Remote sensing for process optimisation

Remote sensing technology delivers process properties in hazardous areas in real time and in agreement with laboratory results

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Explosion hazardous and flammable environments are characteristics of refineries, blending stations, tank farms and petrochemical plants. These plants consist predominately of continuous processes, which require ongoing monitoring of the product quality to prevent production of off-spec materials. It is common to install process analysers close to the place of measurements. This requires an extra investment to place the analyser in ATEX approved enclosures or shelters. Remote sensor technology is a NIR spectrometry based technology, where the analyser is placed in a safe area, such as in the control room. Standard communication optical fibres connect the analyser to its intrinsically safe measuring probes, which are located in the unsafe Ex-Zone. The 3 km distance between analyser and measuring probe is bridged without affecting the accuracy of the measured properties.

Each analyser measures, almost instantaneously, multiple physical properties in up to eight different measuring points, to provide real time, on-line, reliable analytical information to the operators. This is essential to run the process at optimised process conditions, which affords an uninterrupted formation of products conforming to their required specification.

Continuous control of quality parameters is essential to ensure the formation of in-spec products throughout their entire production process. It is a common practice in the refinery business not to rely on the measurement of one single physical property of a process stream to certify the quality of the product. In general, the quality of a petroleum product comprises the quantification of various different physical properties that should all conform to their product specification.

International and local standards or specifications that are agreed upon between the manufacturer and the customer require the implementation of different measuring technologies and methods for characterisation of refinery products by analysers. Normally, these analysers should be installed directly in a hazardous area. This requires the usage of special protective analyser houses, which is quite a complex and expensive task.

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Aside from that, it should also be taken into account that maintenance operations risk technicians being exposed to hazardous environments when these are conducted either on individual installed analysers or on analysers that are installed inside a shelter.

Remote sensor technology

In contrast to on-site observation, remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object. Fibre optics are typically used in remote sensing, either as the sensing element ('intrinsic sensors') or as a means to relay signals from a remote sensor to the electronics that processes the signals ('extrinsic sensors').

Principle of NIR remote sensor technology

Adequate process control requires the availability of real time physical properties of components and products to ensure their quality parameters conform to specification. To achieve this, refineries incorporate on-line process analysers that provide the required data to the DCS.

Process analysers are divided into two groups:

- Conventional ASTM analysers perform measurements exactly according to ASTM methods. These analysers and analytical methods are usually similar to methods applied in the laboratory, so that the results are expected to be fully equivalent to laboratory tests.
- Correlative analysers indirectly quantify a physical property by correlation of physico-chemical properties with spectral measurements, such as NIR, NMR, FTIR and Raman, and by using chemometrics.

The main difference between these analysers is that conventional ASTM analysers provide analytical data, which actually does not need to be further validated with laboratory measurements, since both use the same analytical method and

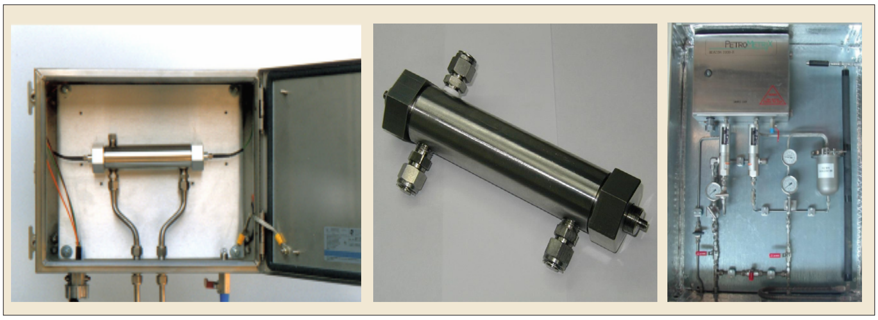

Figure 1 Remote process analytics: the field unit (left), the measuring probe (middle), and field unit with sample conditioning (right)

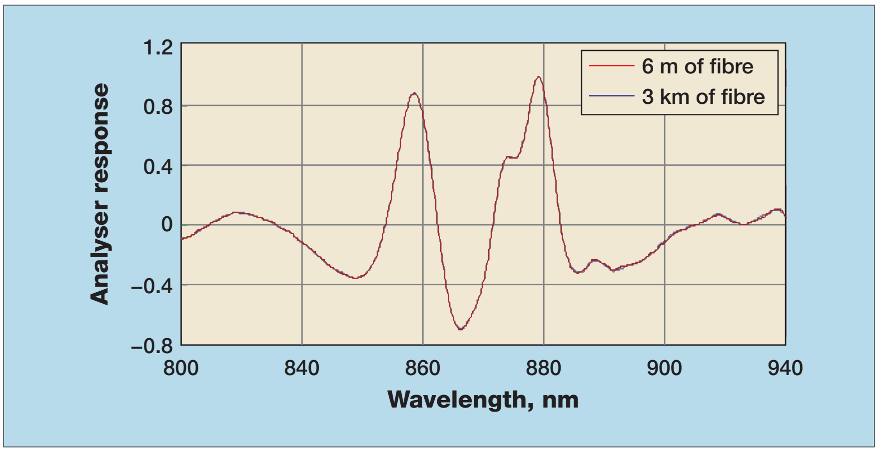

Figure 2 Analyser response at different wavelengths for 6 m (20 ft) and 3 km (2 miles) optical fibre

should give the same result.

However, and similar to laboratory test performances, the analysers are not exempt from calibration procedures on a regular base to prevent inaccuracy in the measured parameter.

Correlative analysers operate differently. They do not measure chemical or physical properties according to well-defined procedures, but use mathematics and algorithms to correlate between the spectrum and different physical properties of a chemical composition. This relates to the effect that overall physical properties and the spectral pattern are the result of the contribution of each individual compound that is present in a chemical composition in a process stream.

Refineries and petrochemical plants are spread over large territories. In many cases, even within a process unit, the complicated construction of distillation towers and/or reactors complicates access to different process streams.

The concept of remote sensor technology (RST) bridges the need of the refinery process units to measure inside flammable and hazardous zones, and the requirement that analysers which are placed in that area must be enclosed in special approved analyser housings or shelters.

Remote process analytics (RPA) provides a solution for safe and accurate measurement of physical properties in Ex-Zone areas by using a NIR process analyser based system. The concept of this technology allows the analyser to be connected by standard telecommunications fibre optics to a multiple set of different field units. These field units are installed at a distance of up to 3 km from the analyser, close to the process. The measuring probes are EX-Safe, free of electricity, without moving parts, and without any material able to generate static electricity.

Field units consist of a measuring probe and sample conditioning system. The process stream flows uninterrupted through the measuring probe (see **Figure 1**).

The NIR analyser is placed in a general purpose zone, a safe zone such as is used for electronic equipment or in a control room. Up to a distance of 3 km there is no optical fibre length effect (see **Figure 2**). This enables a configuration in which an analyser is located at a distance far away from the measuring flow cells, which are placed in the Ex-Zone, and makes the entire analyser system extremely safe for implementation in hazardous environments.

Wherever production units are spread over large areas, bridging the distances between the measuring probe and the analyser by standard optical fibre telecommunication cables makes it easy to control a variety of different process streams from a single location, such as from a control room. This, in combination with the implementation of optical multiplexing, makes it possible to measure almost instantaneously up

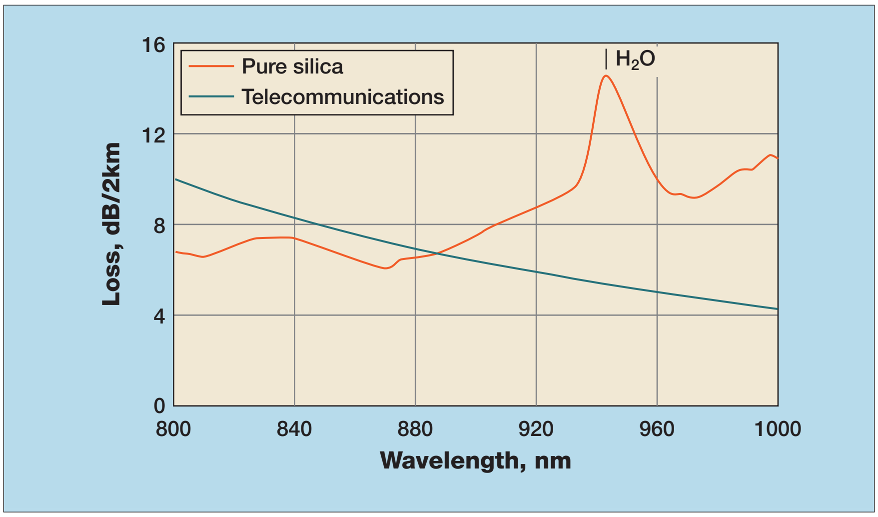

Figure 3 Fibre optic losses at 600-1000 nm

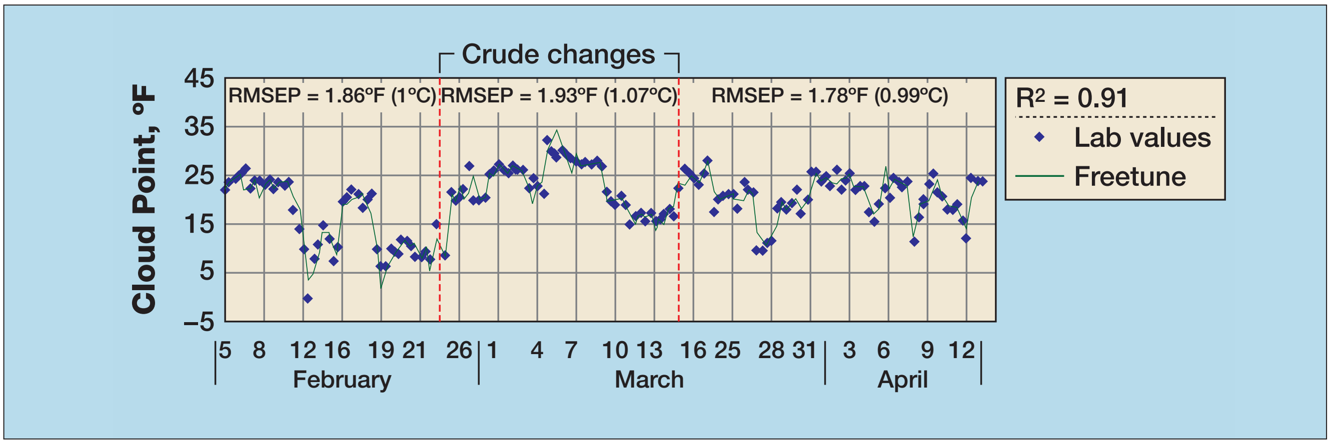

Figure 4 NIR corrective action of the cloud point of diesel oil upon crude switching

to eight different process streams, located at any spot in a refinery.

The use of telecommunications optical fibres has another great advantage over the use of pure silica containing optical fibres: they are relatively cheap and easily obtained. Furthermore, within the spectral range utilised, these optical fibres are not sensitive to water absorption (see **Figure 3**), which is important because high water absorbance can overlap with the absorption bands of interest.

Although the use of standard optical fibres limits the wavelength that can be utilised in the NIR spectrum, it has been proven that the overall design of the analyser and especially the probe design leads to successful implementation of these analysers in the refinery.

The success of NIR spectroscopic methods depends also on the transparency of the sample. A minimum quantity of light is required to pass through the sample to ensure proper measurement. This is especially true for those wavelengths that are affiliated with higher NIR spectral bands of the second and third overtones, which feature relatively low absorbance compared to other wavelengths.

Compilation of accurate and reliable results

So far, the hardware of the analyser, which must be reliable and simple to prevent unnecessary breakdowns in the system, has been described. However, excellent hardware is not enough. The software must be adequate to transform measured signals into trustworthy qualitative analytical data.

Refinery distillates and process streams are not composed of pure substances, but are mixtures of a broad variety of different compounds. Similar to other optical spectrometric methods, NIR spectrometry refers to the overall spectral pattern of the entire compositions, its 'fingerprints', without identifying well-defined molecular fragments.

The success of NIR spectroscopic methods depends also on the transparency of the sample

The Beacon 3000 NIR spectrometer utilises the third overtones in a particular part of the NIR spectrum. In this spectral area, the major absorption bands are mainly associated to the chemical groups CH, aromatics, alcohols, water, and amines, which are characteristic for those chemical substances that are present in refinery process streams.

Application of chemometrics and proper algorithms are the heart of the transformation of spectral data into analytical results. In the first stage, a calibration model is built up by correlating laboratory analytical results and NIR analyser measurements. To prevent any discrepancy between on-line NIR measured samples and laboratory samples, it is critical that NIR measurement is performed at exactly the same time as laboratory sampling. Once enough reference data have been collected, a reliable chemometric calibration model can be calculated, which is utilised to quantify multiple physical properties of process streams.

In contrast to many other NIR analysers, the Beacon 3000 concept has the capability of building up an initial chemometric model with a limited number of samples to start with, or by using its global model. Once measurements start, on-line model corrective actions are started. Time stamped laboratory analyses are fed into the Freetune software, which compares NIR predicted values with real laboratory results. In case of undisrupted non-compliance between laboratory and predicted values, Freetune will perform smart correction of the predicted values to ensure full compliance between laboratory and NIR analyser results.

To start operating NIR technology means to invest time and money in the preparation of an adequate calibration model. To overcome the drawback of continuous investment of time in model updating, Freetune software was developed in order to automatically prevent discrepancies between analyser and laboratory results.

Special attention should be paid to the effect of the software during crude switching in crude distillation. Crude oils originating from different locations are characterised by different chemical compositions,

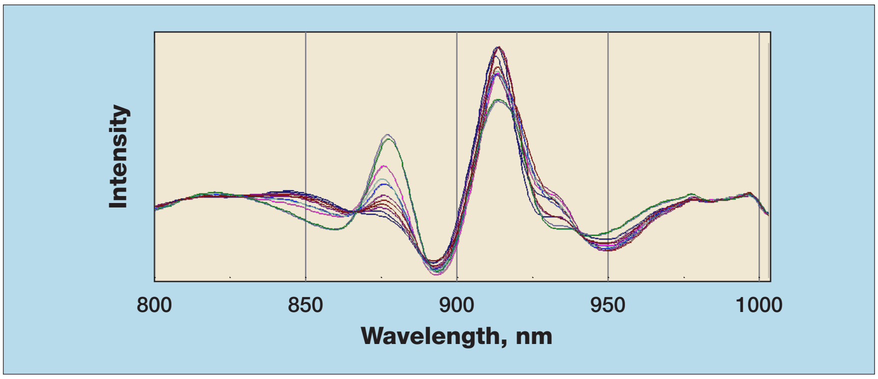

Figure 5 Spectral intensities in gasolines of different compositions

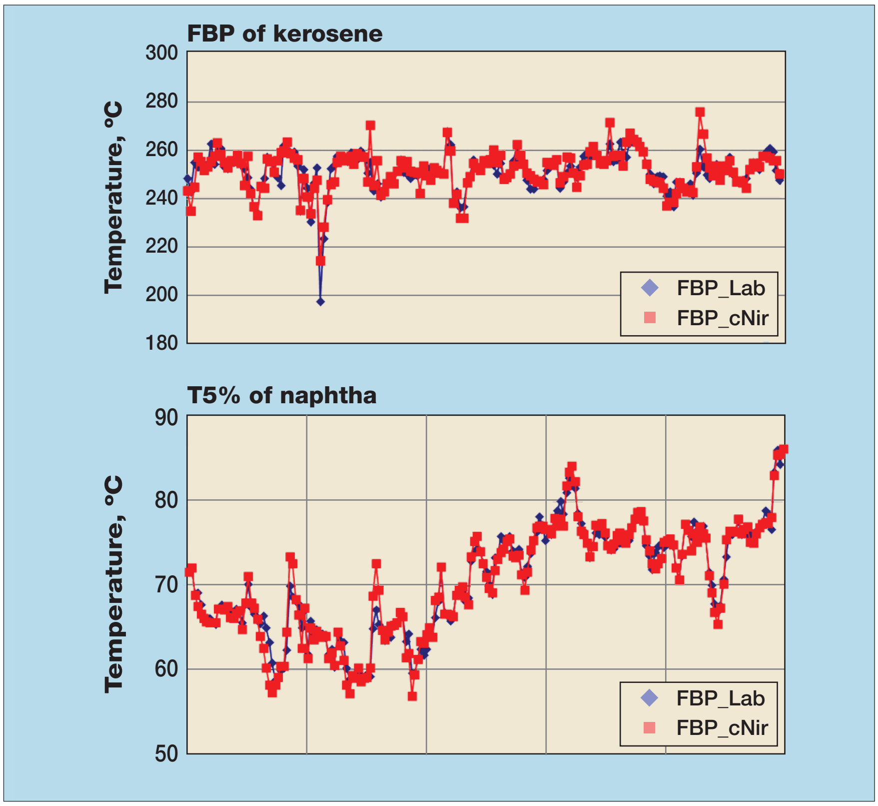

Figure 6 Lab vs NIR, T5% and final boiling point

which also include nitrogen containing heavy molecules and asphaltenes. These heavy molecules distill alongside the desired distillation fractions. Since NIR is not molecular specific but merely based on 'fingerprints' of the entire composition, spectral variation can be expected during crude oil switching, which should be handled properly to avoid discrepancies between real and predicted results.

One method to overcome this drawback is to include spectral data of distillates that represent a broad variety of different crude oils in the chemometric model. However, this option is time consuming and not realistic. In contrast to that, Freetune software has the potential to reduce greatly the influence of crude switching, without creating huge chemometric models that include all different options of crude oil compositions. Freetune corrections accomplish results similar to laboratory measurements immediately following crude switching.

The size and complexity of process units make it desirable to control most of the refinery from a safe area

Figure 4 shows the correcting actions that are performed by Freetune to adjust the NIR measured cloud point values of diesel oil to the laboratory based values. In the absence of the corrections made by Freetune, NIR predicted data will not be fine-tuned to comply with laboratory results, which makes the software indispensable to guarantee the highest accuracy and reliability of NIR measurements.

Value of remote process analytics

The size and complexity of process units, which includes the passages between them, scattered pipe lines, flammability, explosion hazards and toxicity to human beings or the environment, make it desirable to control most of the refinery from a safe area such as the control or equipment room. Introducing remote sensor fibre optic based NIR process analysers has the advantage over other NIR analyser systems that it enables the operator to control the processes from one central point.

Centralisation of all analytical data from different locations in the refinery by one analyser gives the operator an entire quality overview of different process streams. It enables process operators to have continuous control of processes, and to make the correct decisions for actions that are required to correct process conditions.

Remote sensor process analytics in refinery units

The concept of NIR based remote sensing analyser systems can be successfully applied in a wide range of different refinery processes, such as crude distillation, FCC, alkylation and BTX plants. It enables a refiner to monitor physical properties continuously in different refinery process streams. Some representative examples are presented to show different applications of the technology.

NIR spectral responses to different gasoline blend compositions with different physical properties are shown in **Figure 5**. By means of chemometrics these different spectral absorption data are converted into values of physical properties, such as density, MON and RON.

Figure 6 illustrates accurate correlation between NIR analyser results and corresponding laboratory results in the quantification of T5% and final boiling point. The figures illustrate good correlation of measured values with laboratory results

Remote process analytics by NIR systems give operators the opportunity to take immediate actions

required by ASTM methods. The analyser is applied to control a process of multiple CDU process streams. The measured physical properties comprise distillation curve points 5%, 95%, 300°C, 350°C, and final boiling point.

A multi-stream remote process NIR analyser was installed in a gasoline blending unit. Accurate continuous monitoring of RON and MON during gasoline blending is crucial to guarantee the blend to be in-spec at any time (see **Figure 7**).

Real time and on-line measurements provide the opportunity to keep the RON and MON values as close as possible to their lower specification value. This prevents unnecessary giveaways of expensive octane boosters such as MTBE.

A RST based NIR analyser was installed in a petrochemical plant that produces benzene, toluene, xylenes and hexanes to provide on-line analytical quality data of the products in process streams (see **Figure 8**); this shows good compliance between laboratory and analyser results. The advantage of remote process analytics by NIR systems is that they give operators the opportunity to take immediate actions to adjust process parameters based on real time analytical data instead of waiting for six

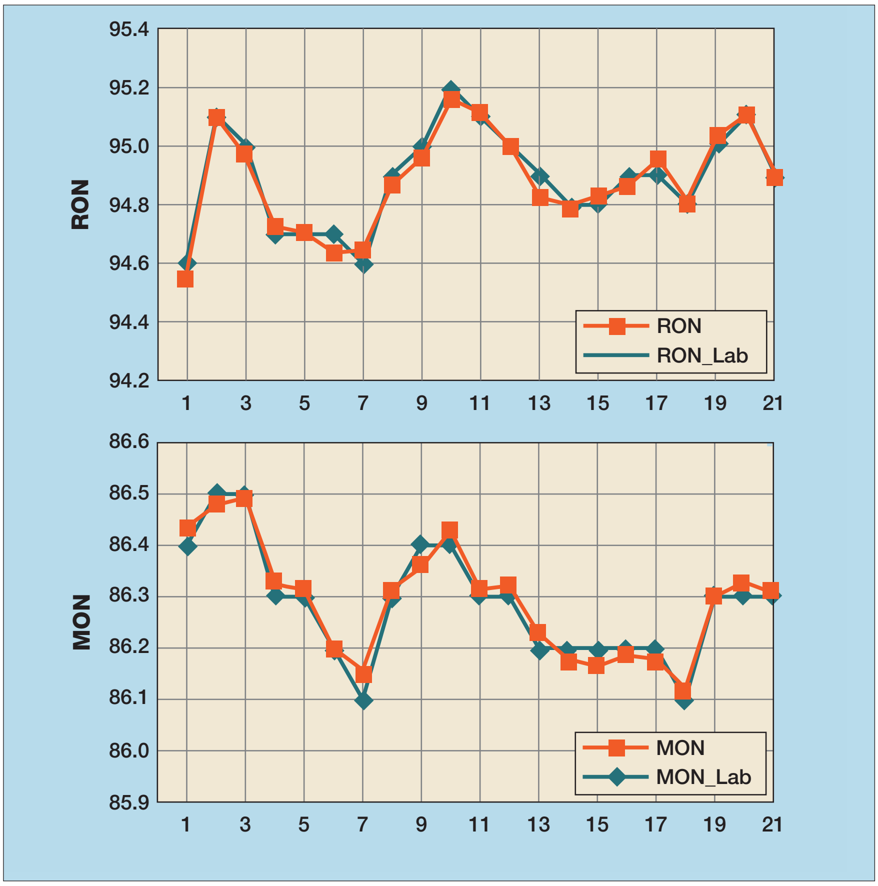

Figure 7 Lab vs NIR – RON (above) and MON (below) of gasoline

Figure 8 Lab vs NIR quality measurements of o-xylene (above) and hexane (below) products in process streams

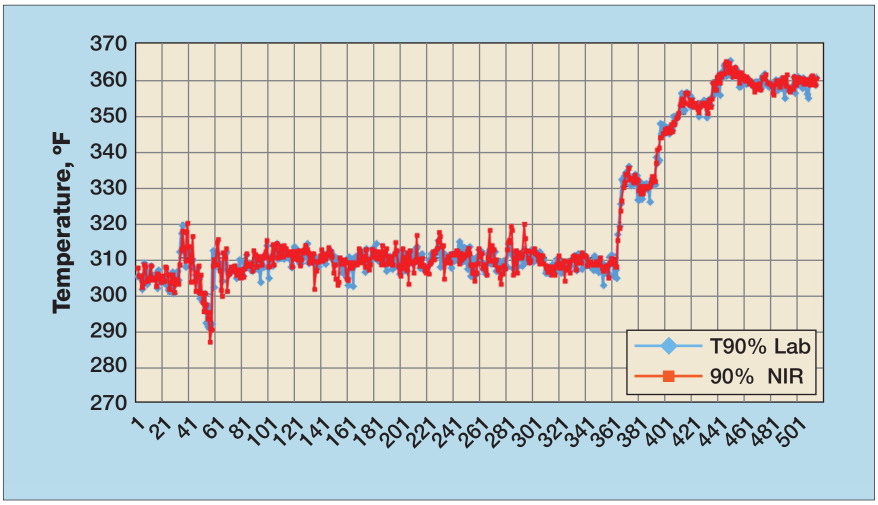

Figure 9 Lab vs NIR: T90% in an FCC process stream

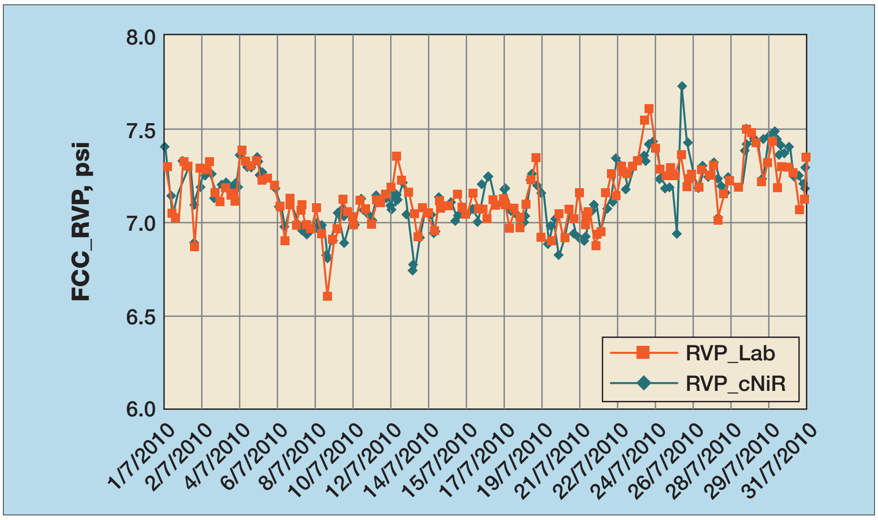

Figure 10 Lab vs NIR and reproducibility: RVP in a FCC process stream

hours to receive laboratory results, to maintain the yields and chemical purities of products during production.

The following examples provide insight into the accuracy of properties measured by the remote sensor NIR system, by comparing its results with laboratory results. The results show excellent correlation between laboratory and analyser results for T90 in an FCC stream (see **Figure 9**).

Similar conclusions can be drawn for the correlation between laboratory and remote sensor NIR analyser measurements of the RVP in FCC naphtha (see **Figure 10**). It should be emphasised that in all samples given in this article, all measurement points are within the range of required reproducibility values according to the ASTM method.

In all cases, the analyser is placed in the control room, which makes it possible for the operator to remotely monitor the quality of products in different process streams. This enables on-line optimisation of process conditions in refinery units that are located far from the control room, to maintain an efficient and stable production process.

Not only in refining

Application of these analysers is not restricted to refinery production units based on chemical or physical processes. Remote sensing makes them effective in blending installations where on-line gasoline is produced by mixing gasoline components from different sources. Similar operations are also performed in diesel oil blending. Both kinds of blending operations are in many cases performed in the tank farms of refineries, blending companies and terminals.

Conclusion

Refineries and chemical plants are spread over large areas, mostly defined as flammable and explosion hazardous areas, and in many cases in the presence of a health hazardous environment. Optimised process control can only be realised by on-line and real time analytical data that enables operators to take immediate actions to maintain a stable and efficient production process that results continuously in an in-spec material at minimum cost and at minimum giveaway.

Achieving this goal requires installing multiple analyser systems, each measuring a single property, and being placed inside an explosion zone. Most of these analysers contain many wearing parts. Hence frequent maintenance operations must be carried out inside unsafe areas. This can be avoided by using remote sensor technology based NIR installed in a central analyser inside a control room, and from that point to measure remotely, up to a distance of 3 km, multiple physical properties in unsafe areas. The ability of the analyser to measure up to eight different process streams provides quality properties at different locations. This broad overview provides the operator with the ability to carry out efficient process optimisations.

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