

Catalytic reforming unit (CCR) optimization

The use of simple robust on-line analyzer technology for the optimization of refinery catalytic reforming units



This white paper uses the example of the catalytic reforming unit commonly found in a refinery to illustrate the options now available for using simple robust on-line analyzers to deliver useful timely and available process stream quality data in advanced process control.

Measurement made easy

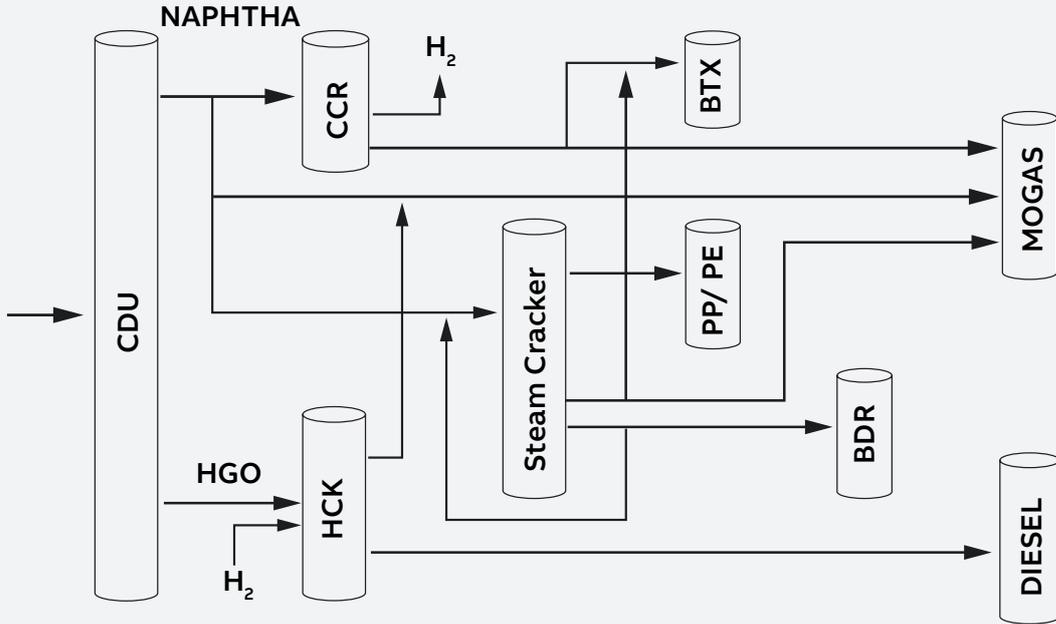
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Refinery

First, we need to consider the background: why optimization of refinery process units is so common and so necessary, and what analytical tools exist to help. The key problem in refining is that, although crude oil refining is a continuous and high-volume process with very significant raw-material and energy costs, it is not steady-state. Crude oil feedstocks vary continuously in quality, availability and cost – while at the same time refinery products and their markets are very dynamic in terms of demand, specifications and pricing. This leads to the use of relatively complex whole-refinery linear

programming (LP) models to manage these changes. Underneath these models, individual process unit Advanced Process Control (APC) packages need to keep the units on target (even though these targets will change) and under control.

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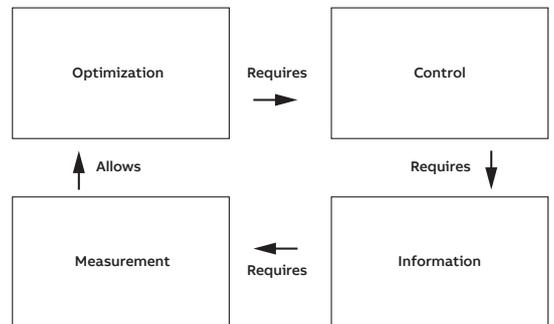
— Cost, capacity, quality, value & demand all change continuously

The refinery naphtha complex with CCR and integrated petrochemical units

If we look at one specific area within the refinery—the so-called naphtha complex, or naphtha conversion area—we can see the interaction between many different process units and streams. Central to these process units and streams is the Catalytic Reformer (CCR) unit. This unit takes low-value heavy naphtha from the CDU and converts it, after hydro-treating, into a higher-value high-aromatics, high-octane feedstock.

Note: in this paper, CCR is used as a generic to indicate a catalytic reforming unit. The arguments presented apply particularly to continuous catalytic regeneration reformers, but can also be applied to fixed bed units. The questions are – what alternatives might there be for naphtha processing or sources of CCR naphtha feeds, and what alternative uses exist for the various unit products?

The above diagram attempts to give a simplified and idealized view of these scenarios. For example, the reformate product from the CCR is frequently directed to the gasoline blending pool as a useful high-octane blend component, but the high octane value of reformate derives from high aromatics (BTX) content. This has alternative uses and, depending on the price breaks between blended gasoline product and the aromatics unit, diversion as an aromatics unit feed might be determined. Similarly, the straight-run naphtha from the CDU, usually hydro-treated as CCR feed, might be better employed as raw material for the naphtha steam cracker olefins unit, again depending on the relative instantaneous profitability of gasoline, aromatics and olefin products.



The cycle of measurement and optimization

Measurement at some level is key to process optimization. Measurement yields information which allows for the possibility of control. What form this measurement takes is a slightly more open question, and one subject to considerable entertaining debate between those (mainly engineers) who like statistics and dislike analyzers, and those (mainly chemists) who do not trust anything which is not a directly traceable analytical result.

This leads to various approaches to APC:

APC based on inferential models

- Use of many basic mass-flow, pressure, and temperature transmitters
- Requires chemical engineering model of unit
- Requires lab test data to calibrate and maintain the inferential quality estimator

APC based on physical analyzers

- Use of many single-property physical analyzers for direct measurement
- Requires extensive maintenance, calibration, training, and spares stockholding

APC based on advanced analyzers

- Use of a smaller number of multi-stream multi-property analyzers
- Requires calibration or calibration model development
- Normally offers significant improvement in speed, precision, and reliability

APC based on actual process stream quality measurements from real analyzers is superficially attractive but fraught with risk.

Historically this approach was hindered by:

- High capital cost
- Limited reliability, high life-cycle costs
- Large infrastructural requirements for installation
- Complex operational requirements (calibration, validation)

Technical advances have led to:

- Wider range of available technologies
- Simpler, more robust, lower cost analyzers
- Significantly reduced installation and operational demands

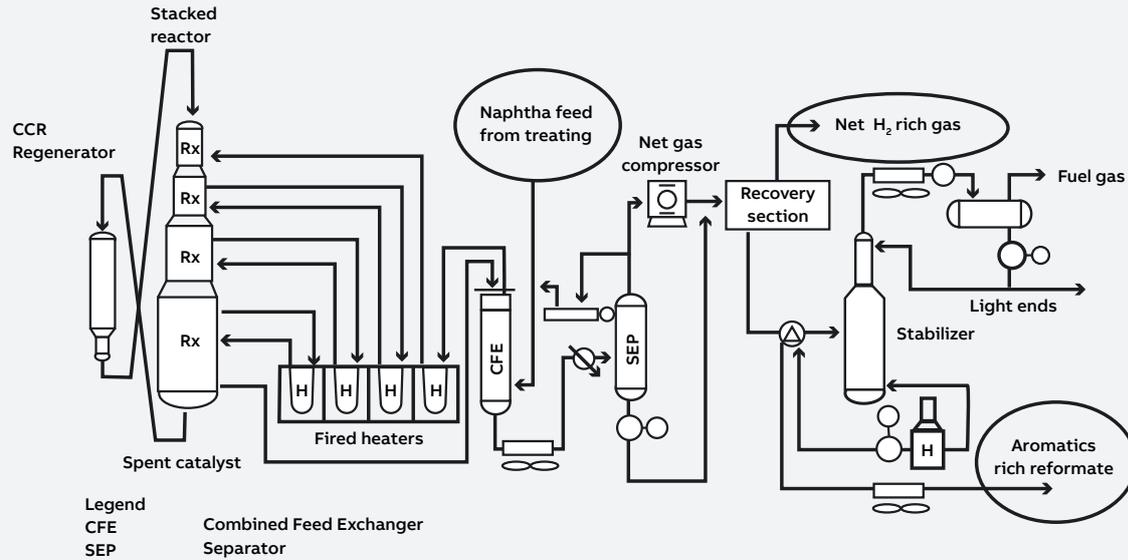
We look here at two examples of modern, robust analyzer technologies that have enabled easier and more reliable implementation of APC strategies based on real-time process-analytical measurement. Long maintenance intervals, low life-cycle costs Fourier-Transform Near IR (FT-NIR) analyzers have offered one route to deal with part of the problem. Chosen wisely, they offer space technology levels of reliability and uptime (quite literally because the technology is routinely used in climate sensing satellites). On-line FT-NIR analyzers now have a proven track record in reliable hydrocarbon stream property measurement (in this case RON & BTX in reformat product and PINA in heavy naphtha feed). The second technology is a solid-state electrochemical sensor-based method for monitoring the hydrogen recycle/net gas stream also critical in CCR operation.



ABB Process FT-NIR analyser TALYS ASP400-Ex



ABB Process Hydrogen Analyser HP30



Typical UOP CCR platforming process unit

In summary, the Catalytic Reforming Unit, whether a CCR, as shown here, or a fixed-bed type, takes a heavy naphtha feed and, by catalytic conversion at reasonably high temperatures but fairly low operating pressure, converts the paraffins and naphthenes to mainly aromatics.

The resulting product is an aromatics-rich reformat stream, and a hydrogen net gas is generated within the unit and partially recycled.

What issues and choices exist for the operation of this unit? As previously indicated, the product of the CCR unit is more than a potential blend-stock for gasoline blending. This is the traditional key product, but with varying markets, and more complex refineries with extensive heavy oil up-conversion, what were previously seen as CCR byproducts now become significant and potentially attractive economic choices.

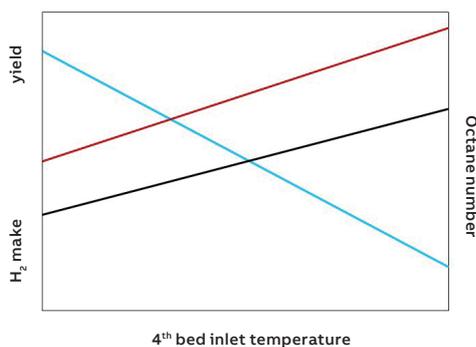
Reforming converts heavy naphtha into:

- High-octane feedstock for gasoline blending
- High-purity hydrogen suitable for use as hydrocracker make-up gas
- High-aromatics (BTX) feed for petrochemicals

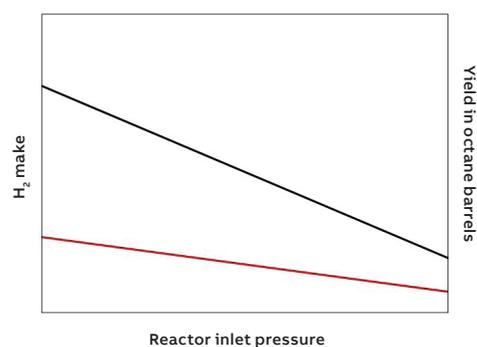
CCR unit operation offers a surprisingly large number of degrees of freedom including severity vs. pressure vs selectivity, which can all be traded off to:

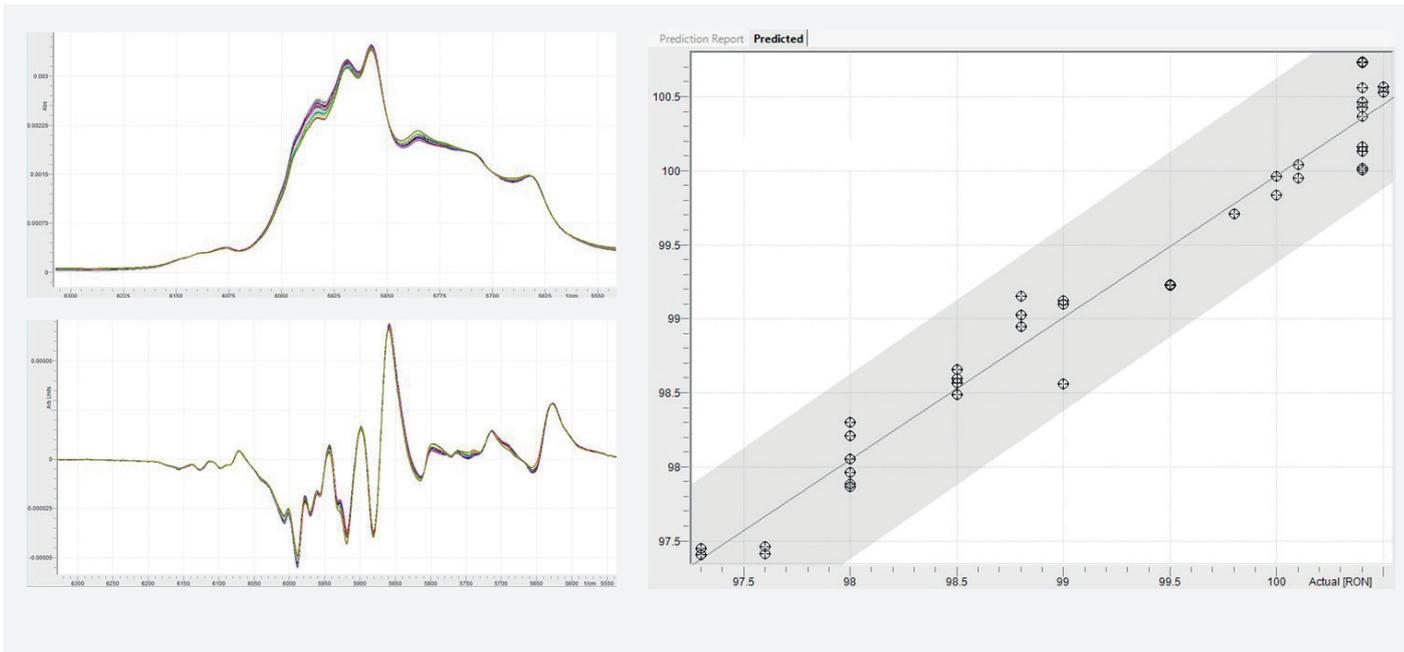
- Run for maximum octane barrels
- Run for maximum BTX yield
- Run for maximum Net Gas
- Run for maximum catalyst life-time
- Run for minimum energy usage

The main operating parameters for the unit will be severity, pressure, catalyst bed temperatures and profiles, which are interlinked and simultaneously affect yield, octane number, aromatics content, and BTX spread along with net hydrogen make.



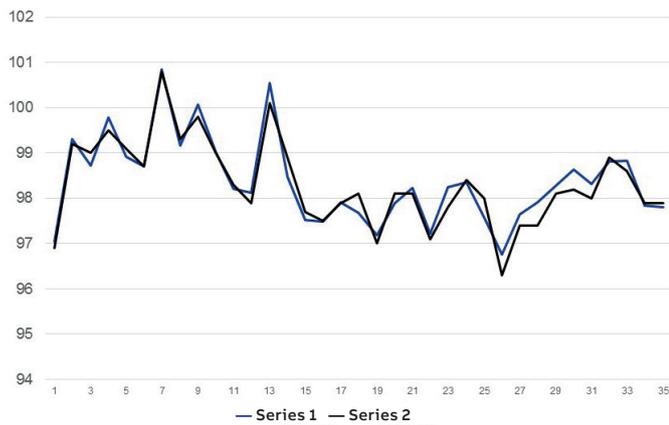
Example operating parameter trade-offs in CCR operation





Calibration dataset, 1st derivative and PLS regression plot for RON

On-line FT-NIR vs Lab Test Method RON



Example validation plot of on-line FT-NIR RON data (Series 1) vs lab test samples (Series 2)

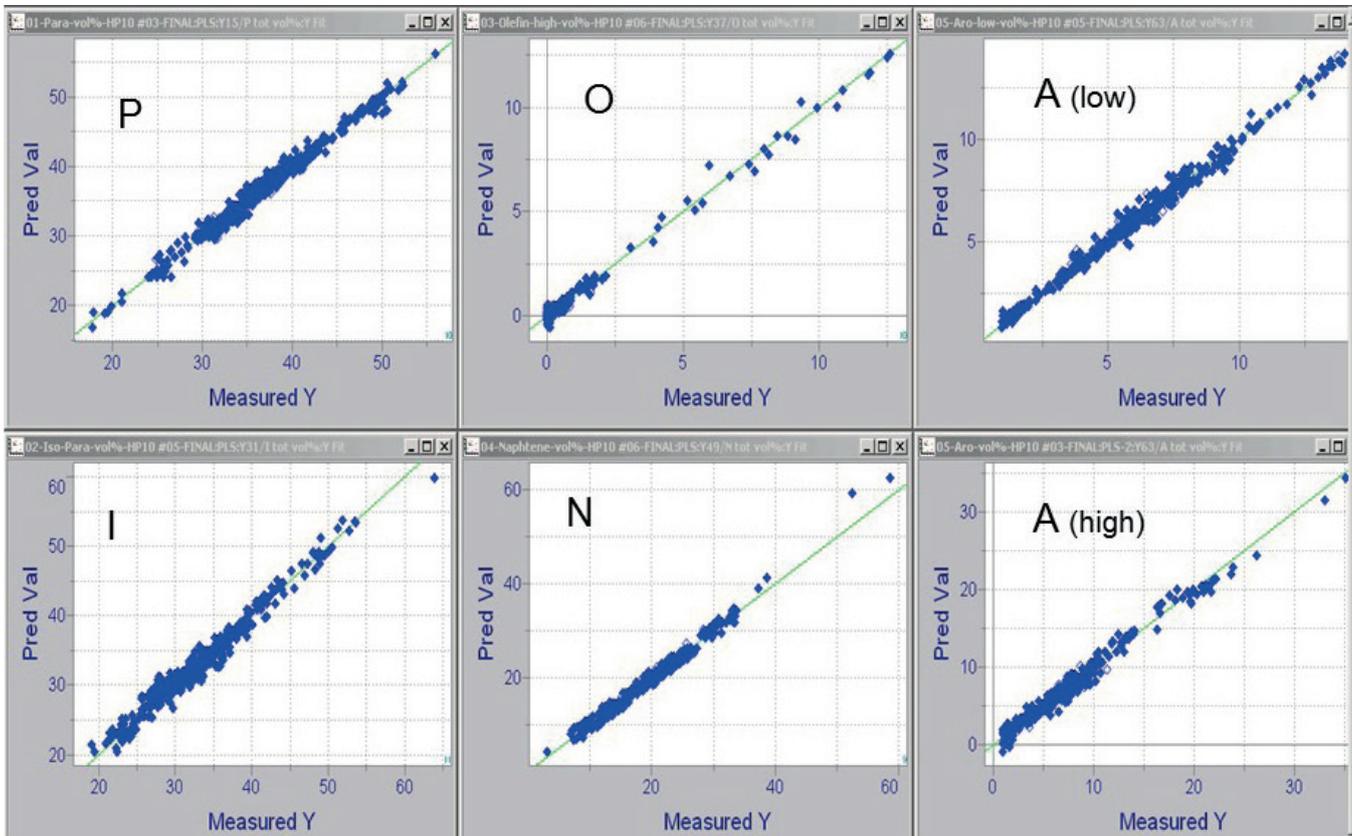
The most basic measurement is octane number monitoring (usually RON) of the reformat product stream as an indicator of reactor severity, to which measurement one can easily add chemical compositional parameters such as total aromatics %, or discrete components such as benzene %, toluene %, and xylenes %.

For illustration, we show a typical RON and aromatics modelling data set, and also the resulting RON calibration model.

Note that the model accuracy (vs lab test) at around 0.2 RON @ 1 sigma is better than the ASTM standard method reproducibility (R) due to good site laboratory precision. Therefore, the on-line FTIR does a better job than would an on-line CFR engine, which would in any case be significantly more expensive overall.

This is the key advantage of advanced optical or solid-state devices for process stream quality analysis: faster, better, and cheaper data.

The second stream analysis, which may be measured using the same FTIR unit as the one used for the reformat product, is the heavy naphtha feed. In this case, the target properties, which significantly affect the CCR unit yield and selectivity, are PINA and distillation.

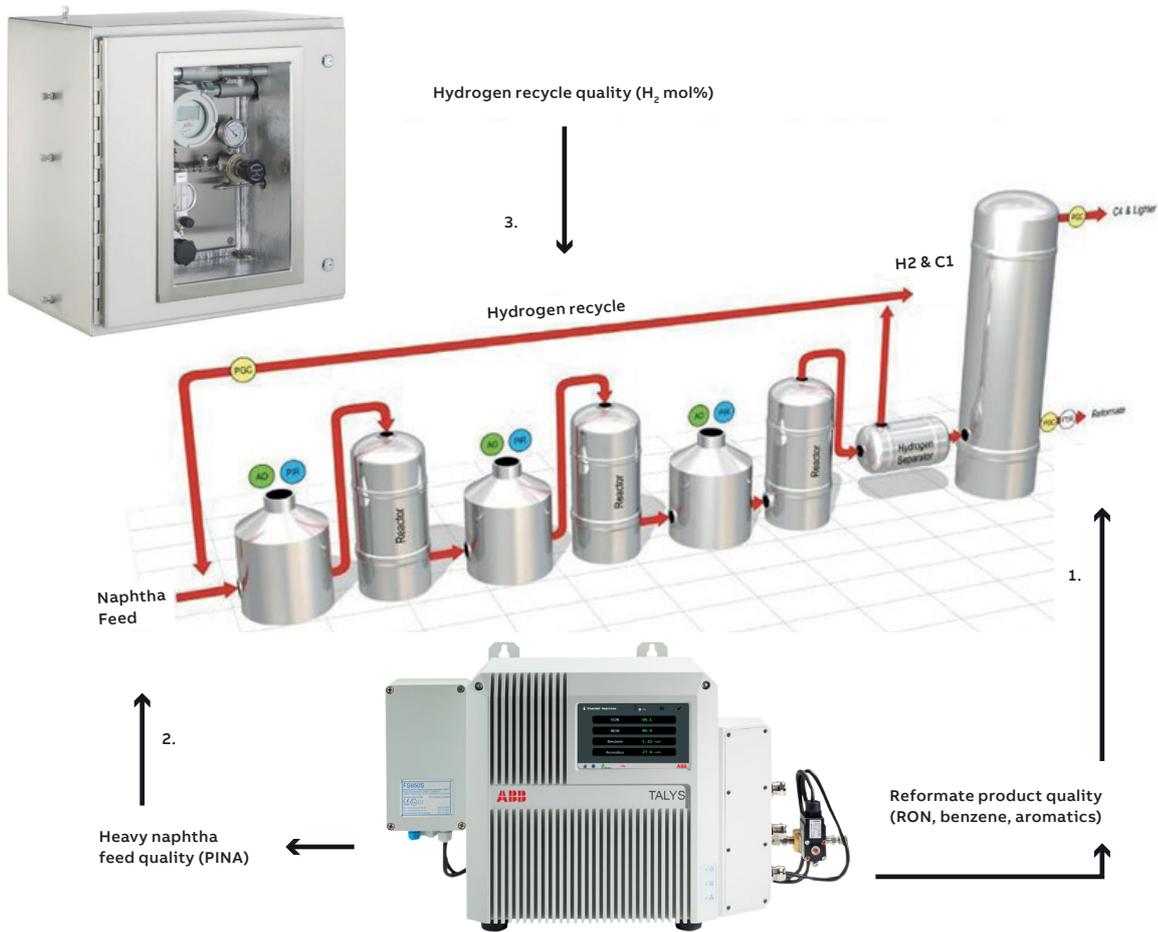


PLS regression calibration plots for PIONA in Naphtha Feed

Naphtha quality variations can arise from varying CDU feedstocks and operation, but also from alternative naphtha feed sources. Where CCR units are run to have excess catalyst regeneration capacity, then sub-optimum heavy naphtha feeds (for example – from the FCC unit) can be run or mixed with conventional straight-run naphtha, resulting in a much more dynamic unit envelope.

For the final measurement in this set of real-time on-line process analyses for unit optimization, we look at the net gas/hydrogen recycle stream. In this case, the key parameter is simply H₂ mol %, but it must be measured in the context of a varying background of mixed light hydrocarbons content. Of course, the net gas recycle stream is not pure hydrogen. It is mixed with other light gases recovered in the separator/recovery stages.

This is a significant challenge for conventional technologies like thermal conductivity detection (TCD) that can only handle a limited number of interfering components (no more than two). The solid-state sensor is specific in response to hydrogen and is also protected against potential contaminants such as H₂S and CO by a diffusion membrane, thus allowing rapid hydrogen transport but blocking larger contaminant species.



Summary

In this white paper, we have reviewed the use of simple and robust yet advanced process analyzer technologies, specifically FT-NIR and solid-state sensor-based hydrogen detection, to the most important process unit streams in the catalytic reforming unit. We have seen that the octane, aromatics, PINA and hydrogen measurements can be made using these relatively straightforward analytical methods, and that this data is reported in nearly real-time (one minute stream cycle time), allowing close integration with unit advanced process control. This allows better management of unit operational parameters, with a view to optimizing the production of high-quality reformat and net gas/hydrogen, with yields and composition better aligned with overall refinery and product market requirements.

References

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