Don't Leave Your Refinery's Profits on the Table

Discover how advanced process simulation technology improves crude distillation unit operations

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Introduction

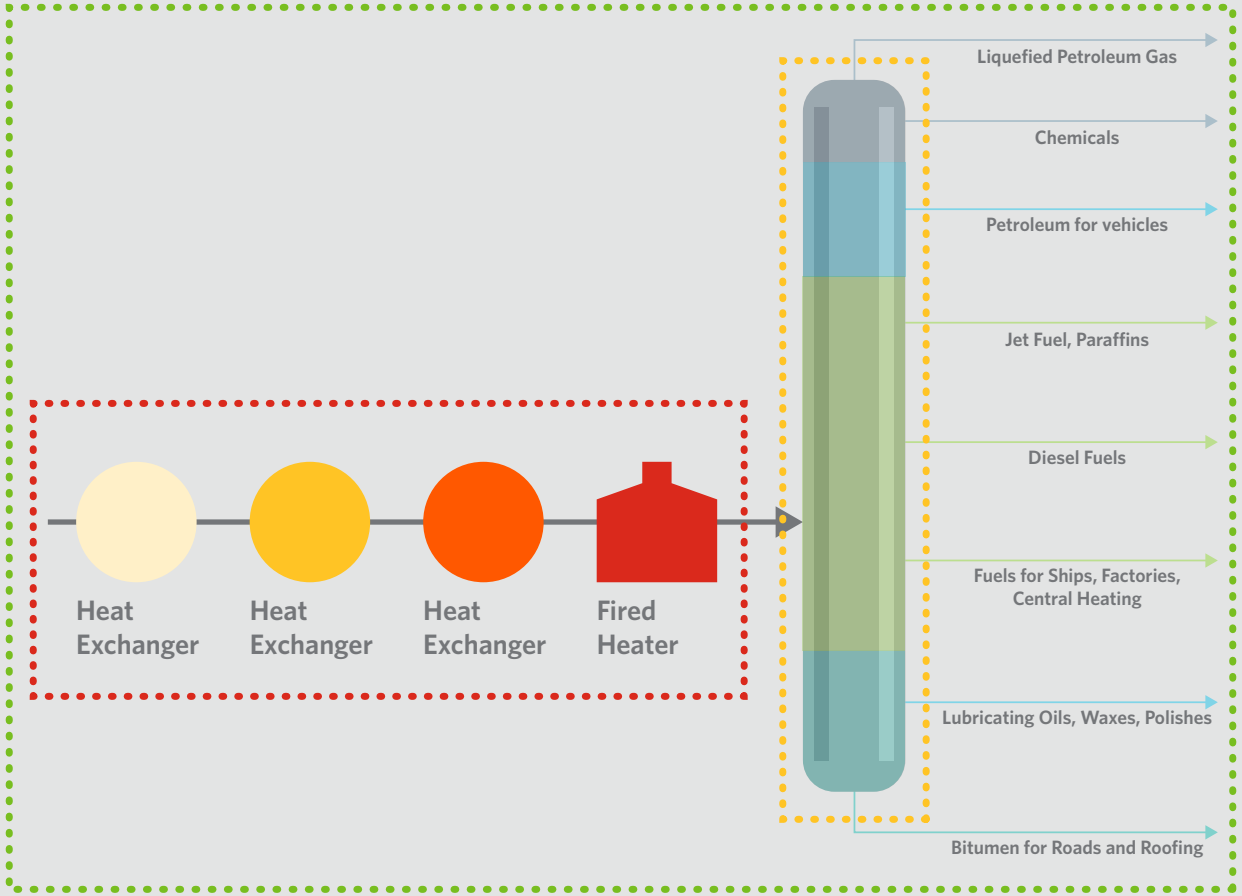
Crude oil refineries typically run on tight profit margins, usually less than 7 percent[1]; therefore, any opportunity to mitigate costs is of significant interest. Given this, it is ironic how many refineries continue to miss out on significant cost-saving opportunities from their crude distillation unit (CDU) operations.

Could this be due to a lack of awareness around new opportunities created by the latest advancements in process simulation technology, or because of misconceptions about the amount of resources and time required to implement meaningful solutions? In any case, key opportunities are missed and profit is left on the table. This white paper is aimed at shedding light on these areas and demonstrating how some refineries are steadily achieving significant savings in this space.

Energy makes up two-thirds of a refinery's operating costs (not considering crude oil costs).[2] The CDU, which exists in every refinery, is the primary unit that separates crude oil into different products that are processed to create automotive fuels or petrochemicals. It is one of the most energy-intensive units in a refinery. A typical CDU requires unprocessed crude oil to be heated to temperatures between 360°C to 380°C (around 700°F)[3], which consumes an equivalent of approximately 2 percent of the crude oil the CDU processes[4]. The CDU operation has a tremendous impact on the rest of the refining process units, making the processing unit critical to a refinery's bottom line.

One of the many operational challenges of a CDU is the fouling of its heat exchanger units. Crude oil frequently fouls heat exchanger units (crude preheat train) on its way to the crude distillation column. Fouling diminishes the heat transfer capability of the heat exchanger unit, which causes additional fuel to be consumed in the fired heaters. In the U.S. alone, preheat train fouling is estimated to cost around $1.2 billion USD per year and in the broader western world, around $4.5 billion USD per year.[5]

Distillation column flooding is another major operational challenge due to the accumulation of liquid within the column. Flooding of the CDU severely limits the processing capacity of the refinery. An operator's incorrect diagnosis of flooding can be equally damaging to the refinery, so many operators run their distillation



Crude preheat network & fired heater

Crude distillation column

Crude distillation unit including crude preheat train, fired heaters and the distillation column

columns conservatively, using far more energy and producing over purified products. An overly pure, expensive-to-make product still sells for the same price as a less refined product, thus diluting profits. Industry experts estimate that over-purifying products on distillation columns often uses 12 percent more excess energy and shaves 7 percent off of refinery production, severely affecting profits.[6]

The INEOS refinery at Lavéra, France, on the other hand, saved nearly $4 million USD per year (of which $1.5 to $2 million came out of a single vacuum distillation unit) from operational improvements achieved by effectively utilizing process simulation technology. Another example is PREEM's refinery in Lysekil, Sweden, which realized nearly $12 million USD per year from operational changes made possible by the same process simulation technology. More details on how these refineries and others achieved remarkable operational improvements will be discussed later in this paper.

CDU Challenges

A CDU is the primary separation unit of a refinery that feeds the rest of the refinery's processing units. Any variation in its operation has massive repercussions for the refinery's yield, product quality, energy usage and, ultimately, profit margins. A CDU's operation is susceptible to variations in many factors such as crude oil composition, weather, conditions of distillation column trays and more. Below are some of the most important factors affecting CDU operations.

Variations in crude oil

With crude oil now extensively trading between regions, the shale oil boom in North America and the lifting of the U.S. crude oil export ban in 2015, global markets today have more crude oil choices than they did a decade ago. Changes in crude oil composition can have a significant impact on the quality and quantity of a refinery's products. This limits the refinery's options in the crude oil it can process, as it is constrained by its existing processes and facility, as well as the products demanded by its market.

Refineries must accurately analyze the economic and processing feasibility of the various crudes available to choose the most optimal crude or blend of crudes. Even for a refinery processing crude oil from the same source, the composition of the crude oil extracted from the same well can vary with the depth of the well and the year of production.[7]

In addition, the nature of crude oil introduces further challenges to this analysis. Crude oil is a highly complex combination of hydrocarbons. Approximately 600 different hydrocarbons have been identified in crude oil.[8] Analyzing these complex crude oils or their blends, by breaking down their compositions and representing them in terms of numerous sub-components, requires considerable technological prowess.

Fouling of heat exchangers

60 to 70 percent of the energy required to heat crude oil is recovered from hot streams tapped out of the crude distillation column using a network of heat exchangers called crude preheat trains.[9] These heat exchangers (primarily shell & tube) are frequently fouled by the crude oil they heat, diminishing their heat transfer capacity and leaving the burden of heating crude oil to the required temperature on the fired heaters. The additional fuel burned in the fired heaters makes up for the heat transfer loss due to fouling and adds to the refinery's operating cost. Fouling also increases hydraulic resistance in the heat exchangers. Throughput reduction, by way of increased hydraulic resistance, is considered the most significant cost of fouling for most oil refineries.[10]

On the other hand, cleaning heat exchangers can take anywhere between 3 and 14 days depending on the severity of fouling and can cost up to $40,000-50,000 USD per heat exchanger — not to mention the lost revenue from the downtime incurred.[11] The economic benefit from cleaning is not the same for all heat exchanger units, so the challenge for refineries is determining the right cleaning schedule. Fouling is not something refineries can readily measure during operation, which is why most predict fouling based on historic trends. In such cases, crude compositions or process conditions, which are both critical factors affecting fouling levels, are accounted for in a very limited way.[12] This clearly does not equal an optimal maintenance strategy.

Additionally, the various types of heat exchangers employed in the CDU such as shell & tube, fired heaters, air coolers and even plate exchangers, requires the refinery operators' knowledge to accurately analyze the operation of each of these equipment types to efficiently manage CDU operation.

Visibility into column operations

To understand the internal operation of a distillation column, both hydraulic and thermal analyses of its operation need to be completed. The complexity involved in the analysis discourages many refinery operators from carrying out such analysis. The sensitivity of the column operations for different operational factors and the implication those operations have on the profitability of the refinery makes it crucial for the refinery's business health. Distillation columns are susceptible to many operational issues such as flooding, weeping, foaming and entrainment, among others.

Flooding is the most common capacity limitation in distillation columns. When a column floods, tray efficiency diminishes, separation deteriorates and products are produced off-spec. In addition to destabilizing the operation of the column, flooding can also cause issues such as cavitation of the bottom pump. To avoid the onset of flooding, operators cut throughput, which causes the plant to lose capacity.[13] This highlights how important it is for refinery operators to have clear insights into the operation of their crude distillation columns. Even for refineries with the capability to conduct detailed thermo-hydraulic analyses, a major challenge is in translating the detailed results of such studies into specific actions that operators can use to improve their column operations.

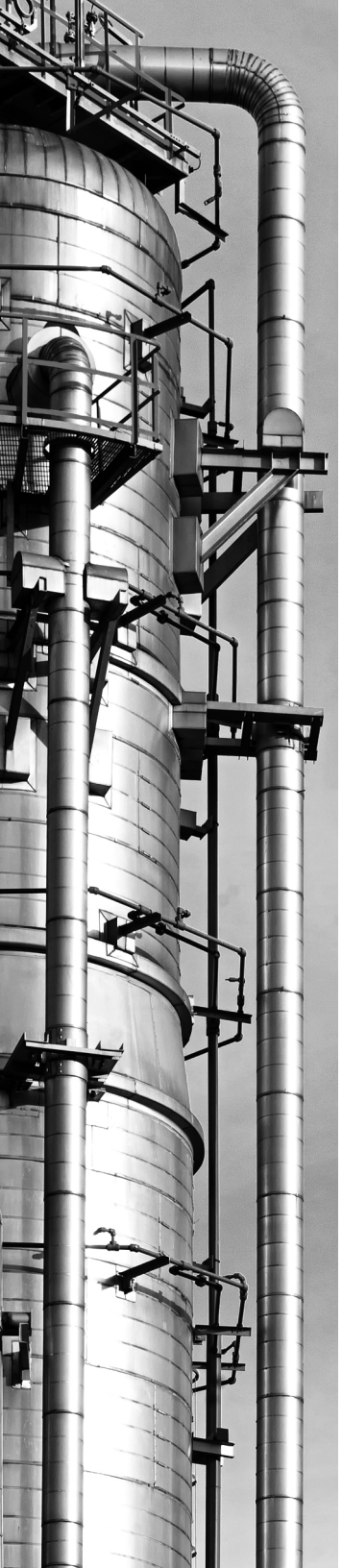
Complexity of the CDU

The CDU entails multiple recycle streams running between the crude distillation columns and the various heat exchanger units in the crude preheat train. The flow rate and temperature of each of these streams depends on the functioning of the distillation column, affects the crude preheat train's heat transfer and thereby affects the fuel consumption of the fired heaters. Accurate analysis of the operation of such integrated systems requires multiple iterations. Moreover, the different types of equipment in the unit such as distillation columns, shell & tube heat exchangers, fired heaters, air coolers, plate exchangers, etc. raises the expertise required to perform an effective analysis. Computer-based solutions designed to analyze such systems have often been cumbersome and difficult to use — but they don't have to be.

Usability of computer-based solutions

There are shortcomings with many of the computer-based solutions available in the market for analyzing and monitoring CDU operations. Many of these solutions require considerable expertise, not only for set-up but also for maintaining it. For instance, these solutions might not support streamlined workflows for validating the model against plant data to ensure they represent the refinery's present operating conditions.

Many refineries do not have the expertise required to maneuver such cumbersome work processes and rely upon external consultants to perform these core business functions. The steep learning curve required to gather enough proficiency to manage these systems discourages refineries from taking the time to even implement them. The difficult nature of some of these solutions hampers a refinery's ability to grow its internal expertise. Many refineries do not have access to technological partnerships and therefore are forced to stay dependent on expensive external consulting companies. These factors have contributed to many refineries lacking basic computer-based simulation models of their CDU.



Essential Elements of an Effective Solution

There are certain capabilities that are indispensable for a solution if it must address all the challenges stated above. The good news is these solutions exist and are used globally with success. The only step left is for refineries to adopt them. The following capabilities are essential to overcome the challenges mentioned in the preceding section.

High-fidelity assay management

Complex combinations of hydrocarbons in crude oil pose a challenge when characterizing a crude oil assay or blend of assays. To accurately predict flow rates and properties of process streams in a refinery, which is critical for an effective operation, one must characterize every stream in the refining process in terms of a uniform set of components. Assay management capabilities in the energy industry's standard process simulation software, Aspen HYSYS®, can break down the constituents of crude oil or any blend of crude oils into a series of distinct hypothetical components. These standard hypothetical components are used to represent every stream across the refinery model. This enables the process simulator to deliver an accurate prediction of both the yields and properties of streams at any point in the refining process.

Inelectra, a Venezuelan engineering company, designed a pump for the bunker products of PDVSA's Puerto La Cruz refinery. The stream viscosity data was not available to the design team at the time, so they leveraged the assay management capability in Aspen HYSYS to predict viscosity values. This enabled the company to reduce their project time by 30 percent by avoiding lost time waiting for measured viscosity data before starting the project. Later, when measured viscosity values were made available, they accurately matched the values predicted by Aspen HYSYS, which was more accurate than the values predicted by another process simulator.

Additionally, the assay management tool used in Aspen HYSYS, Aspen Assay Management™, is the same tool used by the world's most popular refinery planning software Aspen PIMS™. AspenTech is the only integrated solution provider with the capability to allow refineries to foster better collaboration between their planning and engineering divisions, significantly reducing the amount of manual data transfer and errors by easily sharing assay data between planners and process engineers.

Aspen Assay Management also contains a library of crude oil assays. In a recent interview, Khadija Al-Hinaai, a process engineer from ORPIC refinery in Oman, explained how her team's ready access to this crude assay library saved them two to three weeks of time while evaluating different crude blends for their refinery.

Major refining companies are taking assay management capabilities to a whole new level by partnering with cutting-edge technology providers. China's Sinopec, the second-largest refining company in the world, has been working closely with AspenTech to build a capabilities that can characterize crude oil at a molecular level using information that Sinopec has gathered over the years. The companies are working to build a crude oil library in Aspen HYSYS that contains approximately 300 crude oil blends from around the world with molecular-level information, which will enable a more accurate property prediction of refinery process streams when compared to the traditional approach. Sinopec estimates savings of $2 USD per ton, per year when the molecular-level refinery process simulation is fully adopted across its refineries. That is considerable savings for a company that processes 250 million tons of crude oil every year.

AspenTech and Sinopec are working to build a crude oil library in Aspen HYSYS that contains about 300 crude oils from around the world with molecular-level information, which will enable a more accurate property prediction of refinery process streams when compared to the traditional approach.

Integrated, rigorous heat exchanger models

Given the high-energy consumption in CDU operations and the propensity for fouling of heat exchangers in the crude preheat train, accurate simulation of heat exchanger operations in the context of a broader process simulation is important. Advancements in process simulation technology allow engineers to put rigorous models of heat exchangers into the process flowsheet from within the integrated software, without having to switch back and forth between different software. The best example is the integration between Aspen HYSYS and the heat exchanger design and rating software, Aspen Exchanger Design & Rating (EDR). This integration allows users to develop rigorous models of heat exchanger units from within the Aspen HYSYS process flowsheet and allows engineers to incorporate rigorous models of every type of heat exchanger used in the CDU such as shell & tube exchangers, air coolers, fired heaters or plate exchangers.

The mechanical information in rigorous heat exchanger models helps simulate or predict potential operational issues such as erosion and vibration. These are especially useful while troubleshooting operational issues or while conducting "what-if" analysis for possible operational changes. Such insights can only be gathered from the rigorous simulation of the heat exchanger operation within the broader process simulation.

Integration also offers the capability to determine the fouling levels for each of the heat exchanger units in a process flowsheet. The interface Aspen HYSYS has with Microsoft Excel can help operators plot historical fouling trends for each heat exchanger or determine the economic impact of cleaning each unit. Rigorous fired heater models can accurately simulate the amount of fuel consumption. Note that the improvement in heat transfer, from cleaning heat exchangers, may not result in an equivalent saving in fuel consumption. This is due to the loss of heat transfer efficiency in the fired heaters owing to higher crude inlet temperature. This can help engineers determine the most optimal schedule for cleaning.

U.K.-based chemical company INEOS's refinery at Lavéra, France, can process multiple crude oil variations. The variation in crude oil types had a major effect in the fouling of its heat exchangers, therefore INEOS implemented a system to monitor the performance of the heat exchangers in their vacuum distillation unit

(VDU). The system leveraged the integration between Aspen HYSYS, Aspen EDR and Microsoft Excel. The seamless integration between these tools gave the company an accurate tracking of fouling levels for each heat exchanger in an easy-to-read graphical format. This helped determine the most economic cleaning schedule and saved $1.5 million to $2 million USD per VDU and $4 million USD in total plant savings.

Since INEOS initially implemented the solution, they have expanded it to monitor the heat exchangers in their CDU. More importantly, they are transferring this knowledge to other plants and sites worldwide. Another such success story was reported by HPCL refinery in Mumbai, India, which achieved considerable fuel savings at the CDU by implementing a similar solution.

The integration of rigorous heat exchanger models into the process flowsheet can be a very effective tool for refinery reconfiguration studies. This was showcased by PREEM, which wanted to improve the energy efficiency of its refinery at Lysekil, Sweden. The company got an analysis of its crude preheat train network using the integration between Aspen HYSYS, Aspen EDR and Aspen Energy Analyzer™ (helping to conduct pinch analysis) to determine the most optimal heat exchanger configuration. After the preheat train reconfiguration was complete, PREEM recorded a savings of close to $12M USD per year and an additional 10 MW in energy savings.

Visualization of column hydraulics

The nature of the distillation process warrants a rigorous thermo-hydraulic analysis of the distillation column operation, which is made possible by the latest advancements in process simulation technology, such as the column analysis capability in Aspen HYSYS. More importantly, the software presents the results of the analysis in an easy-to-read graphical format. This is critical for engineers who are looking to quickly decipher the results of the thermo-hydraulic analysis and decide on the corrective actions they should take to address operational challenges. Equally important is the usability of such software. Process Engineer Khadija Al Hinaai successfully developed a rigorous model of her CDU in Aspen HYSYS, resolving a perennial problem in just a week.

Another testament to the value of this capability was demonstrated by the Turkish refinery, Tupras, which not only resolved a product quality issue with their Naphtha splitter column but also increased its capacity by 40 percent using Aspen HYSYS.

"We were experiencing several issues with our CDU operations such as column corrosion, off-spec products, jet flooding, etc. Different solutions were tested on our actual plant, which ended up creating more issues and wasting our time. We then tried Aspen HYSYS (for its column analysis capability) to simulate the CDU operation which resulted in a very close simulation of the actual operation. This won our confidence in the software and helped us accurately analyze the effects of corrective actions before testing them in the plant. Aspen HYSYS resolved the issues and saved us significant time, money and effort. The software is designed to enable even beginner-level users to develop rigorous models of their processes relatively fast."

Khadija Al Hinaai, Process Engineer, ORPIC MAF Refinery, Oman

A quick and powerful solver

Process optimization and model calibration are significant challenges that arise when dealing with simulation models of process units with multiple recycle streams and integrated heat exchanger networks, such as in the CDU. This is due to the complexity in integrated systems that requires multiple iterations before the solver in the process simulator can converge the integrated model. The conventional "sequential modular" solver used by process simulators can take an inconveniently long time to converge such models.

However, with the "equation-oriented" (EO) solver technology, available in Aspen HYSYS, integrated CDU models can be solved faster by solving them concurrently. A conventional solver (sequential modular) solves each unit in a process flowsheet sequentially, one at a time. On the other hand, the EO solver simultaneously solves the entire process by treating the process flowsheet as a set of equations. This is especially useful for faster process optimization and data reconciliation (for model calibration) while solving integrated CDU models. The software developers have also built in provisions for refineries to easily convert CDU models (that might be in the conventional "sequential modular" mode) to EO mode at the click of a button.

Refinery data connectivity

Any simulation model is only useful if it accurately represents the current operating conditions of a process unit. Considering that refineries operate in a continually changing environment, the ease of calibration of simulation models is of paramount importance while considering any process simulation technology. AspenTech has built multiple forums to calibrate process models to suit the application and preferences of engineers. Aspen HYSYS has the ability to directly connect to a refinery's data historian or Laboratory Information Management System (LIMS), draw the data, condition the data and calibrate the simulation model. Engineers can also draw in data from the data historian to Aspen HYSYS via the Excel interface using Aspen Simulation Workbook™. If the refinery chooses to set up a system capable of automatically calibrating the simulation model in specific intervals of time, Aspen OnLine® can help complete this. This tool can pull data from the data historian at regular intervals of time, condition the data, calibrate the model and showcase the simulation results.

Easy-to-use interface

The value of any solution depends, to a great degree, on its ease of use. The graphical flowsheet interface of modern process simulators helps users easily build simulation models of their processes, but some of these technologies require considerable training before users can derive any value out of them. Fortunately, AspenTech has given equal focus on developing powerful features and making the user interface as intuitive as possible. Process simulation software, such as Aspen HYSYS and Aspen Plus®, are outcomes of such approaches. The improvement of the user interface has significantly reduced the learning curve for new users and has made it easier, even for experienced users, to access the various capabilities and features in the software.

In addition AspenTech has built significant customer support infrastructure to ensure users have the right information and best practices at their fingertips. This includes video tutorials, example models, getting started guides, knowledgebase solutions and more. Unlike some technology providers who derive their revenue from consulting services, AspenTech derives its business primarily from selling high-value technology software delivering measurable value. It's in their business interest to make their software easy to use and effective for their end users, justifying the huge investments made by AspenTech in recent years to further enhance its software's user interface. The seamless integration of process simulation software with technologies for equipment design and rating, energy and economic analysis and process safety system design expands significantly into what process engineers can achieve using their process simulators.

Arguably one of the most valuable innovations AspenTech has delivered is in the form of their business model. If customers have a need for Aspen HYSYS, they can subscribe to the aspenONE® Engineering suite and get access to the full suite of products, allowing them to experience solutions such as Aspen EDR (heat exchangers), Aspen Capital Cost Estimator™ (cost estimation), Aspen Flare System Analyzer™ (design flare systems) and more. These solutions help companies design, operate and maintain their production facilities and wring the most profit out of their capital investments.

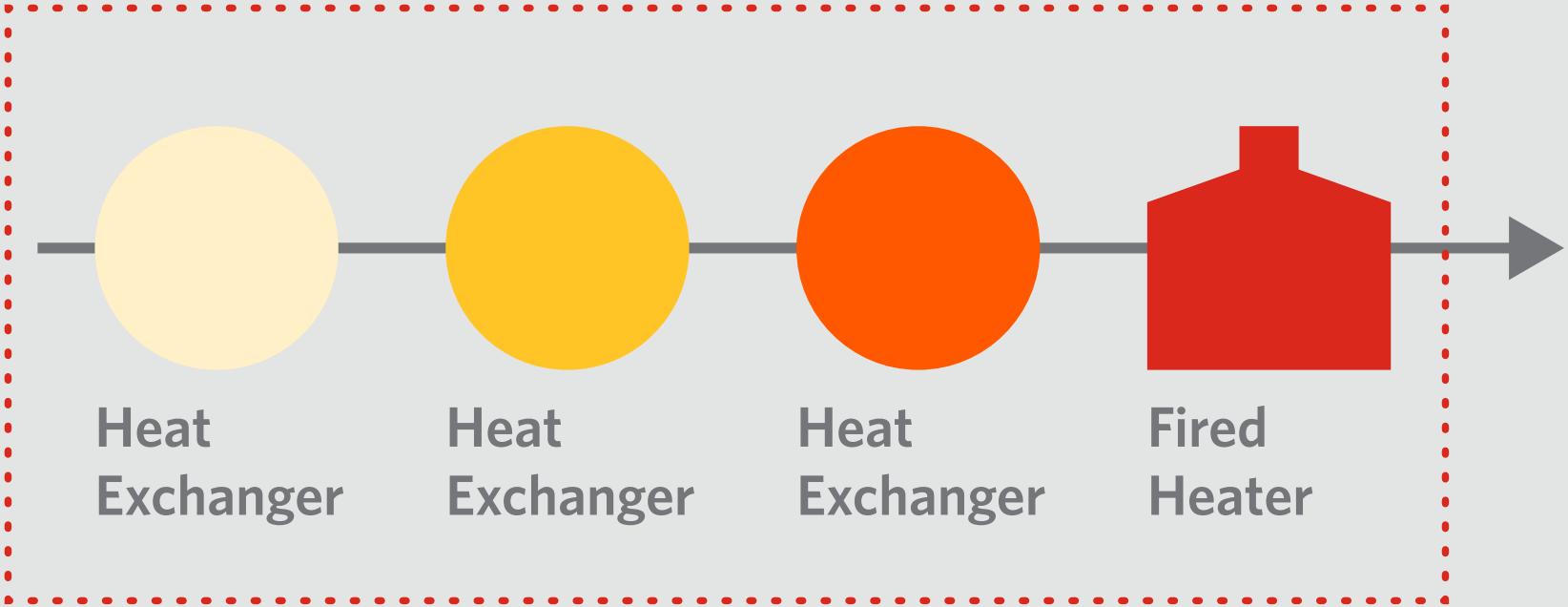
Solutions That Deliver Value

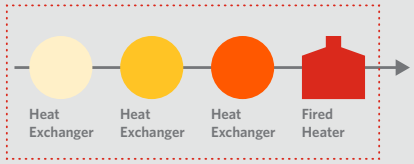
The different capabilities mentioned above can be brought together to build solutions that deliver considerable savings to refineries. The most remarkable aspect is that a refinery can bring together capabilities and deploy an effective, simple solution to start with. Subsequently, as they get more familiar with the technology, they can add additional capabilities to the solution and build it to a higher level, creating a "scalable solution." Most importantly, the refinery can realize substantial savings at every level of the solution.

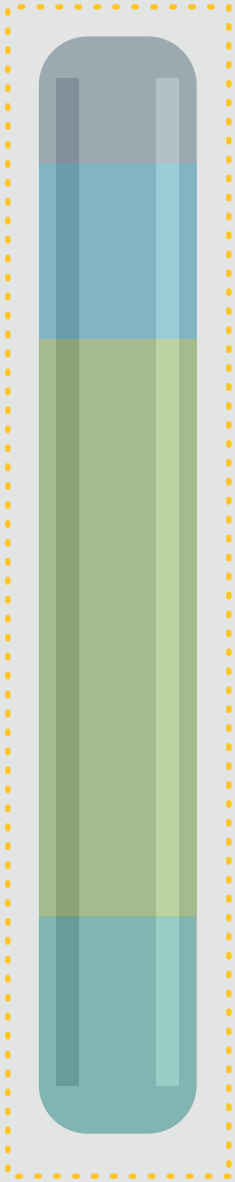
Here are three possible solution levels:

Level 1: Crude preheat train monitoring (using simple heat exchanger models)

The solution at this level entails a simulation model of the crude preheat train that consists of simple heat exchanger models. With the basic introduction to process simulation technology, one can build this type of model. This solution will assist engineers when making decisions on the ideal time to plan the cleaning of their heat exchangers, as well as analyze the feasibility of potential reconfigurations such as adding an additional heat exchanger. In addition to eliminating downtime and the associated loss of revenue, this solution enables refineries to maximize the utilization of their heat exchanger networks while considerably reducing energy consumption.







Level 2 (A): Crude preheat train monitoring (using rigorous heat exchanger models)

This level builds on the crude preheat train solution mentioned above, with the only difference being the heat exchanger models are now rigorous models. With the advancements in Aspen HYSYS process simulators, any engineer can easily convert a simple heat exchanger model in the above solution to rigorous models with the necessary details on the heat exchanger geometry.

Rigorous heat exchanger models improve the fidelity of the process model substantially. With this solution, engineers can predict potential operational issues such as erosion or vibration. They can also accurately predict the fouling levels and pressure drops across each heat exchanger. This helps predict the impact on the pump duty, which is critical for CDU operation. In addition, as mentioned before, rigorous fired heater models can accurately predict the fuel consumption, helping engineers determine the economic benefit of cleaning heat exchangers. Like the previous solution, this can also help engineers evaluate various reconfiguration options but with an enhanced confidence in the results. The INEOS (savings of $4 million USD) and HPCL success stories mentioned earlier leveraged solutions at this level.

Level 2 (B): Distillation column monitoring

This solution can be considered at the same level as the previous solution in terms of effort required in setup, as well as the benefits derived. This solution involves a rigorous simulation model of the crude distillation column. Column analysis capabilities in Aspen HYSYS help users easily develop a rigorous thermo-hydraulic simulation of distillation column operations and it presents visualization capabilities that help engineers easily study the analysis results to determine the right corrective actions.

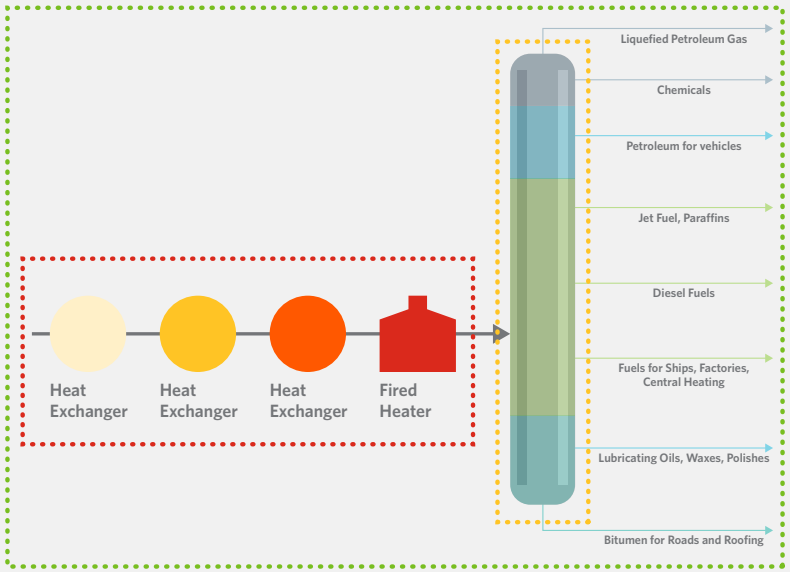
As proved by the example of Khadija Al Hinaai at ORPIC, who developed a rigorous CDU model in only a week, this solution does not require much expertise or time to set up. The solution can help refiners accurately predict the yield and properties of output streams from the distillation column. This is especially crucial while evaluating the feasibilities of potential changes in crude blends. A refinery in New Jersey, USA, previously owned by Valero had set up a model of their CDU in Aspen HYSYS to predict the effect of crude changes on the refinery's operation, as well as make operational decisions. AspenTech has developed several training materials to help refiners implement such solutions. Please refer to the "Additional Assets" section at the end of this paper.

Level 3: Integrated CDU monitoring (distillation column & crude preheat train)

An integrated solution that combines the distillation column and preheat train network provides the most value to a refinery and the most accurate assessment of CDU product yields and properties. This considerably reduces risk in their operational decisions. The PREEM refinery success story mentioned earlier, where the refinery saved close to $12 million USD every year, used an integrated model of the CDU.

Most technology providers have not been able to offer a meaningful process simulation solution for an integrated CDU, owing to the complexities brought in by multiple recycle loops and varying types of equipment. However, the latest technology developments from AspenTech, such as the EO solver in Aspen HYSYS, as well as the capabilities to rigorously analyze different types of equipment, brings together an effective solution to simulate the integrated CDU. This enables operators to run their refineries to the maximum capacity and increases their confidence in the decisions they make. Petrobras from Brazil had implemented the RTO solution from AspenTech for the CDU at their REVAP refinery. The RTO solution delivered process optimization that led to a potential increase in their profit of up to $13,000 USD every day. Again, the focus on user empowerment has motivated these technology companies to incorporate capabilities that make the development of these solutions as easy as possible.

These solutions can be implemented offline or online. Implementing an online solution such as a real-time optimization (RTO) solution would call for assistance from experts in the field. AspenTech has an experienced team of consultants and service professionals who can help refineries set up these solutions. The focus of these consultants and service professionals is in enabling refinery engineers to maintain and operate the solution by themselves. This is very beneficial to refineries as it empowers them to retain and develop the knowledge internally, which is unlike a consultancy-centered technology company who tends to deploy solutions that keeps the refinery dependent on their services, blocking their ability to grow internal expertise.



Conclusion

Refineries today have the technology available to run their assets at maximum capacity while reducing operational risk, although not all have leveraged its value. Improvements in CDU operations can bring a considerable boost to the bottom line of refineries and many have already started significantly profiting from these solutions, gaining considerable competitive advantage. Advanced technology companies like AspenTech have brought significant improvements to their software solutions and continually lower the learning curve required to effectively deploy them.

The scalability of the CDU simulation solution enables refineries to start at a scale that is manageable, allowing them to gradually build the solution to higher, rigorous levels. More importantly, a refinery can derive significant value from every level of the solution, giving them a truly sustainable solution for their CDU operations. Refineries no longer have to leave money on the table by running their CDU conservatively to avoid operational disruption, unplanned downtime and lost profits.

To learn more on how you can implement similar solutions for your refinery, please visit **www.aspentech.com** or contact your local AspenTech representative.

Additional Assets

1. **Self-Training Package on How to Develop a Rigorous Model of the CDU in Aspen HYSYS**
   Article ID: 000037642
2. **Self-Training Package on How to Find the Impact of a Change in Crude Mix on CDU Operations Using Aspen HYSYS** Article ID: 000037710

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