# NIR TECHNOLOGY USED FOR OPTIMIZED COST EFFECTIVE REFINERY PROCESS CONTROL


Nir Merav
Bazan - Oil Refineries Ltd,
P.O Box 4,
Haifa 31000
Israel

Ronny McMurray, Tal Cohen
Modcon Systems Ltd,
P.O Box 22022
South Akko Ind. Park Acre 24121
Israel



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## ABSTRACT


Commitment to continuous and strict quality control is inevitable to guarantee existence and surviving in today's complex geo-political and highly competitive economic environment.

Effective process control is essential to proceed refinery processes at maximum efficiency, maximum accuracy and at minimum cost. It is undisputable that incorporation of on-line process analyzers prevents financial losses, caused by unnecessary re-processing or giveaways. The question is not "IF" to use analyzers but "WHAT" type of analyzer keeps the refinery cost effective at top performance. ASTM based process analyzers to control the quality are an option, but enormous investments are required in purchase and maintenance.

Alternatively, a sophisticated solution of NIR technology is successfully applied in refinery process control and optimization. Fast on-line analyses, based on correlation of NIR spectra with quantified multiple physical properties, guarantee compliance with the product specifications. The uniqueness of this system is that optical fibers transmit NIR beams from the analyzer, in the "safe zone" control room, to and from measuring probes on process streams up to a distance of 2 miles. Multiplexing instantaneously measures different process streams. Incorporated validation software ongoing verifies, validates and adjusts NIR analytical results according to laboratory analyses, which guarantee continuous reliability of analytical data.

# INTRODUCTION

The commitment of continuous and strict quality control is inevitable to guarantee existence and surviving in today's complex geo-political and highly competitive economic environment.

Bazan - Oil Refineries Ltd. (ORL, Bazan) is the oldest and biggest refinery in Israel. This refinery is highly ranked according to the Nelson Index. It produces a wide range of high valued, high quality fuels, petroleum products and petroleum related products such as aromatic compounds and polymers. All ORL products are subject to most recent local and international quality standards. Laboratory analyses are time consuming, and not efficient in optimization of continuous processes. Running the refinery in a cost efficient mode requires the company to be most updated with high performance reliable on-line analytical process analytics with minimum care and maintenance.

Adequate and full process control are the only ways to ensure refinery processes to proceed at maximum efficiency, maximum accuracy and at minimum cost. It is undisputable that the adaption of on-line process analyzers prevents financial losses to refineries as a result of unnecessary re-processing or giveaways. To guarantee continuous production of in-spec high quality products, on-line process analyzers are inevitable. The question is not "HOW" or "IF" to use analyzers for this purpose, but "WHAT" type of analyzer will keep the refinery at top performance and with cost effect effectiveness. In many refineries, the quality of refinery products, produced by various refinery units and gasoline blending, is controlled and optimized by means of conventional analyzers which are based on specified ASTM methods, like octane engines, distillation profile analyzers, RVP analyzers and density analyzers. These analyzers are not influenced by crude quality but their response time is long, they are complicated and complex instruments that require enormous investments in acquisition with including appropriate shelters, and maintenance, which includes a variety of amortization sensitive mechanical parts. As compared to the discrete analyzers, optical spectroscopy analyzers are of low cost in both to purchase and maintain.

Alternatively, process analyzers based on optical spectrometry, such as NIR/FTIR process analyzers, are also incorporated in the refinery array of the refinery operation system. The only need is to pay close attention to the modeling efforts. They are only restricted by the transparency of the liquids. Its reliability depends of the accuracy of chemometric models. Spectral results are influenced by fluctuation in the chemical composition of crude oil, and especially that the presence of substances such as hetero-atomic molecules which are present at fluctuating concentrations depending on the crude oil origin, and distill over together with heavier distillates. This influence is reducible by either minimizing crude switching, incorporation of these compounds in the calibration samples, or by incorporation of model validation and corrective software. Further to that, incorporation of NIR technology in transparent process streams in downstream refinery units, such as the CCR, FCC and alkylation unit, which do not consume directly crude oils, is effectively applied to monitor the quality in process streams of these refinery units to optimize the chemical reaction.

In general, refinery process units are spread out over a broad territory. The size and complexity of process units including the passages between them, scattered pipe lines, its flammability, the explosion hazard and other dangers of materials which are liberated and have the potential to be hazardous to human beings or the environment, makes it desired to control most of the refinery from a "safe area" such as the control room. Further to that, centralization of all real time analytical data from process streams in the control room allows operators taking the right decisions, which are required to adjust processing conditions to guarantee optimized yield and quality.

Common NIR process analyzers are brought on the market by various companies and for various applications, among which refinery applications. However, these analyzers are restricted to be placed in appropriate shelters and housings, which are placed on the site of the process unit. These definitely have to be fire and explosion proof. This is in contradiction to the BEACON concept, where the analyzer is placed in a safe area, such as the control room, and enables remote monitoring of physical properties in process streams far away from the analyzer, without the need to invest additional cost for safety accommodations.

The mission is to lead the NIR analyzer revolution for the oil refining and petrochemical industries and replacing traditional analyzers with the NIR technology.

## PRINCIPLE OF 3$^{rd}$ OVERTONE BASED NIR PROCESS ANALYZERS

NIR technology is based on overtones and combination tones in the NIR spectrum, which generally include the range of 700 to 2500 nm. The intensity of the spectral response reduces upon decreasing the wavelength. Furthermore, restriction of the range of the wavelengths, will limit the overtones that take part in the NIR spectrum. Optical spectroscopic methods do not designate the molecular structure of substances present in a composition. No specificity exists to distinguish between different substances, or chemical functional groups. Its principle it is based on the determination of “fingerprints” of substances. Its accuracy is submissive to impact of weak analytical signal variance of overtone and combination band vibrations, heavy overlapping spectral bands, of non-carbon or hydrogen atoms, which require initially a relatively large population of samples to be included in the building up of the calibration curve.

In spite of the above limitations, NIR spectrometry is very attractive in today's process control, where identification of chemical substances is not requested. NIR process analyzers are therefore very efficient in those processes where physical and chemical properties must be quantified, without getting into the resolution of the chemical composition to be analyzed.

Different refinery units also include different chemical, physical and mechanical processes, such as crude distillations, catalytic reactions in the CCR, FCC, alkylation units and blending of gasoline and diesel. The preferred configuration for optimization of refinery process control is when executed from the central control room. Centralization of all analytical data from process streams in the control room allows operators taking the right decisions to adjust processing conditions to guarantee optimized yield and quality. This goal is easiest achieved by placing the analyser in the control room, a safe area, and connecting the analyzer to various points of measurements, notwithstanding their allocation. This concept was a basic principle in the development of an "all including NIR refinery process analyser".

In last century, an analyzer, dedicated to oil refinery and petroleum industries, was developed and brought on the market that was based on utilizing the 3$^{rd}$ overtone. The long wave portion of the NIR region, 1100-2500 nm, contains numerous combinations of first and second overtones. A wide range of absorptions, characterizes this region, and requires expensive fiber optics. Third overtones of C-H absorb in the range of 700 – 1200 nm. These overtones have a lower absorption coefficient then the 1$^{st}$ and 2$^{nd}$ overtones which must be compensated by a longer path length of the measuring cell, but they enable the application of cheap optical telecommunication fibers, with inexpensive light sources and detectors. [1,2] As an all included NIR refinery process analysers, the first analysers contained a halogen light beam, a mono-chromator, a splitter to divide the light into measuring beams and reference beam, and a 1024 pixel liner as a detector. In addition to that an external multiplexer diverge the beam of light to up to 16 different optical fibers, each connected to a different field units. The optical fiber in the 3rd overtone based NIR analyser concept, are standard telecommunication optical fibers. It was found that up to a distance of 2 miles (3 km), the signal that passes through the optical fiber is NOT influenced by the fiber length, as shown in Figure 1[3]. Both signals, passing through a 6m or through a 3km optical fiber entirely overlap. This feature is a crucial property that enables execution of NIR measurements in large areas, such as refineries, which a spread out of different kinds of production units. This feature also makes it possible to place field units in flammable, explosive, health and environmental hazardous areas within a radius of 2 miles (3 km) away from the central analysers

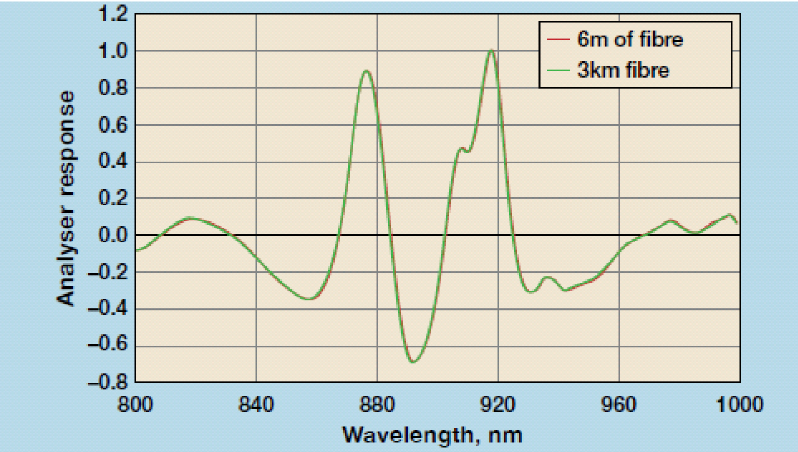


**FIGURE 1. OVERLAP OF THE ANALYSER RESPONSE AT A DISTANCE OF 6 METERS AND 3 KM AWAY FROM THE ANALYSER**

The field units are simple through flow measuring probes that are mounted as a side stream on the process stream. They consist of a measuring probe, an inlet and outlet for process streams and at each side an adaptor to which the optical fiber is connected, as shown in Figure 2. A beam of NIR light is sent from the analyzer in a continuous mode to pass through the liquid. The beam of light that enters and leaves the measuring probe passes through an optical probe head, a set of optical lenses, which separates between the optical fiber and the hydrocarbon to be measured. The process stream, which is measured, flows constantly through the measuring probe. Transmitted light from the measuring probe returns to the analyser for further processing, and compilation of the NIR spectrum. Multiplexing allows fast switching between the optical fibers, and by that, all connected process streams are measured almost instantaneously.

**FIGURES 2. THE FIELD UNIT (LEFT) THE MEASURING PROBE (MIDDLE), FIELD UNIT WITH SAMPLE CONDITIONING (RIGHT).**

Samples in NIR technology must have transparency to let the NIR beam pass through. Temperature variations of the measured liquid as well as its water content affect the measurements. These influences are omitted by adding to the field unit a sample-conditioning system, which contain drying and heating or cooling devices.

The existence of a relationship between chemical structures and physical properties, which also include spectroscopic properties, enables to derive physical properties from the absorption spectra by means of chemo-metrics. Initially, a correlation model is created that correlates between NIR spectral data and quantified values of physical properties which belong to samples taken at the same point of time as where the NIR spectrum is measured

Correlation models transform the measured spectra into quantified physical properties. As previously quoted, NIR spectrometry is based on "fingerprints" of the measured liquid. Any changes in chemical composition will influence the physical properties as well as the NIR spectrum. Commonly the spectrum responds linearly with the changes in the concentration according to the Lambert Beer's Law, $E = \varepsilon c d$. However, in the case of NIR spectrometry, also due to overlapping spectral bands, the spectral variation does not respond linearly with the quantitative behaviour of a physical property. A relatively vast amount of reference samples are required to compile the calibration curve. The lack of linearity prevents accurate prediction of chemical properties by extrapolation of the calibration models. Therefore, to gain highest accuracy it is required that reference samples cover all possible variations of chemical compositions. Of course, this is not feasible, and a compromise is required to reduce the quantity of reference samples to its minimum, while still composing a trustworthy calibration curve. For that purpose, deviation of the physical properties of the various reference samples is essential to reduce the amount of reference samples required for the calibration curve. Moreover, to obtain a calibration curve with a high credibility, it is important to withdraw samples for laboratory analyses, which are accurately marked by the exact time of sampling. This allows precisely correlating between the NIR spectral data and the laboratory test results at the same time.

To start operating NIR technology means to invest time and money in the preparation of an adequate calibration model. Furthermore, in many cases the considerable changes, originated from different types of crude oils with a varying composition of hetero-atomic compounds, are present in distillates. This requires model updating to prevent these changes to influence the accuracy of the NIR predicted results. As a remedy to this drawback, the Freetune™ Software was developed. This software is composed of two sequential blocks. Initially, partial least squares (PLS) regression is used to build a localized sensitive model (LSM), based on just a small number of samples. Its sensitivity to short term (hours) process variations is one of the major characteristics of this model. Since it is localized, the model can be quickly built and validated. This procedure takes up to one week and can be performed prior to the start-up of the system. Secondly, a proprietary software program processes the model, and integrates specified plant data, to accurately quantify physical properties. This second part deals with predicting the long-term product variability [4].

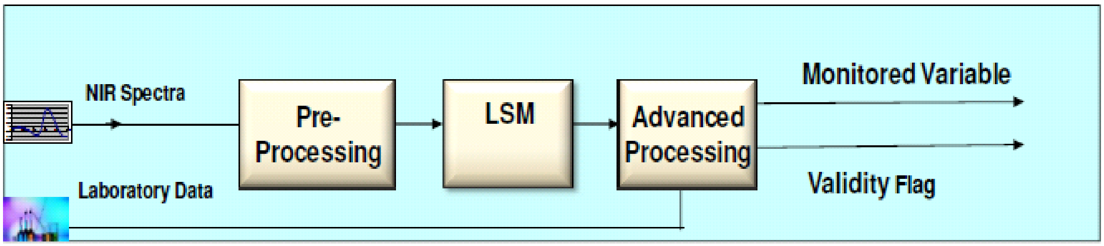


**FIGURE 3. TWO SEQUENTIAL BLOCKS OF MODEL BUILDING**

The guaranteed utilization factor with this technology is at least 98%. The increase of the utilization factor with the model adjusting software can be guaranteed by reducing of those factors, where a process analyzer withhold uninterrupted operation of the process due to maintenance of the hardware and the software alike. Continuous automatic adjustment of the measured values by the software diminishes the time to be invested in model updating. The utilization factor is application dependent with conventional calibration methods. In complicated applications, such as CDU and blending applications, utilization factor cannot exceed 90%, and for the remaining part of the 10% samples there is no red flag alerting the process operator that the readings are outside the required performance for process control. Utilization factor of 98% is feasible for traditional analyzers, but only under strict conditions and at extra cost. For example, typical gasoline blending application requires five traditional analyzers and the combined utilization factor is approximately 90%. [4] Implementation of the software and adjusting the results based on laboratory analytical data that are fed in the system on a regular base reduces drastically time to be invested in frequent calibration model update. The ability of the system to adjust to measured results, which is based on the ongoing validation of previous measurements, guarantees reliability of the analytical results at any time.

Figure 4 shows how this software enables an analyzer to predict results after a crude switching, when usually manual model update is required to accommodate the new sample composition. The software ensures predicted values to comply with laboratory values at any time.

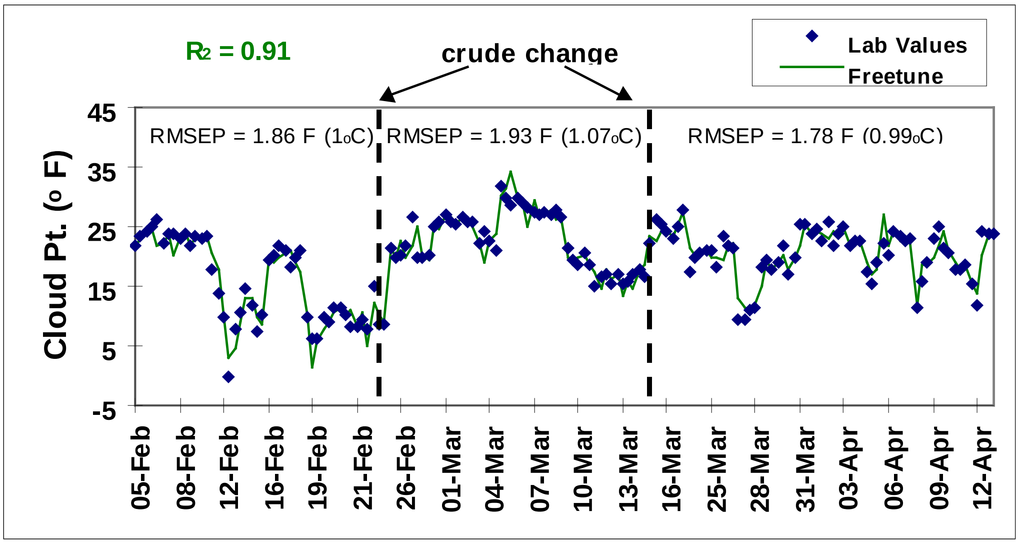


**FIGURE 4. RESULTS OF MODEL UPDATING DURING CRUDE SWITCHING.**

Efficient utilization of the feasibilities of the NIR process analyser with model adjustment software is achieved by placing the analyser in the control room, connected to the DSC by Modbus 485 or TCP/IP, as shown in Figure 5. This allows the operator continuously to update himself by real time analytical data, which are the keystones for NIR technology used for optimized cost effective refinery process control.

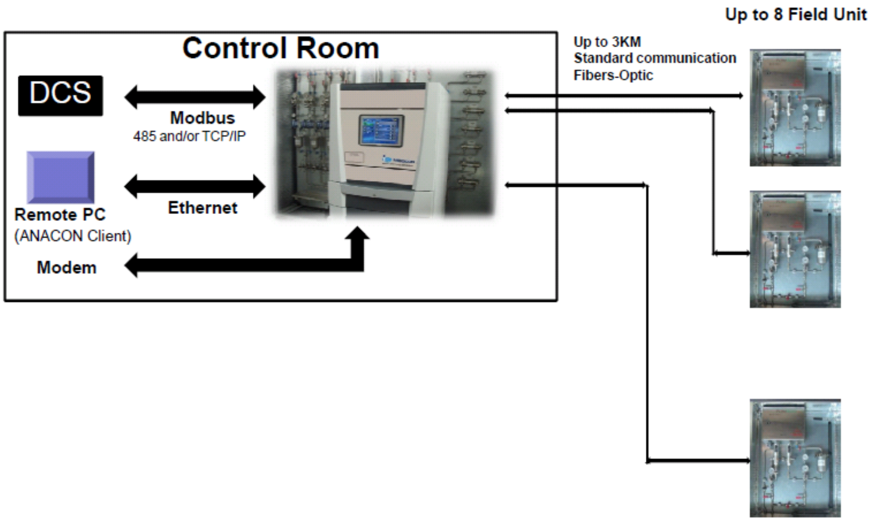


**FIGURE 5. TOTAL PROCESS CONTROL BY NIR TECHNOLOGY.**

## NIR PROCESS ANALYZER IN REFINERY PROCESS OPTIMIZATION.

Refineries are a complexity of different types of chemical and physical processes. The profitability of each individual process contributes to revenue and the profit of the entire refinery, by increasing the refining margin. Optimized refinery efficiency requires strict control of process parameters, based on real-time analytical data of feed and product process streams.

In process units that are based on physical processes, such as separation and distillation processes NIR analysers are very useful in adjusting cutting points of those distillates that are fully transparent, or that are not influence by differences in crude oil compositions, directing towards valuable refinery products. Similarly, NIR process analysers contribute in adjusting process conditions of chemical reaction based refinery units, such as catalytic cracking, isomerisation and alkylation reactions. Monitoring of the reaction products and reaction yields by NIR enables to achieve process conditions that lead to the highest yield in the consumption of catalysts or other chemical mechanisms taking place in a refinery unit. Blending of gasoline is a major application where NIR process analysers are successfully implemented in various refineries and blending stations worldwide. One of these refineries is Bazan - Oil Refineries Ltd in Israel. In the past gasoline blending was a batch wise production process. Each component stream comes separately into the blending tank. After introducing all components, samples of the blend are withdrawn for laboratory analyses. According to the analytical results the batch is approved or must be corrected and retested. The process of repair and retesting continues until achieving a blend with proper physical properties. Alternatively, the preferred mode of blending gasoline is by execution of the blending process in a continuous mode, as illustrated by Figure 6. All streams of gasoline are on line mixed, and the final blend bearing the required properties enters into the gasoline tank.

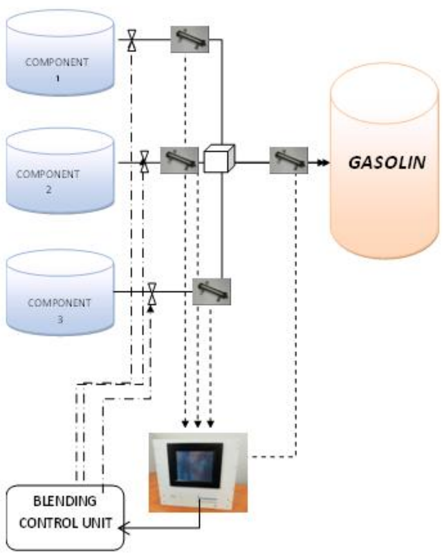


**FIGURE 6. GASOLINE BLENDING STATION WITH NIR PROCESS ANALYZER**

A variety of physical properties characterizes the European Standard for Gasoline, EN 228, or any required standard of gasoline, such as density, octane properties RON and MON, distillation curve, vapour pressure (RVP), aromatics, MTBE, olefins etc. These parameters must be controlled throughout the entire blending process to prevent production of off spec or borderline gasoline. The high cost and slow response time of laboratory analyses makes the investment in on-line process analyzers to control these parameters inevitable.

Conventional discrete on-line analysers have the following restrictions:

1. Each analyser is dedicated to measure only one specified physical property.
2. Measuring time depends on the ASTM method. Several identical analysers are often required for each analysis.
3. Discrete analysers like octane engines are mechanical analysers, based on moving parts, and dictates enhanced maintenance as compared to NIR analysers to guarantee keeping these analysers running in a continuous mode.

To overcome these drawbacks, NIR spectrometry based process analysers are the alternative solution to verify sustained production of in-spec gasoline. The benefit of these analysers is their potency to perform various analyses in multiple process streams, and performed by one single analyser. During the blending process, NIR process analyzers measure the physical properties of the incoming process streams and the final blend. The analyzers connected to the DSC fine tunes on-line the ratio between each individual process stream to maintain proper physical properties of the gasoline stream throughout its entire production. During the production, samples are withdrawn for testing by the laboratory. In any case of discrepancy between the NIR predicted chemical results and the laboratory analyses, the adjusting software will automatically make required adjustments to guarantee credible predictive analytical results.

Figures 7A and 7B illustrate the accuracy of the NIR predicted analyses as compared to laboratory analyses performed according to standard ASTM methods.

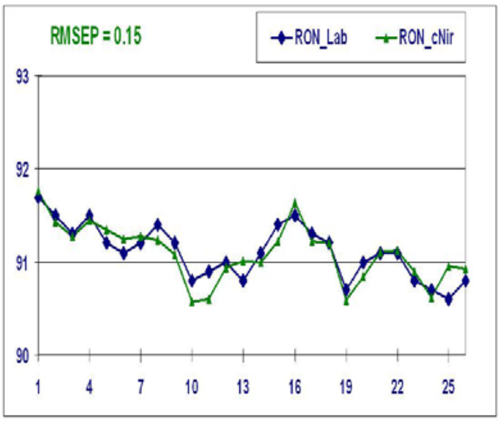


**FIGURE 7A. RON- NIR vs. LAB**

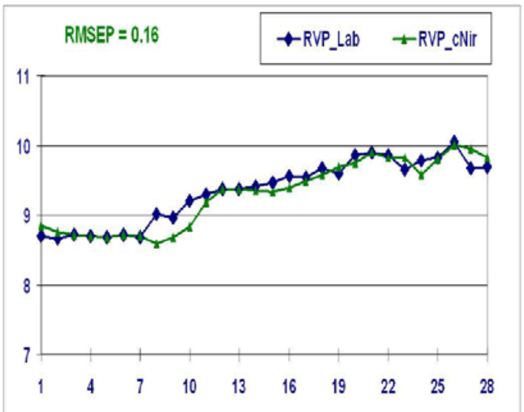


**FIGURE 7B. RVP – NIR vs. LAB**

Both figures show that the accurate accuracy of the analytical results which are provided by the NIR process analyzer is comparable to the accuracy of the ASTM analyses. This means, that the NIR process analysers have the potency to replace the on-line ASTM based process analysers and reduce the quantity of laboratory analyses, without endangering the product quality.

The benefit of such an action is:

1. Reduction of process analysers to one single analyser.
2. The potential to measure multiple properties.
3. Incorporation of an analyser that is free of moving parts.
4. No further need to keep costly and spare parts for just "in case of ".
5. Negligible investment in maintenance.
6. The NIR analyser is placed in the central control room, connected by fiber optics to up to eight different field units up to 2 miles remote. Discrete analysers and other correlative analysers with short distances between the analyzer and the measuring probe require investing, in appropriate fire and explosion proof shelters and electric communication lines with the DSC.
7. Introduction of NIR process analytics reduces laboratory ASTM analyses to final product quality approval only.
8. Maintenance is of NIR process analyzers is almost negligible as compared to ASTM based analyzers. The absence of moving parts reduces makes minimizes the need for complicated treatments of the instrument, and is mainly reduced to some cleaning of the lenses of the measuring probes and occasional changing of the lamps.
9. Model maintenance and calibration: Calibration of ASTM based analysers are generally requires physical changes of the instrument to be adjusted. In NIR process analysers, calibration and model verification is easily be performed by comparing NIR provided results with laboratory results. Particularly in case of persisting discrepancy between NIR results and laboratory results, model updating is required.

## RETURN OF INVESTMENT OF NIR PROCESS ANALYZERS IN REFINERY PROCESS OPTIMIZATION

Laboratory analyses are time consuming and expensive. In many cases analytical results come too late, to establish adequate process control. Integration of the NIR process analyzers in the process control of refinery units prevent the production of borderline and off-spec material, reduces time invested in reprocessing, and prevent "giveaways". NIR based process analyzers are of low cost. Only one analyzer is required to perform multiple streams and multiple variant analyzes of physical properties in process streams that are allocated at a distance far away from the central analyzer. These features, in combination with its low cost of maintenance reduce the return of investment to a short period of time.

## CONCLUSIONS

The commitment of continuous and strict quality control is inevitable to guarantee existence and surviving refineries in today's complex geo-political and highly competitive economic environment**.** Quality control, which is based on intermittent analyzes is not amendable anymore to optimize the capacity and quality in refinery process operations. Stringent control of process parameter is the fundamental to ensure operating a refinery unit in its most efficient configuration. Continuous control of the quality in feed, intermediate and final process streams is undisputable to guaranty the production of in-spec material at the highest possible capacity of the products of interest. Continuous process control requires investing

huge amounts of resources in on-line process analysers, either discrete ASTM based analysers or correlative analysers. Discrete analysers have the drawback of being dedicated to one single analyzes only. Their response time is relatively slow, and they are merely limited to serve one production unit only.
Beyond that, further investment in peripheral equipment and high costs of maintenance and annual payback increase even more the allocated resources for efficient performance of the refinery units. It is not conceivable that refinery must compromise about what equipment is required to minimize the risk of producing off-spec material or give-aways.

In contrast to the discrete analysers, correlatice analysers, such as NIR process analysers are low cost analysers, as compared to conventional ASTM based analysers, in purchase price and in maintenances. These analysers are multi property and multi stream analysers that can cover refinery units in at distance from the central analyser, which is placed in the control room. Bazan, Oil Refineries Ltd, the oldest and biggest refinery in Israel also considered the economic advantage of incorporation of NIR process analyzers in their refinery applications. The herby presented NIR technology has proven to be a sophisticated solution for successful control refinery processes. The basis of these analyzers is the principle of correlation between NIR spectral data with quantified values of physical properties. Fast measurements and data processing allow instantaneous to quantify a large variety of different properties, as required by the product specifications. The instrument is characterized by analytical reliability. Due to the absence of mechanical parts and its simple sampling system costs of maintenance are almost negligible compared to conventional analyzers. The overall NIR process analyzer is unique, as they are installable in the "safe zone" control room, while telecommunication optical fibers transmit the NIR beam to and from different field units. These units are assembled to different process streams allocated at a distance of up to 2 miles away from the central analyzer. Optical multiplexing technology enables instantaneously to measure up to eight different process streams, each with up to 10 measured properties, providing immediate analytical data to the operators in the control room.

Replacement of conventional mechanic analysers, such as on-line octane analysers, by NIR process analysers increased the amount of real time data available to the operators. Reliability and provision of accurate data with a negligible budget of maintenance favoured many refineries incorporate NIR process analysers as a keystone for cost effective process optimization. The outcome of efficiency in process operation is a noticeable reduction in operation costs, without affecting the production capacity or product quality. By that, the refinery increases its revenue, its profit and its economic growth. This enables the refinery to stand firm against any undesired influences which are caused by geo-political and highly and highly competitive economic environment.

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