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Modern advanced control pays back rapidly

A hydrotreater example illustrates the potential

A. J. Taylor, Honeywell Hi-Spec Solutions, Southampton, UK; T. G. la Grange, Honeywell Hi-Spec Solutions, Johannesburg, South Africa; and G. Z. Gous, Sasol Technology, Secunda, South Africa

Applying proven multivariable predictive control (MPC) techniques coupled with robust online product quality predictions is an effective way to maximize unit profitability. This approach has been used throughout during a joint project on a refinery in South Africa. The results for the hydrotreater unit are astounding, with an estimated payback period of less than two months.

Use of MPC is not new in the HPI sector; early generation approaches date back to the 1980s. Modern MPC engines incorporate leading-edge solution techniques to provide maximum robustness and performance, to the advantage of the process operator. This technology has been used extensively to squeeze hidden profits out of processing units worldwide.

With this proven technology readily available, the challenge for control practitioners has been accurate definition of unit constraints for online control—in particular, measurement of product qualities. New online analyzers are often included in control projects but suffer the drawbacks of cost, implementation delays and ongoing maintenance. Calculating product qualities online offers a cost-effective alternative that can often improve project economics substantially.

Many MPC vendors offer libraries of generic algorithms that provide online inferences of common refining product qualities. After initial tuning of the inference, accuracy is maintained by automated update using laboratory results. For the hydrotreater unit, a key product quality inference is developed based on a first-principles approach to the equation form, while another product quality is calculated using a generic algorithm from a library. This hybrid approach results in accurate online calculation of the product qualities that limit unit operation.

Benefits realized from advanced control include a 70%+ reduction in standard deviation of the two limiting product qualities. This allows movement closer to specification limits and results in associated yield and reactor severity reduction benefits. Reactor severity reduction leads to a substantial improvement in petrol product octane number and hydrogen consumption savings. The bulk of the benefits result from reduced product flaring.

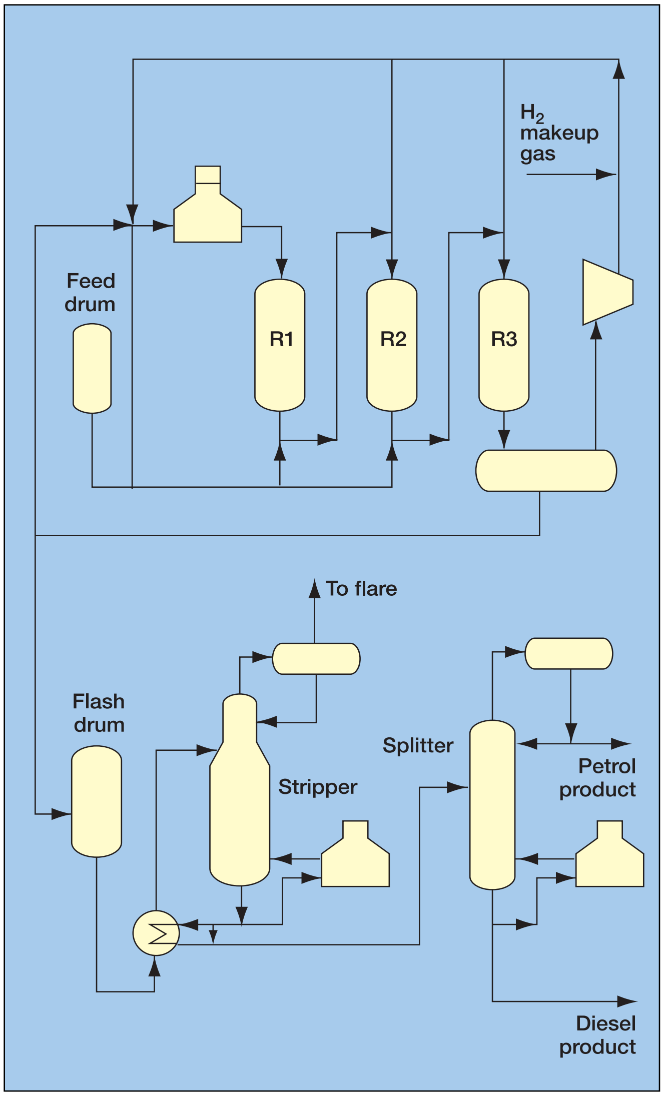


Fig. 1. The hydrotreater unit consists of three reactors in series with an H_2S stripper and product splitter.

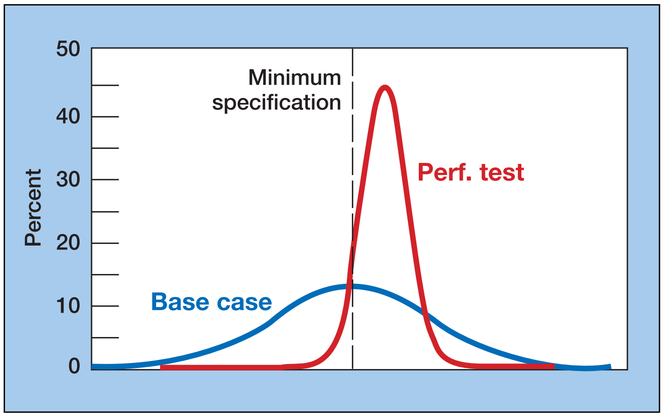


Fig. 2. Diesel flash point distribution.

Process description. The Sasol hydrotreater unit (Fig. 1) is a fairly common refinery unit with a nominal capacity of 100 m^3/h. It consists of three reactors in series with an H_2S stripper and a product splitter. Because the feedstock is sulfur free, dimethyl disulfide is injected into the feed stream to act as an activation agent for the catalyst—this produces the H_2S in the reactor effluent. Feed to the unit is hot rundown direct from the catalytic polymerization unit and consists of a blend of petrol and diesel components with a relatively high olefin content. The three major products are stripper offgas to the flare system and petrol and diesel blend stocks.

The feed stream is split into the three fresh feed flows to each reactor. The charge to reactor #1 is mixed with H_2-rich recycle gas and liquid recycle before entering the charge furnace. The charge furnace effluent enters the reactor where the olefinic components are converted into paraffins. Since the reaction is exothermic, there is a temperature rise across the reactor.

Effluent from reactor #1 is mixed with reactor #2 fresh feed and a slipstream of recycle gas (quench gas) to regulate inlet temperature to reactor #2. Similarly, reactor #2 effluent is mixed with reactor #3 fresh feed and the appropriate quench gas dosage.

Effluent from reactor #3 flows to the product separator. Vapor is directed to the recycle gas compressor suction, while the liquid accumulated flows to either the recovery section flash drum or the charge furnace as liquid recycle. Energy is recovered from the reactor effluent to reduce the charge furnace duty load.

The flash drum bottoms is preheated via a feed-effluent exchanger before entering the H_2S stripper. Stripper bottom temperature is regulated to ensure that adequate H_2S is removed from the bottom product. Stripper bottom product flows to the product splitter, where the petrol and diesel products are separated.

The key product quality constraints are H_2S content in the petrol product, together with the diesel product flash point and bromine number. The bromine number is a reflection of diesel olefin content and is regulated via reactor severity.

Since the unit charge rate is limited by upstream constraints, the main economic drivers are maximizing the combined product value and minimizing utility costs. Currently, the primary objective is to maximize diesel production.

Advanced control approach. The nature of the unit is such that the control and optimization objectives can be elegantly separated between the reactor and recovery sections. This allows the relatively simple approach of two MPC applications to be adopted—one each for the reactor and recovery sections.

Design of the two applications is based on control and optimization objectives for each section. Prior to MPC commissioning, the control objectives were managed open-loop by the DCS operator, while the optimization objectives were not actively pursued. The MPC application has the advantage of rigorously honoring the control needs while optimizing the unit operation in an integrated manner.

Reactor section control objectives:

- Honor diesel bromine number specification
- Honor reactor ΔT and ΔP limits
- Honor furnace and compressor limits
- Honor relevant valve position limits to maintain regulatory control integrity.

Reactor section optimization objectives:

▶ Minimize reactor severity (temperature) to diesel bromine number specification

▶ Minimize fuel gas consumption

▶ Minimize quench flows to reactors #2 and #3

▶ Balance reactor ΔTs.

The objective of balancing reactor ΔTs is introduced as a means of encouraging uniform ageing of the three reactor beds. This also provides some value-added way of soaking up the available degrees of freedom.

Recovery section control objectives:

- Honor maximum H_2S in petrol specification
- Honor minimum diesel flash point specification
- Honor furnace limits
- Honor relevant valve position limits to maintain regulatory control integrity.

Recovery section optimization objectives:

▶ Maximize diesel yield to minimum diesel flash point specification

▶ Maximize petrol yield to maximum H_2S content specification

▶ Minimize fuel gas consumption.

The maximizing diesel yield objective is met by leveraging two mechanisms in the splitter:

1. Stabilizing and controlling diesel flash point just above the minimum limit
2. Maximizing fractionation to improve the cut and (given 1. above) further increase diesel yield.

Online quality calculations. The fast-track nature of the project, coupled with the economic debits associated with installing new product quality analyzers, encourages development of online calculations for key product qualities. Three product qualities need to be calculated: petrol H_2S content, diesel flash point and the diesel bromine number. The nature of the process chemistry coupled with the various options available dictate that a range of approaches is required.

Petrol H_2S content. The nature of the product test, either a positive or negative result, adds some compli-

Table 1. Product quality control improvements

Quality parameter	% standard deviation reduction	Average value movement
Diesel bromine #	77	3.6 Br# increase
Diesel flash point	71	1.3°C increase
Petrol octane number	71	1.75 RON increase

Table 2. Product yield improvements

Product	% net yield increase	% of total benefits
Diesel	0.5	3.6
Petrol	2.4	85.9*

* The benefit calculated includes the effects of RON and RVP increases, combined with the yield increase.

Table 3. Diesel quality/yield options

Period	Average flash point–spec limit, °C	% net yield increase	% spec violations
Pre-MPC	0.0	–	50
Post-MPC	1.3	0.5	8
Proposed post-MPC	0.4	1.3	33

Table 4. Utility consumption shifts

Utility	% reduction in specific consumption	% of total benefits
Hydrogen	12	12.0
Charge furnace fuel gas	18	0.4
Stripper reboiler fuel gas	–4	–0.1**
Splitter reboiler fuel gas	–30	–1.8**

** Debits associated with increased reboiler firing are quantified in relation to the net benefit.

cation to process constraint measurement. Since the primary influence on petrol quality is the amount of offgas from the stripper, we tested the use of a very simple flow ratio calculation (offgas:unit feed) as an appropriate inference of the constraint. Although trivial, this simple calculation proved to be effective in maintaining the minimum offgas flow required to meet the petrol H_2S specification.

Diesel flash point. The diesel flash point calculation is implemented using a generic algorithm from a proprietary library of online calculations. Historical data were used to tune the inference offline, in a spreadsheet environment, before online implementation. The calculation is constantly tuned online by using laboratory results.

Diesel bromine number. The equation form of the calculation is derived using a first-principles reaction rate approach. This results in an easy-to-use equation that uses available plant measurements as inputs. Eighteen months' historical data were used for fitting the three tuning parameters of the calculation. Online inputs used in the calculation are the reactor charge flows, outlet temperatures and the liquid recycle flow. Catalyst loading for the reactors are also important parameters; the tuning parameters will need refitting if the reactors are reloaded with catalyst loads deviating significantly from the current loads. The calculation is fine-tuned online by using laboratory results to ensure ongoing accuracy of the prediction. Development of this calculation will be the subject of a future publication.

Benefits. Following successful commissioning of our MPC applications, a formal post audit of the benefits was conducted. This activity involved comparing laboratory and operating data over three months prior to the start of implementation with a one month "performance test" of the MPC applications.

The application utilizations recorded during the performance test were 98.5+%. This illustrates the excellent operator acceptance and endorses the application designs. Tangible benefits can be categorized into improved product quality control, increased product value and reduced utility costs.

Table 1 illustrates the quality control improvement via the sizeable reduction in property standard deviations. These improvements are a direct reflection of the high performance of the MPC software engine coupled with the accuracy of the online quality predictions. The results endorse the commonly used rule-of-thumb for predicting MPC benefits based on the assumption that the standard deviation will be halved.[1] (Although this has proved to be a conservative assumption in this case, expectations should be considered to be a function of the specific process.)

The increase in diesel flash point was unexpected since the drive in the splitter is to move flash point to the minimum limit (Fig. 2). This result is a function of the base case data, where approximately 50% of the samples violated the specification limit. The post MPC data set showed only 8% of the samples violated the spec. Effectively, the flash point limit was used as a target, whereas the MPC application honored it as a limit. Despite this improvement in product quality, diesel yield was still increased as a result of the improved column fractionation effect.

The total increase in yield of saleable products was 2.9%. The substantial increase in petrol product yield is a function of the improved recovery of C_5 and C_4 components from the stripper offgas stream—this translates into a significant economic benefit due to the uplift being from flare. A 19% reduction in stripper offgas was achieved without violating the petrol H_2S specification limit. The key result here is that the C_5 content in the stripper offgas was reduced by 95%. The petrol yield increase benefit was identified during the functional design phase and resulted in the feasibility study benefits estimate being dwarfed in the post audit.

Offline splitter column operation models were used to predict the diesel yield effect of reducing the flash point again toward the specification limit and tolerating a compromise on the percentage of spec violations. The results were proposed to the planning department for consideration. Table 3 illustrates the three scenarios.

Although utility consumption has an associated cost, not all utility streams were reduced to achieve the overall economic optimum operating point.

Reduced hydrogen and charge furnace fuel gas consumption is a direct result of the reduced reactor severity achieved by controlling and optimizing the diesel bromine number. The increase in fuel gas consumption on the stripper and splitter reboilers is an interesting illustration of the true economics of maximizing yield over minimizing utility usage (i.e., the MPC application chose to maximize fractionation at the expense of furnace duty).

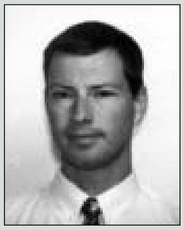
Success of the MPC applications is echoed throughout the client organization from the control room to the boardroom. Project results endorse applying MPC as an effective way to maximize unit profitability with minimal additional hardware and favorable project cashflow.

Key project parameters include:

- No unit shutdown prerequisite for project activities
- Approximately seven man-months of engineering hours consumed (from functional design to completing the benefits audit)
- Operator acceptance extremely high
- Audited benefits more than five times those estimated
- Project payback estimated at less than two months. ■

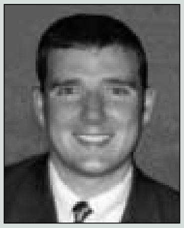
LITERATURE CITED

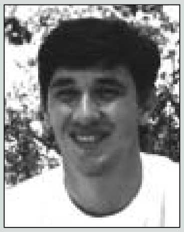
[1] Martin, G. D., L. E. Turpin, and R. P. Cline, "Estimating control function benefits," *Hydrocarbon Processing*, June 1991.



Andrew Taylor *is a consultant with Honeywell Hi-Spec Solutions. His responsibilities include technical leadership and project management on various advanced control projects. Previously, he was involved in implementing advanced control projects with Mobil in Australia. Mr. Taylor holds a BEng (EngSci) (Hons) degree from the University of Auckland and is a chartered professional member of IEAust.*

George la Grange *is a control engineer with Honeywell Hi-Spec Solutions. His responsibilities include controller implementation on various advanced control projects. Previously, he was involved in pyrometallurgical research and development, as well as having responsibility for the pilot plant control systems. Mr. la Grange holds a BEng (Chem) degree from the University of Pretoria.*





Gustaf Gous *is a principal control engineer at Sasol Technology, Secunda, South Africa. His main job functions include advanced process control and managing control projects. He has five years of experience as a control engineer. Prior to that, he was area manager of production at the Sasol Synthetic Fuels Refinery in Secunda. Mr. Gous holds a BEng (Chem) (Hons) degree from the University of Pretoria in South Africa.*