CRUDE control

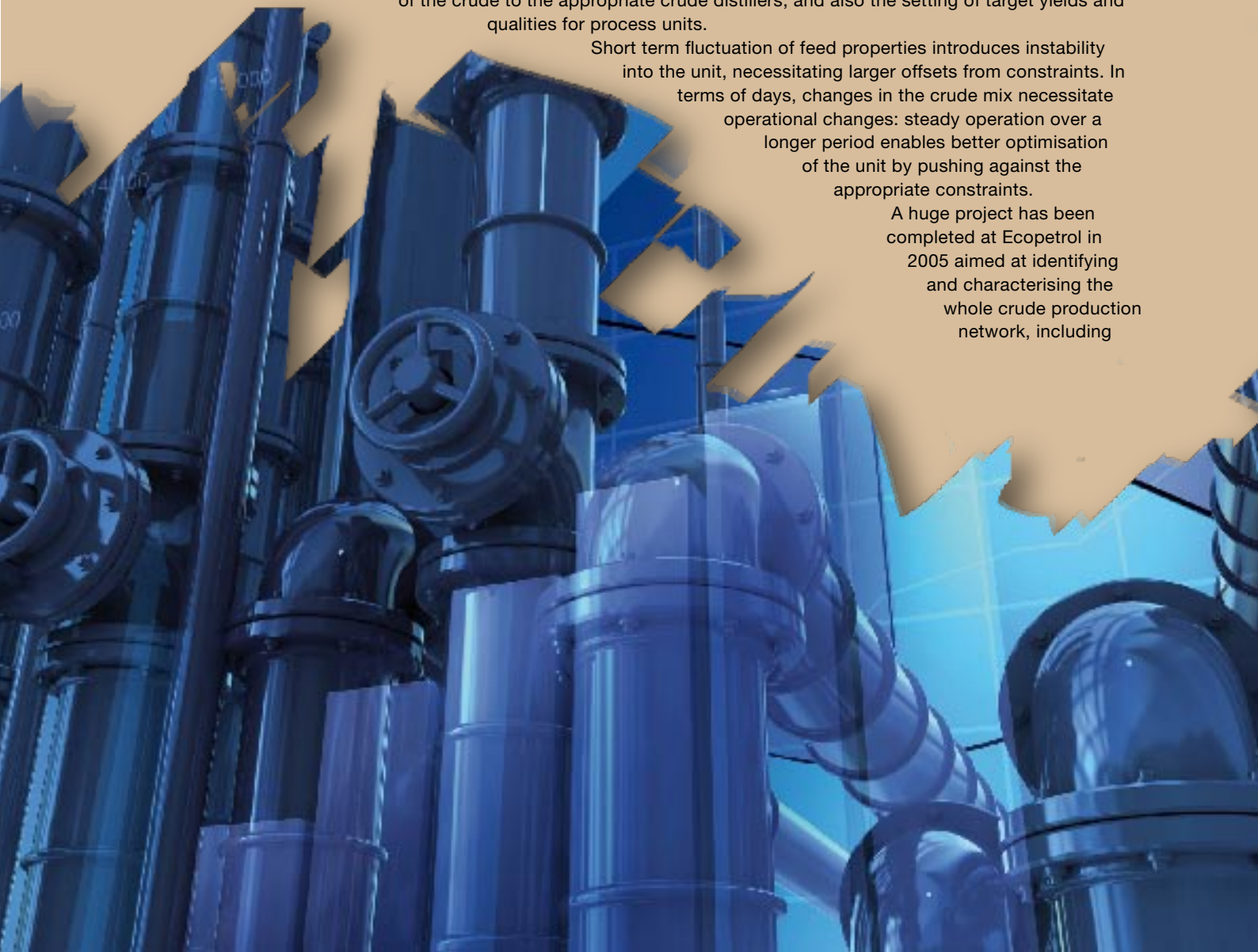
Didier Lambert, Claude Saint-Martin, Bernard Ribero and Michel Sanchez, Topnir Systems, France, Gustavo Lopez, Luz Angela Novoa, Luz Myriam Guerra and Jorge Huertas, Ecopetrol, Colombia, and Diego Martinez and Lina Lozano, Insurcol Ltda, Colombia, discuss systems for crude management and their application at the Ecopetrol crude network.

Crude diet characterisation is crucial for refinery optimisation. It affects the planning and scheduling activities and the optimisation of the individual units as well as the blending of final products. This is particularly important when special products are produced, for instance paraffinic and naphthenic lubricants and bitumen. A good understanding of the crude in the refinery has an impact on the planning and affects all the refinery operations.

Real time knowledge of crude properties is the only way to ensure that full value is extracted from the crude in the refining activity, based on simulated plant operation and product quality. This affects both the allocation of the crude to the appropriate crude distillers, and also the setting of target yields and qualities for process units.

Short term fluctuation of feed properties introduces instability into the unit, necessitating larger offsets from constraints. In terms of days, changes in the crude mix necessitate operational changes: steady operation over a longer period enables better optimisation of the unit by pushing against the appropriate constraints.

A huge project has been completed at Ecopetrol in 2005 aimed at identifying and characterising the whole crude production network, including



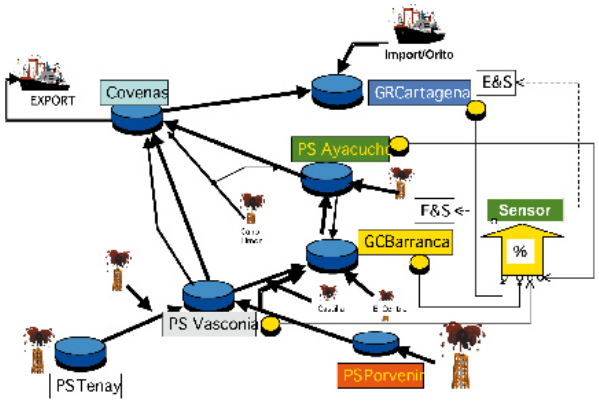


Figure 1. Crude mixture monitoring scope.

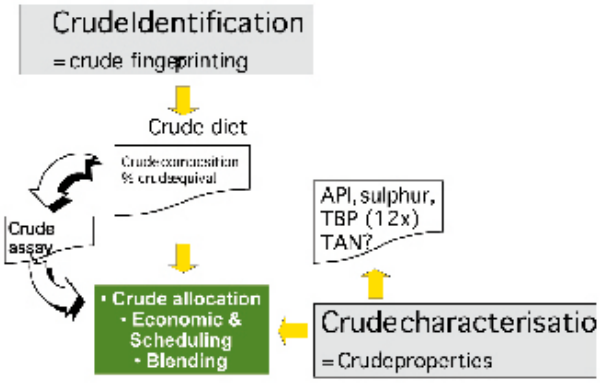


Figure 2. Crude terminology.

both pumping stations linked to inland wells and the two refineries located in Cartagena and Barrancabermeja. This unique identification and characterisation of crude mixture obtained from Topnir and Simcrude led to annual benefits of several million US$, not only for crude operation itself but also for downstream activities such as diesel blending. This article describes the project as well as the technology and real case results.

Objective of project

The project, named the crude diet and property monitoring project, is dedicated to monitoring the composition of crude mixtures:

- At two key pumping stations (Vasconia and Ayacucho) of the inland crude pipe network.
- At the entry points of the two refineries (Barrancabermeja and Cartagena).

This information feeds the SENSOR monitoring system, constituted by the network of Topnir analysers, the planning and scheduling and IT systems. The project also includes the characterisation (monitoring of crude properties) of the crude mixture feed to the topping units at Barrancabermeja and Cartagena. The process is shown in Figure 1.

Previous situation

Barrancabermeja acquires its crude from various locations around the country. The composition of this crude varies greatly in properties such as density, sulfur, salt content and volumetric yield, which consequently varies the quality of the feedstock to the various crude units at the refinery. The following four segregations occur:

- Cusiana: for low sulfur diesel grades (ACPM) and reduced crude is fed direct to the cracking unit.
- Cupiagua: used for paraffinic lubricants.
- LCT: used for naphthenic lubricants.
- Mezclado: a mixture of more than 50 crude oils for the Demex-Unibon-VRII scheme and bitumen.

Although the types of crude to be segregated were well established, before the launching of the crude project the refinery did not have systems that allow characterisation of the quality (assays) of the crude arriving at the refinery. The only properties that were known were salt and BSW. Moreover, there was no control on the quality of the crude fed to each one of the process units, since the only consideration was an average API. On occasion, the homogeneity of these feeds was not good due to differences between the top, middle and bottom samples, which led to instability in the operation of the topping units.

There were no tools in place to allow prediction of the composition of the prepared blend, therefore it was impossible to know the yield of products in the topping units. Also no tools were available to prepare feeds to maximise distillate yield, since the only consideration was an average API. It is worth noting that two crude oils with the same API can have different yields in one crude unit. Finally, with the processing of light crude, topping units were constrained in their overhead systems, resulting both in constrained throughput and increased gas to fuel gas and to the flares.

One example is that some Cusiana crude was purchased in excess of the plan to ensure that low sulfur diesel could be produced and to meet the cetane index in the diesel pool. This resulted in sulfur and cetane giveaway. This was attributed to uncertainties in the crude/component logistics systems.

For Cartagena the refinery operations were reactive to the crude fed to the refinery as they did not know the crude that was in the blend. Crude was segregated according to API and sulfur, not allowing for a proper assessment of product yields and quality prior to feed to the CDU. This situation produced a suboptimal operation of the refinery, where plant capacities were not maximised.

New situation after project completion

An integrated system to control, optimise and schedule the preparation of crude blends that are received at Barrancabermeja and Cartagena Refineries allows for, among other things:

- Automation of transport and storage operations for the various crude that are received in the Barrancabermeja and Cartagena refineries.
- Preparation of feeds for each of the topping units that are sufficiently homogeneous to allow greater stability in these units and for the type of blend defined as appropriate for the operational requirements at the refinery.
- Preparation of feeds that allow maximising the yield

of valuable products, such as Jet A1 and/or ACPM.

- Preparation of homogeneous and optimum feeds for the preparation of bitumen and lubricants.
- Forecasting the properties for the various intermediate or finished products that are produced both in the topping units as well as in the remaining process units in the refinery, to direct production towards valuable products.
- To ensure raw materials regarding quality and quantity for process units downstream from topping units.

The crude composition is known before arrival. A combination of better information in the Ecopetrol transportation pipeline and the use of Topnir/Simcrude technology to predict the composition of the crude blend in the pipelines to the pumping stations and crude tanks at Barrancabermeja and Cartagena now addresses this issue.

In total there are several days crude stocks between the pumping stations and the time when the crude is fed into the CDU when Topnir is available at the pumping stations, giving a good lead time for crude and product scheduling.

Once blend composition is known, product quantities and qualities of all streams in the refinery configuration can be calculated such that refinery throughput is maximised and product qualities are known. A second stage, phase 2, involves installing APC and optimisation on the crude oil blender to trim the blend within constraints given by scheduling. This requires an online NIR located either on the component streams or the blend headers to the topping units. Phase 2 allows the feeds to the individual topping units to be better optimised to take into account transient effects. It will therefore give additional benefit in the areas of:

- Preparation of feeds that allow maximising the yield of valuable products such as Jet A1 and/or ACPM (diesel grade).
- Preparation of homogeneous and optimum feeds for bitumen and lubricants preparation.

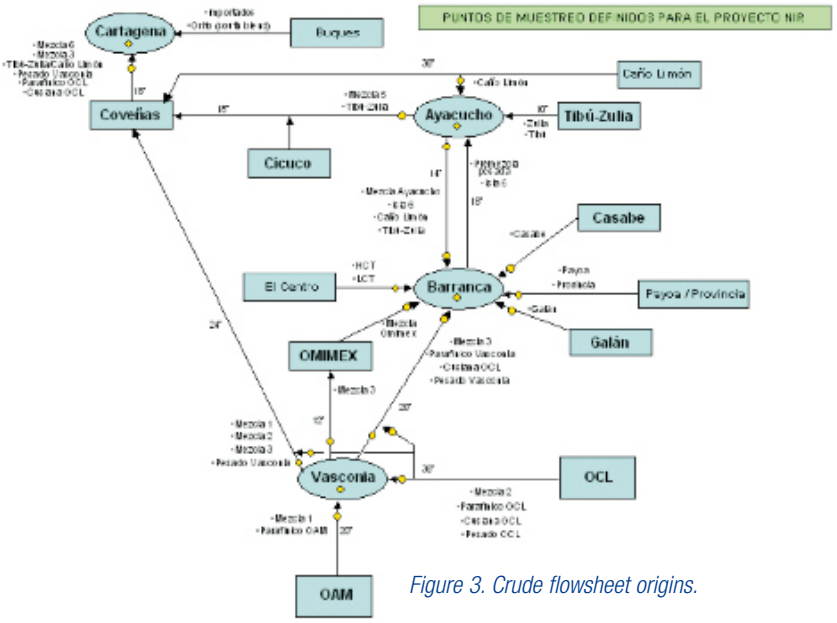
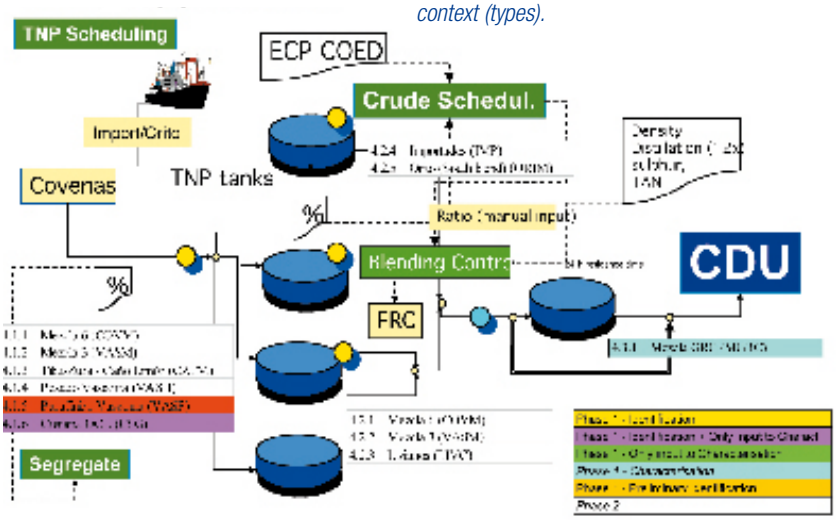


Figure 3. Crude flowsheet origins.

Figure 4. Cartagena crude application context (types).



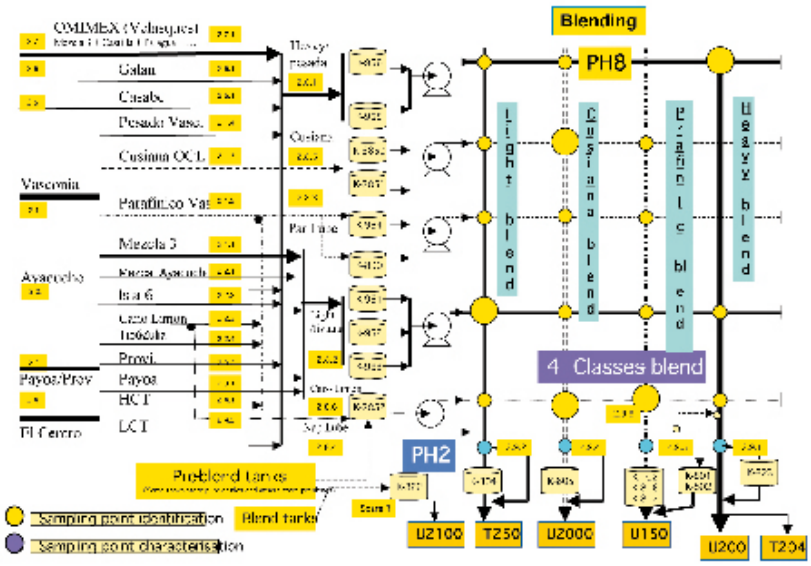


Figure 5. Barrancabermeja crude application context (types).

Table 1. Monitored cutpoints												
Crude	Nafta 1	Nafta 2	Nafta 3	Nafta 4	Medios 1	Medios 2	Medios 3	Gasoleo 1	Gasoleo 2	Gasoleo 3	CRED	FVAC
˚C	15 - 60	60 - 107	107 - 152	152 - 199	199 - 249	249 - 315	315 - 371	371 - 427	427 - 482	482 - 565	371+	565+

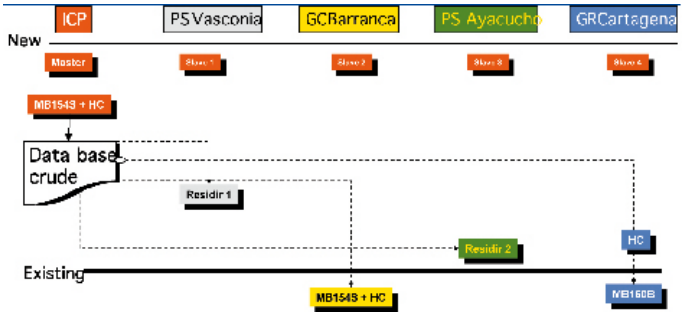


Figure 6. NIR system hierarchy.

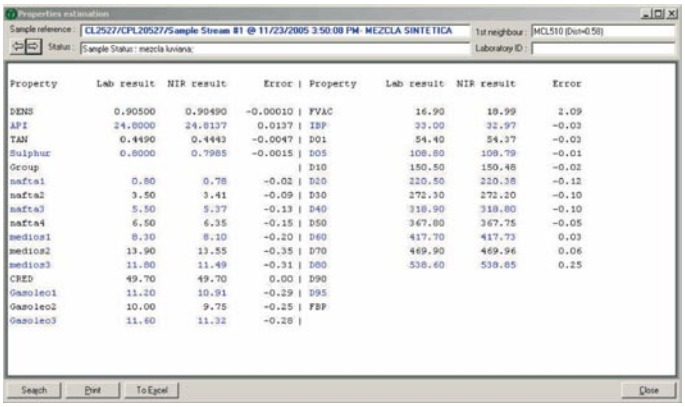


Figure 7. Topnir crude characterisation screen display.

- Forecasting of the properties for the various intermediate or end products that are produced in the topping units, to direct production towards valuable products and to ensure raw materials for the process units downstream from said process.

Project overview

The crude diet and property monitoring system is composed of:

- Two new at-line NIR systems (Topnir Systems AS200 analyser type using NetworkIR FTIR Spectrometer integrated in a cabinet) located in the two key pumping stations (Ayacucho and Vasconia), named Slave 1 and 3.
- Two existing offline NIR systems upgraded at the refineries.
- One new offline NIR system at Instituto Colombiano del Petroleo (ICP), from Ecopetrol, for development purposes.
- Simcrude model and software to provide 'crude identification' application to deliver crude diet/ratio of pure crude.
- Topnir model and software to provide 'crude characterisation' application to deliver CDU feed properties (density, distillation (12 points), sulfur and TAN).
- Additional online NIR systems planned in phase 2 on the feed inlet of the CDU plants at Cartagena and Barrancabermeja.

The terminology applied to crude monitoring has been defined as follows:

- Crude identification to measure the percentage of pure crude in any crude mixture.
- Crude characterisation to measure the exact properties of the crude itself.

Crude identification applies mainly at crude mixtures at the various pumping station but also at the crude arriving at the refinery gate, aiming at facilitating the crude allocation/segregation, as well as E&S inputs.

Crude characterisation is mainly applied at the refinery on the CDU feed to monitor the quality of the blend feeding the various CDUs/topping units. Such data are used for crude blending control/optimisation; this application will therefore be limited to the two refineries.

Figures 3, 4 and 5 show an overview of the project complexity. Figure 3 describes the complexity of the crude oil network in Ecopetrol operations. Figure 4 details the application at Cartagena Refinery while Figure 5 shows the crude flowsheet to be considered in Barrancabermeja Refinery.

Modelling software/NIR calibration

NIR calibration is done through Topnir and Simcrude technology using the topology method and computer database densification. It integrates automatic outlier detection and prediction from the online Topnir database in real time densification.

Topnir

Topnir is a chemometrics software that exploits the NIR spectra to determine a full vector of properties of the hydrocarbon product. The key features of the Topnir technology package are the near infra red (NIR) hardware required to carry out the analysis. The software enables the information provided by the analyser to be modelled and the multiple properties determined. It will then provide system integration to allow the properties to be transferred to the process advanced control system.

Topnir, based on topology, works through pattern recognition and databank densification. It does not use a linear model 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.

Concerning the treatment of outliers, the classical linear 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, every one requiring a specific calibration treatment.

The system takes into account any outlier and does not require any new calibrations of the models. It is a self learning method designed for the reality of industrial operations.

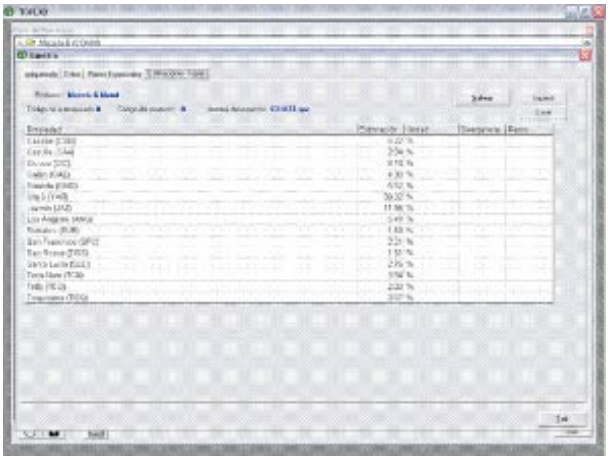


Figure 8. Simcrude crude identification screen display.

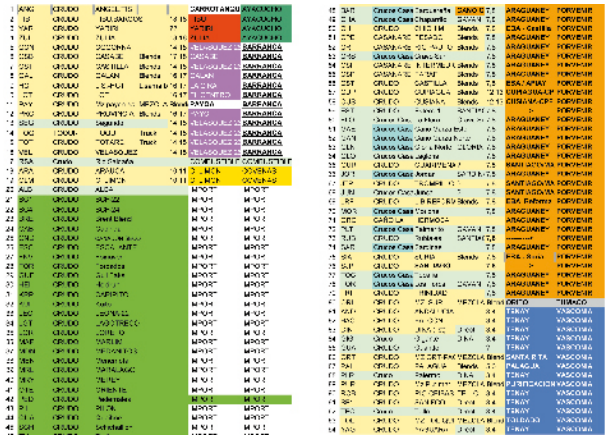


Figure 9. List of crude oils identified in mixtures and characterised.

The principle of topology is to represent spectra of n wavelengths to one point in a set of planes. These planes are defined by some aggregates and are representative of particular chemical characteristics (aromatic, unsaturated ratio). By this concept the spectral vision is reduced to some planes that allow the quick and precise visualisation of the quality of the analysis products.

Only one model is required to determine the full set of properties for one or several grades. Moreover the technique is self learning, as the model is automatically updated every time a new point is entered in the database. Thus, Topnir offers the opportunity to anticipate feed quality changes and to optimise process CDU based on real time quality determinations.

One example is the ability to predict true boiling point (TBP) of a crude mix to the topping. The incentive is particularly important when refineries are switching crude qualities several times per week and have difficulty tracking crude mixture in feed tanks. It is also possible by using Topnir prediction on the TBP curve to calculate the CDU product yields at given cut points.

The benefits from crude analysis are a function of the economics, but the reduction of feed transitions can yield a magnitude of gains, keeping the distillation unit closed to the optimum set of cut points and throughput. Thus, Topnir is used to provide characterisation of the properties of the topping units feed for:

- Five blended crude, mixture of five crude preblends, at Barrancabermeja refinery.
- One blended crude, mixture of five crude preblends, at Cartagena refinery.

Simcrude

Simcrude has been developed, as an extension to the Topnir modelling technique, to satisfy the following requirements:

- Predict the type of crude oil and the properties from an unknown sample.
- Predict the formulation of an unknown crude oil blend and its associated properties.
- Perform as a crude oil tank management tool.

Thus, Simcrude is used as shown in Figure 3 to give the following information:

- Identification of the composition in pure crude:
  - For 15 families divided in eight sampling points at Vasconia pumping station site.
  - For seven families divided in four sampling points at Ayacucho pumping station site.
- Identification of the composition in pure crude:
  - For 15 families divided in seven sampling points at the Barrancabermeja refinery.
  - For 11 families divided in two sampling points at the Cartagena refinery.
- Identification of the composition in pure crude:
  - For six families in crude pre-blends of the Barrancabermeja refinery.
  - For four families in crude pre-blends and one imported crude family of the Cartagena refinery.

Indeed, Simcrude monitors the crude percent from samples collected at various sampling points of the two major pumping stations (Ayacucho and Vasconia) as well as the crude percent from samples collected at Cartagena at the pipe entrance (one line) and at the three tanks and the crude percent from samples collected at Barrancabermeja at the pipe entrance (seven lines) and at the ten tanks.

The two programs, i.e. Topnir™ and Simcrude have been delivered at Ecopetrol sites:

- Topnir™ installed on the laboratory PC at ICP, Barrancabermeja, Cartagena and on CDU online analysers at Barrancabermeja, Cartagena on phase 2.
- Simcrude installed on the laboratory PC at ICP, Barrancabermeja, Cartagena, and on the at-line analysers PC at Vasconia, Ayacucho.
  - One Simcrude database for circa 100 in-land +30 import crude oils for determination of percent in mixtures (identification).
  - One Topnir database/models for approximately 100 in-land +30 import crude oils for determination of stream properties such as distillation (12 points) i.e. percent distillate at each cut point, degree API, sulfur and TAN (characterisation). Regarding the distillation points, it should be noted that the points corresponding to the 12 cuts in Table 1 are monitored.

NIR systems/functions

Five off/at-line NIR analysers are used. The database/models have been built on the master NIR to be installed in ICP while four 'slave' analysers are installed, one in each of the two pumping stations (PS) and the two refineries, to monitor both crude diet and crude properties (only in the refineries). Online NIR analysers on refinery CDU plant feed lines will be used for crude characterisation in phase 2. The databases have been then transferred to these four 'slave' spectrometers as depicted in Figure 6.

The transfer occurred in three steps according to complexity of the crude diet. The four slave apparatus for phase 1 are actually used:

- For monitoring the crude percent from samples collected at various sampling points of the two major pumping stations (Ayacucho and Vasconia).
- For monitoring the crude percent from samples collected at Cartagena at the pipe entrance (one line) and at the three tanks, and monitor the properties of the blended stream (one line).
- For monitoring the crude percent from samples collected at Barrancabermeja at the pipe entrance (seven lines) and at the 10 tanks, and monitor the properties of the blended stream (four lines).

Results and benefits

TBP prediction of a pure crude or a crude blend is achieved by Topnir which procures a unique advantage in daily operations. Indeed, advanced control strategies have been constrained mainly by poor availability of online analysers and dubious robustness of inferential models for stream qualities, especially during transients.

It is also possible by using Topnir prediction on the TBP curve, to calculate the CDU product yields at given cut points. Topnir, Toplab or Topwin are gathered under the same software. The different names are given to highlight specific functionalities.

- Toplab is a Topnir module used to allow Topnir to collect a spectrum with the spectrometer. It is used only offline.
- Topwin stands for Topnir Windows version (laboratory and at-line/online).

All the database work (update, compilation, studies, check up) is done offline, on the laboratory PC. A typical example of screen display is shown in Figure 7.

Simcrude is a chemometrics software that exploits the NIR spectra to determine the percent of the pure crude in a crude blend. Typical Crude identification obtained from Simcrude is shown in Figure 8.

The complexity of the crude oil in-land and import at ECP is very high. The list of crude oils that have been identified in mixtures and characterised is shown in Figure 9.

Moreover, the Topnir/Simcrude system is able to predict outlier as shown in Figure 10 where the spectra, the location of sample compared to the box is displayed as well as the prediction obtained.

Benefits

It is expected that the implementation of phase 1 (at-line Topnir/Simcrude systems) allows the Barrancabermeja

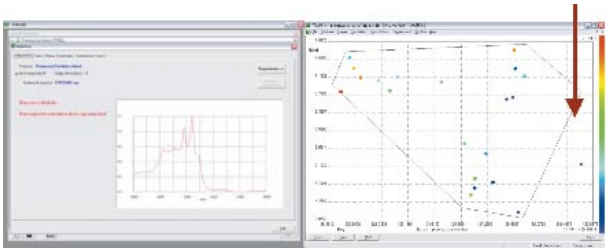


Figure 10. Topnir/Simcrude system is able to predict outlier.

Refinery a 10% of blending product optimisation leading to an annual benefit of several million US$. For Cartagena Refinery, the estimated benefit for better crude characterisation and optimisation is an increase in crude throughput from additional crude processed in the refinery, leading also to an estimated amount of several million US$/yr. Crude management takes half of this benefit and the other half is attributed to scheduling tools. 20% of the product giveaway is also attributed to better crude management.

The second stage, phase 2, involves installing APC and optimisation on the crude oil blender to trim the blend within constraints given by scheduling. This requires an online NIR located either on the component streams or the blend headers to the topping units.

Phase 2 allows the feeds to the individual topping units to be better optimised to take into account transient effects. It will therefore give additional benefit in the areas of:

- Preparation of feeds that allow maximisation of the yield of valuable products such as Jet A1 and/or ACPM (Diesel Grade).
- Preparation of homogeneous and optimum feeds for bitumen and lubricants preparation.
- Forecasting of the the properties for the various intermediate or end products that are produced in the topping units, to direct production towards valuable products and to ensure raw materials for the process units downstream from said process (i.e. cracking, demex, unibon and lubes).

It is currently estimated that this phase gives an additional benefit of about 1% throughput on the topping units.

Conclusion

Topnir/Simcrude technology is able to provide two key pieces of information:

- Direct identification and quantification in ratio of pure crude composition in an unknown crude mixture.
- Real time measurements of full property vector for any pure crude and crude mixture, including full TBP curve, TAN, sulfur and degree API within ASTM warranty, in less than one minute.

The unique system installed at Ecopetrol sites is managing a network involving more than 100 crude oils throughout the country.

The identification and characterisation of crude mixture obtained from Topnir and Simcrude led to annual benefits of several million US$, not only for crude operation itself but also for downstream activities such as diesel blending.