On-line near infrared optimisation of refining and petrochemical processes

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Introduction

Major on-line near infrared (NIR) applications, based on more than 15 years of modelling experience, have been developed and installed on Lavera units such as Steam Cracker, Gasoline Blender, Crude Distillation Unit, FCC for their optimisation. An advanced control system based on NIR has been running since the end of 1991 on the gasoline blender producing 1 Mt/year of motor spirits in a closed loop mode with a multivariable blending control software. This system uses an innovative approach for blending indices computation based on the NIR response of individual basestocks. The steam cracker plant is operated by Naphtachimie, a 50/50 subsidiary of BP Chemicals and Elf Atochem. The on-line NIR analysis of feedstock quality allows to adjust in real time the furnace operating conditions and to optimise the feed transitions. This NIR system linked to in-house on-line optimiser model has been running since 1992. Other NIR on-line applications are in use at Lavera on the Crude Distillation Plant and on the FCC Unit to analyse and control both the feedstock and outlet qualities. Annual benefits from NIR on each plant are estimated around $1M. The BP technology is now available on the market through Technip, an engineering company which has been selected as licensor for closed loop applications.

TOPNIR™ : The solution for NIR systems

On-line analyser systems must have specific features to fit with the industrial requirements.

They have to exhibit an utilisation rate of at least 95% without any prediction error. The analyser must be stable on a long term scale without any drift. Finally, they have to require a minimum system maintenance, both in terms of analyser and models.

To fulfil these requirements, a new and original technique has been developed through a non regressional modelling approach. This technology, based on topology, is called TOPNIR™ TOPNIR™ works through pattern recognition and databank densification. It does not use regressional models for a set of properties (one model per property). TOPNIR™ instantly delivers all the properties required for a given application. Moreover, it offers the possibility of extrapolation from the initial calibration range.

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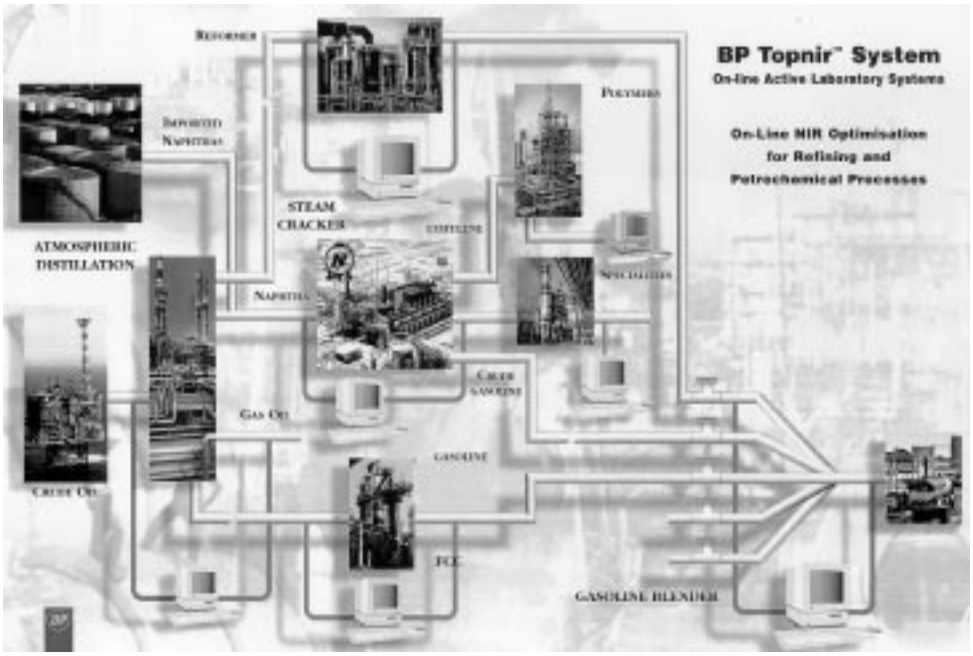

Figure 1. On-line NIR optimisation for refining and petrochemical processes.

Concerning the treatment of the outliers, the classical regressional methods require a very heavy amount of work to maintain the models. It can rapidly become a bottleneck when the application involves a lot of properties, everyone requiring a specific calibration treatment.

TOPNIR™ avoids such tedious work, rather unrealistic within an industrial context.The system uses non regressional methods which rapidly take into account any outlier and do not require any new calibrations of the models. It is a self learning method which fits perfectly with the reality of industrial operations.

TOPNIR™ is the result of 20 years of experience in NIR at Lavera which led to a patent portfolio covering a lot of applications in Refining, Petrochemicals and Polymers areas.[1–4] The most exciting result was the NIR modelling of octane numbers patented on February 1987.[1,5]

Since this date, major on-line NIR applications have been installed on Lavera units such as Naphtachimie Steam Cracker, Gasoline Blender, Crude Distillation Unit etc. (see Figure 1).

Naphtachimie steam cracker optimisation

At Lavera, the Steam Cracker of Naphtachimie (a 50 / 50 subsidiary of BP Chemicals and Elf Atochem) is the first one over the world equipped with an on-line NIR analysis of naphtha feedstock. The 24 furnaces of the plant produce more than 670,000 tpa of ethylene. Since 1991, these furnaces have been controlled by an in-house process control model which uses the 13 naphtha properties provided by the NIR analyser and TOPNIR™ system to adjust, in real time, the furnaces operating conditions.

This realisation is the result of a collaborative research carried out for Naphtachimie by a team of engineers from BP Chemicals R&D Centre and Naphtachimie.

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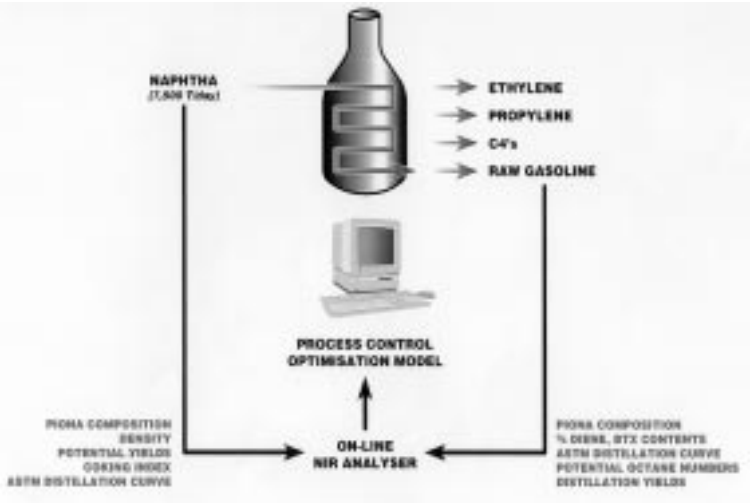

Figure 2. On-line NIR analyser on a steam cracker.

The NIR analyser includes a spectrometer, a multiplexer and two measurement cells, these different parts being linked together with optical fibres. The second measurement cell is devoted to the NIR measurement of raw gasoline properties. The general scheme of this application is displayed in Figure 2.

Thus, this analysis displays thirteen key properties of naphtha in less than one minute: the density, the potentiel yields in methane, ethylene, C3 and C4 unsaturated compounds, the chemical composition, the average molecular weight and the coking index.

The results are transferred directly to the DCS of the plant. The furnace operating conditions are then adjusted in real time from the naphtha quality variations measured by the NIR system.

Alternatively, 16 properties are measured on the raw gasoline such as the density, the chemical composition as well as the potential yields of distillation cuts, the octane number potential values of these cuts and the ASTM distillation curve.

In our industry, quality variations on naphtha are common and depend on the spot imports as well as on the naphtha coming from the refinery upstream.

Previously, the naphtha was characterised in laboratory by off-line gas chromatography (GC), a time consuming method resulting in a deoptimisation of the cracker during feedstock variations. The consequence was that the operating cracking conditions were no longer suited to the feedstock in use. This led to production losses and sometimes to safety problems resulting from overloading of the distillation towers when the cracker was running flat out.

Such rapid feed transitions are shown in Figure 3 which gathers the quality variations of naphtha over one month. Two sharp transitions in feedstock (a few hours) can be observed resulting in a change of 10% of linear paraffinic content.

With a classical off-line analysis, such changes cannot be detected rapidly which means a deoptimisation of the transition leading to a loss of production. On the contrary, the on-line NIR analysis allows a quick reaction and adjustment, through the optimisation model, and the furnace outlet temperatures on the plant to take into consideration the new quality of naphtha.

The power of the on-line NIR analysis, measuring the feedstock properties every two minutes, allows now to optimise every transition which was not the case with a single laboratory analysis. In this view, Figure 4 compares the amount of information provided from the off-line analysis and

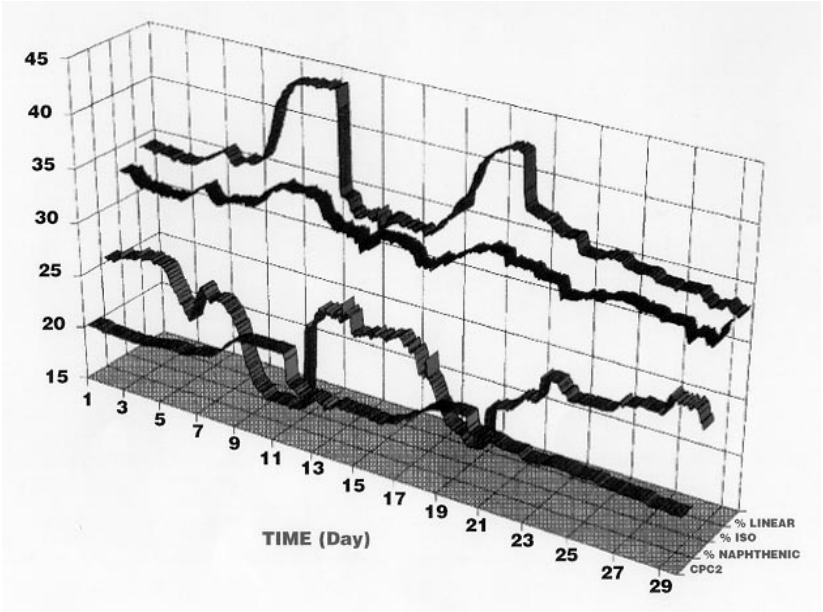

Figure 3. Naphtha transitions monitored by NIR on the Lavera stream cracker.

from the on-line NIR analysis. It shows clearly the advantage of the on-line NIR analysis in terms of measurement frequency leading to a consistent benefit on the plant optimisation.

The benefit, based on naphtha transition optimisation, is estimated around $1M per year with a very rapid pay back.

Gasoline blenders

The BP Lavera Refinery is a complex site where there are major plants such as the Crude Distillation Unit, vacuum distillation towers, Reformer and Isomerisation units and also FCC, Hydrocracker and Visbreaker units. A selective Hydrogenation unit is devoted to the elimination of dienes in the steam cracked spirit received from the BP Chemicals site.

The gasoline pool gathers more than 16 basestocks including oxygenates and import materials. Three main grades of finished products are produced by blending basestocks from this pool namely M98 Unleaded, M95 Unleaded and M97 Leaded.

The scheme of the NIR-based blending system is illustrated in Figure 5. Our main goals for this system were the minimisation of product give-away and the optimisation of recipes, the increase of blender flexibility by avoiding reblending and the reduction of storage capacities for blended products in the future.

The first step in the process is the measurement of the basestock NIR spectrum. This directly provides the NIR blending indices on Reid Vapour Pressure (RVP), Distillation points, Volatility, RON and MON clear and leaded for the three grades of finished products.

Once this information is obtained, it is transferred through computer link to the Planning Department where Blending Order calculations are performed from these NIR blending indices. Data are then transferred to the Offsites Department for incorporation in the blender control system.

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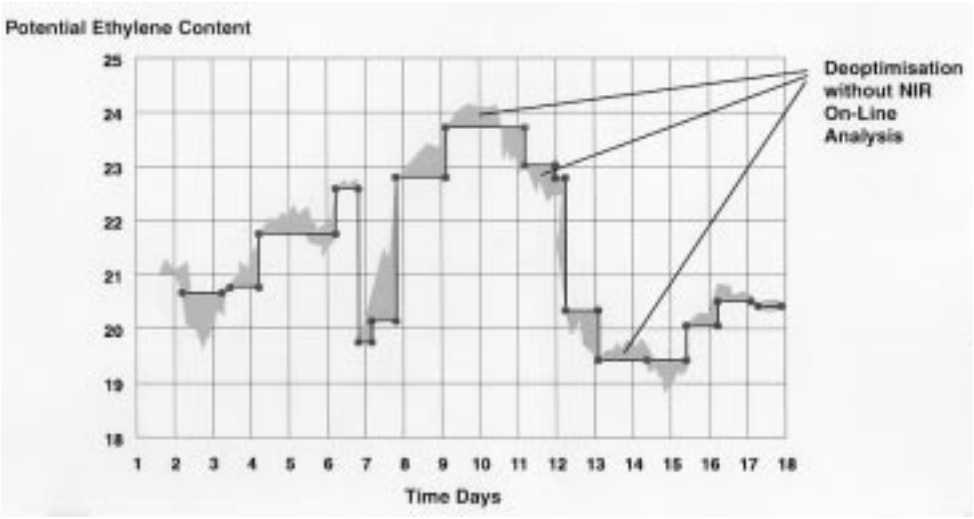

Figure 4. Advantages of on-line NIR analysis versus classical analysis for plant optimisation. Variation in potential ethylene yield with time.

During the run, the Blender is monitored by a multivariable control software, ANAMEL®, commercialized by TECHNIP. This software gives the set point to the component control valves according to the Blending Order and integrates the quality of the blend from an on-line NIR analysis which measures every 45 seconds the RON and MON as well as the RVP, Density, Volatility and Distillation Points. Additional properties can be also measured such as the percentages of Benzene, MTBE, Oxygene, Sulphur and Gums.

Figure 5. From 12 basestocks to four gasoline grades using NIR.

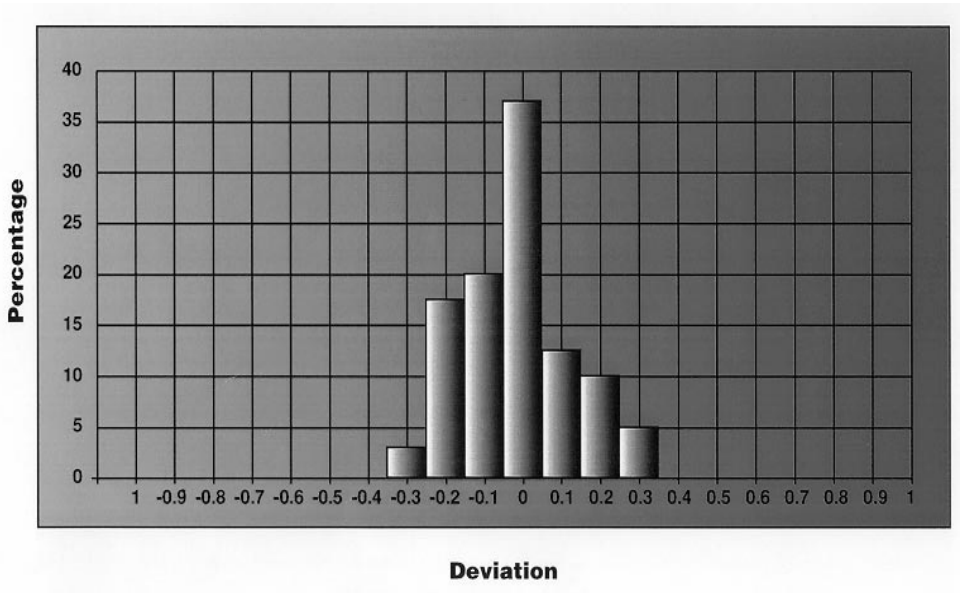

Figure 6. NIR—Hits reference standards (MON results over six months).

Figure 6 shows the distribution of differences on the MON between the laboratory and on-line NIR measurements over six months operation. The results show a strong consistency with a standard deviation on the differences of 0.12 and a maximum deviation of 0.3.

These successful results means also that reblending operations have been never required. The CFR engines are now only used to check periodically the status of NIR lab and on-line analysers.

The NIR indices are now used for LP scheduling as well as for the monthly evaluation of Refinery performances. These new indices allow maximum use of basestocks and reduce the blender occupation time, the final blend being always perfectly in line with the blending order.

The use of new and more accurate NIR blending indices, in conjunction with the high reproducibility of the NIR technique and the reliability and the robustness of the associated in-house models, has led to an optimisation of blending policies and blending operations resulting in a sharp reduction of give-away and in an annual benefit of around $2M.

Crude distillation unit

The on-line analyser characterises the crude and distillates quality. The system has been running since the end of 1992 on the crude and was recently extended, through a multiplexer, to five distillation outlet streams. The NIR system was installed just after the desalter.

Concerning the crude oil, the analyser determines the TBP (true boiling point) and the specific gravity. On the distillates, it calculates key properties such as the flash point and the freezing point on the ATK, the cloud point on the gas oil etc. The density, the PIONA and the distillation points are also calculated on specific streams. All the results are transferred to the DCS of the plant.

The benefit, based on an annual throughput of 10 Mt, is estimated at a level of $1.7M per year with a crude plate between 10 and 20. The main added value of the NIR system is to allow in real time the monitoring of crude transitions.

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Other applications

Other on-line NIR systems are in place on the FCC Unit to analyse both the feed and the outlet products as well as on a PIB (PolyIsoButene) plant to control the quality of the polymer.

Additional systems are being installed on the Reformer (feed and product) as well as on the Gas Oil Blender.

Conclusions

A new approach of modelling NIR spectra has been developed. This technique, based on topology and called TOPNIR™, fits perfectly with industrial requirements in terms of accuracy, reliability and maintenance.

Thus, on-line NIR analysers included in closed control loops have been installed at Lavera on major industrial units such as Gasoline Blender, Crude Distillation Unit and Naphtachimie Steam Cracker.

This know how, protected by several patents, is now available under license on the market through Technip, our licensee for closed loop applications.

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