Reactor feed ?sulfur content at minimum

The model output: is

- Octane loss

The model is structured as follows:

- Same structure than model used for process design
- Octane loss is estimated from reactor operating condition
  (temperature profile, feed properties, ppH_2, LHSV…)
- Activity is updated using the model result for outlet sulfur and the on-line analysis of sulfur on HCN product

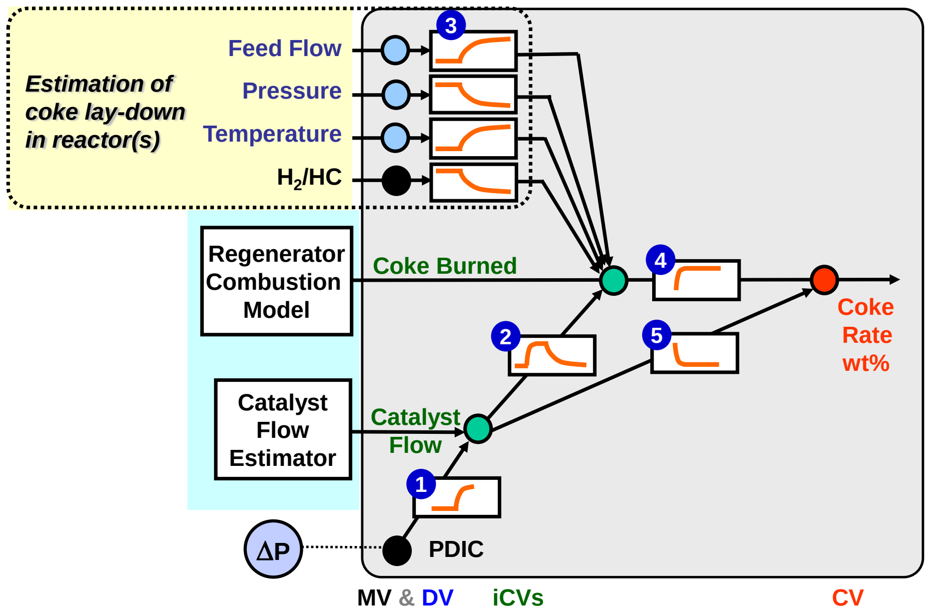


4.2. Catalyst coke rate in a CCR

The objective fixed for the coke rate controller in the APC strategy is to achieve the coke rate target that has been fixed in order to maximize the catalyst selectivity.

The coke rate varies depending on the reactor conditions and is controlled via the manipulated variable, ΔP on the master lift and the hydrogen / hydrocarbon ratio target.

The reactor conditions such as Feed flow, Pressure, Temperature are disturbance variables, DVs, which are measured but are not manipulated by the coke rate controller.



Coke Rate State Space Model with two intermediate CV

Due to the extended time, more than one day to reach steady state, traditional model identification from step test data cannot produce satisfactory dynamic models.
Axens process expertise and operational experience, has been used to develop models and to validate them with plant operation data. This control philosophy is patented.

Model 1 defines how the catalyst flow is controlled by the master lift ΔP. The static gain is estimated using Axens' catalyst lift model. The time to steady state corresponds approximately to the time between transfers.

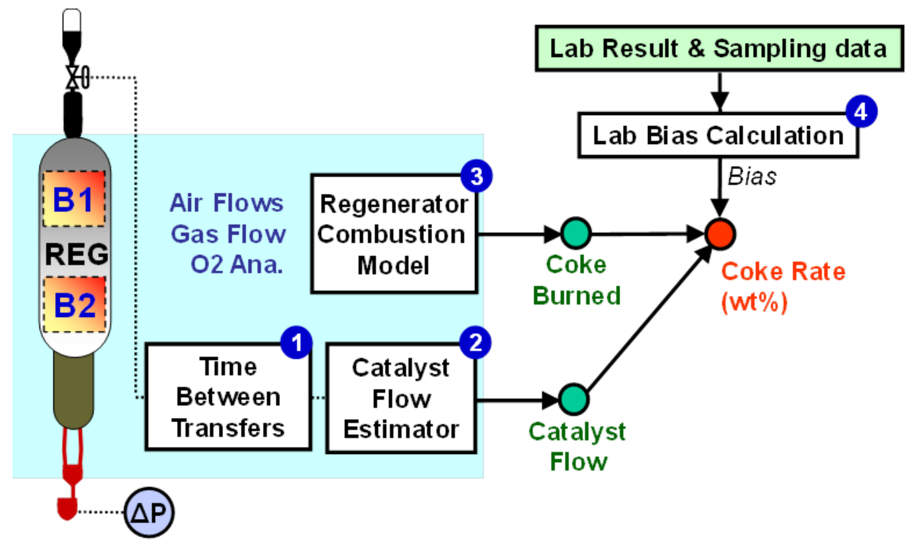
Model 2. In steady state conditions, the coke burned is equal to the coke lay-down generated by the reactor operating conditions: flow, pressure, temperature and the H_2/hydrocarbon ratio.
Although the catalyst is introduced in batches into the regenerator, the slow catalyst flow can be assimilated to continuous flow.
If there is a step increase in catalyst flow there would initially be a high coke burned because of the increased catalyst and coke in the regenerator. Then, as the system stabilizes, the quantity of coke burned approaches the quantity of coke laid down in the reactor.
This configuration results in a complex zero gain dynamic model.

Model 3 links the reactor operating conditions: feed flow, pressure, temperature and the hydrogen / hydrocarbon ratio to the coke burned. The static gains are estimated using Axens' kinetic models, and the time constant corresponded to reactor catalyst inventory.

Models 4 and 5 These models combine the Coke Burned (kg/hr) and the catalyst flow to obtain the coke rate (wt%).

The coke rate inference is structured as follows, with four calculation steps.

1. Time between 2 catalyst transfers batches from the upper hoper into the regenerator
2. Catalyst flow, using the volume, density and the time between catalyst transfers
3. Coke burned, using the oxygen consumed, established from combustion gas flow meters and on-line oxygen analyzers.
4. Coke rate is the ratio between the coke burned and the catalyst flow

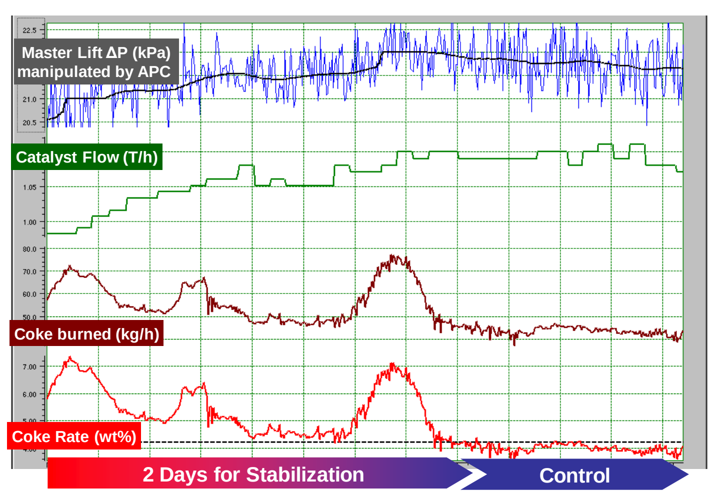


CCR coke rate inferential schematic

Finally, the inferential is adjusted daily using lab results to compensate for any bias. Statistical process control techniques are applied to validate the new calculated bias before update. In fact, it can be observed that inferred values obtained are very close to measured values and bias is very small.

The coke rate controller executed every twenty minutes, with a time to steady state of three days, raises a lot of doubts and interrogations from panel operators and APC staff.

Thanks to the robustness of the design and to extensive off-line simulation testing, this controller performs excellently, as illustrated in Figure below: when the controller is switched ON, Coke rate is maintained at his target of 4.5% after 2 days of stabilization.



Three days of industrial results, coke rate control

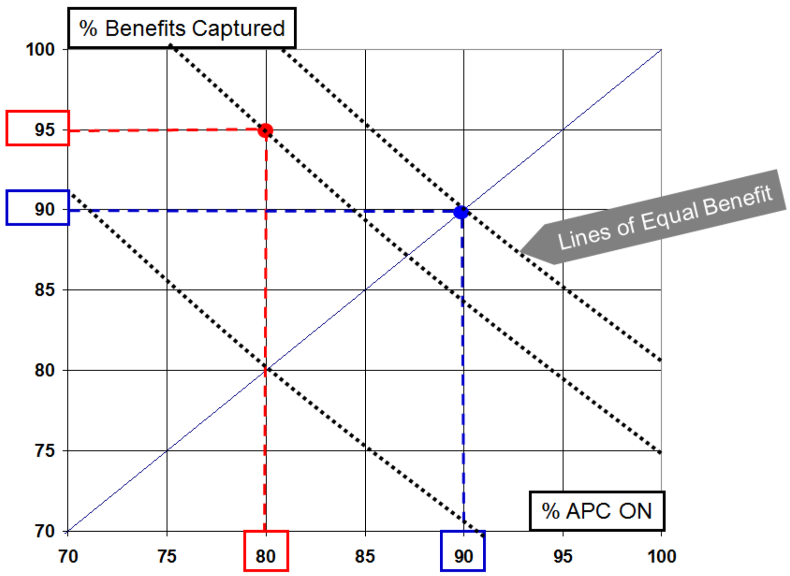
5. Clever control strategies

With too many MVs and CVs, control strategy and model design can be difficult to build. Then, when controller is running, control moves can be difficult to understand by operators, and application maintenance can become tricky or even impossible.

Another advantage of the licensor's process design and operation knowledge is the possibility to focus the control strategy on the main key operating parameters.

As illustrated is the graph below it is more profitable to capture

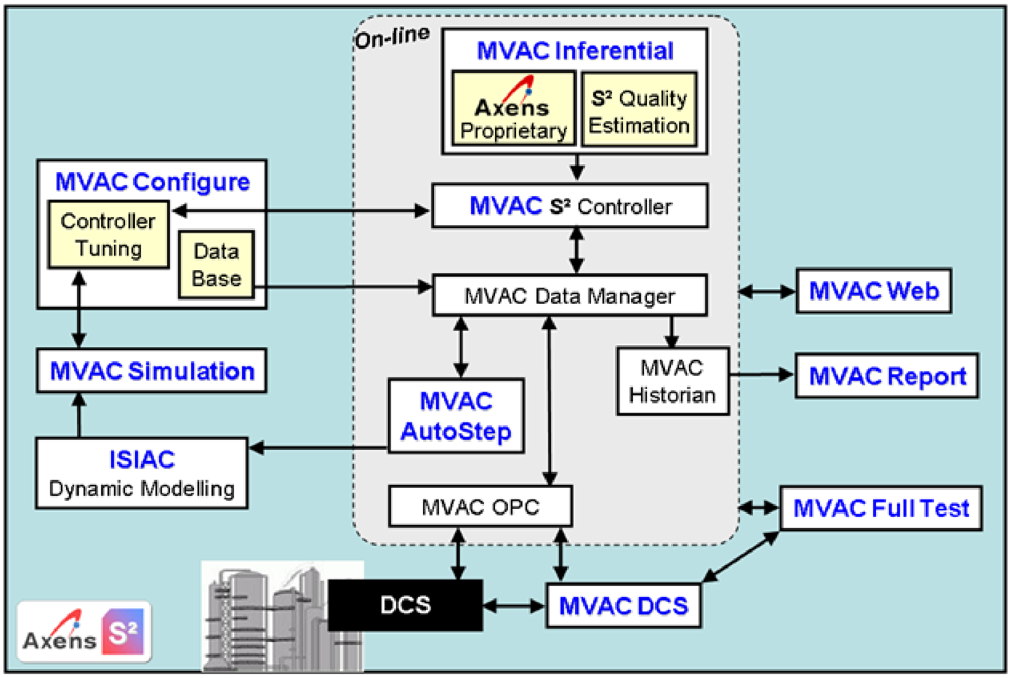
- 90% of the potential benefits 90% of the time, than
- than 95% of the potential benefits 80% of the time



The resulting APC application with limited number of MVs and CVs has a reduced complexity and consequently is easier to understand and to maintain.

6. The right APC tool

Axens has at disposal S², its State Space APC suite, designed to efficiently implement and maintain plant-wide APC applications. S² allows robust control and safe capture of plant benefits.



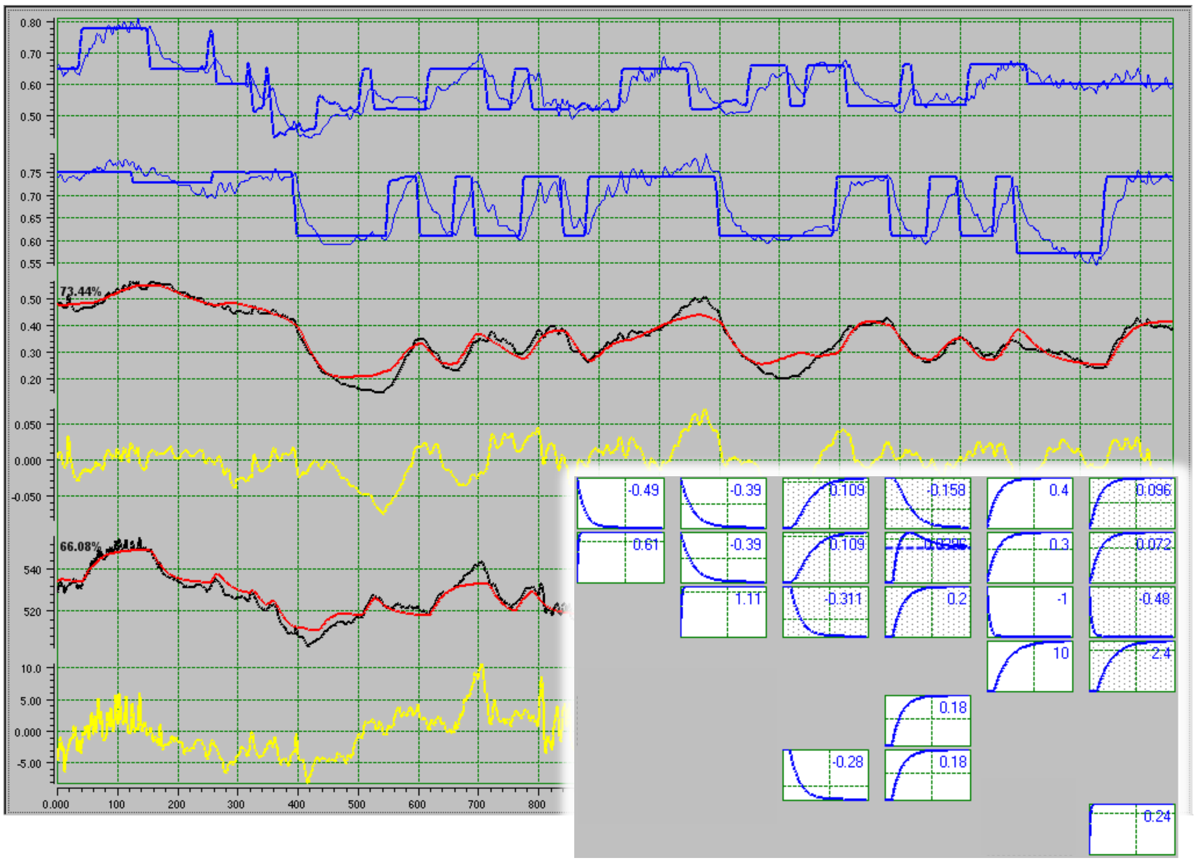
The main powerful module of this suite are:

- The identification software (ISIAC)
- The simulation module
- The State Space controller

6.1. Identification module: ISIAC

ISIAC is a powerful modelling platform, used to identify the dynamic behaviour of the plant.

Individual transfer functions are assembled in a final control matrix



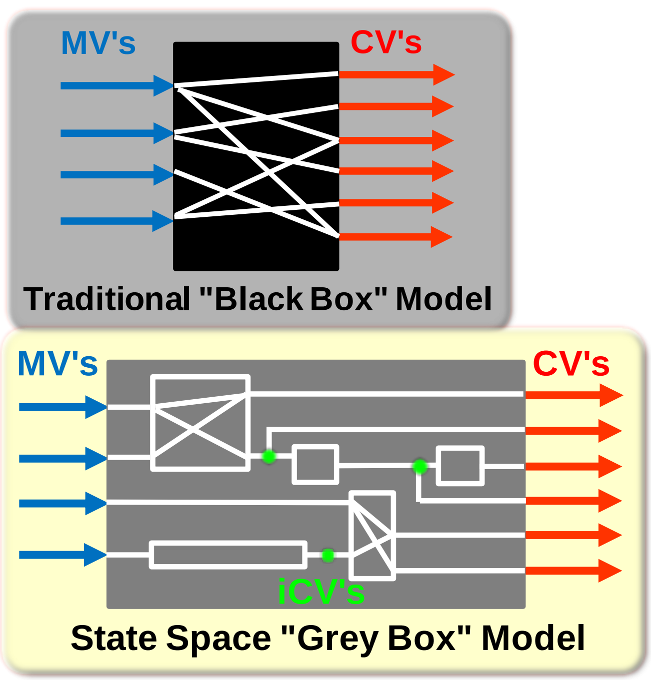
6.2. State space controller module: MVAC

MVAC is Axens' proprietary State-Space multivariable controller, providing superior performances, thanks to the use of latest generation control algorithm.

MVAC provides:

- All the classical control functions
- A complete set of robustness features
- Specific features allowed by the state space technology embedded in the MVAC kernel:
    - Use of intermediate variables (grey box modelling)
    - Use of calculated variables (combination of MV, CV & DV)
    - Estimation of non-measured disturbances (better predictions & better control)

Grey Box Modelling: the State Space approach



The traditional black box modelling has only inputs (MV) and outputs (CV)

The relationship between MVs and CVs is extended to describe how unmeasured disturbance affects the process.

Measurements of process variables that are not explicitly controlled provide valuable information about the internal state of the process.

'Grey Box' model adds known internal causes and effect relationships into the model.

The use of intermediate variables enhances controller performances:

- early and accurate disturbance detection is a prerequisite for superior control
- extended model provides the means to determine the dynamic state of the process and its future trajectory
- the controller is less sensitive to individual model inaccuracies
- control actions are more robust, less aggressive, and better timely coordinated.

6.3. Simulation module: MVAC Simulation

MVAC Simulation, mainly used to validate the robustness of the controller tuning, allows the user to create different simulation scenarios, and to introduce different levels of plant-model mismatch for controller testing.

Following are some of the key features of the simulation tool:

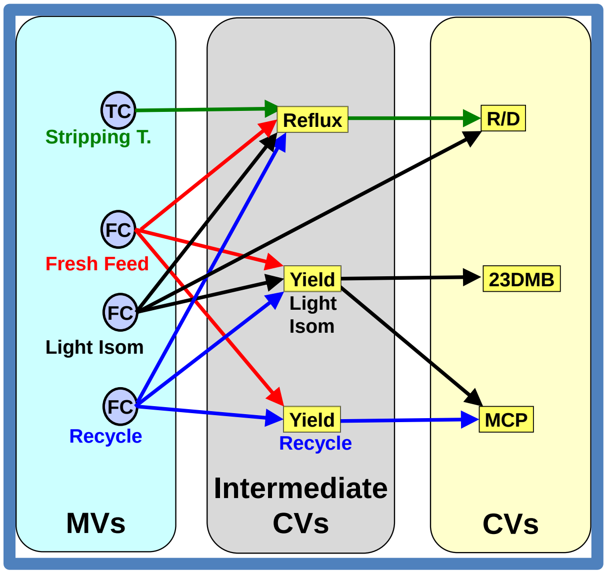
- Configuration of predefined scenarios
    - changes in MV or CV limits or targets,
    - drop out of measurements,...
    - replay with different tunings

- Plant model used for simulation
    - same or different from control model
    - detailed process models can be used
    - noise and intermittent signals can be added anywhere in the loop

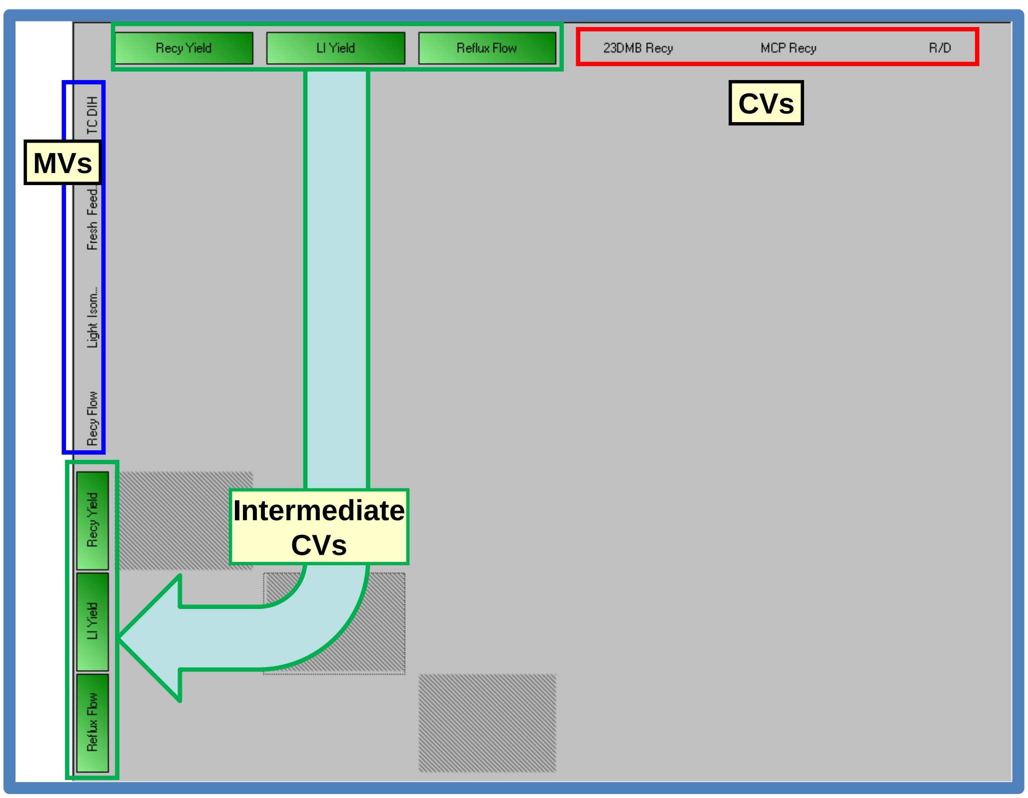
HDT unit simulation, with noise, analyser and operator changes on CV target and on MV limits.

6.4. Example of State Space structure (Isomerization)

State Space structure with iCVs: iCVs are CVs for MVs and also, MVs for CVs



State Space control matrix with iCVs: MVs as rows, CVs as columns, iCVs as columns duplicated in rows



6.4. Example of State Space dynamic simulation (Isomerization)

First, feed flow disturbances are rejected by appropriate APC actions

Second, CV targets are changed, and APC performs smoothly moves requested to reach new targets