4IR's AI-60 Petroleum Analyzer for Optimizing Crude Distillation Unit

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Comprehensive and adequate control of the process parameters of the Crude Distillation Unit (CDU) is an obligatory requirement for the optimal production of naphtha, kerosene and gasoil. This has a direct impact on the economics and the profit of the refinery.

Integrated real-time and on line monitoring of the feed and the distillates allow immediate adjustment of the process conditions. This increases the capacity to produce high value distillates by stringent cutting, and reduces the impact of the fluctuations that occur during the process.

Utilizing the 4IR AI-60 Petroleum analyzer (based on an NMR technology) along with propriety software ensure the operation of the CDU to produce its distillates continuously, effectively and at the highest yields.

The Challenges

Optimization of the process conditions for the crude distillation unit is a main challenge for each refinery. It results in maximum profit at minimum cost.

To achieve this target, full real time monitoring of the quality of the incoming crude oil and outgoing distillates is a minimal requirement in order to ensure:

- ✓ Minimum influence on the production capacity of each distillate and its quality due to changes in crude oil.
- ✓ Maximum production of high value distillates on the account of heavier distillates of lower value. This is achieved by shifting the cutting temperature as such that the T90 – FBP of the high value distillate will be as high as possible and the IBP – T10 of the heavier fraction as low as possible.
- ✓ Maximum stability of the product quality of each distillate throughout the entire distillation process.
- ✓ Prevention to produce borderline or off-spec material due to failures.

Full control of the product quality can only be achieved by employing the NMR analyzer to monitor continuously and simultaneously the quality of the incoming crude oil and the outgoing streams (Naphtha, Kerosene, LGO, HGO and the vacuum distilled products LVGO and HVGO). This enables real time actions to be taken to allow the CDU to be operated with optimal production effectiveness.

Refineries include a complex of processes. If these processes are not controlled properly it will have its impact on the efficiency of the refinery. It will affect the product quality, the product yield and the energy consumption. This leads directly to an increase of the cost of production for each distillate.

Complete on-line and continuous monitoring and control of the process parameters reduces the danger of an inadequate production of the required petroleum products.

The efficiency of a refinery to produce its petroleum distillates directly linked to:

1. The crude oil that is delivered to the refinery.
2. The equipment of the refinery.
3. The maximum throughput of the crude oil and the petroleum products alike.
4. The ability to produce the distillates with the highest value at maximum yield.

Each refinery is built differently according to its initial destination, the sources of crude oil and the required quantity of different petroleum products, which is based on the direct request of the market and long-term planning according to the trend of the price fluctuations of each distillate.

The quality and the cost of the crude oil highly depend of its origin. Blending of various types of crude oil is required to reduce the cost of the crude oil feed to be distilled. Furthermore, as each refinery is constructed differently, blending of different types of crude oils may be inevitable to obtain a proper feed that can be processes in the equipment available in refinery.

Different sources of the crude are of different compositions. The result is that under similar process conditions a different distribution of the distillates, as produced by the CDU, is obtained. To achieve a maximum production efficiency and product yield, continuous readjustment and fine tuning of the process conditions is unavoidable.

Inadequate on-line and real time control of the crude oil and the product quality will directly affect the efficiency and the profit of the refinery. Failures in continuous chemical processes do occur, and result in the production of non-desired materials or the need for a partial or total shut down of the plant. Time consuming investigations are conducted and taken corrective actions have to be implemented.

These actions directly affect the overall efficiency, the profit and the economics of the production plant, an answer has to be given to:

IDENTITY – What *is observed*?

LOCATION – *Where is the problem observed?*

TIMING – *When is the problem observed?*

MAGNITUDE – *How many similar occurrences are observed now and in the past?*

COST – *What is the short term and long-term price to be paid?*

These investigations are complicated. In many cases failures are not the outcome of one single event. Often, they are the result of a combination of several events that occur together.

Off line laboratory quality control, which includes sampling and laboratory analyses is time consuming. Any delay in data collection will affect optimal and effective control and adjustment of the process parameters.

Continuous on-line monitoring of the product properties minimizes financial loss due to unexpected failures or inappropriate production conditions.

The Solution

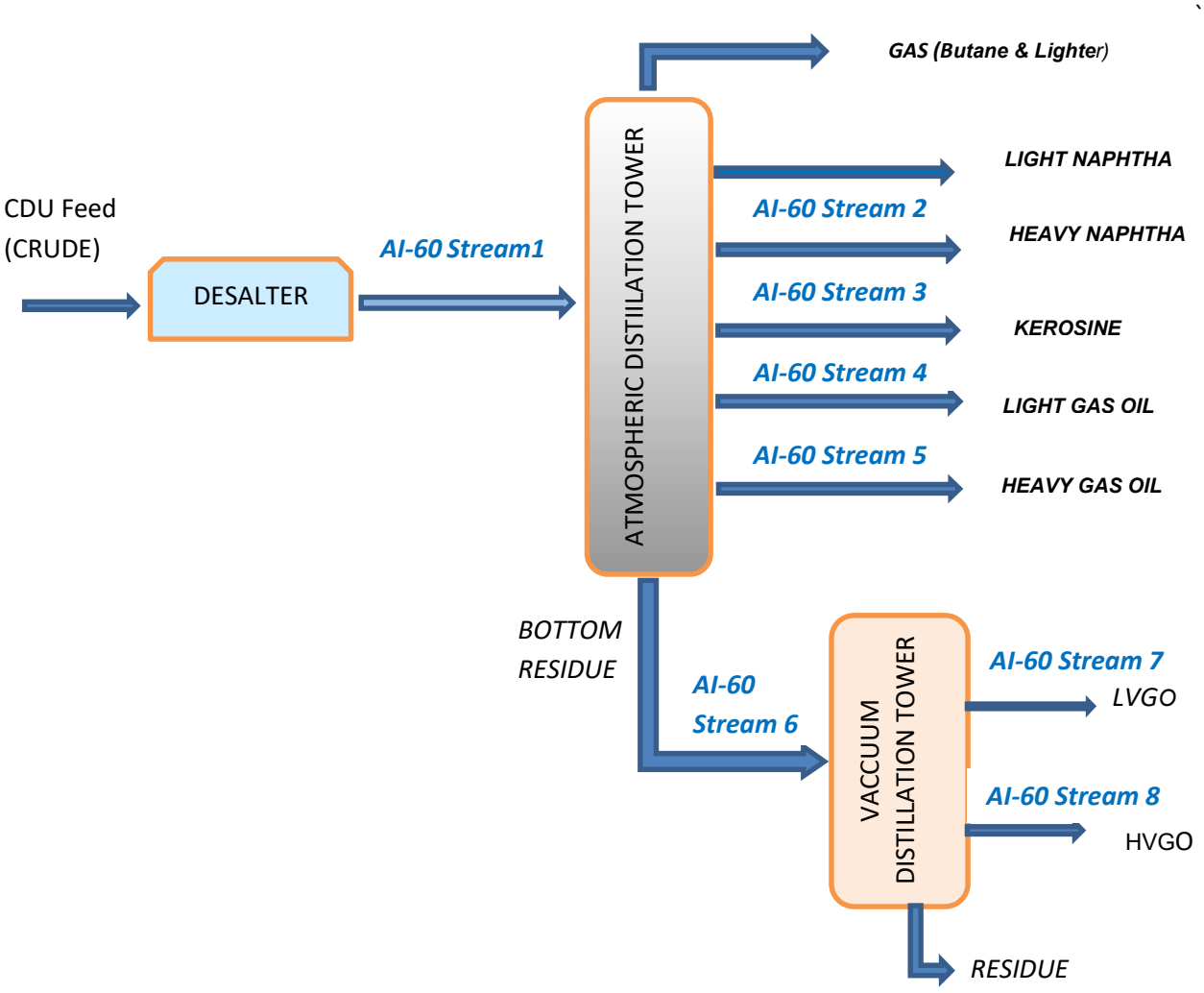
4IR AI Ltd. has a total solution for the CDU to allow control of the process in an economic manner and at low cost.

4IR Ai's solution covers the entire CDU processes, starting from the incoming crude oil, the feed, and the distillates.

4IR AI total refinery monitoring system includes:

1. AI-60 Petroleum Analyzer (based on NMR technology)
2. Process NMR software
3. Model Gate Way software

A combination of this analytical method along with distinctive software, establishes a continuous and overall monitoring of the entire refinery processes.



CDU Feed

Physical and chemical properties of crude oils correlate directly with the chemical composition of these, and vary according to their place of origin.

Quality properties determine the market value of each type of crude individually. Most important quality characteristics are the density, the TAN and the sulfur content. The API (Density) ranges from light crudes (high API, low density) to heavy crude oils (low API, high density). Sulfur is present in crude oils as hydrogen sulfide and as polysulfide. Partially these sulfur containing molecules will decompose during the distillation, while hydrogen sulfide evolves. The sulfur content and other acidic components in crude oil, such as naphthenic acids, are highly corrosive, and responsible for the crude oil to be of a sour or sweet character.

High TAN crude oils, crude oils with high acid numbers/value, are heavy crude oils with high acidity. High TAN crude oils are characterized by fewer light components, high density and viscosity, low solidification point, high nitrogen content, high gel-asphalt content, high salts and high heavy metals contents and a low yield of light oil distillates. It causes water – oil separation by the De-Salter being more difficult than in conventional crudes. These properties also cause these crudes to give low quality products and being very corrosive. Commonly, these TAN crude oils are called “opportunity crude oils”.

CDU Distillate

Crude oil is transferred from the de-salter to the CDU to be fractionated according to their TBP into:

- Gasses with low boiling points (≤32 °C)
- Light Straight run naphtha (32-88 °C)
- Heavy straight run naphtha (88-193 °C)
- Kerosene (193 -271 °C)
- Light gas oil (271-321 °C)
- Heavy Gas Oil (321 – 427 °C)
- Vacuum Gas Oil (427-566 °C)

Cutting temperatures between the distillate streams must be maintained as such the IBP and FBP of final distillates and other physical properties comply with the specification of the final product. The cutting points for distillates that are blended or further processes are determined a to achieve maximal production capacity, with an optimum use of various distillates to achieve final product to comply with the required specification, i.e. diesel-oil, or the requirements needed if further processed. Overlap between the boiling ranges of neighboring distillates is common. It is up to each refinery to specify the exact cutting point, to allow a production capacity for each product according to their marketing commitments.

The distillation residue from the atmospheric tower is further distilled under vacuum into light and heavy vacuum gas oil (LVGO) and (HVGO), used for further processing.

Physical properties of a distillate are the outcome of their chemical composition which correlates with each other. This enables NMR spectroscopy to be applied to quantify different physical properties.

Predication of a physical property by using NMR spectrometric method is based on a statistical correlation between quantitative value of a certain physical property and its corresponding measured spectral data. The accuracy of correlative methods depends entirely on the quantity, quality and the variation of reference samples.

The product streams are scanned instantaneously during the production and analyzed by NMR spectrometric method. The data obtained by these measurements mathematically converted to required parameters of the product which is produced.

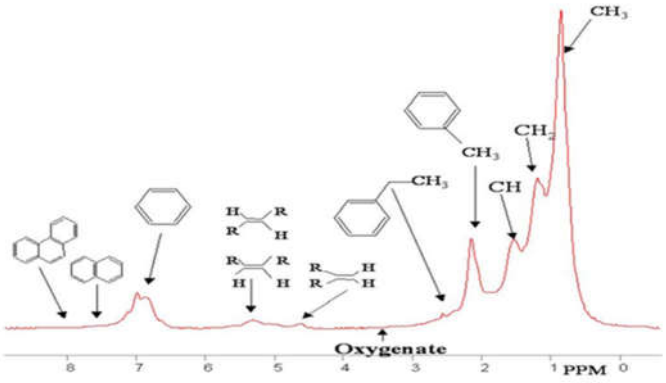
4IR AI monitors the product quality in the CDU by applying the Nuclei Magnetic Resonance (NMR)

4IR's NMR Technology

Nuclear Magnetic Resonance - is an effect whereby magnetic nuclei in a magnetic field absorb and re-emit electromagnetic (EM) energy at a specific resonance frequency. The introduction of on line NMR technology is a unique tool to monitor the feed and the distillates of the crude distillation unit.

Its spectrum is an outcome of the arrangement of carbon, hydrogen and oxygen atoms in the molecule. The NMR spectrum of crude oil and petroleum distillates, depend directly on the distribution of hydrogen atoms in the molecule and is influenced by the type of carbon-carbon bond to which the hydrogen atom is connected. Quantification of the molecules is achieved by concentration of the hydrogen atoms assigned to each peak response

NMR can distinguish between compounds which are present in petroleum distillates. These include linear and branched olefins and aliphatic, mono-aromatics and poly-aromatic, substituted aromatics or oxygen containing species aliphatic, parafines, olefins, acids, oxygenates and water.



H-Types Observed in a Gasoline ^{1}H NMR Spectrum

Optical spectroscopic methods (UV, IR and NIR) are limited to transparent solutions only. However, NMR spectrometry allows opaque, none transparent solutions to be measures.

This feature allows NMR technology to be applied for monitoring crude oil and heavy distillates from the CDU.

The combination of the specificity of the signal according to their chemical structure and the linear spectral response to the quantity of hydrogen atoms assigned to the molecular species, allows accurate correlation between the physical properties and the spectral data.

Statistical correlating between the NMR spectral data and the results of the analytical laboratory allow the physical properties to be predicted at a high accuracy.

NMR spectral data collected from each stream will predict the following physical parameters of crude oil and the CDU incoming crude and distillates products:

Crude Oil	Naphtha	Kerosene	Diesel Oil	LGO	HGO
API	Density	API	Density	Density	Density
Distillation	Distillation	Distillation	Distillation -	Distillation	Distillation
ASTM D 86	ASTM D 86	ASTM D 86	ASTM D 86	ASTM D 86	ASTM D 86
Aromaticity	PONA	Flashpoint	Cetane Index	Pour Point	Cloud point
Water in crude	RVP	Freeze point	Cloud Point	Cloud Point	Pour point
Pour Point		Aromatics	Viscosity	Flash point	Flash point
Sulfur		Olefins	Pour Point		
		Naphtalenes	CFPP		
		Hydrogen-Content	Flash Point		

Major benefits of NMR technology:

- ☞ Allows analyses to be performed in dense and opaque materials (Crude oil, LGO, HGO).
- ☞ Linear Spectral Response across broad range.
- ☞ Allows multi-property analysis in one single run.
- ☞ Allows real time, continuous flow-through stream analysis.
- ☞ Physical properties correlate accurately with spectral data.
- ☞ Replaces conventional analyzers and provide much faster results (e.g. PIONA in seconds.
- ☞ Reduction in response time from Lab allows tighter control.
- ☞ Requires simple sample conditioning (no water removal).

These features along with the **Process NMR software** and the **Model Gate Way software** allow 4IR's AI-60 Process Analyzer to monitor on line observation of any discrepancy in the production process and the product quality. It allows immediate corrective actions to be taken whenever required. The result is a reduction loss caused by producing of off-spec material. It also eliminates the need for frequent sequential laboratory analyses until the process is back on track.

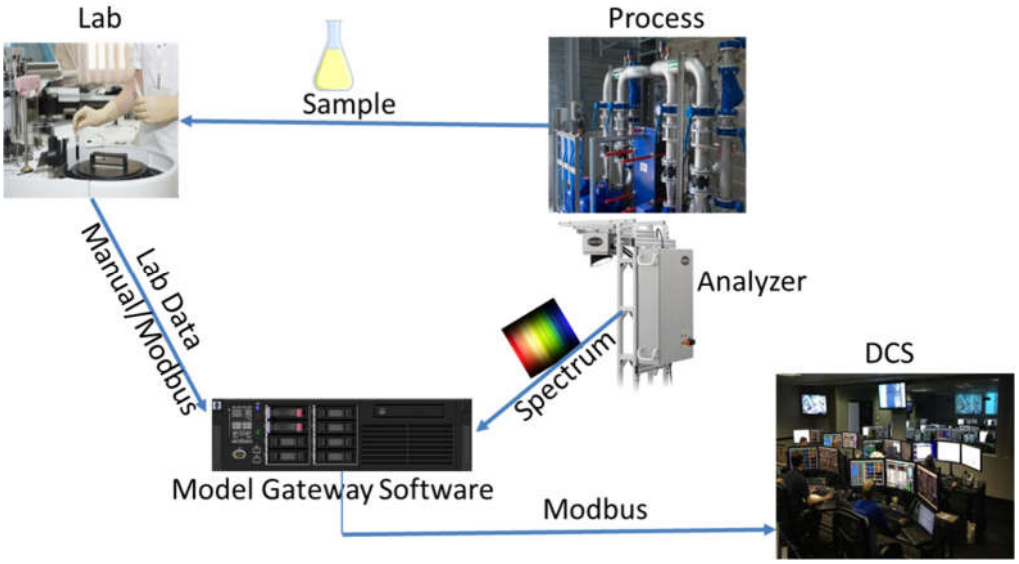
Process NMR Software

The AI-60 Process NMR software is a GUI, windows-based application that controls the NMR analyzer operation along with the Sample Conditioning System and the Stream Switching System through TCPIP and/or Modbus and enables the user to perform the following operations:

- NMR scan
- NMR Signal Processing
- NMR Analyzer Shimming
- Archive results
- Report predicted values through Modbus protocol
- Enable the NMR Analyzer to run in a fully automatic mode for process control

Model Gate Way Software

- Software only solution (Windows XP or higher)
- Automatic generation of PLS models (Patent protected)
- Supports most correlative analyzers
- Integrates with Plant network through Modbus protocol
- Supports traditional Thermo Grams models
- Graphic model comparison
- Automatic / Manual feeding of lab data
- Reporting / Alerts / Status indications



Comparison between NIR and NMR

	NIR Analyzer	NMR Analyzer
Method	Near Infra-Red (Optical)	Magnetic resonance
Sample Probe	Allocated near the sample line (no lag time)	Fast loop bypass pipes (introduce lag time between the actual sample to the predicted results)
Multi-Streams	Optical multiplexer (no need for sample switching system	Require sample switching system
Chemometric Models	No-linear Response; Cannot perform extrapolations of the model	Linear Response; Allow extrapolations of the model
Sample properties	Applicable to transparent distillates only	Applicable for transparent and opaque samples
Crude Changing influence	Influenced by compounds, containing others than carbon or hydrogen atoms.	No sensitivity to Crude changing. Depended on the hydrogen content only.

- ✓ NMR spectrometry characterized by a better linear response then NIR spectrometry with respect to changes in the composition of the distillates.

- ✓ NIR is restricted to transparent distillates only (Naphtha, Kerosene and Diesel). NMR is applicable to transparent and opaque distillates which cover the entire product range of the CDU.

Case Study: CDU Optimization Yanshan Refinery (Kerosene yield)

	Before NMR Commission	After NMR Commission	
Month	2012	2013	2014
Jan	9.77	9.87	11.7
Feb	9.28	9.95	10.58
Mar	9.26	9.54	11.32
Apr	9.23	10.09	10.98
May	5.06	10.03	12.22
Jun	9.29	11.03	11.14
Jul	9.9	10.59	11.29
Aug	9.51	12.9	11.85
Sep	9.06	10.9	11.51
Oct	9.26	11.57	11.37
Nov	9.19	11.39	11.37
Dec	6.25	11.29	11.34
Average yield	8.76	10.76	11.39
Yield improvement		2.01	2.63

After commissioning of the NMR analyzer: Kerosene yield increased by 2% to 2.5% which is equivalent to additional of 5000 to 6500 barrels of Kerosene per day! (for a typical Refinery of 250K BPD capacity)

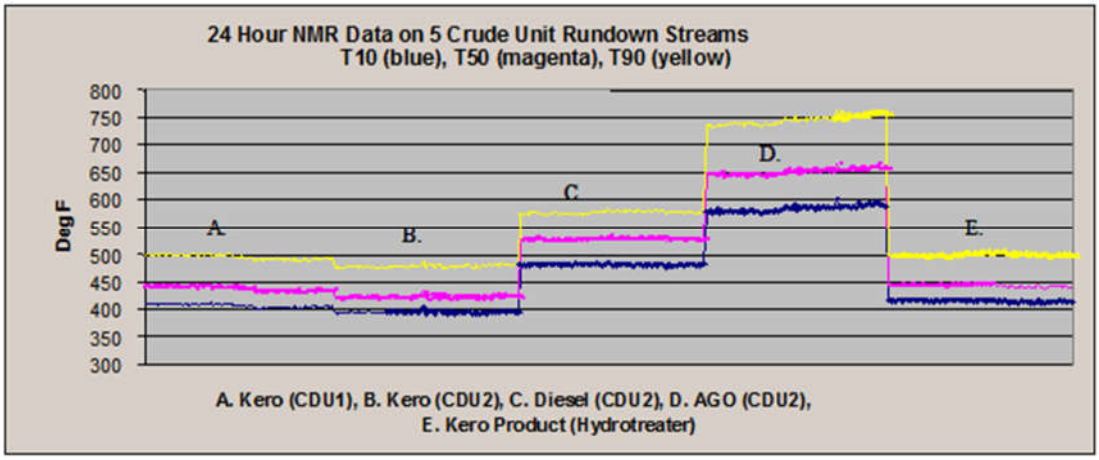
Given the Kerosene average price in 2015 was $1.735, the total saving on Kerosene is ***$3,157,000 USD per Year.*** Obviously, there is additional saving on the other distillate as well.

Conclusion

The efficiency of the crude distillation unit is linked to its capability to change the production conditions as such that an optimal yield of naphtha, kerosene and diesel oil is achieved. The demands for certain distillates in the marked and prices these have its impact CDU to produce the most valuable distillates at maximum capacity. Process conditions have to be adjusted to shift of the production ratio between the distillates without affecting its quality. This requires clear control over the initial and final boiling points of the

On line monitoring of each distillate allows accurate measurement of the upper distillation points (T90 – FBP) from the (IBP – T10) lower boiling distillate with accurate measurement of the lower distillation points. It allows accurate cutting between two neighboring distillates towards the fraction of higher value (i.e. kerosene in diesel, diesel in AGO) from the heavier cut.

This can be achieved by adjusting the distillation tower temperature profile. Uncontrolled adjustment of the process conditions may lead to the production off spec distillates. On-line monitoring of the quality of distilled naphtha, kerosene and diesel is inevitable. It shows the stability of the process and avoid while changing the process conditions to prevent overshooting.



With strategic implementation at the crude unit mid-section, on-line NMR analyzer will enable the recovery of additional 300-500 barrels per day of critical distillate products from a typical 100,000 barrel per day crude distillation unit.

4IR On-line NMR analyzer along with the Model Gate Way software, offer a viable means for accurate process analysis and control of the CDU, from crude feed to finished distillates.