1. Introduction

An Advanced Process Control application was implemented on the distillation section of a refinery Hydrocracker Unit. The scope included the Main Fractionator column, a Vacuum Fractionator column, and a furnace in front of each of these columns. The reaction section of the HCU already had an APC application, and this was then also integrated with the new multi-variable controller on the distillation section.

The HCU receives a mixed feed of Hydrowax and VGO, which is cracked in the reaction section and then separated into different fractions in the distillation section. The distillation products are Light Naphtha, LPG, off-gas, Heavy Naphtha, Kerosene, Gas-oil and a Hydrowax residue.

The main optimization objective was to firstly maximize the reaction section conversion against constraints in the back-end distillation section, and secondly to maximize the yield of more valuable distillates, especially with regards to Kerosene, Heavy Naphtha and Gas-oil.

2. Challenges

The most challenging part of this project was the integration of the reaction section multi-variable controller with the new application over the back-end distillation section. Previously this MVC controlled the WABT for each of the two reactor trains between tight operator given limits. In the revamped version, these WABT limits were opened and the controller now gets the opportunity to maximize the WABT (for both of the parallel reactor trains) against clearly defined constraints in the distillation section. However, for practical purposes, the manipulated variables - reactor quench temperatures of the cracking reactor beds - and the controlled variables - those particular back-end constraints that are heavily influenced by the maximization of the conversion - are assigned to different sub-controllers. Unfortunately SMOC technology calculates a dynamic move plan that is optimal only within a particular sub-controller. That meant that some relatively simple custom code had to be implemented to ensure that the conversion gets maximized at an acceptable rate, which prevents severe dynamic excursions in the distillation section, especially with regards to the flow rate of the Main Fractionator distillate and off-gas. The WABT high and low limit constraints, one for each parallel reactor train, was kept active when we started maximizing conversion, and then increased in small engineer-defined steps whenever the steady state solution saw the room for pushing conversion. This way the constraints were approached slowly when there was room for conversion maximization.

Another challenge was the integration of the two furnaces with the Main Fractionator and the Vacuum column. Operators were used to running a fixed furnace outlet temperature. The new application opened these limits and pushed the furnace duty up against distillation column constraints. The operators were not used to setting the furnaces free for this kind of maximization.

3. Results

A post-implementation review, comparing base case data from the summer of 2011 to post-commissioning data from the summer of 2013, shows a marked increase in the yield of more valuable distillation products. This translates to a generous annual benefit of 16 million US$ (12.6 million euro), based on a conservative low throughput of 5000 t/d. The maximum throughput is about 7200 t/d.

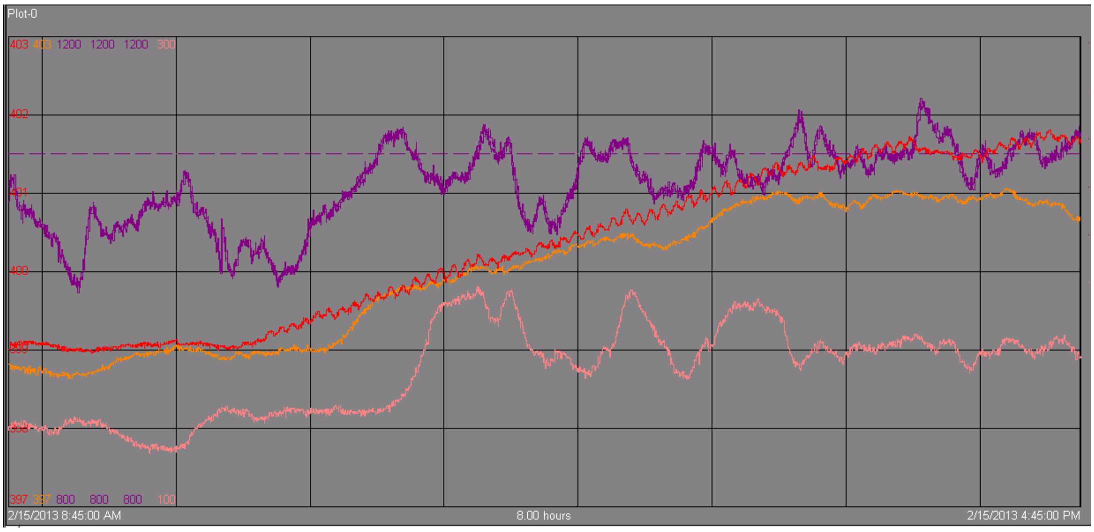
These average yields were calculated based on 1-minute data extracted from PI over a 2-month period for the base case, and selected data over 3 months from the summer period of 2013, excluding a plant shutdown, a period of very low throughput and some process upsets where the APC application was not turned on.

These calculated results have been checked against the official monthly refinery production mass balance data, comparing product yields for every month from March to October between 2012 and 2013, which confirmed a similar trend.

Please note that these values are preliminary and may still be challenged by various role players. The results have yet to be verified by the Economics & Scheduling department.

	Yields (%)			per t/d feed	price		
	base-case	post-impl	difference	5000	US$/t	US$/d	US$/year
MF top (LN + LPG)	14.963	18.568	3.605	180.25	500	90125	
MF off-gas	2.541	2.451	-0.09	-4.5	371	-1669.5	
HN	8.514	10.037	1.523	76.15	599	45613.85	
Kero	7.631	7.949	0.318	15.9	643	10223.7	
GO	27.231	29.871	2.64	132	618	81576	
HW	39.12	31.124	-7.996	-399.8	455	-181909	
	100	100	0	0		43960.05	16045418

Some tangible and intangible benefits are also obvious when looking at trends of the controller behaviour below. The first screen shot shows the controller starting to maximize both reactor WABT's at about 2 hours into the 8h trend. As conversion of the hydrowax/VGO feed increases, proportionally more light products reach the distillation section. The Main Fractionator overheads distillate and off-gas flows increase. As the distillate flow gets pushed towards and against its CV high limit, the rate at which the WABT's rise reduces until it eventually flattens out and reaches a steady state. It is clear that due to running closer to the limit, more distillate will be produced.

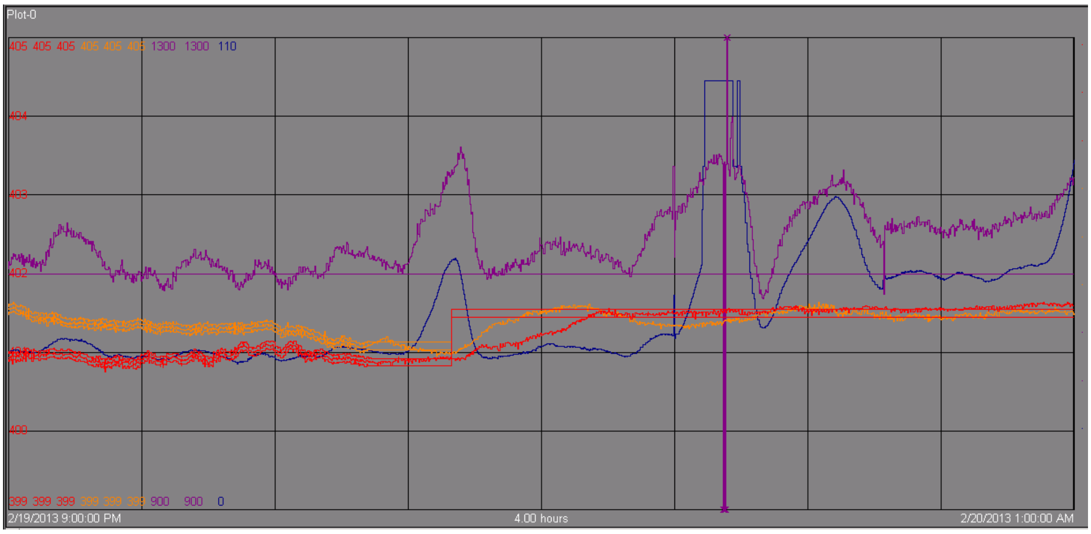


WABT R1/R2 **WABT R3/R4** **MF OFF-GAS**

MF DISTILLATE FLOW & HIGH LIMIT

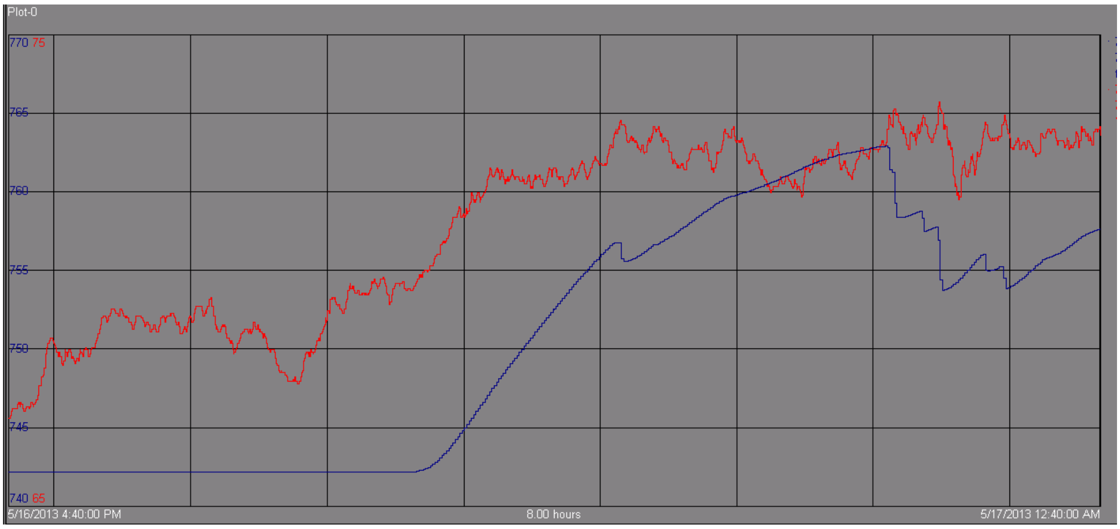
Stability in the overheads of the Main Fractionator seems to be an intangible benefit over and above the fact that conversion maximization produces more of the valuable product. The Main Fractionator distillate flow is an important plant constraint due to pump capacity. It happens regularly that the operator sets the WABT targets too high and due to the increase in light products, the MF reflux drum fills up. The long delay in between makes it difficult to take action at the right moment. It takes a few hours to recover from such a disturbance. When SMOC maximizes the conversion against this high limit, it both predicts and provides feedback every single minute, moving the reactor WABT's down before the distillate increases to the point that it cannot be pumped away and the reflux drum runs full.

The screen shot below shows how operators switch back from conversion maximization to setting a fixed WABT range, in fact decoupling the reaction section APC from the distillation section (at about 1.5 hours into the 4h trend). They even increase the WABT limits, and then approach the scenario where too much distillate is produced and the valve goes fully open.



WABT R1/R2 & LIMITS **WABT R3/R4 & LIMITS** **MF OFF-GAS**
MF DISTILLATE FLOW & HIGH LIMIT **MF DISTILLATE VALVE**

The following screen shot shows the heavy naphtha product draw being maximized the moment the APC application is switched ON. The product draw temperature rises until it eventually becomes a limiting constraint.



HN PRODUCT DRAW TEMPERATURE **HN DRAW**

4. Conclusion

The implementation of APC on this Hydrocracker Unit delivered immense benefits, both tangible - in terms of an increase in the yield of more valuable products, and intangible - in terms of stability. Most of the benefits were achieved by the implementation of standard APC functionality. The integration between the reactor section manipulated variables (quench temperatures) and the distillation section constraints, by maximizing the WABT, was an innovative approach which delivered some additional benefits.

When process conditions still allow increase of the VGO cloud point, the MPC application is expected to increase VGO yearly production to a maximum of 1.6%, resulting in benefits on the order of 250k USD per year.

A post-implementation review, comparing base case data from the summer of 2011 to post-commissioning data from the summer of 2013, shows a marked increase in the yield of more valuable distillation products. This translates to a generous annual benefit of **16 million US$ (12.6 million euro)**, based on a conservative low throughput of 5000 t/d. The maximum throughput is about 7200 t/d.