Refractive index measurements perk up petrol profits

Traditionally, lab-based analysis has moved into the process environment.

BY JOHN GROETSCH JR.

In the mass production of refined oil products, the measurement and control of concentration is an important quality parameter. Continuous monitoring enables uniform product quality and minimum waste.

Unlike periodical sampling, continuous monitoring can provide instant feedback on changes in the process. Instant feedback can then lead to real-time process control.

Light incident on a solid object, liquid, or gas can reflect, partially reflect, or penetrate that substance. The degree of each is a characteristic property of the medium.

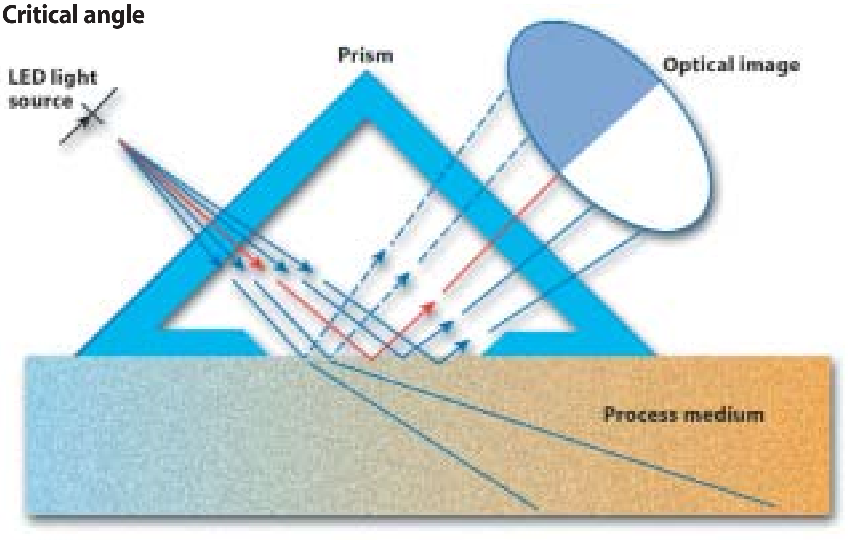
In addition to varying with the medium, the degree changes with the concentration of dissolved solids. The study of this property of light has developed into the science of refractometry.

One simple example of this property of light shows up when one puts a pencil in a glass of water. It appears the pencil is bending when in fact the light is bending. The rays distort by passing through the water, glass, and air, not because the pencil itself bends.

The amount of the apparent bending is characteristic of the water and the amount of dissolved solids. The presence of bubbles and suspended solids in the water does not affect the bending.

Light travels at different speeds in different media. The more dense a medium, the slower the speed of light in that medium. When light passes from one medium to another at any angle other than 90°, it changes not only speed but also direction at the boundary between the two media.

Critical angle



It is impossible to have an angle of refraction greater than 90°. It follows that for all angles of incidence greater than the critical angle, the light will experience total internal reflection.

In order to utilize this principle to make a useful process measurement, the generated reflected/refracted image must focus on and project onto a measuring element. This focusing element is a prism.

The light passes into a prism, which directly contacts with the process fluid. The light contacts the prism/process interface at various angles. Some rays are totally reflected, and some rays refract. The transition point between total reflection and refraction defines the refractive index of the process fluid.

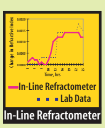
The refractive index of a medium is the speed of light in air divided by the speed of light in the medium. This calculation method is the transmission method of determining refractive index. It is useful in the laboratory but not for process measurements.

When light passes from one medium to a more optically dense medium, there is both reflection and refraction for all angles of incidence. Starting with a small angle of incidence, there will be a weak internally reflected ray and a strong refracted ray.

As the angle increases, the angle of refraction also increases. At the same time, the intensity of the reflected ray gets stronger than that of the refracted ray. Finally, at the critical angle of incidence, the angle of refraction becomes 90°.

As the concentration of dissolved solids in the process fluid changes, the refractive index changes. Increasing concentrations of dissolved solids increases the amount of refraction and reduces the amount of reflection. As the amount of dissolved solids decreases, the amount of refraction decreases, and the amount of reflection increases. From these changes in the optical image, the measurement occurs.

In-line RI applications enrich refinery ops

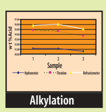


Lube oil processing: The refractive index of lube oils relates to the viscosity index (VI), which determines the quality of lube oil. The crude oil type also influences the final VI of lube oil.

The challenge to the refiner is the selection and blending of the crude type to optimize the production of the desired lube oil. An in-line refractometer can help control the final quality or final VI of the lube oil.

Several types of process changes can affect VI, including the blend stock rates and extraction tower temperature. There is a finite residence time for the effect of a given process change to pass through the process unit.

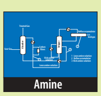
However, lab samples often cannot take place fast enough to avoid a deleterious effect to the process. Only an in-line sensor can establish the correlation between the rapid process changes of VI that can lead to an adjustment to the efficiency of the process.



Sulfuric acid alkylation: The alkylation process used in refining is the reaction of isobutane with an olefin to form an isoparaffin compound with superior stability and antiknock characteristics.

The compounds improve the octane rating of aviation gasoline and motor fuel. In the sulfuric acid alkylation unit, sulfuric acid helps convert isobutane into isooctane.

The process depletes the acid's strength. It is important to measure the acid strength to prevent a runaway reaction that occurs at low acid levels. In-line monitoring provides earlier warning than titrating samples in the lab or using a hydrometer and allows dramatic reduction of the actual runaway set point value.

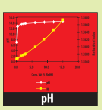


Amine/Acid gas sweetening: Refineries that process high sulfur or sour crude oil generate hydrogen sulfide (H_2S), a pollutant that the refinery must capture. An acid gas unit uses a water-based amine solution to remove the H_2S.

There are three types of amines: monoethanolamine (MEA), diethanolamine (DEA), and methyldiethanolamine (MDEA), with each having a unique relationship between RI and concentration.

MDEA absorbs the greatest amount of H_2S, while MEA absorbs the least. Due to the increasing amount of sour crude oil processing, most amine units use either DEA ($0.50/pound) or MDEA ($1 to $1.50/pound) because of their higher absorption.

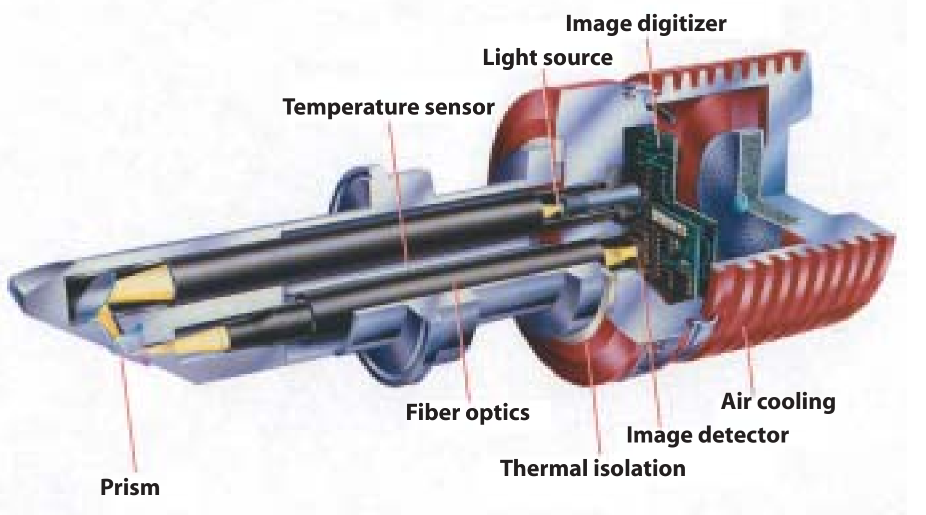
RI sensors can install in three locations—rich amine, lean amine, and the reflux accumulator—to reduce amine consumption and improve the process.



Scrubber applications: Scrubbers remove unwanted components from process streams. The removal may be necessary because the product is corrosive or its discharge is limited due to environmental regulation.

Acids are a commonly removed component. Removing the acid prevents system corrosion, meets environmental regulation, and improves production. Sodium hydroxide (caustic) neutralizes the sulfuric acid.

Fresh or makeup caustic adds as it depletes. An in-line monitor system ensures that the sudden drop in pH that can occur when the caustic concentration falls in these kinds of reaction doesn't.



Refractometer report card

Concentration is an important final quality parameter. Refractometers work in many industries and are a quick, effective way of measuring concentration. Their application requires only that the measured component be a dissolved solid or miscible liquid into another solution.

Refractive index measurements of liquids, which have traditionally happened in the lab, are taking place in the process environment. The process measurement of refractive index is now reliable, simple, and cost effective.

An in-line process measurement of refractive index works as a real-time predictive tool for the final concentration, viscosity, and other process parameters. The speed of response enables production optimization.

Cost reduction is possible by reducing the variation of the mean average product concentration and depends on the component's value.

The refractometer determines the concentration of a solution by measuring the optical refractive index. Ernst Abbe invented the refractometer in 1874 when he published a description of an apparatus for determining the refractive index (RI) of solids and liquids.

The RI is a lab technique that has made the transition into process measurement. This transition required that laboratory sensors get much tougher. In-line sensor construction must withstand harsh conditions.

The internal in-line sensor construction has three basic components: a light source, an optical prism, and an image analyzer.

An all-digital in-line process refractometer uses a charge coupled device (CCD) microchip to determine the position of the borderline and relates its position to refractive index and concentration. The CCD then converts this optical image into a digital signal. This conversion eliminates drift, increases the stability, and eliminates human error.

An instrument that measures by digitizing the optical image truly determines the liquid's refractive index and concentration. The interference, due to back scattering from suspended solids and bubbles, does not register because it occurs outside the critical angle region.

This advancement to digital signal processing yields a high accuracy and stable dissolved solids concentration measurement unaffected by typical interference.

Cost analysis

A sensor installed in a reflux accumulator can save money by reducing amine chemical losses and steam usage.

If the amine concentration in the reflux is high, this means that the system is losing amine in the reflux. By lowering the reboiler temperature, less amine escapes, and less steam is necessary.

This data is for a typical refinery that processes 100,000 barrels per day of crude.

Amine costs	$US	Amine losses/ RI savings
DEA	$0.45–$0.50 per pound	15,000 pounds/ month (about $80,000/year)
MDEA	$1.05–$1.50 per pound	3,000 pounds/ month (about $40,000/year)
Steam	$3.50 per 1,000 pounds	60,000 pounds/ hour—RI saves about 2% of this ($32,000/year)
Lab technician	$25.00/hour, 3 hours/day	$25,000/year

The RI is temperature dependent. To generate a stable, accurate, and reliable temperature measurement is important.

Due to the effect of temperature on RI, mounting and location of the prism is important to the measurement. Locating the sensor in turbulent flow region away from pipe walls keeps the prism at the same temperature as the process fluid.

A precise temperature measurement ensures the proper concentration indication.

If process residue fouls the sensor's prism, an accurate in-line measurement can't happen. Typically, either a water or steam wash is used to wash the prism. Steam works when the monitored liquid is particularly sticky or tenacious. In applications where steam may bake the process liquid onto the prism, pressurized water works as the prism wash medium.

A process refractometer needs to measure refractive indices over a wide range and with high accuracy. The typical range of a refractive index is between 1.3 and 1.6. Suspended solids or bubbles do not influence the refractive index, whereas the solution's total density is affected. An RI will remain constant for a saturated or supersaturated solution.

This analyzer species works in refinery processes such as sulfuric acid alkylation, amine gas treaters, caustic scrubbers gasoline interface, hydrotreater, and lube oils production.

The ability to make this measurement has eliminated sampling, improved product consistency, and reduced waste. IT

Behind the byline

John Groetsch Jr. has a degree in chemical engineering and more than 14 years' experience in optical and acoustical-based in-line instrumentation. He is a member of ISA and AIChE. He is the general manager of K-Patents, Inc. Contact him at j.groetsch@kpatents-usa.com.