1) Optical fuel quality sensor for measuring combined physical properties in hazardous and non hazardous areas

2) Background of the Invention:

2.1) Field of the invention

The Present invention relates to a measuring device to determine properties of liquids by optical means because optical constants depend on chemical composition and therefore are unique to every type of liquid.

3) Description of the Prior Art:

There are various types of sensors on the market today:
-Refractive measuring devices can only determine one property
-Electro chemical sensors can determine many different properties, but these devices require constant cleaning and calibration
-Spectrometric measuring devices for analytical determination of liquids

However, neither of these systems are able to determine fuel quality on its own in the field. These output laboratory quality results which makes them expensive and quite difficult to operate. Also by nature, handling of fuels is hazardous and requires very specific safety compliances of sensors. Measurement principles are therefore limited to the capabilities of compliance outlined in UL 913 and IECEx.

3.1) Description of prior art for refraction

There already do exist refractive measuring devices that can determine the physical properties of liquids. However, all of these systems use complicated optical arrays and cavities to determine the properties, which make them expensive and quite difficult to operate. The prior products use a point source light, usually a LASER light source, with one light receiver, pointed at an angle through what is being measured. The light then refracts and the receiving device, usually a CCD, determines the shift in the light path. See diagram 1

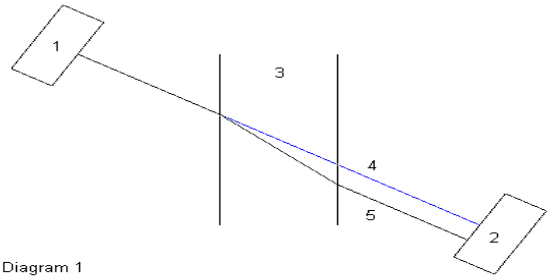


Diagram 1

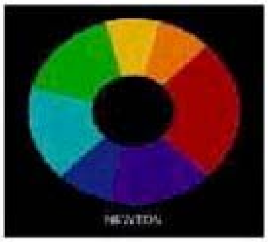
This system uses sophisticated components, often together with lenses (not shown). This makes for an expensive product.
1 – Point light source, usually a LASER.
2 – Light receiving device, usually a CCD
3 – Liquid being measured, either flowing or stationary
4 – Extension of original light beam (un-refracted) from light source (1), to show difference in comparison to beam number 5
5 – Refracted Light beam.

3.2) Description of the prior art for polarization

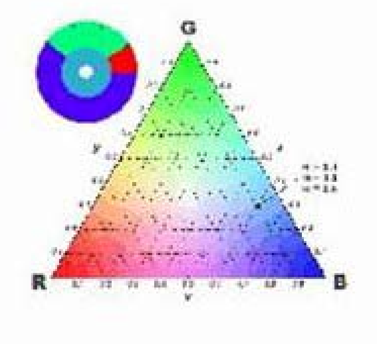
US4158506 and DE3931540 describes an ellipsometer .Techniques disclosed in the prior art evolved for laser sources. Similarly, the extensive use of waveplates as well as optical detectors which are not of significant importance for discriminating purposes. Furthermore, the Stokes parameters acquired form these elements are not sufficient to clearly distinguish the Polarization State of the optical beam for sensitive circumstances

3.3) Description of prior art for colour

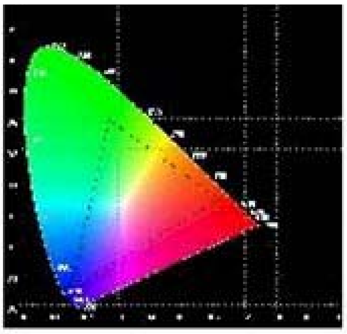
The three most popular color models are the following:



Maxwell Triangle:
Very popular, it describes all colors with reference colors with three axis, the X, Y and Z



CIE Chromaticity Diagram:
Very popular, it describes all colors with a scientific approach in U and V coordinates.



Color detectors in their simplest form produce an output for a specific color from a surface or liquid. This is done with specific lights or specific filters. Color sensors of this kind are typically used in applications with known colors like in the printing industry. Other known devices are sophisticated color sensors for scientific purposes. They always relate to CIE or Maxwell's triangle and are manufactured with various technologies. All of these color sensors have the disadvantage of being too simple or too sophisticated. None of them fulfill the need from the industry which wants to measure or "teach" a color in the one axis rainbow spectrum.

3.4) Short definition of fuel quality

A. Crude oil comes in many variations
B. Gasoline and diesel fuels depend on the refining facility and type of crude oil used
C. Bio fuels from corn and alcohol from sugar cane consist of many different chemical substances
D. Knowledge from water content, toxicity and alterations from fuel is desired
E. Consistence of fuel changes also over time, depends on the ambient temperature and is sensitive to environmental factors like pressure, exposure to light and so on.

4) Summary of the invention:

The present invention relates to a device which is capable to determine quality of any kind of fuel. A combination of all or part of the following physical measurements is used to determine quality of fuel

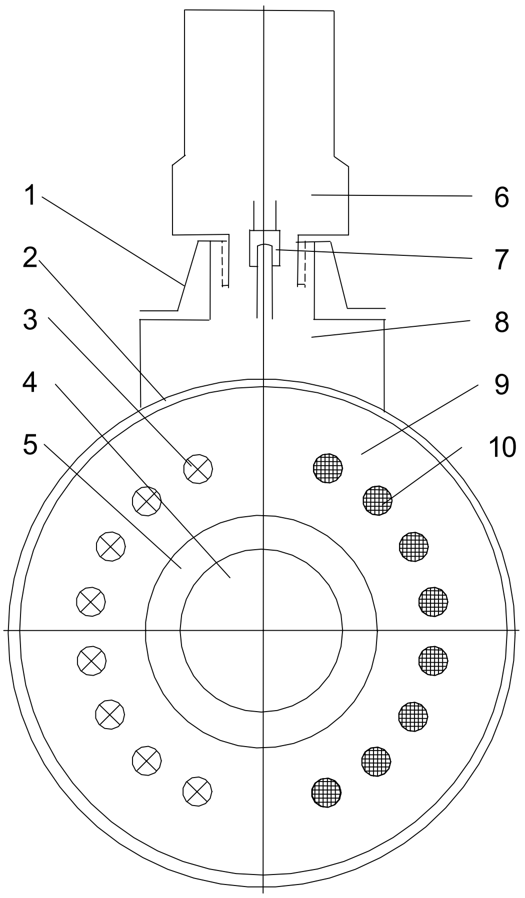
A Index of refraction
B Polarization
C Color
D Fluorescence
E Spectrometry

Quality of fuel and its definition of content can be made with the results and combination of these measurements.

4.1) Brief description of the principle and how the sensor works

Fuel passes through a non-opaque tube. Around the tube are lights on one side and light sensitive detectors on the other side. Every light and every detector are constructed in a way to determine refraction, polarization, color, fluorescence and spectrometry.

4.2) Mechanical construction

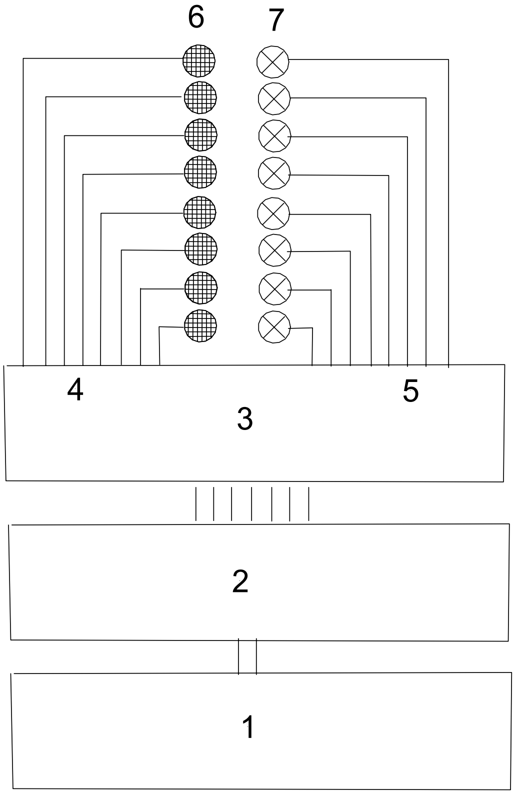


1 = Earth clamp to ground battery housing to sensor
2 = Sensor housing
3 = Lights	Typical for refraction = 2
Typical for polarization = 2 to 4
Typical for color = 2 to 4
Typical for fluorescence = 1
Typical for spectrometry = 1
4 = Fuel passing through
5 = Non-opaque tube
6 = Power pack
7 = Power – Sensor connection on a screw flange for replaceable power pack
8 = Radio frequency transmitter for data transmission
9 = Electrical circuit board in sensor
10 = Photo sensitive detectors – typically one for each light

This construction allows compliance to safety regulation

4.3) Electrical construction

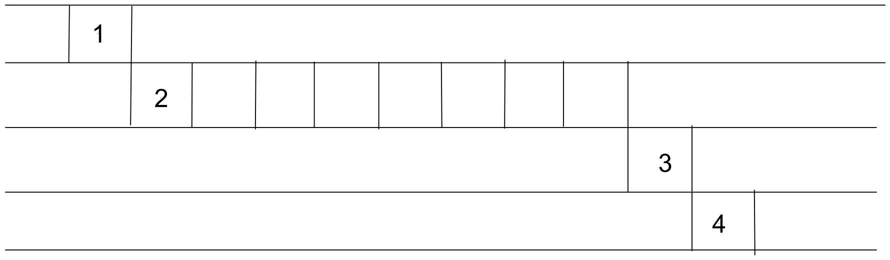
A microprocessor switches the lights on sequentially and at the same time the microprocessor captures results from photo detectors. With this construction interference from one to another measurement is not possible.



1 = Power pack
2 = Radiofrequency transmitter
3 = Microprocessor
4 = Input for detecting signals from photo detectors
5 = Output for switching lights
6 = photo detectors
7 = Lights

Lights are switched in a time sequence for measuring refractive index polarization and fluorescence

4.4) Time sequence



1. = Command via radio frequency to start measurement
2 = Switching on one light after another and capture data from foto detectors sequentially
3 = Process data from foto detectors to physical values
4 = Send data out via radio frequency

5. Detailed description of the measuring principles:

5.1) Refractive Index

5.1)1. Scientific principle

The principle of this part of the invention is based upon Snell's law:
$n_1\,\theta\sin_1 = n_2\,\theta\sin_{2.}$
In this equation n_1 is the refractive index of the surrounding medium and n_2 is the refractive index of the substance being measured.
θAnd $_1$ is the angle at which the electromagnetic wave (Referenced as em or electromagnetic wave or light through θout document) touches a substance with respect to the normal and $_2$ is the angle at which it goes in to the liquid with respect to the normal.
– The line perpendicular to the surface at which the angles are measured in reference to.
Index of Refraction – determined by dividing the speed of light in the medium by the speed of
light in a vacuum (C_0 / v)

5.1)2. How it is done practically in this invention

The system uses one or more light emitting devices opposite one or more light detecting devices as in figure 2. Figure 2 shows an example involving 2 emitters and 2 detectors, although they can be arranged in other ways also, they do not have be in equal quantities. A slit or pillar is put in front of both light emitting devices to break the electromagnetic wave down into two separate ones. This is done because the light in the middle of the emitter will fall at an angle of 180 degrees on to the curved or straight liquid holder or directly on to the liquid, which will result in no refraction. However the remaining light will refract and give us our reading.
In the following figure 1, this basic refraction principle, on which the product is based can be seen.

Description of Figure 1

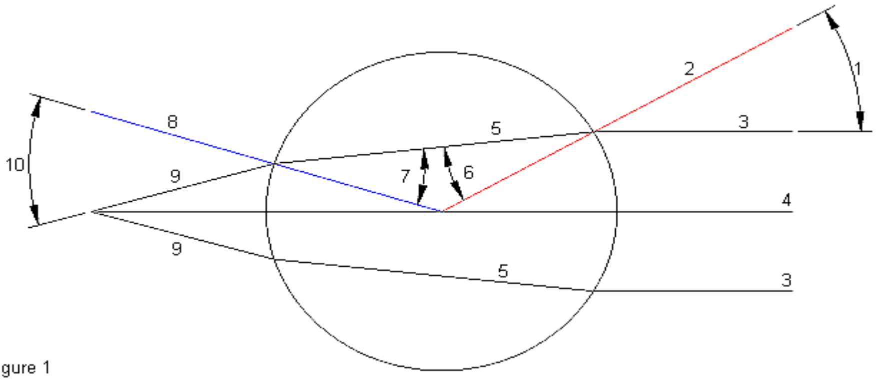


Figure 1

* - Lines 3, 5 and 9 represent electromagnetic waves.
1 – Angle of incidence of incoming electromagnetic wave 3 from the surrounding medium into liquid.
2 – Normal for lines 3 and 5.
3 – Incoming electromagnetic wave
4 – Center line
5 – Refracted incoming electromagnetic wave, following from line 3.
6 – Angle of refraction of incoming electromagnetic wave 5 from the surrounding medium into liquid.
7 – Angle of incidence of incoming electromagnetic wave (now outgoing) from liquid to surrounding medium.
8 – Normal for lines 5 and 9.
9 – Refracted outgoing electromagnetic wave, following from line 5.
10 – Angle of refraction of outgoing electromagnetic wave 9 from the liquid to the surrounding medium

Description of Figure 2:

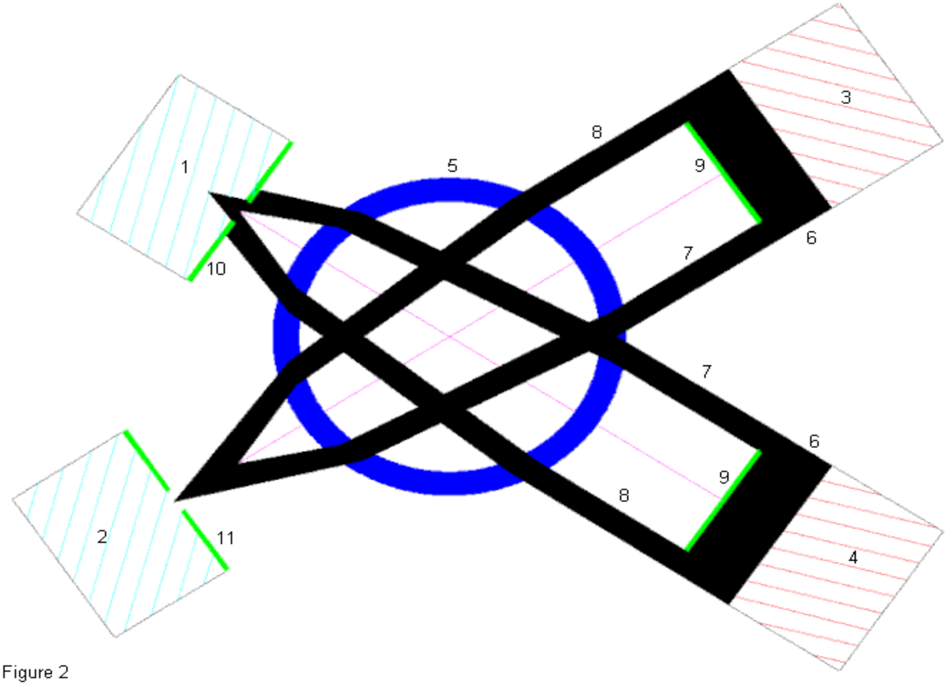


Figure 2

1 – Light detecting device receiving light from light emitting device 4.
2 – Light detecting device receiving light from light emitting device 3
3 – Light emitting device directing light to light receiving device 2
4 – Light emitting device directing light to light receiving device 1
5 – Liquid being measured. The liquid may be flowing or contained in a container of any shape.
6 – Light emitted by light emitting devices before reaching masks (9).
7 – Light emitted by light emitting devices after passing through masks (9).
8 – Light emitted by light emitting devices after passing through masks (9).
9 – Mask or pillars put in front of light emitting devices to change the way light reaches detectors. It can be in any shape or size.
10 – Mask placed in front of light detecting device. It can be any shape or size.
11 – Mask placed in front of light detecting device. It can be any shape or size.

Remember also that when a beam of light strikes a curved piece of a non-opaque substance, the thru light will go to a common focal point. The focal point is determined simply by the diameter of the curvature and the index of refraction of the substance. See figure 3. A circle is shown for ease of reference.

Focal Length = n D / [4 (n-1)]

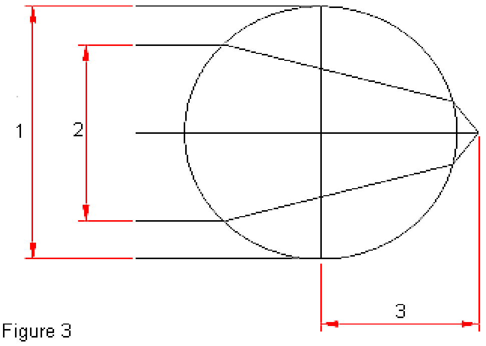


Figure 3

<u>Description of Figure 3:</u>
1 – Diameter of curved non-opaque surface
2 – Incoming light
3 – Focal Length

The curved piece of material in this invention is the tube through which the liquid flows. Therefore the focal length will remain constant unless liquid flows through. This change of focal length is what the circuit requires.

As with the light emitting devices, the light receiving devices also have masks or posts in front. As can be seen in figure 2, the photo-transistors can be placed in different locations, one is further back than the other with respect to their incident LED’s. This means that each photo-transistor will receive different amounts of light depending on the liquid or purity of the liquid being measured.

5.2) Polarization

5.2)1. Scientific principle

A polarization meter is designed for determining the Polarization State of a monochromatic optical light pulse produced by a light emitting diode. Using polarization filters, each polarized beam is fed to two photodetectors that measure intensity. The advantage of such a device is to enable optical polarization analysis without the use of mechanical moving parts. Stokes parameters are obtained from the intensities measured from the four photodetectors and polarized intensity is calculated

The present invention relates to a polarization meter, a device that senses the Polarization State of monochromatic light. The device measures all the parameters of the polarization state of light: the degree-of-polarization, azimuth angle, ellipticity and the polarized intensity through Stokes parameters calculations. Since there are no moving parts, the device requires only a short time for data acquisition while maintaining high precision and accuracy, solving previous problems encountered by polarization meters with moving parts, hence enabling a wider range of applications and lower costs.

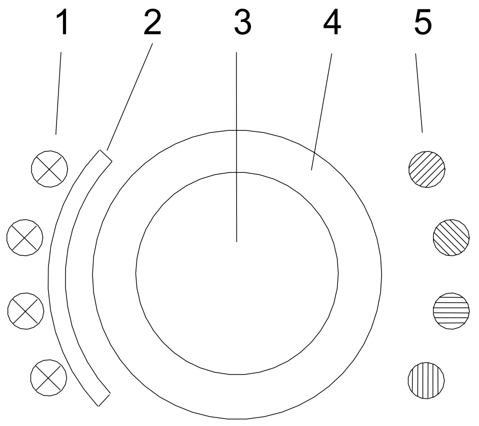
Briefly, the subject invention is directed to an effective, inexpensive and precise way to define the effect of a clean, well-conductive smooth surface on the polarization of monochromatic light using ellipsometry techniques.

Primarily, the source of light used in this device is an LED designed to give a pulse of light when required. Previously, continuous light sources or laser beams were used, the first is a slow technique and unnecessary, while the latter is of very short pulse width that accuracy and information are compromised. Therefore, a pulsating LED with a controlled pulse width is the optimum solution with high accuracy.

Determining the parameters of an optical pulse involves an array of four photodetectors. A polarizer, each with a different orientation, covers each photodetector. This configuration is ideal for obtaining the Polarization State of monochromatic light. Previously, we discussed prior arts using waveplates and a higher number of photodetectors to obtain parameters. We have found that with only four photodetectors, their polarizers and no waveplates you can obtain the same parameters, hence, saving time, cost and space while maintaining accuracy.

The electric signals acquired from the photodetectors are used in conjunction with a microprocessor to produce information about the state of polarization. These calculations involve Stokes parameters, however, further calculations and derivations (e.g. Linear polarization) were required to obtain a clear and significant discriminator on the effect/change materials inflict on the polarization state of light, particularly, the effect of subclasses of certain materials on the orientation/state of polarized light.

Description of Figure:
Side view of polarization sensor



1 = Lights
2 = Filters
3 = Glass tube
4 = 4 photo detector with different orientation

The operational principle of the device representing the invention is the following: each element of the four-element photo detector array is connected to a microprocessor, where a program is designed to acquire the values from the four elements sequentially. These values then undergo signal conditioning and calculation to obtain all the parameters of the Polarization State of monochromatic light.

To capture the intensities for the polarization state parameter calculations, the photo detectors are covered with polarizers oriented in 4 direction each 45 degree phased as shown in the drawing

This section gives a mathematical description of the calculation of the degree and orientation of the polarization of a beam, based on the observed intensities. Each target exposure measures the component of the incoming light polarized in two different orthogonal directions. The symbol I_{α} is used to represent the intensity of the component polarized at an angle α to the reference direction, then in each exposure the **O** ray image records I_{α} and the **E** ray image records $I_{\alpha+90}$.

Consider a beam of light in an arbitrary state of polarization that is analyzed by four different types of polarizers. The four transmitted intensities are given by I_0, I_{90}, I_{45}, and I_{135} where:

$\alpha = 0 \rightarrow I_0$ and I_{90}
$\alpha = 45 \rightarrow I_{45}$ and I_{135}

- I_0 is the intensity after propagation through an isotropic polarizer
- I_{90} is the intensity after propagation through a horizontal linear polarizer
- I_{45} is the intensity after propagation through a linear polarizer oriented at 45º
- I_{135} is the intensity after propagation through a linear polarizer oriented at -45º

Malus' law gives these intensities as

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- I_{90} is the intensity after propagation through a horizontal linear polarizer
- I_{45} is the intensity after propagation through a linear polarizer oriented at 45º
- I_{135} is the intensity after propagation through a linear polarizer oriented at -45º

Malus' law gives these intensities as:

$$I_0 = I_p \cos^2\theta + \frac{I_u}{2}$$

$$I_{90} = I_p \cos^2(90-\theta) + \frac{I_u}{2} = I_p \sin^2\theta + \frac{I_u}{2}$$

$$I_{45} = I_p \cos^2(45-\theta) + \frac{I_u}{2}$$

$$I_{135} = I_p \cos^2(135-\theta) + \frac{I_u}{2} = I_p \sin^2(45-\theta) + \frac{I_u}{2}$$

Here, I_p and I_u are the polarized and unpolarized intensities of the incoming light, and θ is the angle between the plane of

Here, I_p and I_u are the polarized and unpolarized intensities of the incoming light, and θ is the angle between the plane of polarization and the reference direction.

In 1852 George Stokes proposed the use of a vector which contains only four observable quantities in order to describe the Polarization State of light. The stokes parameters are defined as:

$$I_0 + I_{90} = \left(I_p \cos^2\theta + \frac{I_u}{2}\right) + \left(I_p \sin^2\theta + \frac{I_u}{2}\right) = I_p\left(\cos^2\theta + \sin^2\theta\right) + I_u$$

$$= I_p + I_u$$

$$= I$$

$$I_0 - I_{90} = \left(I_p \cos^2\theta + \frac{I_u}{2}\right) - \left(I_p \sin^2\theta + \frac{I_u}{2}\right) = I_p \cos^2\theta - I_p \sin^2\theta$$

$$= I_p \cos 2\theta$$

$$= Q$$

$$I_{45} - I_{135} = \left(I_p \cos^2(45-\theta) + \frac{I_u}{2}\right) - \left(I_p \sin^2(45-\theta) + \frac{I_u}{2}\right) = I_p \cos^2(45-\theta) - I_p \sin^2(45-\theta)$$

$$= I_p \cos 2(45-\theta) = I_p \cos(90-2\theta)$$

$$= I_p \sin 2\theta$$

$$= U$$

Using these definitions the following can be derived,

$$I_p = \sqrt{Q^2 + U^2}$$
$$\theta = \frac{1}{2}\tan^{-1}\frac{U}{Q}$$

Where, I_p is the polarized intensity and θ is the orientation of the plane of polarization.

We found there is no need to implement two more photodetectors and waveplates to acquire the value of the last Stokes parameters ($\boldsymbol{V}$), since it can be derived from the previous equations by substituting the acquired values to obtain $\boldsymbol{\varepsilon}$ as follows:

$$Q = \cos 2\varepsilon \cos 2\theta$$
$$V = \sin 2\varepsilon$$

We found that the Stokes parameters are not enough to distinguish between subclasses of materials where the differences

are small, therefore, further calculations are required:

$$P_l = \sqrt{Q^2 + U^2}$$
$$P_c = \frac{U}{I}$$
$$P_e = \sqrt{Q^2 + U^2 + V^2}$$
$$P_d = \frac{P_l}{I}$$

Where,
$\boldsymbol{P_l}$ is the linear polarization
P_c is the circular polarization
P_e is the elliptic polarization
P_d is the degree of polarization

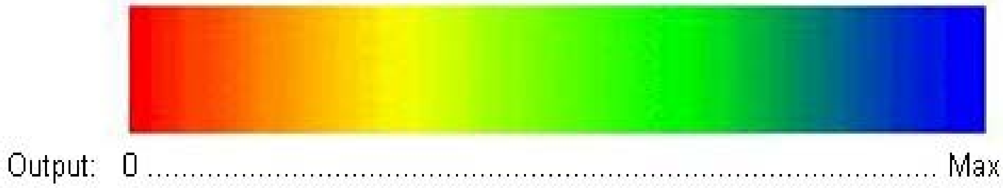
We find clearly that the effect of the material is on the orientation of the elliptically polarized beam, as linear polarization increases, circular polarization decreases, and vise versa for an elliptically polarized beam.

5.3) Colour

5.3)1. Scientific principle

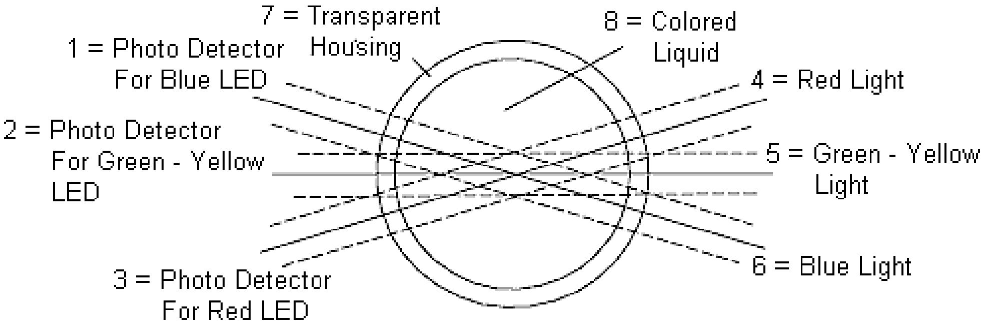
This invention uses a new method of reading colors. The color sensor is relating the output to the rainbow colors starting on blue over green and yellow to red and into violet. This is made with flashing colored lights in blue green yellow and red built in to the sensor.

Figure 1



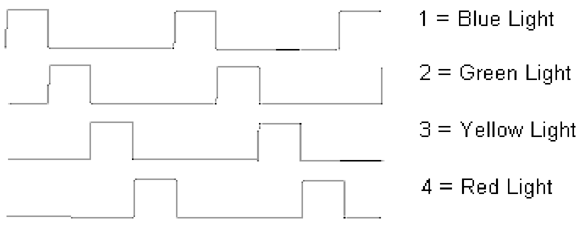
The geometric configuration of the colored lights in liquid:
Colors are subtracted to conclude proper color.

Figure 2



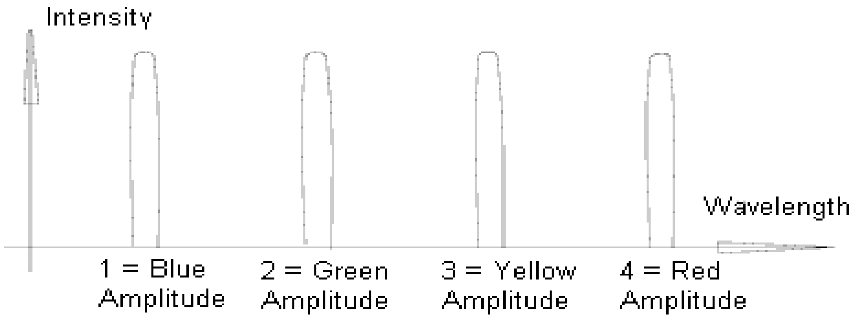
Shows an example with 3 colored lights: blue, green and red.
1, 2, 3 = photo detector
4, 5, 6 = colored lights
7= transparent housing
8 = colored liquid to measure color

Figure 3



Shows an example with 4 colored lights: blue, green, yellow and red.
Light is shifting from one color to the next. Periodically one light is switched on and off one after another in the sequence 1, 2, 3, 4 shown in the time diagram

Figure 4



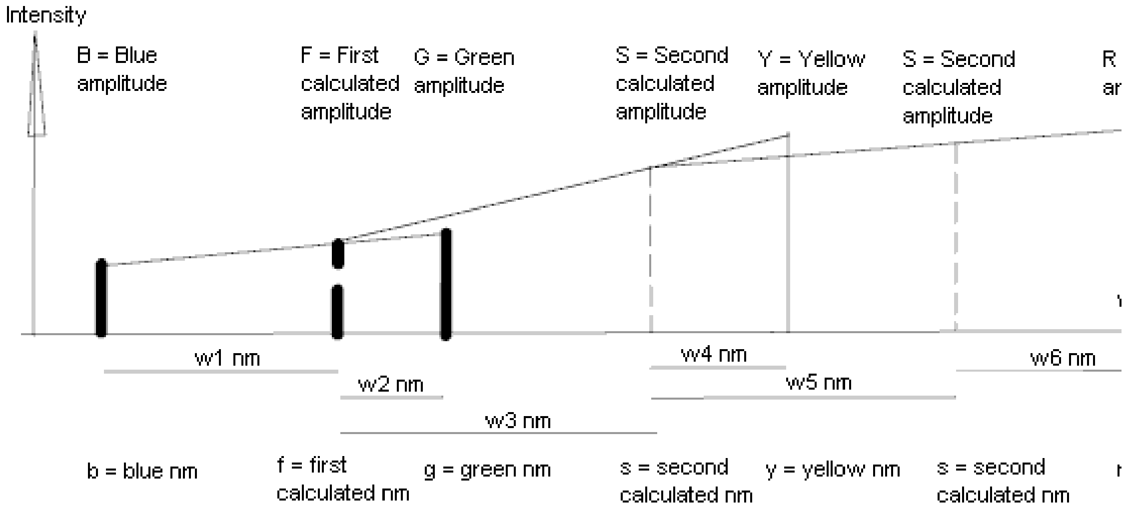
Shows an example with 4 colored lights: blue, green, yellow, and red.
Output from the photo detector of the rainbow color sensor. Each light makes an output in the photo detector. The scattered light from a surface is known by its wavelength. Each light when switched on results in an output in the photo detector.
1, 2, 3, 4 = amplitude measured from the photo detector. Each can vary from 0 % to 100 %

$$w_1 + w_2 = g - b$$

$$\frac{G}{B} = \frac{w_1}{w_2}$$

Figure 5

Calculation for step 1



$$w_1 = \left(\frac{(g - b) \times G}{G + B} \right)$$

If G > B:

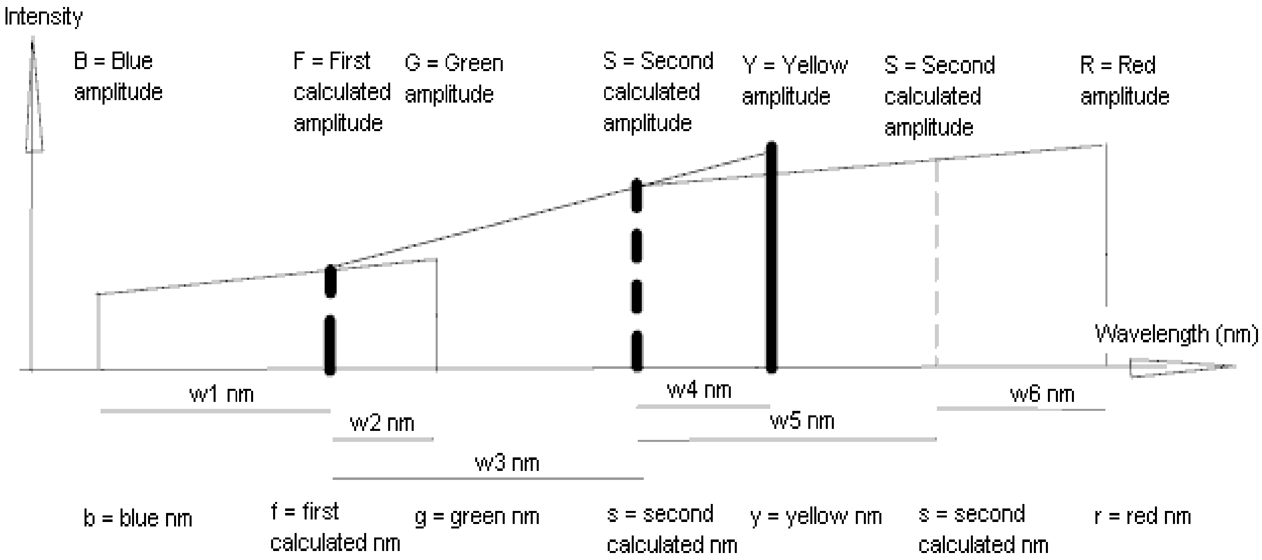
$$F = \left(\frac{(G - B) \times G}{G + B} \right) + B$$

If B > G:

$$F = \left(\frac{(B - G) \times G}{G + B} \right) + G$$

Figure 6

Calculation for step 2



$$w_3 = Y\left(\frac{(y - b - w_1)}{F + Y}\right)$$

If Y > F

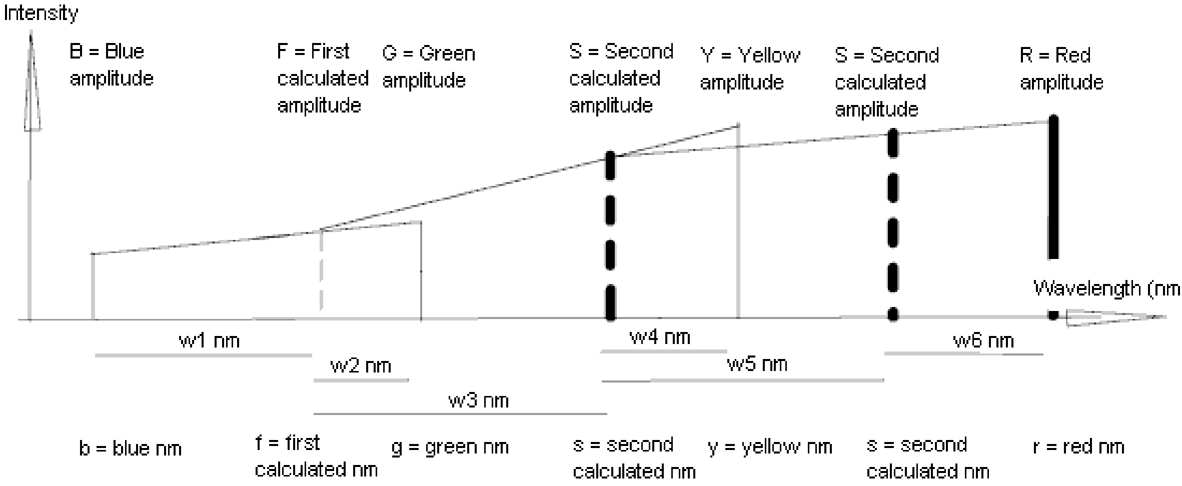
$$S = Y\left(\frac{(Y - F)}{F + Y}\right) + F$$

If F > Y

$$S = Y\left(\frac{(F - Y)}{F + Y}\right) + Y$$

Figure 7

Calculation for step 3



$$w_5 = R\left(\frac{r - b - w_1 - w_3}{S + R}\right)$$

Total result = rainbow = output color = w1 + w2 + w3
For liquids result is inverted because liquid acts like a filter for light

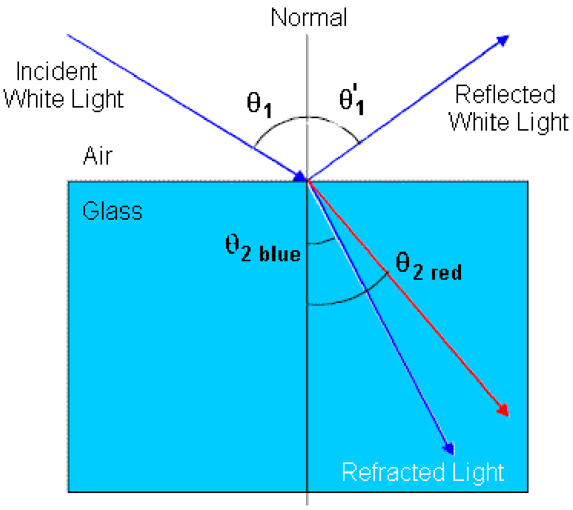
5.4) Fluorescence

Near ultraviolet or ultraviolet light causes in certain fuels fluorescence – meaning if light passes through fuels it changes not only its spectra but also quantity that more light is

5.5) Spectrometry

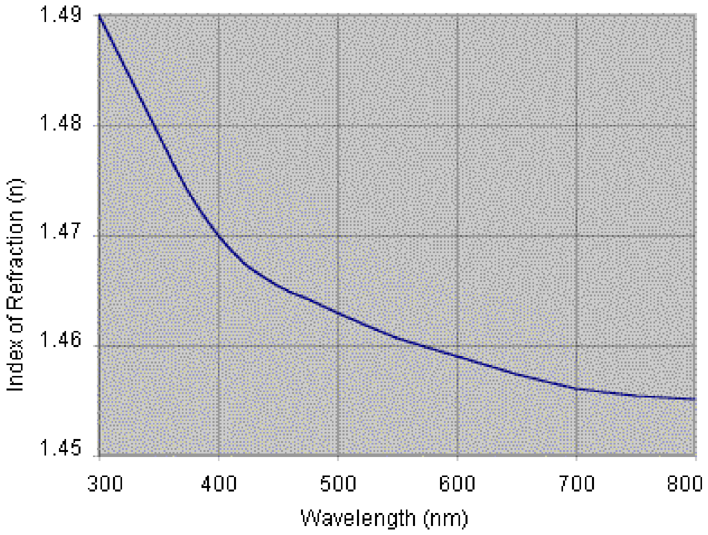
The principle of obtaining the spectra of light is basically refraction. Simple, single wavelength refraction consists of the incident beam, the reflected beam and a single refracted beam.
However, to obtain the spectra of light, white light is used, which is made up of the whole visible spectrum. Now, as the graph below shows, different wavelengths have different refraction coefficients (n values). And since white light has many wavelengths incorporated into it, it can easily be seen that there will be many

refracted rays. This is called chromatic dispersion, in which "chromatic" refers to a colour associated with each wavelength and "dispersion" refers to the separation of the wavelengths of colours. This then produces the pretty spectra. The figure aside shows the blue and red rays, all others, green, yellow, violet are in between. Generally, the index of refraction in a medium is larger for a shorter wavelength (blue light) than for a longer wavelength (red). This means that when white light refracts through a surface, the blue components bend more than the red components, with the intermediate colours undergoing intermediate bending.



The index of refraction as a function of wavelength for fused quartz. Light with a short wavelength, corresponding to a higher index of refraction, is bent more upon entering quartz than light with a long wavelength

.



Actual representation of the prism spectra

Claims

6.1 General claims

6.1.1 Fuel sensor using physical values for defining quality

6.1.2 Fuel sensor built with a transparent tube and lights on one side shining through the tube, through the fuel and on the other side into photo detectors

6.1.3 Fuel sensor with lights and photo detectors and optical masks, filters and lenses mounted in a way that refraction, polarization, color, fluorescence and spectrometry from fuel can be calculated and processed and quality assessed.

6.1.4 Fuel sensor with built in opto-electronics with WiFi data transmission and a battery pack certified for use in hazardous areas

6.2 Refraction claims

6.2.1 A liquid refraction measuring device which uses 2 or more light sources to obtain a complementary reading over a preferably round flow of liquid.

6.2.2 A liquid refraction measuring device with a mask placed in front of each light source, creating the desired light “shape”, preferably eliminating the light in the middle, for it will not refract.

6.2.3 A liquid refraction measurement device were the light receiving devices Are placed in different positions with respect to their incident light emitters. One is further back than the other. This allows for different amounts of light to reach each light receiver depending on the liquid being measured.

6.2.4 A liquid refraction measurement device with 4 or more light beams, the device allows for maximum deviation, while using minimum power. Also it allows the use of low power consumption which in turn allows the device to be certified for use in hazardous areas.

6.2.5 A liquid refraction measurement device where the design allows the creation of a portable liquid detector. This device can be slid over a non-opaque pipe with liquid in it

6.3 Polarization claims

6.3.1 A liquid polarization measurement device without moving parts

6.3.2 The system as defined by claim 6.3.1 herein comprises of an
ellipsometer with no moving parts, consisting of one or more LED light sources and four photo-detectors, each covered by an independently oriented fixed polarizer.

6.3.3 The system as defined by claim 6.3.2 herein comprises of four fixed photo-detectors and polarizers placed in a way that the Polarization State of monochromatic light can be measured

6.3.4 The system as defined by claim 6.3.3 herein comprises of four polarizer elements having mutually orthogonal angles of transmission in one orientation ⇒ 0° and 90°, while the second orientation for the other two polarizer elements having mutually orthogonal angles of transmission at ⇒ 45° and -45°

6.3.5 The system as defined by claim 6.3.4 herein does not require waveplates for calculating parameters of polarization, on the contrary, software application is to compensate and mathematical computations are the substitute.

6.3.6 The system as defined by claim 5 herein comprises signal conditioning and amplifiers to obtain higher accuracy.

6.3.7 The system as defined by claim 1 herein comprises a microprocessor to simultaneously capture the various intensity values from the photo-detectors and compute/calculate all required parameters giving results in msec. The system as defined by claim 7 herein comprises computation based on Malus’ law and Stokes parameters from the intensities acquired from the photodetectors. Where I_0, I_{90}, I_{45}, and I_{135} are obtained: the first Stokes parameter (I) is computed as $I = I_0 + I_{90}$, the second Stokes parameter (Q) is computed as $Q = I_0 - I_{90}$, the third Stokes parameter (U) is computed as $U = I_{45} – I_{135}$, and the last Stokes parameter (***V***) is computed through substitution in the above equations to obtain ε and then compute ***V*** as ***V*** = ***sin2***ε.

6.3.8 The system as defined by claim 7 and 8 herein requires further computation to clearly distinguish the effect of materials on the Polarization State of light. Therefore, the polarization states — linear ($\boldsymbol{P_l}$), circular ($\boldsymbol{P_c}$), elliptical ($\boldsymbol{P_e}$), and degree of polarization ($\boldsymbol{P_d}$) — are calculated:

$$P_l = \sqrt{Q^2 + U^2}, P_c = \frac{U}{I}, P_e = \sqrt{Q^2 + U^2 + V^2}, \mathit{and}\ P_d = \frac{P_l}{I}$$

6.3.9 The system as defined by claim 1, 7, 8 and 9 herein will output a single value from claim 9 to distinguish and discriminate clearly and accurately between materials and their sub-categories

6.4 Color claims

6.4 .1 A liquid color measurement device with a result over color in a rainbow sense in one axis along the wave length.

6.4.2 A liquid color measurement device with light channels in a way that unwanted reflection is diverted.

6.4.3 A liquid color measurement device with a clear definition of the colored lights in minimum and maximum wave length

6.4.3 A liquid color measurement device that also can be used in a larger spectra from ultraviolet to infrared.

6.4.4 A liquid color measurement device with a limited specific measuring range a liquid color measurement device with up to 4 light beams with known spectra, sequentially activated in a design with low power consumption which in turn allows the device to be certified for use in hazardous areas