Optimisation of a refinery crude unit

A case study of results from real-time optimisation to maintain economically optimal operation against frequent feedstock changes. As well as economic benefits, improved consistency in process operation has also been achieved

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An offline analysis of the feed blends being used in a crude distillation unit at the Isla refinery on the island of Curaçao indicated that significant potential benefits could be gained from the application of real time optimisation (RTO). In the presence of the frequent feedstock changes taking place at the unit, this could maintain economically optimal operation. As a result of this analysis, in June 2001 an RTO project was initiated.

Crude distillation unit No. 3 (CDU3) at Refineria Isla, Curaçao, processes 180 000bpd of crude and operates in two modes, each with a different crude feed blend: a paraffinic blend for lube oil production and general purpose blend for fuel production. The crude blends range from 26–30 API. Crude blend switches take place every two to three days, resulting in a shift in operating conditions and product yields from the process.

Since the RTO project was to be executed by plant engineers, with consulting services from the vendor, the proprietary ROMeo RTO package was chosen. The project included installation of an Invensys Process magnetic resonance analysis (MRA) online analyser to provide critical real time crude physical property and product quality measurements to the advanced control and RTO systems.

In the current environment of unstable crude costs and product prices, refiners face increased pressure to improve asset utilisation and maintain profit margins. Increasing throughput, product yields and improving product quality through use of advanced automation technology plays an important role in this effort.

Since the economic optimum of virtually all industrial processes occurs at an intersection of process constraints – that is, where multiple operating constraints are active and limit further moves to improve process economics – the objective is to locate and continually push the operation of the process against these constraints. Two important tools in this effort are advanced process control (APC) and RTO. The role of APC is to reduce variation in important process variables and thus allow their set points to be placed closer to their respective constraints. However, APC in itself is unable to identify which constraints are active at the optimum.

Local linear programming (LP) solutions based on linearised process models are limited in this task since they do not account for all process variables that are important to economic operation or process nonlinearity. The role of RTO, based on rigorous process models, is to identify and track the constraints that define the economic optimum, and to pass operating targets to the APC to enforce operation against these constraints. By running at regular intervals, an RTO system ensures that changes in the plant or economic environment that shift the active constraint set are tracked and that the APC is continually pushing the proper constraints.

While RTO and APC technology has been applied in process plants for decades, historically they have been under-utilised due to the complexity and expense of implementation, and poor maintainability. This is particularly true of RTO, where early generation software required significant domain expertise for implementation. Installed systems typically had short lifespans, since the same domain expertise was required to perform even routine maintenance operations, and this expertise was rarely available at the plant.

Advances in software technology have led to the development of rigorous online modelling with equation-based optimisation (ROMeo), a state-of-the-art modelling and optimisation environment that overcomes many of the traditional implementation and maintenance difficulties associated with RTO. This modelling and optimisation environment provides a common look and feel to user interface for all aspects of an RTO application, from flowsheet modelling, data reconciliation and configuration of the economic objective function to the configurational tasks associated with scheduling and sequencing an application for execution in real-time. Maintenance and other offline uses of the model utilise the same user interface, enabling the user to quickly configure required maintenance changes or conduct offline case studies.

An important aspect of the success of any APC or RTO application is the availability of reliable and accurate process measurements. Real-time measurements such as temperature, pressure and flow are the mainstay of both technologies. Real-time composition and physical property information is rarely utilised, due to expense and poor maintainability of online process analysers.

In the CDU3 RTO application, a new generation of process analyser has been employed that overcomes the reliability problems typically associated with this technology. The Invensys MRA provides real-time physical property information on the crude feed stream to the RTO, as well as quality measurements on important product streams to the RTO and APC system.

Objectives

Given the frequency of crude switches in the CDU3, already mentioned, operators place their priority on stabilising plant operation and expend considerable time and effort in accomplishing this goal. After each crude switchover (between paraffinic and general purpose crudes), operators set key operating variables based on established guidelines that are known to satisfy product quality constraints and result in stable operation.

While these guidelines help minimise the time required to stabilise plant operation after a crude switch, they also provide significant leeway in choosing a final operating point. Offline studies indicated that the potential existed to substantially improve product yields and the overall economic performance of the unit by employing an RTO, which would continually enforce economically

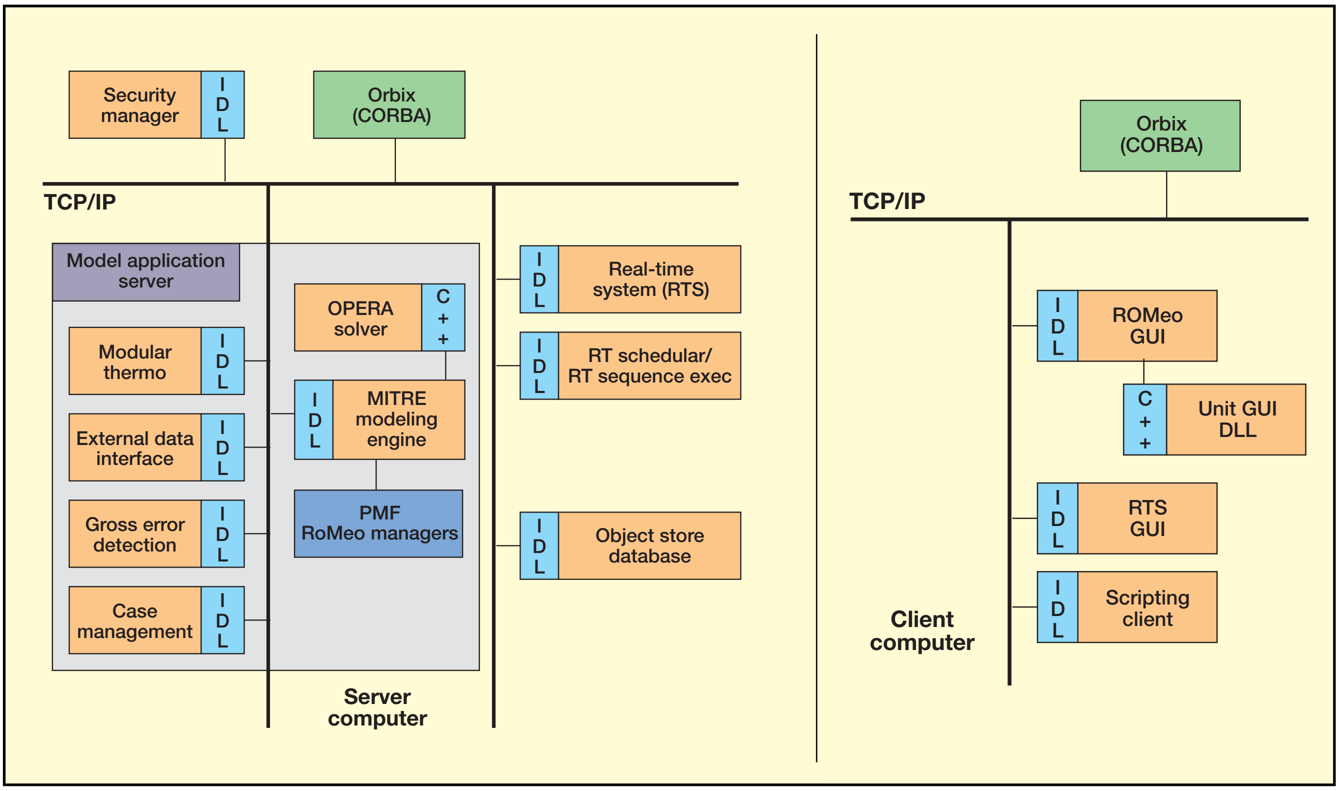

Figure 1 *ROMeo architecture*

optimal operation. The areas where the greatest benefit might be obtained from RTO included:
—Maximising valuable products such as kerosene, heavy gas oil and LPG
—Adjusting circulating refluxes to maximise heat integration with the gas section
—Adjusting crude and vacuum furnace duties
—adjusting column pressures, reboiler duty and reflux rates in gas section to minimise fuel gas
—Achieving a uniform operating philosophy that would be acceptable to all shifts.

Thus, the overall objective was to install a state-of-the-art RTO system that would be integrated with online process MRA to enhance economic performance, and that both systems would be maintained by local plant personnel. The objective was to begin the ROMeo design in July 2001, start application configuration in September and have the system operational by February2002.

RTO

As illustrated in Figure 1, the proprietary ROMeo RTO system is based on an open, distributed object architecture, with communication between distributed objects handled via an object broker, Orbix, that conforms to the common object record brokering architecture (CORBA2). The client is an Intel desktop PC, running Windows NT or 98, and the server is a high end Intel-based PC running Windows NT. The ROMeo system provides a graphical user interface (GUI) for configuring flowsheet models and the associated functionality (instrumentation, controllers, objective functions etc) required to transform a basic flowsheet model into one that is useful for real-time optimisation.

Additional functionality, such as unit and flowsheet customisation (for modifying the fixed/free status of variables at the unit or flowsheet level, and addition of variables and equations to enhance models), a powerful TCL-based scripting language and a system for easily integrating user-written or custom models is also provided.

A separate GUI (the real-time system, or RTS) allows users to configure and schedule tasks that automate all the operations required to run a flowsheet model as a RTO system (tasks for importing and exporting data, detection of steady-state conditions in the plant, running a flowsheet model in data reconciliation and optimisation modes, validating solutions etc). Custom tasks that enable the RTO system's scripting language are also available, allowing users to manipulate or modify system or model objects at any point in an RTS sequence.

The system utilises best-in-class third party software where possible to maximise system performance. For example, ObjectStore is used for case and model database storage and, as mentioned above, Orbix is used for object request brokering. As shown in Figure 1, ROMeo distributed components are linked on a TCP/IP bus, with each component supporting an interface definition language (IDL) layer. The IDL layer works in coordination with Orbix for movement of information between objects in the distributed environment. The primary ROMeo components are PMF, Mitre,

The PMF information engine supports operations required to configure and run models in three modes: simulation, data reconciliation and optimisation. These modes provide handling of unit specifications, automatic re-specification of units after mode changes (controllers are inactive in data reconciliation mode, but active in simulation and optimisation modes), objective function configuration and management, case management, squareness management (checking that user-created variables and equations in customisation units result in a square system – same number of variables as equations).

With Mitre, the system's model engine supports a powerful object-oriented algebraic modelling language (Milano) specifically designed for chemical engineering models. Mitre compiles and checks the flowsheet math model, which is then passed to OPERA for solution. Model customisation through addition of variables and equations is supported from the flowsheet GUI, as well as the addition of custom or user written models. Custom models can be written in Milano (open equation) or C, C++ or Fortran (these models can be open equation, closed form black box, or a combination). Modular Thermo performs all thermodynamic calculations for ROMeo models. Custom or user-added models also have direct access to Modular Thermo. Flowsheet models and all their associated data are stored in an ObjectStore database. Case storage is also supported. External data interface (EDI) provides links and automated transfer of data between ROMeo models and external databases. The proprietary @aGlance/IT or any ODBC-compliant database is supported.

RT sequence and RT scheduler (real-time system, RTS) automates all the functions required to implement an on-line closed-loop optimisation system. They provide a GUI environment for users to create sequences of tasks and schedule their execution (start time or frequency of execution). Statistics on optimisation system utilisation are also generated. Custom tasks that enable ROMeo's TCL-based macro language are also supported, allowing users to access system and flowsheet model objects for manipulation at any point in a sequence (import crude lineup information to the thermo system and trigger blend recalculation). The system's nonlinear programming solver (Opera), is a reduced Hessian quadratic programming algorithm employing sparse matrix techniques.

In ROMeo's object oriented environment, users have great flexibility in adding equations and variables (these are treated as objects in the RTO system's modelling language) and changing the fixed/free status of existing model variables through unit and flowsheet customisations. In open-equation modelling, maintaining the squareness of a model as customisations are added has traditionally been a challenging aspect of configuring a complex model.

However, this problem is all but eliminated with ROMeo. All library units in the system are square at the moment they are placed on the flowsheet. Unit data entry windows support a predefined set of specifications that the RTO system ensures will preserve unit squareness. Users may further alter variable specifications through unit or flowsheet customisation. Here the potential exists to create variables and equations that violate flowsheet squareness.

ROMeo PMF greatly aids this task by monitoring squareness as variables and equations are added or respecified (fixed/free status) in customisation units. A customisation unit that has resulted in a nonsquare specification remains red on the flowsheet, alerting the user to the nonsquare situation.

Magnetic resonance analysis

Accurate and reliable physical property measurement from online analysers can benefit APC and RTO in many ways. In RTO, the accuracy of predictions from a refinery unit model relies on accurate knowledge of feed characteristics. In the case of a crude unit, crude assay data, often in the form of TBP analysis and one or more bulk properties such as API gravity and molecular weight are used as the basis to perform feed. However, the reliability of this information is often in question, since the TBP analysis may be outdated, and it may not accurately reflect the material that is actually fed to the unit.

For example, the true feed might be affected by feed tank stratification, mixing with other refinery slop/residue streams, or the feed might be a mixture of multiple crude and recycle streams the proportions of which are not precisely known. In ROMeo, this uncertainty in the feed characterisation is remedied to a certain extent during online data reconciliation runs, where feed composition is varied in order to more accurately match model predictions with available plant data on downstream temperature, product flows and qualities. Direct measurements on crude feed properties from an online analyser can be expected to significantly improve the accuracy of this data reconciliation process, as described below.

Since RTO and APC benefits derive from locating active constraint sets and pushing operation to them, direct and more frequent information on constrained variables, often product qualities, naturally leads to improved performance and economic benefits from these technologies. Recognising this need, software vendors have devised inferential and soft sensors that provide frequent predictions of physical and chemical properties of refinery streams. These approaches rely on plant temperature, pressure and flow measurements, and infrequent laboratory measurements on the predicted quantity for updating prediction offsets (corrections).

Soft sensor predictions are empirical in nature and degrade during periods of upsets or after long periods without updating from laboratory data. The value of soft sensors can be greatly enhanced when measurements from an on-line analyser are available, allowing frequent updating of prediction correction factors. The resulting improvement in accuracy of predictions allows APC to push constraints closer to their limits.

Despite the recognised benefits of online analysers, they have fallen out of favour with refiners due to high installed cost and poor reliability. However, recent advances in analyser technology based on magnetic resonance analysis have sparked a revival in interest in online analyser technology for refinery applications.

Previous IR-based analyser technology gave a picture of the functional groups in an organic molecule, but provided little information on its hydrocarbon portion. Process MRA fills this gap by developing information on the hydrocarbon structure at the atomic level. This information is made available without the need for temperature preconditioning or chemical pre-treatment, thus is equally applicable to refinery black streams.

Samples are analysed at the condition best suited for the process stream and do not require water removal for repeatable and sustainable measurements. Furthermore, Process MRA works with a noninvasive sample probe, as will be described in more detail. The resulting sample system is simple, non-invasive and reliable, all but eliminating the sampling problems that plagued earlier generation online analysers in the refinery environment.

Magnetic resonance was first exploited as a laboratory measurement technique in the 1950s. Since the late 1980s, online versions of the technology have been developed, and refiners on both sides of the Atlantic started to use it as an online instrument. The breakthrough that significantly enhanced the utility of the technology was achieved in the mid 1990s when established laboratory high resolution magnetic resonance was combined with advanced chemometric software algorithms and sophisticated processing electronics.

In Process MRA, the system examines the behaviour of 1H (hydrogen proton) nuclear spin, in a homogeneous magnetic field. A nucleus with spin gives rise to a small magnetic field, which is described as a nuclear magnetic moment, or a vector. If a fluid is introduced into the magnetic field, the random orientations of the vectors align. If the sample is further exposed to a short duration radio frequency pulse, at the system's resonant frequency, say 60MHz, the vectors rotate. When the RF pulse is stopped the vectors return to their original state. This relaxation time is a function of the 1H proton position within the hydrocarbon chain. A Fourier transform (changes information from time to frequency domain) is applied to reveal the underlying structural of the molecule.

Physical and chemical properties relate directly to bond structure and since energy absorption across the spectral range is linear, predictive chemometrics models such as partial least squares can be developed for property predictions. For heavy streams such as crudes, the technique leads to predictions of TBP curves, API gravity, sulphur content and yield.

For lighter product streams, key product qualities such as TBP, and point properties such as flash, freeze and cloud, as well as PIONA, can be obtained. Many of these properties carry key product quality constraints, and therefore the benefit of the MRA measurements to APC and RTO systems is apparent. Process MRA sampling works with a non-invasive wide bore sample probe removing the need for ultra fine filtering (self flushing steel pipe, no scattering effects, no solvent required for cleaning).

Only a course filter is required for valve seat protection. A fast loop design utilising process control pumps wherever possible for sample return back to process, is the preferred option.

The success of an online analyser project depends as much on good project execution as it does on the accuracy and reliability of the underlying technology. Project definition and basic design require a clear understanding of the requirements of a particular application. In a project as complex as that of Isla CDU3, which required sampling on multiple product streams as well as the combined crude feed stream, an installation can be completed in approximately 12 months.

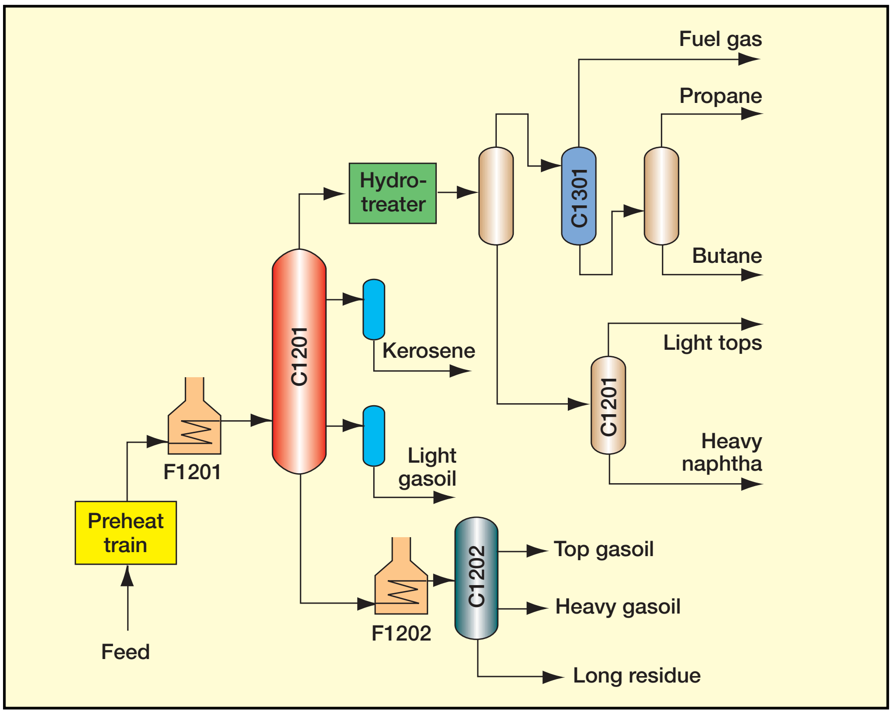

Figure 2 *CDU3 system overview*

Optimiser configuration

An overview of the CDU3 is shown in Figure 2, and consists of the crude distillation section, the naphtha hydrotreater and the light ends separation section. All the major process units in the CDU3, except the naphtha hydrotreater, were modelled with ROMeo flowsheet library units, which are based on rigorous chemical engineering models. The hydrotreater was modelled with a simple library component separator, as will be discussed further.

Configuration of a flowsheet model for an RTO application proceeds in a logical sequence that corresponds to the three modes of operation of the model: simulation, data reconciliation and optimisation. With the flowsheet model complete and successfully running on test data in data reconciliation and optimisation modes, the sequencing and scheduling tasks required to automate model execution in real-time are configured. This is accomplished with the system's RTS.

The objective in flowsheet model building for optimisation purposes is to include all units that are necessary to achieve a satisfactory level of overall model rigour, while avoiding undue complexity. Generally speaking, model detail that is inconsequential to the optimisation result should not be included in the flowsheet model. This is a judgment call that requires knowledge of the process, its constraints and operating characteristics.

As a simple example, parallel heat exchangers should be modelled as single units where changing flow distribution to the individual exchangers will not affect the downstream model. If each parallel exchanger is heat integrated with a different downstream unit, then correct modelling of the flow split will affect the accuracy of predictions of the integrated downstream units, and therefore should be included.

In the CDU3 case, an existing proprietary PRO-II model was available and was helpful in estimating potential benefits from an RTO as well as to determine an appropriate level of model rigor.

ROMeo flowsheet modelling proceeded from the feed section forward, with each section initialised and solved before proceeding to the next. Heat exchangers were modelled with the system's HX linker, which allows an exchanger to be run as two single-sided exchangers during flowsheet building, and then as a fully integrated two-sided exchanger when the flowsheet has been completed and is ready to be solved with full heat integration.

Since stream connectivity and sensor placement is based on physical trays, column building was accomplished using the RTO system's tray-to-stage mapping facility. Underlying models in ROMeo distillation units are based on rigorous stage equilibrium calculations, but the mapping feature allows a user to configure the column and view data on a tray basis, and to utilise actual plant data for data reconciliation from sensors

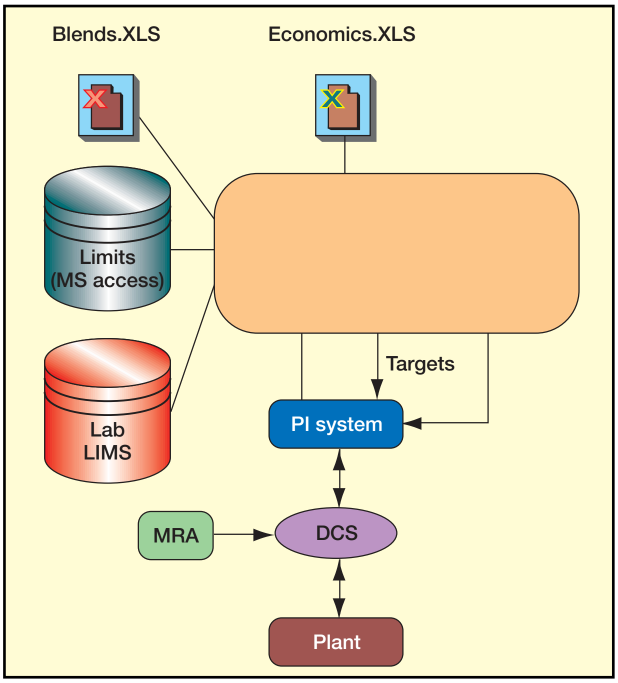

Figure 3 *System information flow*

attached to trays. After the flowsheet model was solved in simulation mode, it was prepared for data reconciliation mode by adding flowsheet measurements, tuning parameters and a feed composition estimator. The EDI was configured to establish direct links between the external databases (arrows crossing the ROMeo box in Figure 3 represent data with EDI links) and the flowsheet measurements. Heuristic data screening was implemented on each measurement using built-in features of the system's flowsheet measurement unit.

To accommodate automation of ROMeo blends after crude blend switchovers, EDI was configured to import crude lineup information into the system's assay and blending facility. The procedures for automation of feed characterisation and data reconciliation are further discussed. To complete the model building process for running optimisation mode, controllers were added to the flowsheet, including the system's multivariable controller (MVC) flowsheet unit. The flowsheet MVC is a convenient way to automate functionality associated with multivariable controllers (limit handling, reconfiguring of associated variables in the event of bad measurements or a deliberate change in status of variables commanded by an operator etc).

To complete the model specification for optimisation mode, an economic objective function was configured. Much of this activity is configured automatically by the RTO system, with only simple pricing information added by a user (bulk prices or composition/quality dependent values of product streams, utility costs etc). When objective function customisation is required, ROMeo's objective function manager provides a number or features to define alternate objective functions, or to add specialised terms such as user-defined penalty functions that penalise operation in predefined operating regions of a variable. In the CDU3 application, pricing information in the flowsheet model was updated by creating EDI links to an external spreadsheet that contained current pricing information.

The final step in the application building involved configuring the RTS. In RTS, a user configures sequences that consist of pre-defined tasks and custom user-defined tasks. Sequences control the scheduling (start times or execution frequency) and sequential execution of tasks that automatically perform specific operations when the sequence is placed online. These include steady state detection, importing and exporting of data, checking controller status, running the model in data reconciliation and optimisation modes and validating the results, to name a few. Sequences are easily configured in the RTS flowsheet environment with tasks connected by streams that define execution path through the sequence. A number of tasks allow conditional branching based on pre-configured conditions or user-defined tests. This feature allows a user to configure different sequences of tasks to be executed depending on the outcome of a particular task, or to respond to changes in plant conditions if these are being tested.

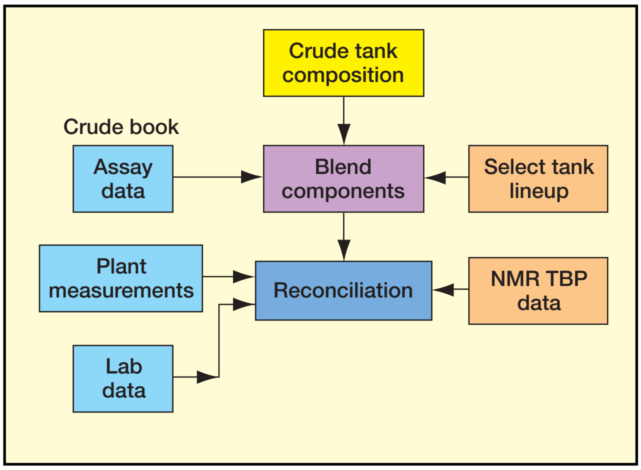

Figure 4 *Feed characterisation scheme*

For example, the model execution task provides a separate branch for a failed run, allowing tasks to be set up to respond to the failure. This might involve modifying some aspect of the model or data processing to allow the run to be repeated. The sequence in this case would contain a branch that contained the desired tasks, perhaps including some custom tasks to perform non-standard operations (implemented using ROMeo's Tcl-based macro facility), with the sequence path eventually returning to the input of the model task. Alternatively, a user might configure a path with a task to save the failed case followed by sequence termination.

Consulting was provided whenever questions arose in the model building and configuration process. This was facilitated by remote access to the RTO system, using PCAnywhere.

System and implementation

An overview of the various operations and data input required for feed characterisation and data reconciliation is shown in Figure 4. Since crude assay information is rarely updated, this information was imported once into the RTO's thermodynamic calculation facility that performs assay characterisation and offline blend calculations. The rest of the elements indicated in Figure 4 participate in real-time for blend updating and data reconciliation, as follows: when a crude lineup change occurs, it is necessary to import the new lineup information into the RTO's flowsheet thermodynamic facility for updating of the flowsheet feed blend.

This is a one-time operation that occurs before the data reconciliation run is initiated, and is accomplished with tasks in an RTS sequence. Since crude blends are fixed in the period between blend changeovers, this blend updating in ROMeo need only occur when the plant crude blend changes. While a flowsheet blend unit is included that performs open equation blending during solution of the flowsheet model, it was not necessary in this case.

Data reconciliation is performed at each optimisation cycle, to match the model to current plant data. Data

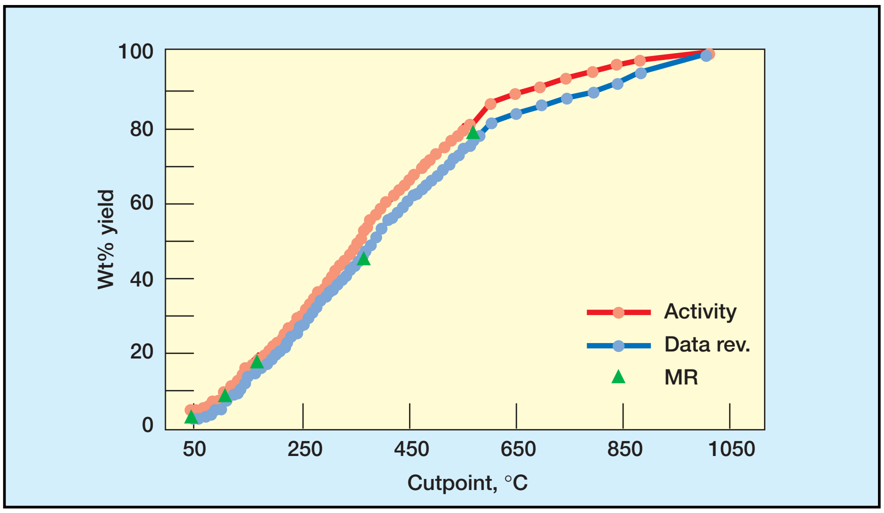

Figure 5 *Crude composition adjustment in data reconciliation*

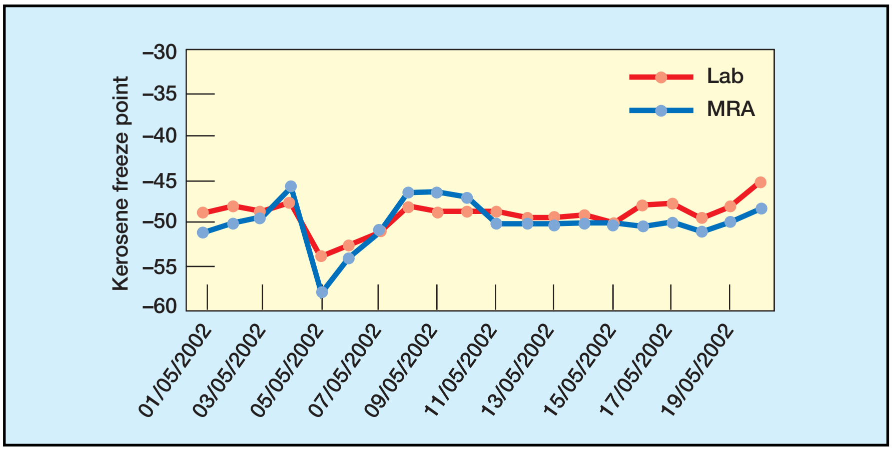

Figure 6 *MRA validation against lab data: kerosene freeze point*

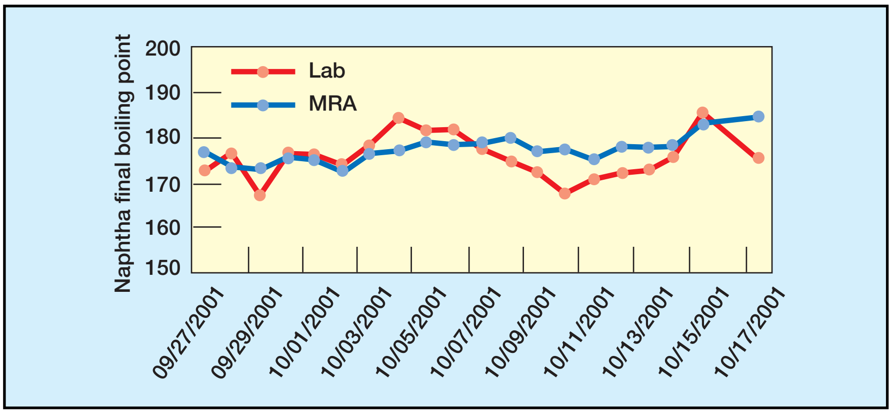

Figure 7 *MRA validation against lab data: naphtha endpoint*

reconciliation utilises all available plant data (with good quality), including real-time MRA data on crude feed TBP and other measurements on product quality. The CDU3 flowsheet contained a feed composition estimator on the combined feed stream, allowing the RTO system to change feed composition to better match model predictions to downstream measurements.

The MRA TBP data on the feed has a significant effect on this composition adjustment, as indicated in Figure 5. The top curve in the figure is the TBP curve obtained from offline blending of assay information from a particular blend of crudes. The bottom curve is the TBP curve resulting from adjustments to feed composition during data reconciliation.

In addition to feed TBP information, the MRA system provided API density, paraffins, naphthenes and sulphur content. Not all this information was used in ROMeo, but nevertheless was helpful to operating staff.

The online MRA also provided freeze and flash points on the kerosene product stream, and 7-pt distillation, Iso- and N- paraffins and naphthenes on the heavy naphtha product stream. Where soft sensors were employed, these measurements were used for offset updating.

MRA results were validated against lab data, with examples for kerosene freeze point and naphtha endpoint shown in Figures 6 and 7 respectively. All MRA measurements were found to be with the repeatability range of the laboratory instrument. The MRA analyser cycled at a frequency of 12 minutes on each stream.

Real-time implementation

A typical ROMeo installation utilises multiple RTS sequences. In the CDU application, three were used: a steady-state detect (SSD) sequence running at a frequency of 1 minute, an MSAC (model sequence activation control) sequence running at a slightly slower frequency, and a model sequence whose execution was triggered on command by the MSAC sequence. The SSD sequence imports process data snapshots for 32 measurements selected as being representative of the dynamic/steady state of the process and performs statistical tests for the presence of steady state by examining data from the previous 60 minutes.

If the steady state criterion is satisfied, a flag is set and exported to the plant data system. The MRAC sequence reads the SSD flag and if steady state is indicated, and other criteria are satisfied, it triggers execution of the model sequence. This sequence contains all the tasks required to perform a complete optimisation cycle, including data import and export, testing of the status of controllers, executing data reconciliation and optimisation runs and validating the results, and finally, determining if the optimisation moves should actually be transmitted to the process (process still at steady state, controller status not changed etc).

At the completion of a successful optimisation cycle a timer is started that keeps another model sequence from being executed before a specified elapsed time, three hours in this case. This corresponds to the settling time of the process, and allows the process sufficient time to reach steady state after implementing optimisation moves.

Project execution

Two plant engineers travelled to Houston, Texas, to receive a three-day ROMeo training course prior to project kickoff. A week long kickoff meeting, with participation from Invensys consultants, refinery engineers and operations personnel, took place in June 2001. The consultants received a detailed process description, and details of current operating practices, constraints and objectives. During the meeting, the design basis was frozen and activities required to produce a detailed optimiser design were defined.

Plant engineers prepared a detailed design for the ROMeo application, which was reviewed by Invensys. Included in the design were details of the interface to import data into ROMeo from the online MRA, the plant process information system and the Foxboro IA DCS (refer to Figure 3).

With the detailed design in place, flowsheet modelling began in September 2001. At each stage of the optimiser configuration, consultants provided input where necessary. This consulting activity was facilitated by remotely accessing the RTO system using PCAnywhere, as mentioned earlier. This strategy enabled the plant engineers to complete all aspects of the optimiser configuration in approximately four months. The most difficult activity was tuning the system for data reconciliation, including transitions between data sets representing different operating modes. This activity required approximately two months to complete.

With the flowsheet successfully configured and tested for data reconciliation, the next step was to prepare it for optimisation mode. This was accomplished by configuring an objective function and providing all pricing information, adding the remaining multivariable controllers and ensuring that all system constraints were in place. Once a stable optimisation run had been achieved, the flowsheet was further tested on multiple data sets to ensure smooth transitions between data reconciliation and optimisation modes.

The final step in the configuration was to define sequences in the RTS system to perform the operations necessary to implement the online system, as previously described.

The system was first tested in online open loop mode beginning around January 2002. In this mode, the RTS sequences were placed online (activated for execution according to scheduling type: start-time or frequency, or on-demand from another sequence) resulting in initiation of optimisation cycles and importing of real-time data when the specified criteria were satisfied.

Optimisation moves were calculated, but not transmitted to the DCS. Instead, they were transferred to a network computer where they were reviewed by operations personnel. After several weeks, operators became satisfied that reasonable moves were being calculated by ROMeo, and they began implementing the setpoint moves manually. A review of plant data during this period indicated significant improvement in product yields. This mode of operation continued until approximately mid-February when a planned short turnaround in the CDU3 unit was performed.

An additional benefit of the RTO system was realised at this time: unit performance data obtained from online data reconciliation runs indicated that a planned opening of a distillation column and a few heat exchangers was not necessary, reducing the turnaround time. When the unit was returned to service near the end of February, multivariable controllers and ROMeo were placed back in service, this time with the system in full on-line closed-loop mode. That is, optimisation moves were transmitted to the DCS.

The execution time of the solver, including solution in data reconciliation and optimisation modes, is approximately 12 minutes. Precise statistics on optimisation system performance are not available, but the fraction of successful runs has been extremely high.

The steady state detect algorithm performs as expected, rejecting the initiation of optimisation runs when unsteady conditions are present, which occurs mostly during the period following crude switchovers.

Results

Preliminary performance during the first several months of closed loop service indicates significant improvement in yields on kerosene, gas oil and LPG. Total benefits in the range of 3–6 cents/bbl of the crude processed have been calculated. These preliminary benefits correspond to the period immediately following the turnaround when plant throughput was approximately 70% of capacity.

The unit was subsequently turned up to 90% and ROMeo continued to run successfully. It is expected that the benefits achieved for the 70% operation will also be achieved at the 95% throughput level, when yields are compared to previous periods of 95% operation when no optimisation was performed.

An important objective of the project was to attempt to standardise unit operation between shifts. Operators have available a set of guidelines that provide operating ranges for key process variables as a function of crude blend. While these guidelines are helpful in minimising the time required to stabilise the plant after a crude switchover, they also provide significant leeway in choosing a final operating point. Stabilising the process while maintaining products on specification is the primary objective of operators, and operating point may differ between shifts based on operators' own experience on how best to achieve this goal.

The optimiser was expected to produce benefit by virtue of locating and enforcing an economically optimal operating point, but it was also hoped that it would improve operational consistency among shifts by recommending targets on key process variables. Experience to date has indicated that this has been the case. As operators gain confidence that optimiser moves are resulting in significant improvement in yields and other variables that affect the economic performance of the plant, while ensuring constraint satisfaction and stable operation, their inclination to fine tune the process has declined. An example of this was column circulating reflux rates, which now receive targets from the RTO.

The performance of the online MRA has been excellent, with greater than 90% online availability. Product qualities determined by MRA are within lab repeatability ranges. The improved precision of soft sensors for kero freeze and flash points and naphtha end point has resulted in closer operation to their constraints. As previously shown, MRA data on crude feed TBP has resulted in more precise data reconciliation results.

Benefits

Including the detailed design, the entire project was completed according to schedule and in approximately six months. The optimiser was configured by refinery engineers with consulting assistance. Preliminary online benefits are in the range of 3 to 6 cents/bbl, deriving primarily from improved kerosene yield and more efficient heat integration.

In addition to these direct economic benefits, the ROMeo system has resulted in a more consistent process operation between plant shifts, by determining operating levels for key process variables that operators have traditionally fine tuned from shift to shift.

The system is expected to produce benefits from offline usage as well. In a plant turnaround, several heat exchangers and a distillation column previously scheduled to be opened were not after examining the results of online data reconciliation runs. The RTO model is expected to be used for offline case studies, to predict the effect on downstream units of different crude blends.

Measurements on feed TBP have improved the quality of the RTO system's data reconciliation, and data on kerosene freeze point and flash point, and naphtha end point have allowed operation closer to constraint boundaries, when the RTO has determined that these constraints should be pushed.

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