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Advanced Process Control and Optimization for Oil Refining

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INTRODUCTION

After the removal of the restrictions imposed to stop the advance of the COVID-19 pandemic, the energy market has registered a faster-than-expected recovery, the demands for liquid fuels continue to increase in most countries, so it is imperative to increase inventories of distillates to supply the local and global demand for hydrocarbons at values close to those registered before the start of the pandemic. However, the projection for the consumption of liquid fuel is not as favorable as expected, according to the report "Short-Term Energy Outlook. July 2023" published by the U.S. Energy Information Administration EIA, consumption of liquid distillates will increase by only 1.8 million barrels per day (b/d) in 2023 and by 1.6 million b/d in 2024 Vs. 2.3 million b/d in 2022.

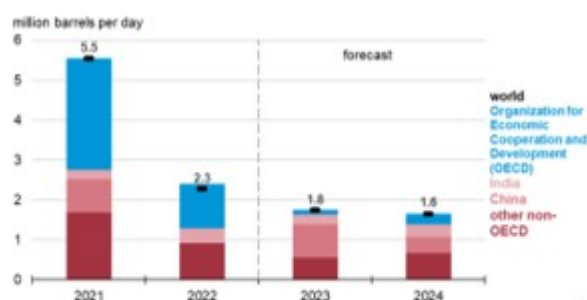


Figure 1. Annual change in world liquid fuels consumption (Data source: U.S. Energy Information Administration, Short-Term Energy Outlook. July 2023)

According to the report "Oil 2023 Analysis and Forecast to 2028" published by the International Energy Agency IEA, this trend of low consumption of liquid distillates will continue until at least 2028, due to increased production of biofuels and increased demand for electric cars that will possibly bring oil demand to a record low of 0.4 mb/d in the year 2028.

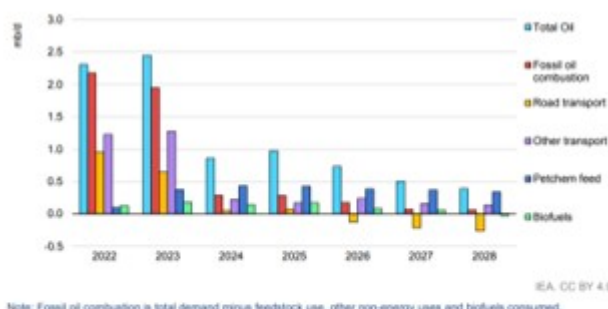


Figure 2. Annual oil demand growth, 2022-2028 (Data source: International Energy Agency IEA, Oil 2023-Analysis and forecast to 2028)

Given this not-very-encouraging situation for the liquid hydrocarbons sector, the use of software and mathematic tools for controlling and optimizing chemical processes should be a priority to maximize production and minimize energy consumption. Complex product disposition scenarios require an exhaustive analysis of the entire supply chain and the operation of the different process units to optimize the entire production line without compromising the quality of the products.

However, there are exceptions to the downward trend in distillate consumption, according to the report "Annual Energy Outlook 2022 Reference Case" published by the U.S. Energy Information Administration EIA, The US total consumption of petroleum and other liquids will increase in most years through 2050. But regardless of some local scenarios, downstream companies at a global level continue to promote automation/optimization projects, with advanced process control (APC), LP models, and real-time optimization (RTO) that allow increasing refining margins.

REFINING MARGINS

The objective of oil refining is to satisfy the demand for fuels, lube oil, and some other distillates, to generate a profit that allows covering costs. Therefore, the most important economic parameter of oil refining is the:

The refining margin: The difference between the value of the products obtained and the cost of the crude oil processed in the refinery, after deducting the variable costs.

OPPORTUNITIES TO IMPROVE REFINING MARGINS

The profitability of the refining business will always be affected by variations in the price of crude oil and distillates, and on many occasions, the only alternative to maintain a favorable refining margin is to minimize energy costs, avoid unscheduled plant shutdowns and maximize product performance. For this, there are various alternatives, techniques, and tools aimed at minimizing fuel consumption in furnaces and boilers, prolonging the equipment operation cycle (for example: minimizing fouling of heat exchangers), and maximizing the production of high-value distillates.

Many refineries use Linear Programming (LP) as their primary optimization technique, which allows operations to be mathematically optimized based on objectives and constraints. Through linear programming, highly complex refining processes can be modeled as a system of multiple equations, whose solution allows to optimally satisfy the business needs, maximize its objective function, maintain production within quality parameters, minimize costs, and meet market commitments. The success of linear programming (LP) in refineries is contingent on advanced knowledge of operations, constraints, and objectives, as well as high reliability of input data, adequate information processing, and successful disclosure of directions to the different levels of operation.

The second tool to improve the refining margin is the Advanced Process Control (APC) which is typically based on model-predictive control (MPC) technology and consists of empirical models with multiple inputs and multiple outputs that manipulate variables of the different units until finding an optimum operation point. The advanced process control is implemented to:

- Maximize process capacity.
- Reduce product off-spec.
- Minimize downtime.
- Optimize energy consumption.

The third optimization tool is the Real Time Optimizer RTO, a rigorous, large-scale model made up of multiple systems of differential-algebraic equations and thermodynamic equations that describe refining processes. This type of model acquires process and laboratory

data through online connections to the DCS, runs simulations and data reconciliation, infers product quality and operating conditions to finally estimate the optimum operation point, and sends operating targets to one or many APC controllers.



Figure 3. Hierarchy of the Advanced Process Control and Optimization Tools

Even the oldest refineries have increased their level of automation and control, with the aim of optimizing their productive processes. The correct installation and maintenance of key instrumentation will be essential for the successful implementation of APC and RTO. Otherwise, refineries will face model convergence and tuning problems derived from misreading field values.

ROLE OF REAL-TIME OPTIMIZERS AND APC

Undoubtedly, implementing stand-alone multivariable controllers in refining units is a good alternative to obtain economic incentives. Regardless of the design of the refinery or the needs of the local market, any refinery is susceptible to catalyst deactivation phenomena, equipment fouling, and service supply failures, among others, to maintain the production rate, the APC controllers need to operate in sync with the directions of the Planning and Scheduling team and the goals of rigorous real-time models.

To successfully integrate the LP models with the optimization and control tools, it is necessary to send the different optimization vectors from the planning team to the lower levels and keep the effective communication of operational limits and optimization directions to supervisors/operators simultaneously and immediately. In addition, it is required that the optimization models can understand the existing limitations in the plant reflected in the

APC controller (for example, hydraulic limitations). Otherwise, the increase in the refining margin will be conditional on human intervention, not only on the advanced process control engineers who carry out the appropriate maintenance and tuning of models but also on operators and supervisors who allow APC controllers to operate with the necessary degrees of freedom and under the limits of controlled and manipulated variables appropriate to the design and planning.

Many industries in the downstream sector have opted for cross or hybrid planning schemes where logistics, operational and process objectives are combined to find the sweet spot of maximum performance and minimum expense. For this, the different units are linked through individual APC controllers coordinated by a real-time optimizer that estimates economic benefits and generates critical targets for cut-off temperatures in main separation towers, reaction temperatures, reflux flowrates, and pump-around flowrates.

The optimization of any refinery should consider three relevant aspects:

GENERAL REQUIREMENTS FOR ADVANCED APPLICATIONS:

Not all process units in a refinery require the implementation of APC, some effluent treatment plants or plants where several physical separation processes intervene without an adequate level of automation will be candidates for the implementation of highly complex control applications at the basic/supervisory control layer of the Distributed Control System (DCS). In the case of highly complex plants, with a large number of controlled and manipulated variables that end up forming a matrix of great magnitude and interconnection, with several disturbance variables and a high level of operational flexibility, it will be recommended the implementation of APC, which will allow the future implementation of an optimizer that synchronizes plans of the refinery with the plant, but it should be noted that in cases of control applications of high complexity in the DCS, the ability to align with the refinery planning will not necessarily be lost, it will only be required to make it clear which variables should be controlled and manipulated by the console operators.

CONTROLLER SIZE AND REAL-TIME OPTIMIZER:

For many refineries it is crucial to implement APC controllers with effective gain matrices that are easy to identify and maintain, one ideal premise for APC implementation should be to

map the largest number of controlled variables by manipulating the necessary variables, with empirical models, identified under robust mathematical techniques. When trying to integrate APC with a real-time optimizer, the matrix of the different APC controllers must be replicated to the optimizer model, to contemplate for the real-time optimization, all the dynamic and hydraulic effects considered in the empirical models.

MISMATCHES BETWEEN APC AND LP:

If the objectives built into multivariable controllers are different from the objectives built into the LP, the plant will run at a different operating point from the one suggested by the LP or the schedule. If the constraints set in the APC controller differ from the constraints set in the LP model, the optimization in the control system will be incorrect.

REFINING MARGIN USING APC AND LP MODELS

A typical increase in refining margin capture by APC implementation is approximately \$0.3/b. An accurate LP model can improve the refining margin by \$0.5/b. The optimal operation of both technologies in a refinery with a small capacity of 100 -thousand-b/d would mean a capture of \$29 million per year.

OIL MARKET AND REFINING MARGIN

According to the report “Oil 2023 Analysis and Forecast to 2028” published by the International Energy Agency, gasoline consumption in the world will decrease by 0.3 mb/d in the coming years. The downstream companies should adapt their facilities, change unit operating conditions, and implement precise and updated control and optimization systems that allow maximizing the production of high-demand distillates vs. the production of gasoline.

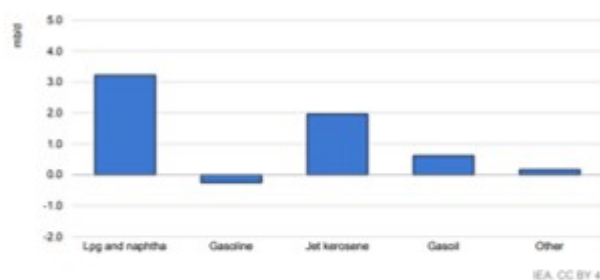


Figure 4. Global cumulative oil demand growth by fuel, 2022-2028 (Data source: International Energy Agency IEA, Oil 2023-Analysis and forecast to 2028)

Diesel is one of the distillates with the greatest optimization options through the development of blending systems for intermediate streams from the atmospheric distillation unit, FCC unit, Hydrocracker unit, Delayed coker unit and HDT unit. Diesel blend optimization models are typically implemented to maximize Diesel production while staying within specification on key properties (e.g distillation points, sulfur).

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