ABB MEASUREMENT & ANALYTICS | WHITE PAPER

Fast and efficient solution for crude oil measurement for refiners using NIR technology to optimize the CDU process rapidly and proactively

The ability to measure crude oil properties, production units and refinery processes has improved considerably. Rapid online measurement allows efficient process control and optimization from feed input to product output.

Allan Rilling
Global Product Manager for Oil & Gas
Upstream and downstream measurement

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01 Crude distillation unit (CDU) sometimes called an atmospheric distillation unit (ADU) due to fractionation or distillation of incoming crude feed at atmospheric pressure

Abstract
Historically, optimization in the refinery has been concentrated on final products, (e.g., gasoline and diesel), and has slowly shifted focus to conversion and upgrading process units within the refinery, such as for naphtha conversion, catalytic conversion, upgrading units, and alkylation. Still, there remains one especially important element of the refinery that has not been well optimized: rapid and online characterization of crude oil composition. The need to identify reliable crude oil quality attributes or qualities is essential to optimize yields and maximize profit in a competitive industry where profit margins are extremely tight. Laboratory methods exist to determine the state of important crude oil parameters known as the “crude assay.” Crude assays, however, require specialized equipment, time, and operator expertise, which are expensive and time consuming. As a result, full crude assay testing is non-existent or performed infrequently, based on historical supplier information. Refiners must often rely on outdated or inaccurate data to plan production. This white paper discusses and demonstrates how ABB near-infrared spectroscopy (FT-NIR) provides a fast and efficient online crude oil characterization solution, enabling planners to optimize their processes based on accurate real-time knowledge of a given crude oil input.

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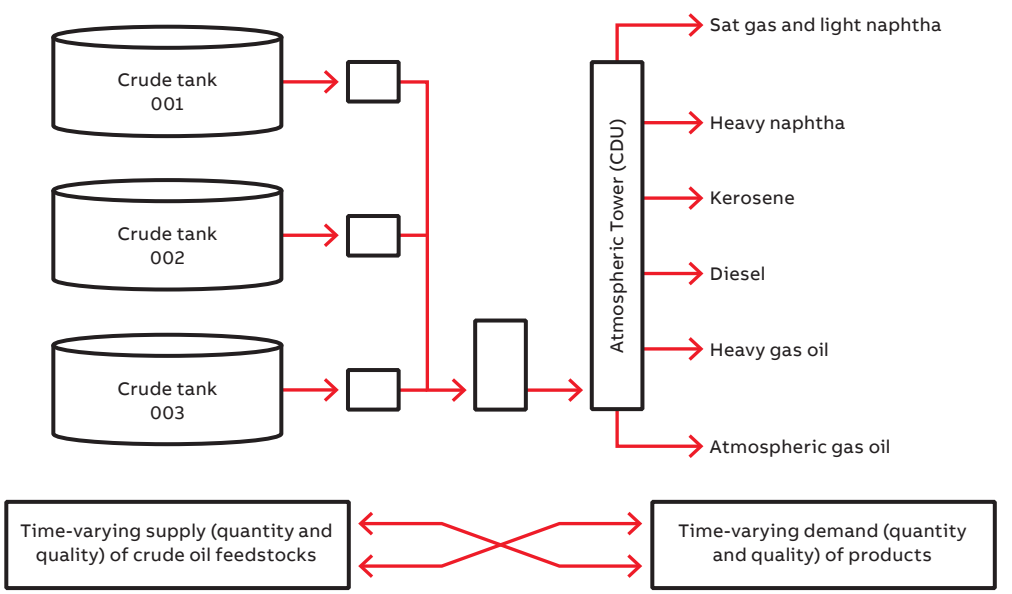
01 Balance required in the refinery to deal with time-varying supply with time-varying demand of products

Crude oil chemistry and characterization challenges
Crude oil must be refined to generate final products that can range from base fuels (e.g., gasoline, diesel, jet fuels, etc.) to complex petrochemicals (e.g., BTX, ethylene, propylene, lube oils, etc.). The range of products is dependent on the complexity and processing capabilities of any given refinery. Crude oil is a rather complex mixture of hydrocarbons ranging from sweet to sour content (i.e. low to high sulphur), and other elements, depending on source extraction, that affect the proportion of light to heavy hydrocarbons in the crude. Such factors have a great influence on the price of crude and also on the yields and quality of final products. A major challenge is that crude oil properties and chemistry are not consistent, even when they originate from the same source (or same well). Furthermore, most refineries obtain their crude from a variety of sources that literally come from around the world. Crude oil is often purchased on the spot market with the balance of crude pricing dependent on the desired qualities and chemical makeup.

In this context, the differences in yield for crudes acquired at different times can be significant. The most obvious and important characteristics of crude oil are its distillation parameters, which are characterized by the TBP (true boiling point) curve and consequential cut-point yields, the sulphur content, and the total acid or naphthenic acid content (TAN or NAN). These key properties have impacts ranging from changes in cut-point yields, atmospheric residue %, and effects on downstream clean-up requirements by hydro-treating and, managing CDU process train corrosion issues.

For crude processing, the refiner's challenge is to process a time-varying supply quality going into the CDU and a time-varying demand for the distillation products coming out as side draws. This problem is typically addressed by the refinery LP (linear program) model, which tries to manage these variations and keep supply quality, CDU constraints, and final product demands in balance to maximize the refining margins. As refinery operations may have only partial or historical information on the crude properties, this task is made even harder and, in some cases, impossible to plan properly or efficiently. In most cases, crude oil, as received at the refinery, comes with paper crude assays that are old or generic, and, sometimes, simply based on the extraction site. The actual crude properties for the crude purchased may be quite different over time, which will impact a refinery in its ability to plan refinery operations to respect customer product quality and meet profit margins.

The importance of crude oil characterization before processing
Having improper crude quality, or flawed knowledge about the crude composition, affects downstream feed quality to other processing units. This can result in failure to meet intermediate or final product specifications, affect cost optimization (quality, energy, etc.), and have considerable impact on production planning. When the process input varies as much as crude oil does, effective analysis tools help maintain a controlled and balanced production flow. Successful identification of a given crude slate results in increased yields and reduces dependence on supplier-based data.



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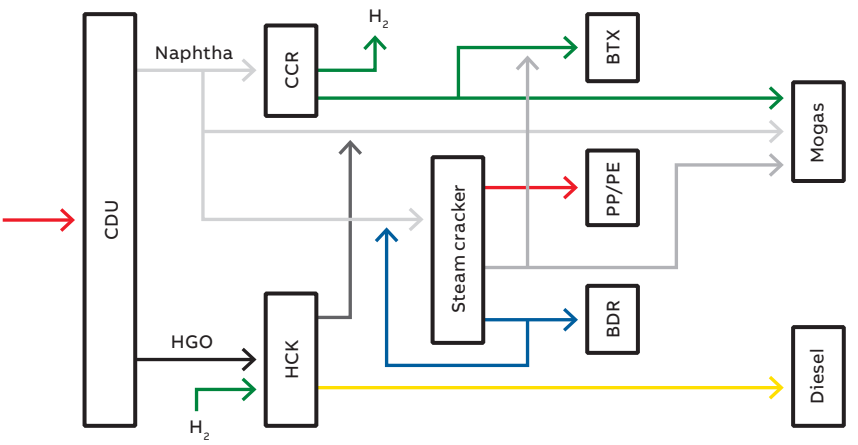

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01 Simplified representation of downstream intermediates and petrochemical products originating from the CDU

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02 Example of various sample FT-NIR spectra acquired for various sample streams (light to heavy) in the combination band region (4000-4800cm^{-1}). Similar absorptivity for different hydrocarbon streams despite very different composition and colour

Unfortunately, traditional crude assay testing methods are complex and expensive ($10K to $20K per single crude assay) and, time consuming (up to 2-3 weeks), therefore, typically not done for every delivery of crude received at the refinery. The information on quality is essential, however, to precisely determine the sulphur and acid levels, boiling points, viscosity, water levels, among other qualities, to give detailed quality breakdown and allow adjustment of CDU parameters accordingly. Therefore, it is critical for refineries to characterize the quality of the crude purchased.

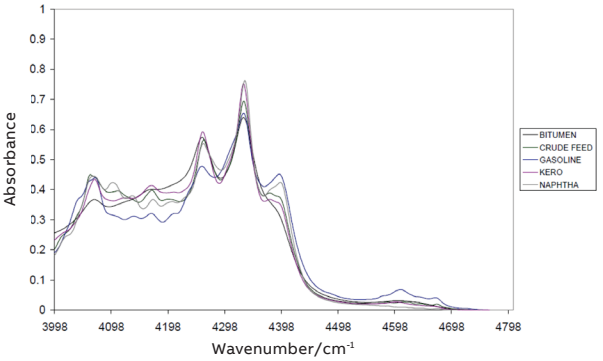
There are two main reasons for this. First, there is a high degree of commercial competition in this field and crude sometimes comes from questionable sources, or operators. Second is the need to verify, in near-real time, the quality of crude processed in the refinery and applied to processing units, including the crude distillation unit (CDU) and its impact for downstream operational units in timely manner to allow rapid control and optimization.

Failure to characterize crude oil before introduction into the CDU can result in millions of dollars per year of optimization loss for refiners, caused by process adjustments to compensate for varying properties of crude oil as well to handle crude transitions.
The operational process units in the refinery must be fine-tuned depending on the nature of the raw crude to be refined. Changing crude compositions has a large impact on distillation/fractionation (i.e., yields), as well as downstream to the various conversion and treatment units within a refinery. The actual impact in dollars will be dependent on the refinery's capacity and throughput of crude while the primary issues are common to every refinery.

In an industry tackling ever-decreasing profit margins, refineries have optimized about every compound extraction and refining processes. Production requires constant monitoring and state-of-the-art analytical equipment. Vertically integrated or not, refineries need to rely on contemporary data about the crude oil they introduce into their process. The returns represent millions of dollars, given the volumes at stake and the added value of output.

NIR Technology: A proven fast and reliable analysis solution

FT-NIR spectroscopy provides a multi-component analysis of critical physical and chemical properties through a single measurement: the NIR absorbance spectrum. It enables multi-property determination on a complex sample or mixture. NIR technology is widely used in the modern refinery as well as in other industries, including food, chemical, pharmaceutical and semiconductor. ABB has successfully applied FT-NIR technology extensively in final product blending and to various conversion/upgrading process units within the refinery to provide fast and precise multi-property analysis. ABB FT-NIR analyzers can also be used for crude oil analysis, offering real-time data on crude oil composition before it enters the CDU, thus allowing process efficiency with fast online measurement for control and optimization, replacing the expensive and time-consuming laboratory methods for crude oil assays. An online pre-distillation analysis procedure thus represents the next step in refiners' efforts to maximize crude oil refining efficiency and profits. The ABB FT-NIR based solution enables proactive process adaptability, instead of reactive planning process modifications caused by inaccurate or flawed data.



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01 Conversion of absorbance spectrum to chemical and physical properties. Calibration models applied to absorbance spectrum to produce values. Calibration models are essentially learning sets with ASTM laboratory reference values.
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02 Conversion of absorbance spectrum to chemical and physical properties. Calibration model performance is dependent to local laboratory quality (r) while typical better than the ASTM repeatability (R).
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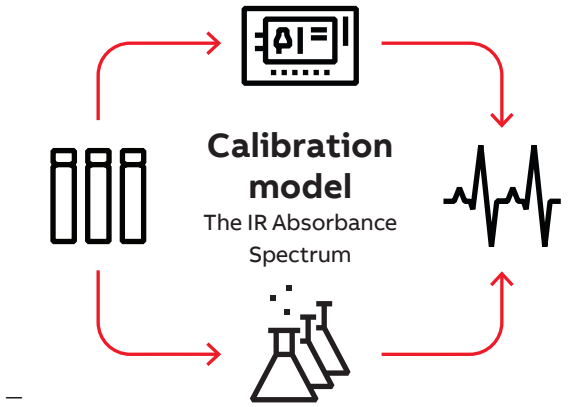
03 Example of laboratory to process FT-NIR analyzers

Near-infrared (NIR) technology measurement, as a correlative technique, requires preliminary calibration of the analyzer (spectrometer) against a reference method for each property of interest. The absorption property of near-infrared (NIR) light in the combination band region is similar for all liquid hydrocarbon streams, independent of colour or chemical makeup. The combination band region is defined from 4000 cm^{-1} to 4800 cm^{-1}. It is the limit between the traditional mid-IR and near-IR spectrum regions, defined by combination of fundamental vibrations. Absorbance spectrum in combination band region (4000-4800cm^{-1}) where absorptivity is similar for light to heavy hydrocarbon streams.



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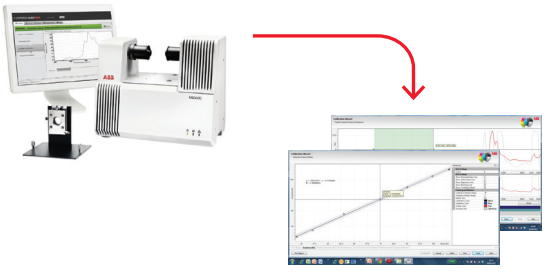

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Once calibrated, the NIR analyzer can be used for routine analysis instead of the more time-consuming traditional measurement methods. The analyzer will exhibit similar accuracy (i.e., reproducibility) as the reference measurement method against which it was calibrated and will typically provide superior precision (i.e., repeatability) as the technique is free of any operator-related error. NIR analysis, performed within minutes, allows frequent testing of important quality parameters without the need for highly trained personnel and multiple pieces of specialized equipment on site, and without the need for consulting external service laboratories.

Existing NIR crude oil characterization solution using ABB crude assay and heavy oil analyzers

ABB provides lab-based analyzers, with the MB3600-HP12 model and online process analyzers, including the FTPA2000-HP260X or TALYS-ASP400-EX models, for crude characterization. Sample conditioning is essential to ensure reliable measurement and limited maintenance. Over the years, ABB has developed an extensive expertise handling crudes and other viscous or heavy products. All aspects of the process have been considered (heating, filtering, flushing, redundancy, stream switching, etc.) within a specific sample conditioning system (SCS) adapted for crude handling to provide reliable solutions for hydrocarbon analysis.

MB3600-HP12 (lab) | TALYS ASP400-Ex (process) | FTPA2000-HP260X (process)

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FT-NIR technologies also have the benefit of low noise, rapid response, and highly repeatable real-time measurements that can be applied to replace laborious and time-consuming routine standard tests on crude oils and heavy feeds. This efficiency is backed by a powerful multi-property physical and chemical analysis feature that enables a single analyzer to identify a wide array of crude properties (TBP curve [points], TAN, API Gravity, Conradson Carbon, KV50, KV100, PAH), all on multiple physical streams per analysis. Measuring single/multiple streams can be easily achieved with the fibre-optic based TALYS-ASP400-EX (single channel) and the FTPA2000-HP260X (8-channel) analyzers using a customizable sample conditioning system adapted for crude.

Mastering the crude CDU output measurement has allowed ABB to considerably increase yields for crude oil refiners by reducing measurement times, implementing efficient sampling, and allowing planners to work with up-to-date data and maximize process flow. The next logical step was to develop a solution to tackle crude oil variability, whether at the extraction site or when crude shipments are received at the refinery.

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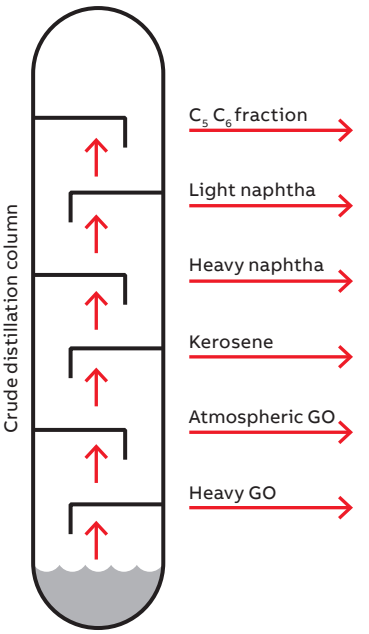
01 ABB FTPA2000-HP260X multi-channel FT-NIR online analyzer for multi-stream CDU optimization

Crude feed



Fibre-optic flow cells to remote FT-NIR analyzer SiO_2/TE InGasAs @ 75 °C for heavier streams

ABB's crude oil input analysis solution
The measurement solution developed by ABB aims to replace expensive formal crude assays and enable refinery planners to optimize the CDU process before downstream process units. The full online apparatus can be customized to match the slate of crudes as used by a refinery. The online ABB crude oil analysis solution, and its operating system, allows each system to be fully personalized and adapted to the refiner's needs or product specialization.

The online crude oil FT-NIR analysis must be performed on a sample representative of the product flowing through the pipeline. Once the sample is brought to the analysis station in a timely manner, it must be conditioned for proper filtration to avoid any particles and droplets that could interfere with the measurement. ABB's state-of-the-art sample conditioning system (SCS) is designed for this difficult task, considering the nature of the product. The principle of the SCS is to maintain continuous operation, with minimal maintenance, achieved with dual-stage particle filtration at high temperature and with redundancy.

The system also offers the possibility to operate on one fast loop while the other is subjected to an automatic cleaning cycle. The SCS also controls the sample temperature for optimal water emulsion separation and measurement performance. Like every ABB SCS, stream switching capabilities are integrated to allow for automatic analyzer reference measurement. Pressure and temperature feedback are transmitted to the analyzer for adequate system control and monitoring.

Once the SCS is defined, the end users need only calibrate the analyzer using existing relevant assay results to correlate data with the NIR spectrum. Crude assay databases, as managed by Intertek for example, or spectral standards, validated by crude assay, will therefore be the baseline by which crude oil shipments will be characterized and optimized in real-time. The calibration step consists of establishing a numerical relationship between the NIR spectrum of a sample and its assay value as measured by a reference method. This usually involves some mathematical modelling and the use of chemometric algorithms that maximize the covariance between spectral features and the property of interest.

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01 Online crude analyzer with full shelter and sample conditioning system

Once the online apparatus is deployed and calibrated, it becomes an effective crude oil analyzer configured for integrated data acquisition, analysis, sample control, and reporting. The solution, with its configurable settings for extensive customization, facilitates routine analysis of physical and chemical properties, and eliminates operator generated errors. Offering a comprehensive status display for concentration analysis history, the ABB crude oil input analysis solution is a complete measurement and reporting solution for refiners. The technology also has a built-in real-time analyzer health monitoring function guaranteeing data reliability and comes with a series of tools enabling easy data export and archiving, thus ensuring that crude oil measurement is accurate and functioning properly.

The robust and reliable ABB sampling conditioning and analysis equipment gives production planners access to real-time crude allocation and segregation data, crude blending optimization parameters, and more reliable crude switching (or transition) optimization. Furthermore, with the distillation properties (TBP), contemporary crude assay data and a crude stability index always available, planners can efficiently implement feed preparation for enhanced process stability. Most of all, the readily available data means they can optimize feed for different CDU modes, resulting in CDU throughput efficiency and ensure downstream needs to process units are properly met.

Key advantages of FT-NIR crude oil input analysis solution

Crude trading & crude management
- Helps purchasing and allows quality assurance to be carried out on the incoming crude against specifications.
- Improves refinery yield prediction with up-to-date and actual crude analysis of all crude imports.
- Allows optimal management and scheduling of crude storage.

Crude blending
- Maximizes refinery performance by effectively controlling the crude blend formulations of CDU feed as close to the ideal crude composition as possible while taking into account tank farm constraints.

Improved CDU control and optimization
- Helps achieve tighter control of CDU by minimizing the variations of crude properties at source.
- Allows user to feed the actual crude and rundown property measurement to a rigorous dynamic model linked to both the APC and refinery LP.
- Links to APS and MES systems to achieve Refinery Operational Benefits.

Conclusion

The use of NIR technology to perform precise determination of several crude oil attributes revolutionizes traditional monitoring solutions for refiners, enabling fast pre-process crude oil measurement to allow efficient feedback and control. The key elements of crude oil composition, that have an impact on CDU optimization, can therefore be easily identified with a high level of precision, replacing missing or costly crude assays with a fast online measurement.
This creates the opportunity for refinery production planners to perform crude oil analysis before distillation, enabling CDU optimization and effective product control downstream to other refinery process units.

Furthermore, the ABB NIR online crude oil measurement solution allows the simultaneous determination of multiple properties for all new samples, with accuracy comparable to the traditional laboratory assay methods. These analyses can easily be performed by operators without analytical backgrounds. As a result, the number of routine analyses can be significantly increased, while the cost per analysis is dramatically reduced compared to traditional assay methods.

A primary benefit of NIR technology, applied to crude oil analysis, lies in its unique combination of versatility, precision, and ease of use. The latest generations of NIR analyzers are also extremely robust and virtually maintenance-free as they do not require any consumables or preventive maintenance. Central to the solution is the sample conditioning system (SCS), which enables online sample integrity and therefore ensures that NIR readings are uniform and reliable. In addition, previously stored sample spectra can be evaluated using new added calibrations to increase data space for deeper sample analysis. It is also possible to perform analyses on different sample types (crude mix, altered crude, regional crude extract comparison) to maximize CDU throughput efficiency with significant savings by lowering operational costs. The ABB NIR based crude oil input analysis technology is a powerful and complete solution for all refiners.

References
Nelson complexity might be good to refer to as amount of processing possible by a refinery
https://en.wikipedia.org/wiki/Nelson_complexity_index#:~:text=The%20Nelson%20complexity%20index%20(NCI, of%20various%20refineries%20and%20units

Crude oil assay
https://en.wikipedia.org/wiki/Crude_oil_assay

World listing by countries–can seek info to almost every refinery
https://en.wikipedia.org/wiki/List_of_oil_refineries

Top 15 listed for capacity
https://en.wikipedia.org/wiki/List_of_oil_refineries#World's_largest_refineries

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