1. Introduction

In the refining processes, the bottoms of the crude distillation unit (CDU) are typically sent to a vacuum distillation unit (VDU) in order to further improve recovery of gasoil and separate the very heavy compounds from the wax cut, which typically feeds fluid catalytic cracking units (FCCs).

Depending on the market conditions and on the refining process schema of each refinery, increasing the vacuum gasoil (VGO) recuperation in exchange of wax can be economically attractive. One of the product qualities specifications that can limit the maximization of VGO recovery in a VDU is the cloud point. The maximum allowed VGO cloud point is defined based on the final diesel product specifications and on the properties of all streams which are combined in the diesel pool and their quantities.

The cloud point of a sample is considered to be the temperature at which the first appearance of wax crystals is detected during a standardized cooling process. According to ASTM D5773, a test sample is cooled at a constant rate of 1.5 °C/min. The sample is continuously illuminated by a light source. An array of optical detectors continuously monitors the sample for the first appearance of a “cloud” of crystals.

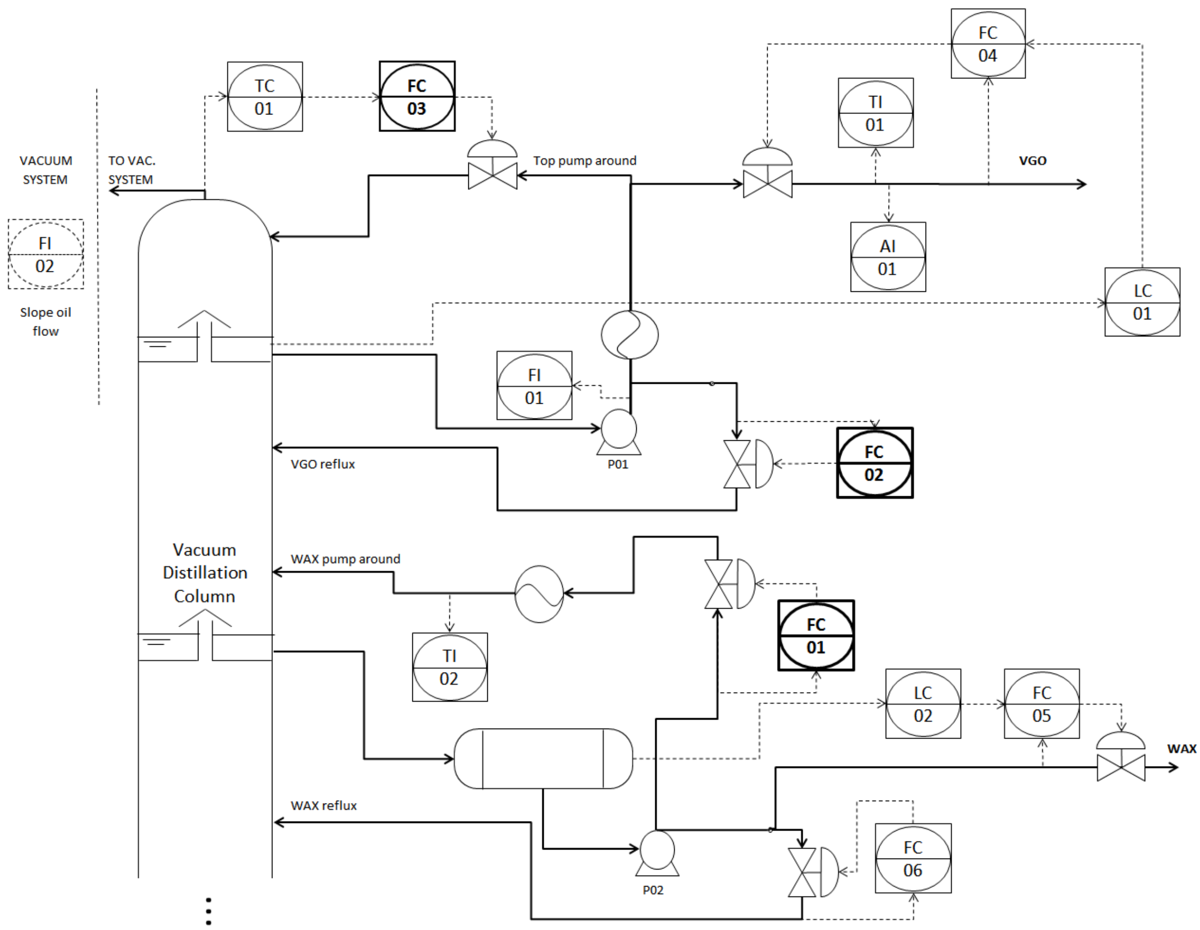

Figure 1 – Vacuum distillation column top section control scheme

Figure 1 shows a typical top section of a vacuum distillation column and its typical base layer control schema. In order to cool down the internal streams and ensure minimum amount of hydrocarbons losses through the top to the vacuum system, part of the side products streams is sent back to the column after exchanging heat typically with the feed in the heat recuperation battery.

These streams are called "pump around" and they are sent back to the vacuum distillation column normally on heat exchange only stages, i.e., stages which are not meant to promote fractionation but only heat exchange with the cooled pump around stream instead. There is no internal liquid flow descending the column from the stages where these streams are taken from, i.e., they are taken from total draw-off stages. In Figure 1, these streams are labeled FC01 (WAX P.A.) and FC03 (top P.A.)

In order to promote fractionation, another part of the side streams taken from the total draw-off stages is sent back downwards to the column, where the descending liquid will get in contact with upcoming vapours from bottom stages in the fractionation packing's. In Figure 1, these streams are labeled FC02 (VGO reflux) and FC06 (WAX reflux).

At constant pressure and feed type, the cloud point is usually a nearly-linear function of the VGO total draw-off stage temperature. This temperature is mostly affected by the wax pump around and by the VGO reflux flows. The higher the cloud point, the more heavy compounds are let go up through the column, which means also that VGO product flow is expected to increase as the cloud point increases for a given range of operating top temperature – TC01, in Figure 1.

The top temperature can be controlled in a flexible range: it needs to be warm enough to ensure that no water will condense inside the vacuum column and cold enough in order to avoid hydrocarbon losses to the vacuum system via the column top. Losing hydrocarbons via the column top is not only an economical loss but also an operational risk: oil in excess can flood the vacuum system, which in turn means that the vacuum is lost and the VDU furnaces must be shut down to avoid coke formation in the whole unit.

Other VGO recovery limitations are related to the wax and the VGO streams. Wax pump around flow must be above a certain minimum limit to ensure enough liquid flow to the heat exchange internal devices. Wax temperature must not exceed the external cooling devices design conditions. The VGO product off-take temperature must also not exceed the maximum storage temperature allowed. Moreover, if the external top cooling system is constrained, the top pump around stream can no longer reduce the top temperature, potentially leading to a positive feedback which can only be stopped by increasing the duty removal in the wax section.

It is thus clear that pushing the column to its limits is better done with the help of an MPC application. This article describes the results obtained with an MPC application installed in a VDU to maximize the VGO production while keeping its cloud point in specification and keeping the unit operational process parameters in control. An inferential expression to anticipate the cloud point analyser value has been implemented together with the MPC application.

2. Cloud Point Inferential

In order to improve the control of the VGO cloud point, an inferential expression based on continuously available process data has been developed to anticipate the analyser value. The inferential calculation runs once per minute, allowing thus the MPC application to react immediately on coming changes of the VGO cloud point.

Every time the analyser provides a new sample, the inferential package software validates the new sample and calculates a bias to shift the expression result value to the same value provided by the analyser. The bias is calculated comparing the analyser value to a filtered copy of the inferential expression raw result so that the anticipation effect of the inferential is cancelled for bias calculation purposes. This is necessary in order to make the bias calculation dynamically consistent. MPC uses then the analyser biased corrected prediction for control purposes

Figure 2 shows the comparison between the analyser value and results provided by the inferential expression.

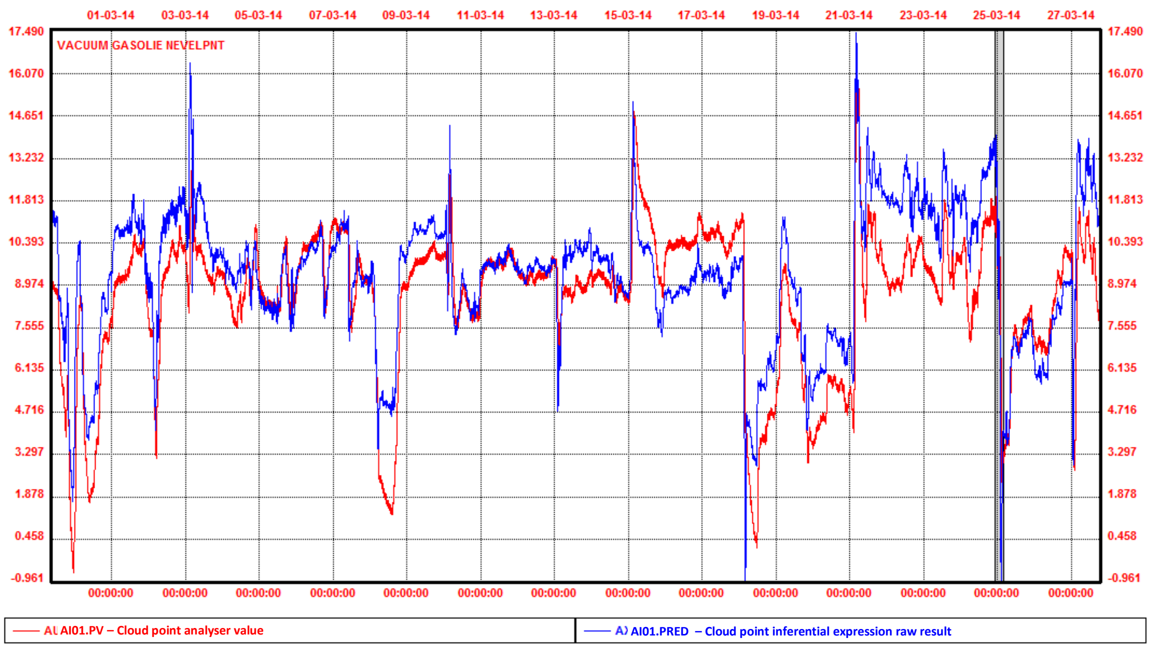

Figure 2 – Cloud point analyser (red) and inferential expression (blue)

3. Results

The positive results of the MPC application for cloud point control are mainly:

- Reducing variability of VGO cloud point
- Keeping product in specification
- Maximizing VGO production, given process and product constraints

Figure 3 shows VGO cloud point variability reduction with use of MPC. Figure 4 shows MPC bringing cloud point back to specification right after it is turned on. Figure 5 and Figure 6 show VGO production increase when the plant is operating with relaxed process parameters and VGO cloud point is below maximum limit.

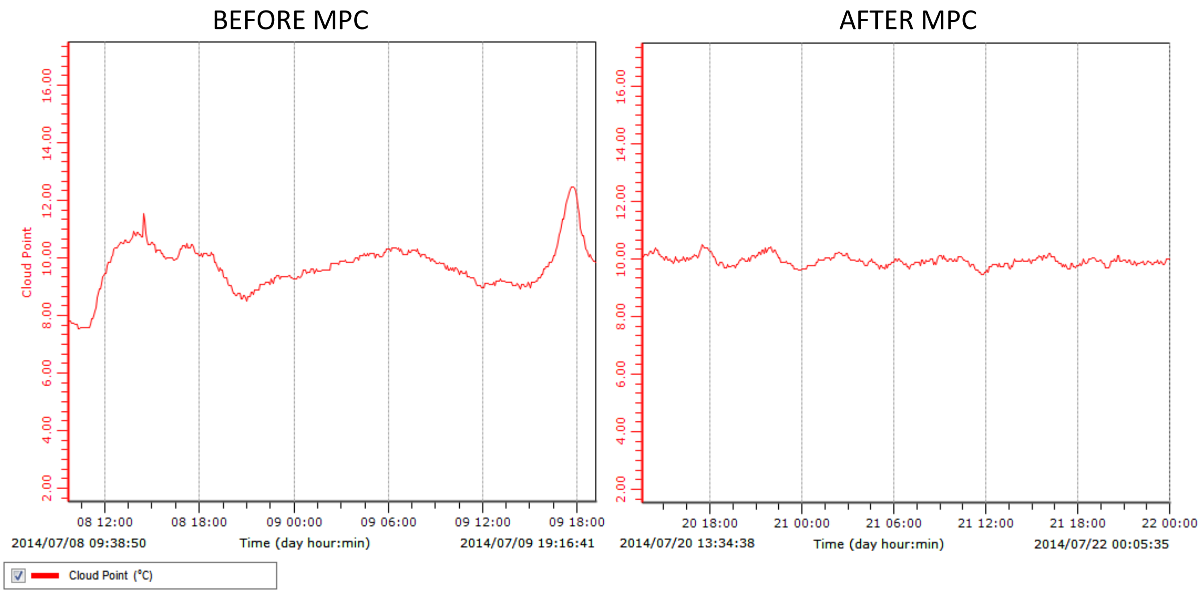

Figure 3 – VGO cloud point stabilization

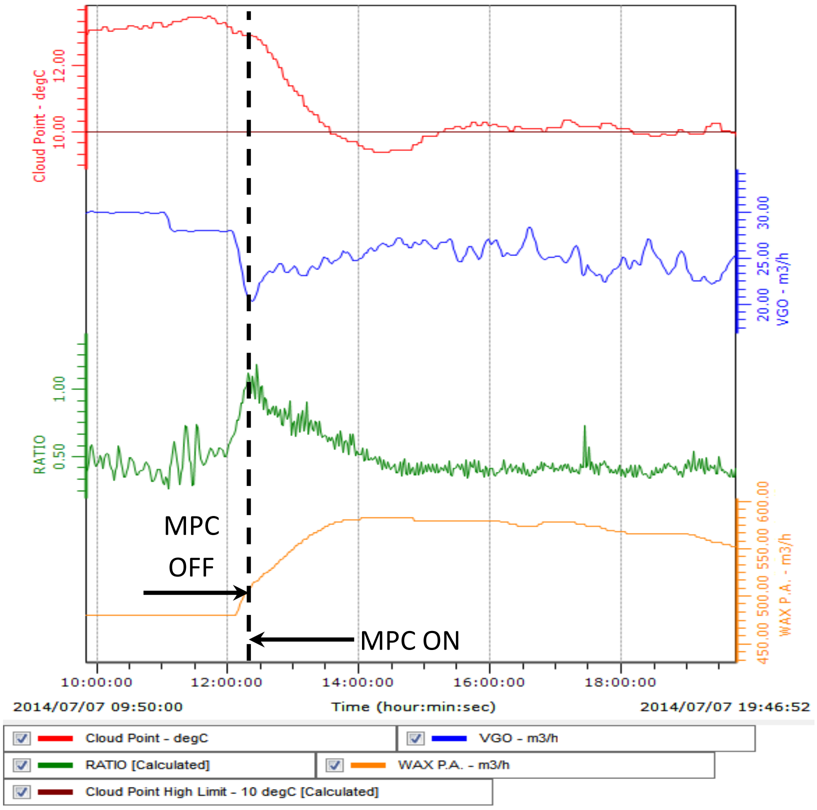

Figure 4 – VGO cloud point brought back to specification after turning MPC ON

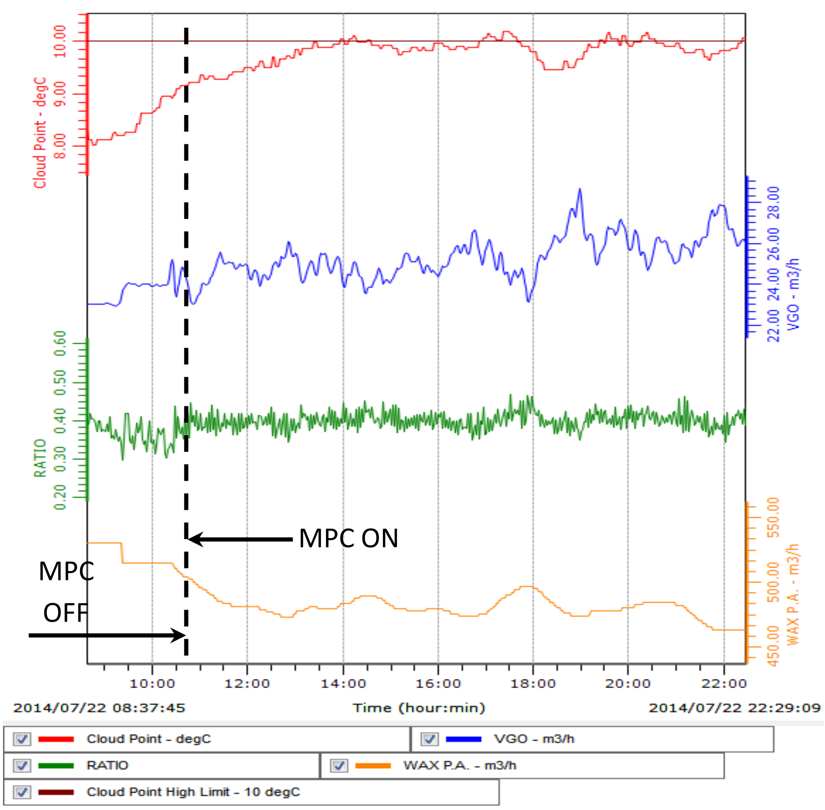

Figure 5 – VGO production maximization while keeping cloud point within specification (1)

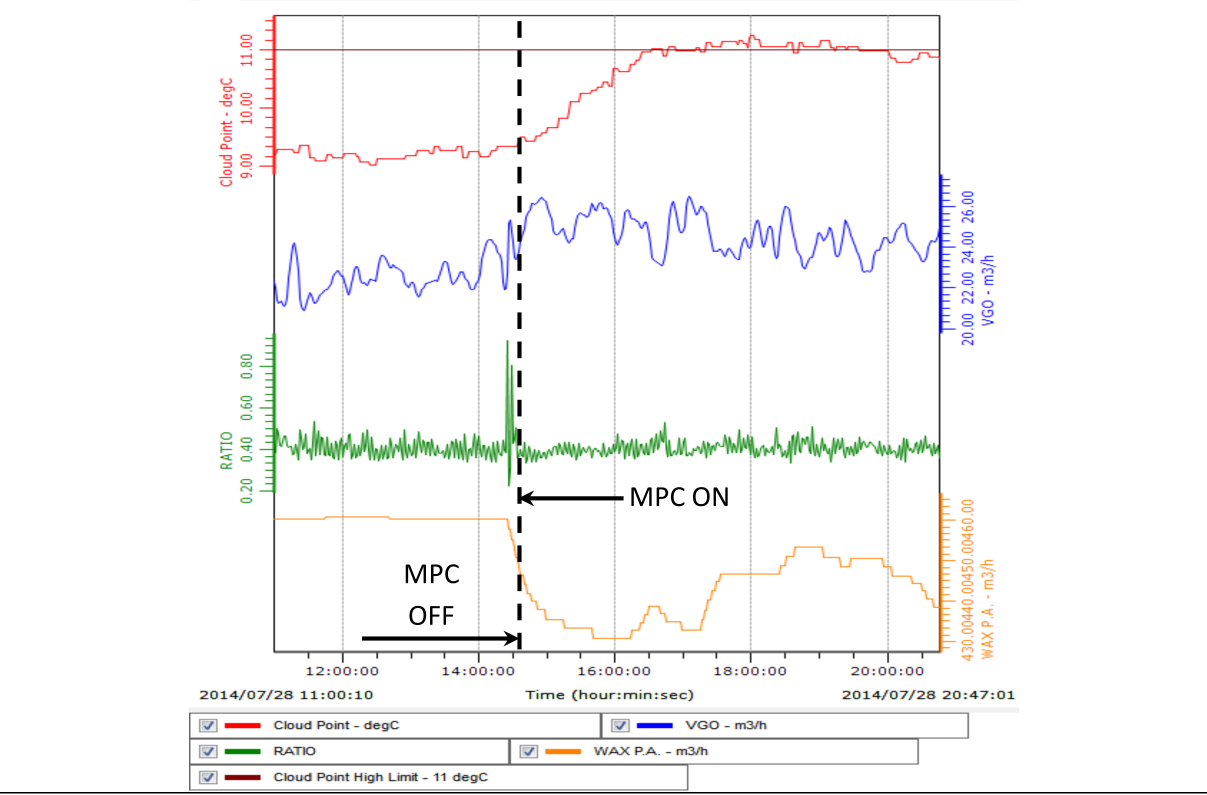

Figure 6 – VGO production maximization while keeping cloud point within specification (1)

The typical constraint scenarios for the controller are:

1. Cloud point at maximum
2. RATIO at minimum
3. VGO reflux valve at minimum opening
4. Wax pump around at minimum flow
5. Bitumen runs

If scenarios 2, 3 and 4 are hit simultaneously, it is no longer possible to increase VGO cloud point, even if it is below its maximum value. If scenario 5 is the case, the controller is not meant to be in service.

During the feasibility study phase before implementing this MPC, a potential benefit calculation has considered that the VDU unit runs on bitumen mode during 25% of a calendar year time. Taking into account the observed occurrence of scenarios 2, 3 and 4 simultaneously, the MPC application is expected to increase yearly VGO production from 0.6% to 1.6%, depending on the cloud point specification and the minimum allowed RATIO. The specification changes according to logistic request with regards to final product blending. RATIO minimum limit may be increased to improve fractionation. Occurrence of scenarios 2 and 4 is mainly dependent on the type of crude oil being processed in the crude distillation unit.

With all limitations in consideration, and already taking into account the opportunity cost of not processing an equivalent volume of WAX in the FCC units due to the incorporation of its light end to the VGO, the MPC application is expected to result a yearly benefit of 250k USD on average.

Full project implementation has taken place for 5 months and consumed about 30% of one FTE, including documentation. APC infrastructure was already present and functional. Computed project time does not take into consideration setup time for computers, network and APC software.

4. Conclusion

The MPC solution has shown excellent results with respect to VGO product maximization while keeping its cloud point in specification. This goal is achieved by minimizing the vacuum column wax pump around and the VGO reflux simultaneously.

An inferential expression for the cloud point is used in order to provide anticipated information for the MPC application.

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.