Crude-unit control system pays off at Louisiana refinery

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Marathon Ashland Petroleum LLC's Garyville, La., refinery is using DMCplus multivariable control to maximize the profitability of its 255,000 b/d crude and vacuum unit.

A large DMCplus controller has been used on the complex since March 1996, with conservatively estimated benefits of $3.6 million/year, or about 4.1c/bbl of crude charge.

The advanced control system has maintained a high return on investment (ROI) for the 2.5 years since its commissioning. One reason for Marathon Ashland's high ROI is its commitment to employee training and project support since the beginning of the project.

This approach to advanced control implementation has resulted in high control utilization and benefits. The system has paid for itself more than 40 times over thus far.

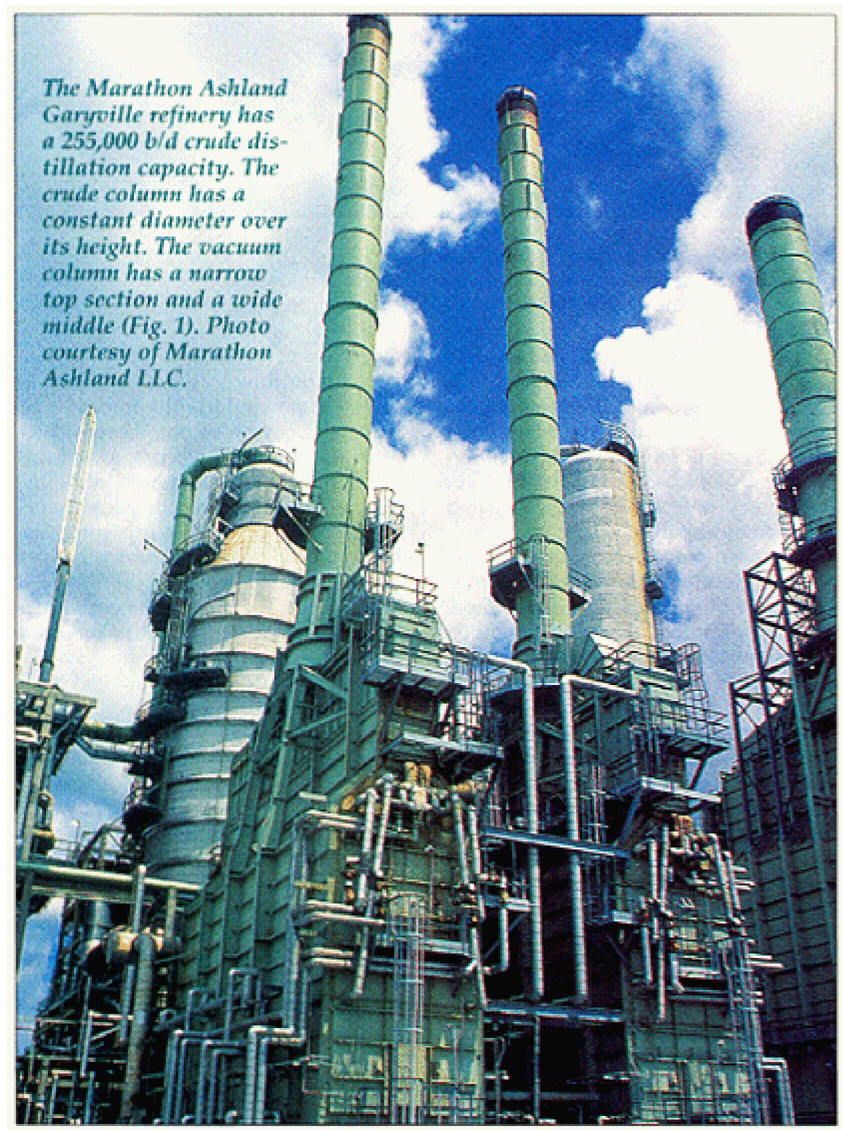
Unit overview

The Marathon Ashland Garyville refinery is the newest major grassroots refinery in the U.S., having been built in 1976.

Originally, the refinery was mainly a fuel-oil refinery. Since then, Garyville has undergone four major upgrades, adding cracking, reforming, isomerization, and ROSE (residual oil solvent extraction) facilities to greatly reduce heavy oil production and increase transportation-fuel yield.

Located on the Mississippi River, 25 miles from New Orleans, the refinery receives the majority of its crude from the Louisiana Offshore Oil Platform (LOOP).

The 255,000 b/d facility includes crude, vacuum, naphtha splitter, stabilizer, and deisopentanizer (DIP) columns. Fig. 1 shows the crude and vacuum columns with several furnaces. A simplified flow diagram of the unit is presented in Fig. 2.



The Marathon Ashland Garyville refinery has a 255,000 b/d crude distillation capacity. The crude column has a constant diameter over its height. The vacuum column has a narrow top section and a wide middle (Fig. 1). Photo courtesy of Marathon Ashland LLC.

The crude slate is varied, and optimal refinery operation requires the crude unit to switch between production of varied outputs. The need to handle changes in crude type and mode switches presents a significant challenge for the advanced control system.

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Fig. 2

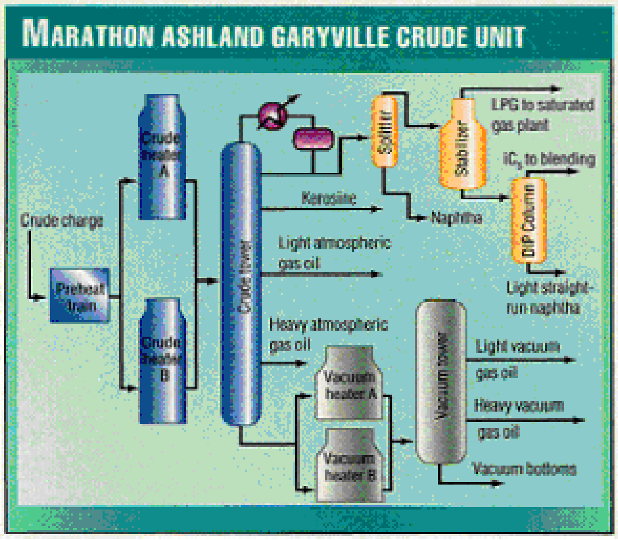
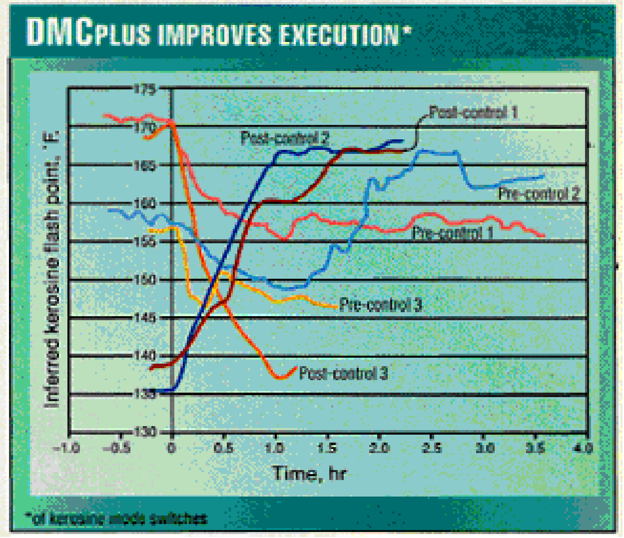


Fig. 3



DMCplus overview

DMCplus is Aspen Technology Inc.'s multivariable advanced process control product, designed to push process plants to multiple simultaneous constraints and hold them there safely.

The DMCplus control algorithm uses linear dynamic models of the process to calculate both optimal steady-state targets and dynamic move plans to achieve and maintain those targets.

The dynamic models of the process are obtained empirically by performing controlled step tests and analyzing the plant data collected. Large scope processes can be handled within a single advanced controller allowing multi-variable constraint interactions to be handled explicitly and optimally, thereby achieving maximum utilization of the process equipment. DMCplus controllers typically run approximately once per minute, existing in the control system hierarchy above traditional advanced controls and below real-time optimization systems.

The DMCplus software consists of a set of tools, on multiple computer platforms, to build, test, and comm-ission advanced controllers in a Win-dows-based, graphical environment. Software tools are provided for plant testing and data collection, data analysis and model development, controller building and simulation, and on-line controller execution and management.

Advanced control overview

The advanced control system comprises a large DMCplus controller for both the crude and vacuum columns. A separate DMCplus controller, discussed in a paper presented in 1997, handles the split-ter, stabilizer, and DIP columns.

The crude and vacuum towers' large scope was carefully selected to allow the unit's economic objectives to be pursued under many combinations of active constraints.

This philosophy produces a robust controller design that will be reliable under widely varying conditions of equipment fouling, crude type, and ambient conditions. This same philosophy produces a control system design with many controlled variables to address as many potential constraints as possible.

Marathon Ashland's crude unit controller has 59 controlled variables and 29 manipulated variables, making it a moderately large application by modern standards. A large proportion of the controlled variables act as constraints only, with the DMCplus embedded linear program (LP) pushing unit economic objectives to the most limiting constraint set and leaving other variables inactive until needed.

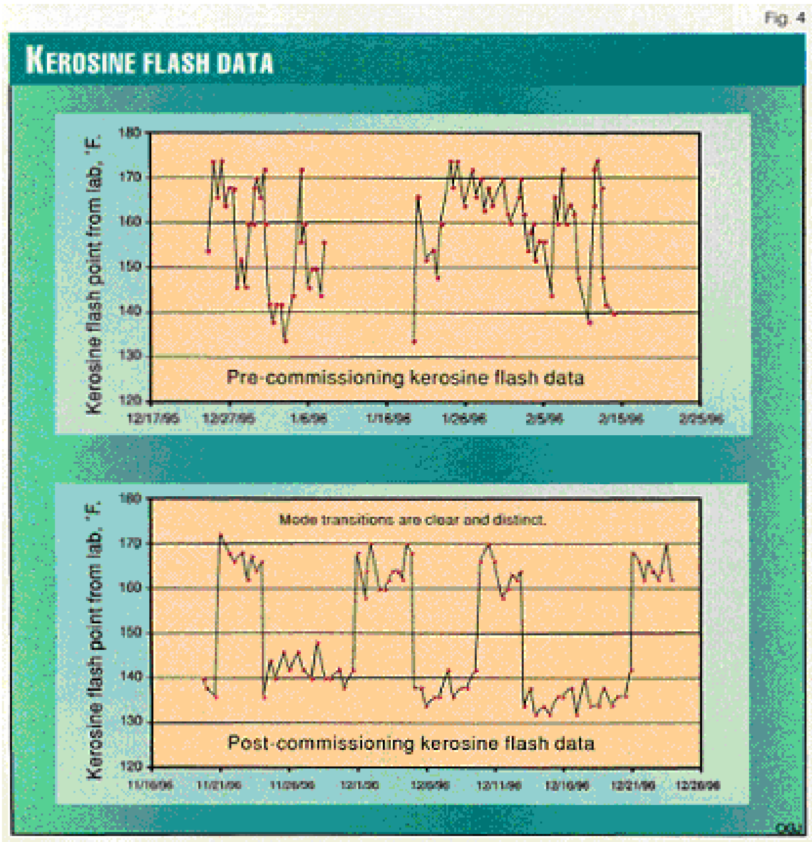
The important advantage of a large number of controlled variables is that many combinations of constraints can be handled seamlessly without any loss of optimality in unit operation.

The advanced control system's economic objectives are configured by the objective function for the LP. This function can be changed as often as needed to reflect varying refinery economics and logistics, allowing for unlimited flexibility in directing the system's operation.

Getting an LP "on-line" and closed loop with the process is often one of the greatest benefits of implementing this kind of application; strategy can be communicated to the unit in quant-itative terms and will be vigorously implemented at the next control interval. Most of the time, however, many controllers' econ-omics require only infrequent updating, such as that to reflect seasonal gasoline vs. distillate economics.

Marathon Ashland's crude unit controller requires very infrequent updates to the objective function. The current configured drives favor crude charge maximization, light product yield maximization, pressure min-imization, and crude preheat max-imization.

The DMCplus controller uses inferred product quality calculations as controlled variables. These calculations



estimate the naphtha 98% distillation point; the kerosine 5%, 10%, and 95% distillation points; and the atmospheric gas oil 95% distillation point; as well as the kerosine flash point.

The inferentials are critical to the successful operation of the advanced control system and are always active constraints in the applications drive to maximize desirable product yields.

Some of the inferential calculations are derived from first principles models of the unit and others are the result of regressions of data sets gathered during controlled experiments. In each case, the type of inferential calculation was chosen to be the most suitable for the variable being inferred.

Control system implementation

Dynamic Matrix Control Corp. (DMCC) began the advanced control project on the crude unit in the fall of 1995. The project was completed with control system commissioning in early March 1996. AspenTech acquired DMCC in January 1996.

The original commissioning used DMC version 5 software, and in June 1998 the controller was upgraded to DMCplus version 1.2.

At the beginning of the project, Marathon Ashland appointed a project team of representatives from operations and engineering to work with the DMCC team. This early and detailed involvement by a senior operator, the unit process engineer, and two refinery control engineers helped achieve greater understanding and buy-in from all the groups affected by the advanced control.

This team participated throughout the project, assisting with each phase as appropriate. The refinery control engineers assisted with every part of the work from pretest to data analysis, computer interface configuration, and commissioning.

The operations representative focused on control system design, advising on likely constraints and operating modes as well as "usability" issues from controlled variable selection to display design. The process engineer was important for advice on operating philosophy, safe operating limits, and unit economic drives.

The refinery team's contribution complemented the talents of the DMCC/AspenTech team to improve the quality of the final product. The high level of involvement by the refinery people also enabled their effective support and maintenance of the controller following commissioning because they were already very familiar with the application.

Control system benefits

The operational impact of the control system commissioning was immediately apparent. An internal refinery technical bulletin from Process Engineering dated Mar. 14, 1996, summarizes the impact:

"The DMC controller has been commissioned and is controlling the crude/vacuum towers resulting in the following benefits:

1. Crude overhead pressure has been reduced from 10-12 psig to 6-8 psig while maximizing steam to the bottom of the tower, resulting in reduced crude bottoms flow and maximized product draw rates.

2. Crude tower pumparounds are controlled to maximize crude preheat.

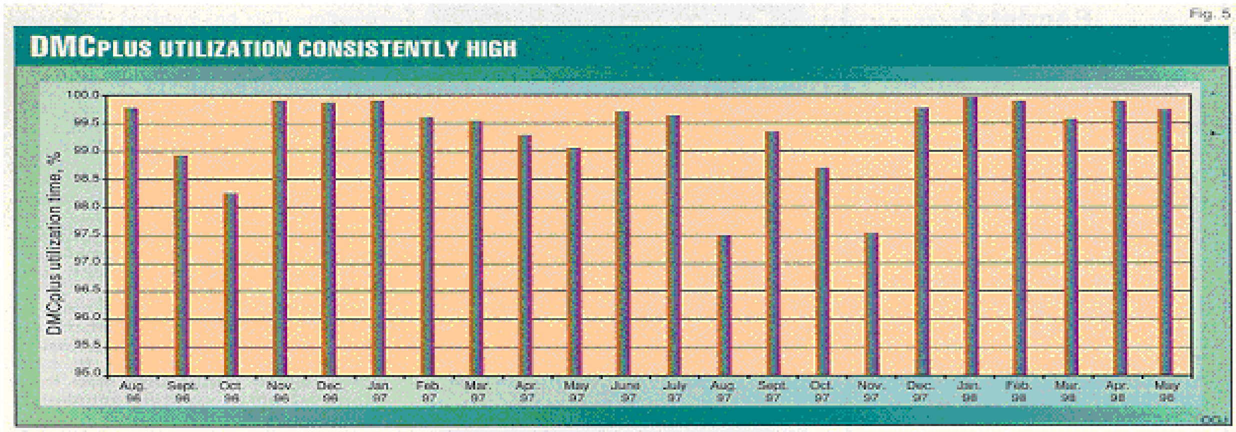
3. The amount of off-spec product has decreased due to laboratory analysis tracking with the DMC inferred calculations.

4. Product specification changes have been accomplished more efficiently.

5. Product quality specifications have been maintained during crude switches without reducing charge rates."

The economic benefit of the DMCplus controller has since been conservatively estimated at \$3.6 million/year, providing a project payback period of around 1 month.

The benefit estimate is primarily derived from two mechanisms, improvement in yields and successful



meeting of planned targets, although there are other associated benefits that are difficult to quantify. This situation is typical for advanced control projects. Although those people familiar with the unit see many clear benefits, only two or three mechanisms can be easily quantified in dollar terms.

The primary benefit of the controller is improvement in yield structure via pressure minimization as well as via stripping steam and pumparound optimization. This has reduced resid yield and increased gas oil yield by approximately 0.75%. This shift has reduced bunker fuel production and cut purchased gas oil for FCC feedstock.

The ability to consistently meet planning targets for crude charge rate is another large benefit. The controller is configured to maximize charge, and the planning target is entered as a high limit to this maximization. This often means the control system does not so much maximize the unit charge as much as prevent reductions from the scheduled rate by working around unit constraints.

This ability to relieve constraints, for example, by adjusting atmospheric column pressure or by adjusting pumparounds, has resulted in more stable, higher crude rates than those before advanced control commissioning.

Because the refinery does not simply maximize crude charge, but rather optimizes the charge target using a refinery-wide objective, the economic benefit is not obvious. Within the refinery, however, the consensus is that crude rate maximization is one of the largest benefits of the control system.

Kerosine mode-switch benefit

Another benefit that has been quantified is the improved handling of kerosine mode switches using the DMCplus controller. These mode switches alternate the minimum kerosine flash point specification between 135° F. and 165° F. at a constant 95% point. Making this switch requires simultaneous adjustments of naphtha reflux and kerosine draw rate while re-balancing the pumparounds. This significant shift in column operation is challenging to do manually and requires highly skilled operators as well as prompt laboratory test results.

Fig. 3 shows the inferred kerosine flash point during six mode switches, three of which were done manually before DMC commissioning, and three of which were automated using the DMC controller. The plots are shown with the start of each mode switch aligned at zero time.

The manual switches are generally too conservative, initially achieving less than half of the desired 30° F. change. Lab sampling and further adjustments would eventually achieve the remainder of the mode switch and allow the rundown tank to be swapped, usually within one 12-hr shift. The automated mode switches, with the benefit of the inferred property calculation, achieve the transition in 1-2 hr.

The first lab result is generally on specification for the new grade, and the tank can be switched. The longest of the automated mode switches shows two hesitations caused by the controller preventing constraint violations as external disturbances affect the unit.

Figs. 4a and 4b present raw lab data for kerosine flash point before and after DMCplus commissioning. The alternating modes are much clearer in the post-control data set, illustrating the improved performance of these transitions. The pre-commissioning data set contains a gap during unit turnaround maintenance.

The direct economic benefit of this mode switch improvement has been estimated at $200,000/year via reduction in product downgraded between starting the transition and switching the tank. The intangible benefit is probably greater, as the refinery planning and scheduling personnel find they can rely on consistent execution of mode switches with reduced uncertainty.

Intangible benefits

Many additional intangible benefits can be found. DMCplus has brought about an increased understanding of the true process limits of the refinery. The controller's LP tirelessly follows the economic objective function and manipulates all the available handles until every degree of freedom has been used to push against a constraint.

This results in as many active constraints as there are manipulated variables, with the controller reporting shadow prices for each active limit. The shadow price is the incremental objective function value that would be obtained by relaxing the constraint and is useful in understanding and prioritizing the unit's limits.

The console operators have often examined shadow prices to identify the specific constraints that are preventing crude charge from being increased.

The active constraints are displayed clearly on the advanced control displays by backlighting the relevant limit. This helps the entire refinery team be at a common understanding of which limits are truly important to the operation and which may be myths.

An interesting additional benefit has stemmed from the off-line, PC-based simulator that is part of the DMCplus tool set. The refinery has found the simulator to be useful for studying options for relieving unit constraints. Recently, the simulator was used to evaluate the potential result of increasing the maximum pressure constraint on the crude column. The study observed the behavior of other important constraints, such as heater duty limits, under the proposed scenario and concluded with the pressure limit being relaxed.

Advanced control robustness and longevity

Many advanced control applications suffer decaying performance after commissioning, and some eventually become unusable and are turned off. This often happens because minor maintenance work is neglected, allowing small problems to become significant and cause unacceptable control performance.

In other cases, unit operation evolves after control system commissioning, resulting in changed objectives or constraints. If the controller does not recognize a new constraint or the system's scope is too small to cope with a new objective, then the application becomes irrelevant and out-dated. These types of problems have destroyed the reputation of advanced process control in some plants.

Marathon Ashland has avoided such problems at the crude unit. Its controller delivers benefits as consistently today as it did after commissioning 2.5 years ago.

Marathon Ashland operators have continued to use the controller over time, as illustrated by the 22 months of percent utilization data in Fig. 5. Over this period, monthly averaged control utilization has not dropped below 97.5%.

This success has been achieved in a changing operational environment. Equipment fouling and then cleaning has shifted the unit's active constraints.

In January 1998, the refinery pigged the crude column heater and cleaned key exchangers, shifting constraints away from heater skin temperatures and pumparound heat transfer rates to overhead condenser capacity.

Mike Odell, operations team leader, explains, "The constraints have evolved over time from heater duties to the pressure valve to pump hydraulic limits. Always being able to be at that active limit is the key."

The controller has proved itself robust and flexible. It has remained in service at crude charge rates varying from 247,000 to 160,000 b/d.

How has this longevity and robustness been achieved? Careful design of the original controller to ensure a robust scope, diligent maintenance, and operator training all played a part.

Maintenance and support

Marathon Ashland made sure those supporting the project understood both the technology and the specific application by assigning refinery control engineers to the project.

Equally important was to maintain the continuity of support after the initial commissioning excitement had passed. Marathon Ashland's management has provided the resources to make sure that an engineer is always available to perform maintenance tasks or to respond to requests from operators.

In many plants, engineers familiar with the advanced control applications have moved on to other jobs, and support is not available. The refinery control engineers stay on top of the small maintenance tasks as soon as they appear. In this way, they have gained the confidence of the operators. This results in prompt reporting of any issues that do arise, and a positive cycle is sustained.

Operator training

All the members of the crude unit team emphasize that good operator training is a critical element of success in an advanced control implementation. Operators must be able to correctly interpret the information presented on the DMCplus distributed control system (DCS) displays and understand what the controller is trying to do and what the important constraints are.

On-the-job training was a large part of the process of commissioning the controller, but this type of training should not be relied upon alone. Following commissioning, all of the console operators received a 6-hr classroom training session presented by the AspenTech project leader.

Each of these sessions was videotaped and the tape has since been used for new console operators. Marathon Ashland considers training for the operations group to be a constant process.

Future plans

The Marathon Ashland Garyville refinery is continuing to look for ways to further improve the crude unit control performance. Many on the team would like to rework the calculation of the controller's economic objective function by building a more rigorous spreadsheet calculation that considers yield and utility information in a more detailed fashion.

Another idea being discussed is to incorporate vacuum tower bottoms viscosity as a controlled variable either by building an inferential quality calculation or by installing an on-line analyzer.

Reference

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The Authors

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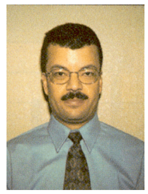

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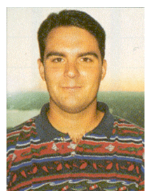

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