Modelling for ULSD optimisation

On-line coordination and optimisation of refinery process units led to a 10% increase in middle distillate production

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The Chevron Pembroke oil refinery is a complex and large (220 000 b/d) processing site. This case study examines the improvements achieved by a project with a high return on investment, which resulted in better operation of the process units involved in middle distillate production and higher ultra low-sulphur diesel (ULSD) output. This article describes how as much as a 10% increase in middle distillate production can be achieved essentially without investment in process units or equipment, mainly through the upgrading of cracked feeds, higher average distillate cut points, optimisation of the process unit and diesel rundown blending. These significant improvements, which are estimated at $10 million per year (minimum), have been realised through a team effort involving various departments of the Pembroke refinery, in particular the following groups of people:

- Operations organisation, including white oils, black oils and cracking
- Planning and scheduling teams
- Process engineering group
- Control and information system department, where the process control team resides
- Apex Optimisation, supplier of medium-term closed loop optimisation technology.

The Pembroke refinery blends middle distillates directly from the process unit to hydrotreaters. The day-to-day operation of the two downstream hydrotreating units (HTUs) is challenging as throughput has to be maximised subject to a variety of process constraints and the availability of the various feed components, which include kerosene, several straight-run gas oil streams and FCC product streams such as HHCN and light cycle gas oil (LCGO). The decision-making process for these blends involves several refinery areas and console operators in different control rooms across the site.

Hence, as part of the improvement programme, a new large-scale, multi-unit coordination tool (GDOT) was implemented. The GDOT (patent pending) software supplied by Apex Optimisation is used within Chevron Pembroke for medium-term optimisation problems. This system, which is basically an on-line refinery linear programming (LP) model, runs in closed loop and has been in service since late 2006 at Pembroke with essentially 100% utilisation even during significant changes in crude slates.

Day-to-day operation of the two downstream HTUs is challenging as throughput has to be maximised subject to a variety of process constraints

This article describes the issues, challenges and constraints that the Pembroke refinery faces when ULSD becomes the most valuable product most of the time.

Like many other ULSD-producing refineries, the Pembroke site blends middle distillates directly from the process unit rundown lines prior to hydrotreating. The main advantages of this approach, compared to a conventional batch blending system, are lower tank storage and manpower requirements, and the swing cuts of the upstream process unit can be optimised in real-time to operate the hydrotreaters at multiple ULSD quality constraints. However, the rundown blending approach also results in a more challenging day-to-day operation of the downstream HTUs, especially if the throughput is to be maximised subject to a variety of process constraints, taking into account the availability of the various feed components.

The Pembroke diesel system has two HTUs, HTU1 and HTU2, which are fed by a rundown blending header. The configuration of the Pembroke refinery diesel system is shown in Figure 1.

The operations department with the console operators is organised into three areas: black oils (crude and vacuum distillation), white oils (hydrotreaters and naphtha processing) and the cracking area. Traditionally, the scheduling department advises the area operators, through a daily schedule, on how to set diesel blending component flow rates and middle distillate component cut points from the crude and vacuum distillation units. Now, using the medium-term optimisation tool, the coordination of the units is done automatically online and, instead of fixing diesel component flow rates, the scheduler

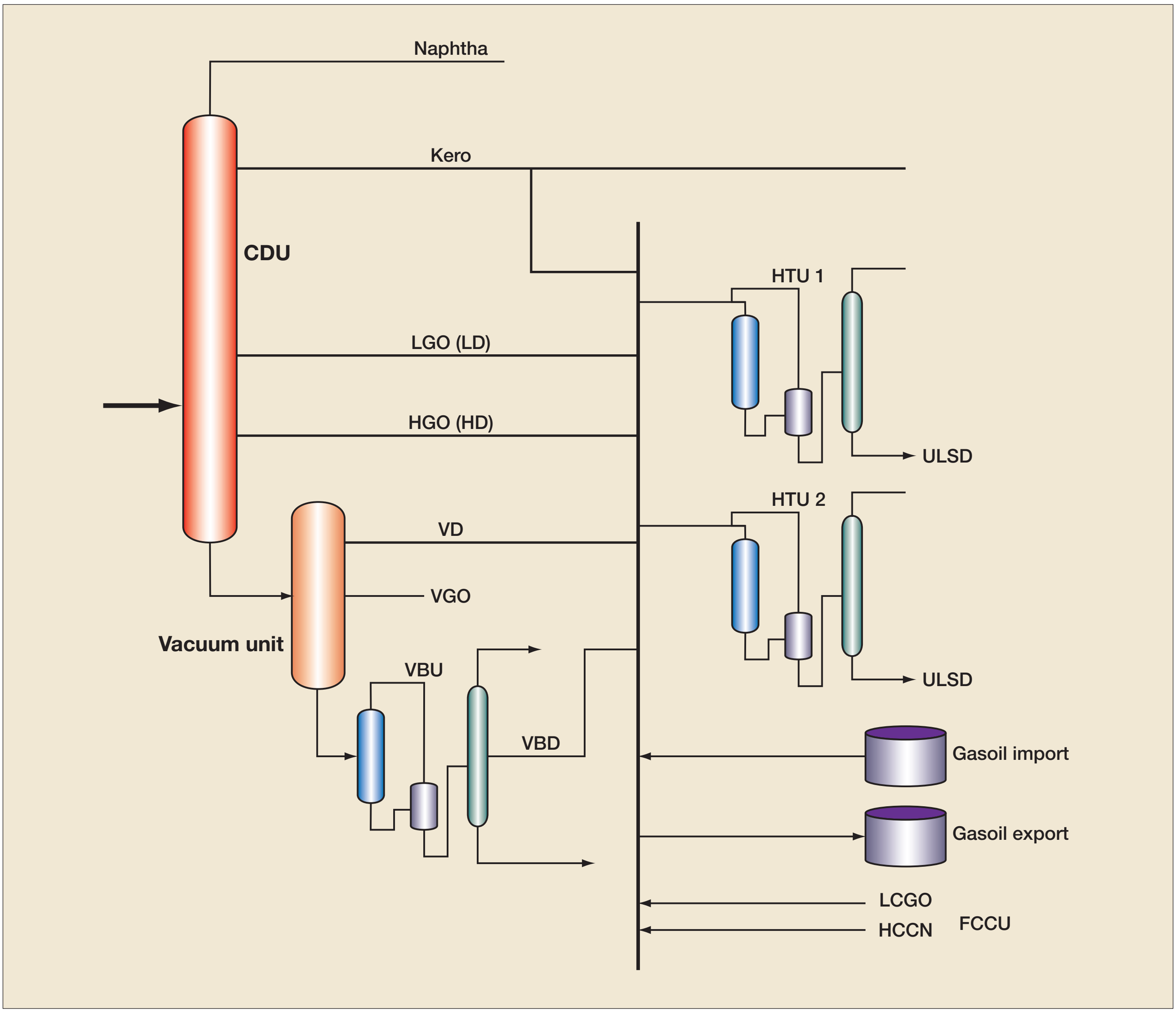

Figure 1 Pembroke refinery diesel system

specifies the product specifications and the key swing cut points to be optimised by the system.

Maximising ULSD production

Feed quality management is one of the keys to maximising the performance of a HTU, subject to constraints. A highly constrained HTU can be very sensitive to incremental changes in the individual component flows of the feedstock. Therefore, the challenge is not just to push the rate through the unit to the maximum, but to establish the optimum blend that enables throughput to be maximised subject to product quality constraints. A different feedstock composition will significantly change the hydrotreater operation, which will have an impact on the maximum possible feed rate dictated by unit constraints. The following list highlights some of the difficulties with feedstock components and constraints observed at the Pembroke refinery's HTUs

- Maximisation of cracked feed (eg, LCGO) results in higher reactor temperatures and high hydrogen consumption
- Maximisation of kerosene and light cracked feeds results in constraints on the operation of the product stripper columns. In the past, this has caused operational problems, including a positive doctor test requiring costly diesel reprocessing, which led operations to put conservative limits on the throughput of the unit
- Maximisation of heavy feedstock, such as the back end swing cuts from the crude and vacuum distillation units, requires high reactor temperatures to meet the sulphur specification, which aggravates HTU heater constraints.

There are essentially 18 variables available to control the production rates and the qualities of the three middle distillate products of the refinery: kerosene, diesel and gas oil. During the winter period, it is typically best to run at minimum flash points on all three products and at maximum cloud points on gas oil and diesel, while also meeting production rate targets on one or two of the three streams. In the summer period, the 95% point or density typically replace the cloud point as the back end constraint on the diesel.

The sulphur content is controlled within the diesel hydrotreater, but other diesel qualities such as density, cloud point, flash point and distillation must be controlled upstream of the hydrotreater; that is, by the side stream cuts and the feed blends.

Given that both HTUs are heavily constrained, there is a strong incentive to utilise all available hydrotreater capacity and to avoid reprocessing as a result of off-spec production. Hence, the optimum operating strategy for the diesel system can typically be summarised as follows:

- Always keep diesel production on grade with minimum giveaway
- Fill the hydrotreater capacities with available feedstock subject to constraints
- Maximise cracked feed over straight-run middle distillate
- Maximise heavy feed components over lighter components.

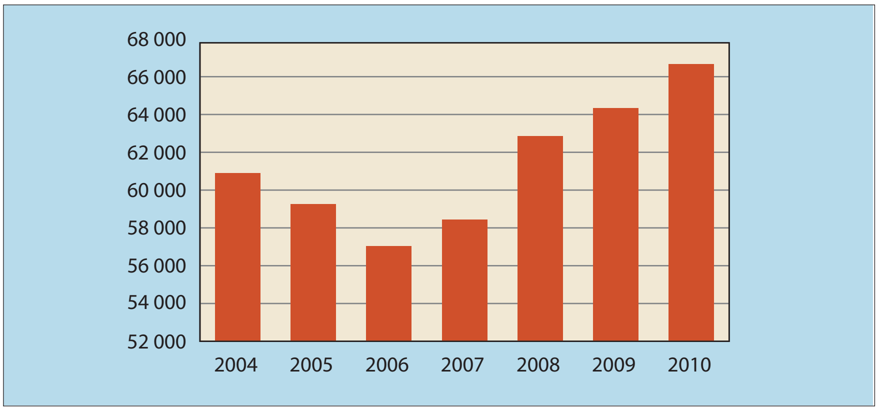

Figure 2 Diesel production from HTU1 and HTU2, barrels per stream day

Operator training and coordination issues

One of the important challenges is to train the CDU, cracking and VDU operators so that they are more aware of the operating objectives and constraints of downstream units when making moves on their units. In large and complex refineries, operators traditionally control to the targets that have been specified for their particular unit and are not necessarily aware of operational constraints on downstream units and any opportunities to minimise giveaway on the product rundown lines.

The training required for console operators is mainly related to an understanding of the concept of online coordination of multiple process units, intermediate product flow rates and quality targets. The GDOT tool can significantly improve this decision-making process, making sure that the upstream units are optimised in a coordinated manner and keeping all units within acceptable operating ranges. This enables the operators to work better together and achieve an improved overall performance of the refinery.

Chevron has selected the GDOT

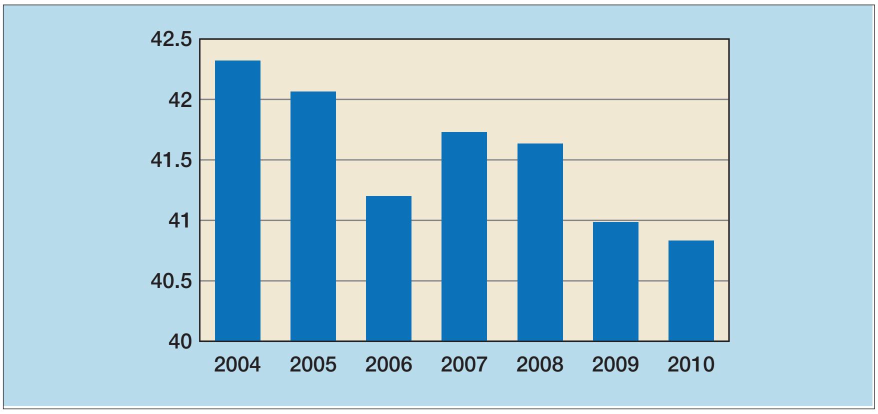

Figure 3 Kero flash point,°C

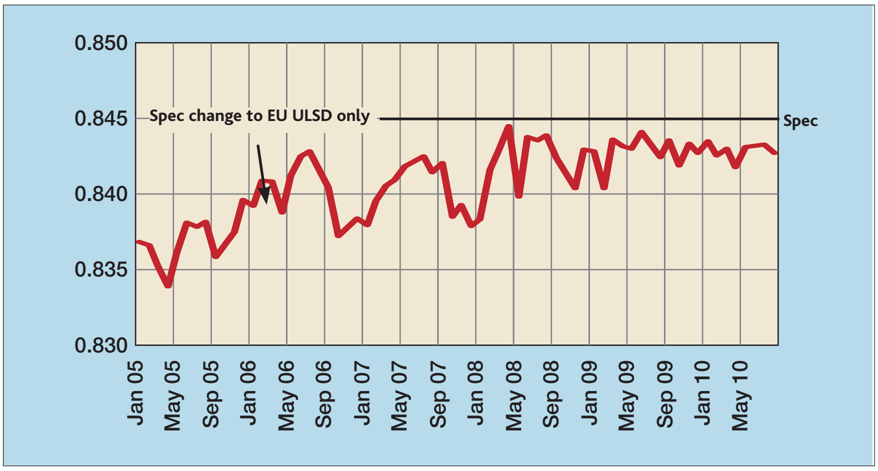

Figure 4 Final tank density

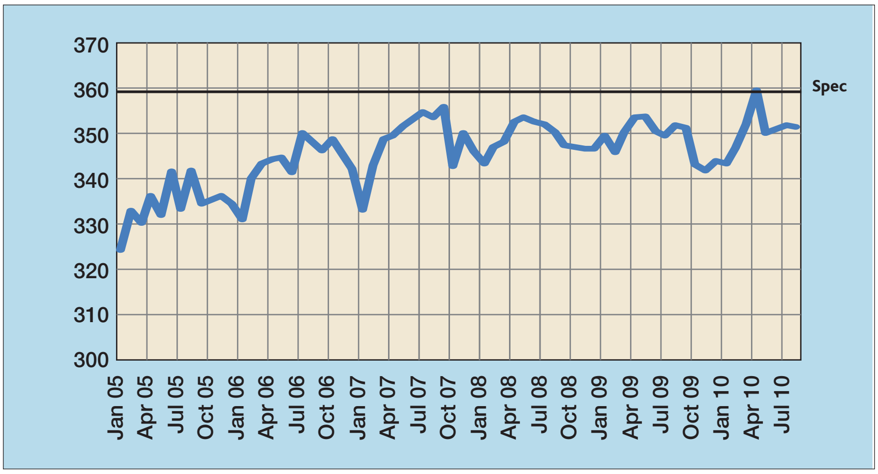

Figure 5 Tank 95% distillation, °C

tool for coordination of production areas such as the diesel system. It is important to note that the system does not require any specialised staff and is maintained by the same process control engineers who are responsible for the multivariable predictive control (MPC) applications.

GDOT provides an on-line console interface for engineers and operators. For this project, however, it was decided to let the four console operators use the interface of the 12 MPC controllers (based on Aspen DMCplus) instead. Also, GDOT has been configured to track the status and the limits of the MPC variables. By using the existing interface, operators did not need to be retrained, resulting in a smoother transition and faster operator acceptance. However, the user interfaces of the individual MPC controllers will obviously not give the complete picture of a current optimised solution for the entire diesel production system. Hence, customised database displays have been made available to operations and production planning staff.

Robustness and maintenance

What maintenance effort is required for an advanced dynamic coordination system like GDOT? Our experience has been that once commissioned, it is important to allow some time for fine-tuning of the system for different operational scenarios, some of which may not have been considered in the original design. Also, during the transition phase, where a team effort is required to use the system to gradually move the operation towards the global optimum, additional training, discussions and possibly further adjustments may be required. After that, however, the installation requires almost no maintenance.

Project execution

Process data and models available from the existing MPC systems were sufficient to develop most of the models required for GDOT. This meant that the project was able to proceed with minimum impact on the refinery's operation. The preparatory site work included the installation and configuration of a server on the process control network.

The building of the GDOT model is typically done by the vendor (Apex Optimisation) in their offices, following a two-week kick off meeting and information-gathering visit, including interviews with refinery departments such as operations, planning and process engineering.

The second visit is typically dedicated to the software installation and the loading of the model and optimiser, which is then typically put on-line in an advisory (open loop) mode. The following visits thereafter are dedicated to closed commissioning and fine-tuning.

During the first year of system operation in closed loop, follow-up visits and remote monitoring are performed to make sure the

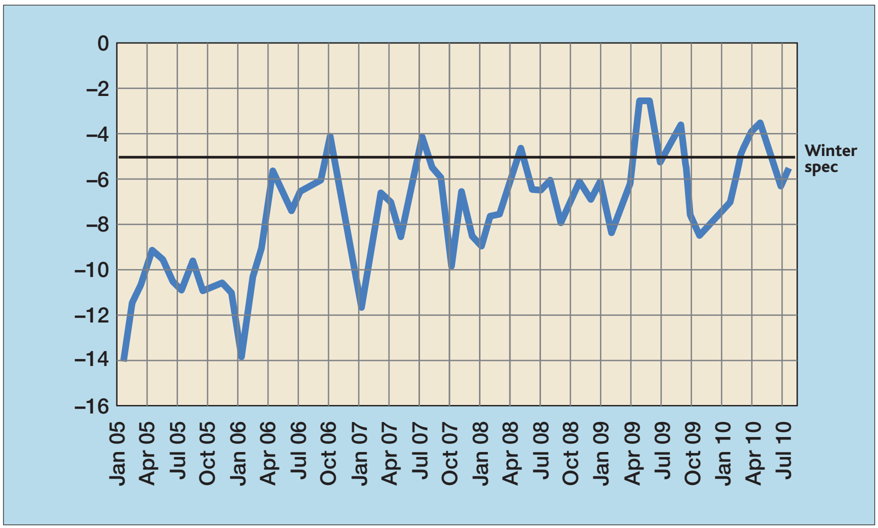

Figure 6 Final tank cloud point

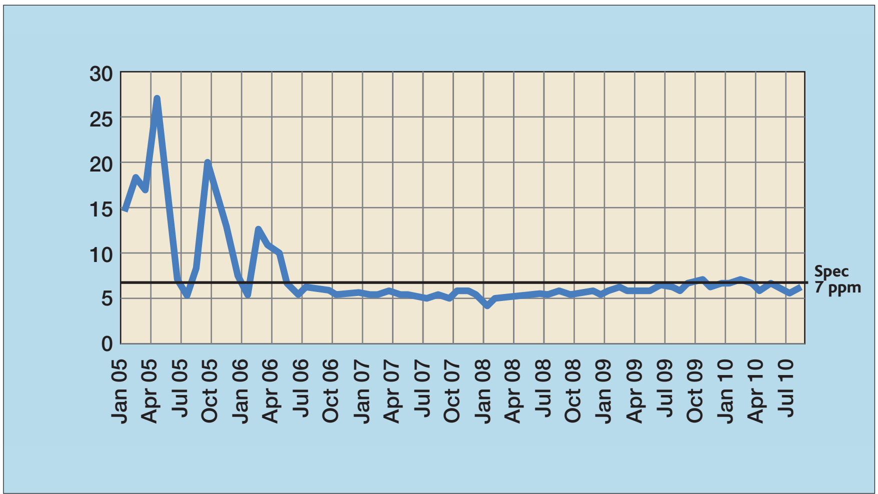

Figure 7 Final tank sulphur, ppm

optimiser is performing at its best under all common constraint scenarios and for the typical operating strategies, such as different modes of operation.

Post-audit results

The key objective of this project was to optimise the middle distillate cut-points, the uplift of cracked feed and the middle distillate blending to achieve a higher yield of ULSD and gas oil sale. It should be recognised that the entire Pembroke organisation has contributed to the significant improvement in the operation of the refinery. GDOT is merely a tool that the organisation is using to consistently implement a more profitable operating strategy. Figures 2 and 3, which show data from 2004 to 2010, should give an understanding of the improvements achieved.

Analysing quality data from the final diesel shipment indicates how well the system and organisation perform over a longer period. It is important when analysing long-term data to consider significant product specification changes. One of those changes was in 2006 when UK ULSD was changed to EU ULSD 0.845 density specification. Figures 4–7 show the final quality improvements for ULSD diesel sold to customers.

The change in specification from UK ULSD to EU ULSD involved an improvement in sulphur of 1 ppm. This might not sound much, but at this level it is equivalent to a change of 4°C on average reactor bed temperature and significantly increases catalyst lifespan.

Conclusions

The diesel production improvement project has been a success, with overall benefits valued at $10 million, including a large increase in diesel production. The hard work of many people from various areas of the Pembroke refinery has contributed significantly to this success.

The main benefit of the GDOT system is that it allows operational instructions and strategies to be consistently implemented, minute by minute, day and night, driving the units towards more profitable operation and improving the competitive position of the refinery. The system deals with daily operational issues. The GDOT modelling approach, using dynamic non-linear models, is capable of adapting to all expected and unexpected operating scenarios and has proven to be very robust. Uptime statistics are excellent.

The ULSD improvements project did not require any major unit upgrades or revamps and took nine months from start to finish. The payback for this improvement project was achieved in a few weeks. Another conclusion from this project is that multi-unit coordination systems should be considered as one of the next logical steps for a refinery to improve operation further with an existing configuration.

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