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Techniques for Determining Small Fractions of Oil Components in the Sea Water Flow by Rotation of Vibration Plane

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Abstract: In this study, the results of the effect of water-flow rate and air fraction component on intensity, I, are presented and discussed. The study which was carried out at Bergen University in Norway, presents the impact of monochromatic defects on polarization and measurements of small oil fractions of various crude oils are presented. When there was refraction, it was observed that in static sea-water $\mu_{static} = 0.38$ and in running water $\mu_{flow} = 0.42$. When refraction was eliminated by grafting windows in the pipe, $\mu_{static} = 0$, $\mu_{flow} = 0.11$ and in both cases μ_{flow} was independent of the flow rate. Air fraction component, $\alpha \rangle 0.12$ reduced light intensity. With rate flow Q = 13.6m$^{3/}$h and Q = 27.2 m$^{3/}$h critical air fraction was found at $\alpha_c = 0.18$ and $\alpha_c = 0.12$ respectively. For $\alpha_c = 0.18$ up to $\alpha = 0.87$ at Q = 13.6m$^{3/}$h and $\alpha_c = 0.12$ up to $\alpha = 0.78$ at Q = 27.2 m$^{3/}$h, light intensity was found independent of α. The highest rotation was found in Gullfaks crude oil, followed by Heidrun, the rotation is Statfjord crude oil was less than one in Heidrun and the least rotation was observed in $\overset{o}{A}$sg$\overset{o}{a}$rd crude oil. At 40ppm, the rotation was as follows: Gullfaks $\phi = 27.0 \pm 0.2^o$, Heidrun $\phi = 23.9 \pm 0.2^o$, Statfjord $\phi = 20.0 \pm 0.2^o$, and $\overset{o}{A}sg\overset{o}{a}rd$ $\phi = 10.0 \pm 0.1^o$.This method studys very well when small oil fractions from 5.0-70 ppm are in sea-water flow. This technique can be deployed to monitor the environment and to control the re-injected process water.
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Keywords: Vibration techniques, rotation

INTRODUCTION

The main purpose of this study was to detect 1% salt water in mineral oils and 40ppm of mineral oil in salt water. This method can be (Brown, 1981) recommended to be used to as an environmental monitor to detect oil fractions to 10 ppm and also be applied in controlling re-injected processed water with oil fractions between 100-2000 ppm during oil extraction processes of getting oil from sea water. In mineral oil industry to date, small fraction components of oil in process water can be detected by pulse neutron activation_PNA) and nuclear magnetic resonance (NMR) techniques. NMR and PNA are more complex and use expensive technology (Thorn *et al*., 1997).

There is a need in oil industry (Abro and Mortensen, 2001) for a simple instrument that can be used to detect oil fraction components and this detector can be used for environmental monitoring (where it is required that the amount of oil in the process water is in the range of 0-100 ppm) and controlling re-injected process water (to measure the oil fractions between 100-2000 ppm). The authors also discuss the theory of wave propagation through optically active liquids and experimental results. The study also presents the application of optical activity to determine small oil fractions in sea-water flowing in a pipe (Harvey, 1970). The study aimed at preventing environmental health hazards caused by oil exposure to the natural and biophysical environment (Mucunguzi-Rugwebe, 2000). This is a global problem which is usually caused by oil extraction in water bodies leads to environmental degradation (Barth, 2001). The experiment was meant to detect the amount of oil to gauge if it measured up to the acceptable level which is established by the World Health Organisation (WHO).

METHODOLOGY

The method used indicate that when a beam of linearly polarized light is directed along the optical axis through optically active medium the vibration plane is rotated through an angle, θ given in (1). At the same time, optical activity is caused by asymmetry of molecules that have spiral shape. The relationship between optical activity and molecular structures results from the interaction of plane-polarized light with the electrons in the molecules. The molecular groups that contribute directly to most optical activities have loosely bound electrons which interact with light. Due

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to the asymmetry of molecules, the binding force on electrons is not symmetrical. Electrons which are displaced from their equilibrium positions along one direction have a greater "spring constant" than when displaced along another direction (Brown, 1981). Since propagation of electromagnetic waves through materials is a process of electrons absorbing and reradiating this energy. Given that electrons respond differently in one direction from another, results in the waves to be transmitted at different speeds in different directions. The eigenwaves for a given direction of propagation have well-defined phase velocities and directions of polarization.

Besides, linearly polarized light may be considered as the sum of two circular polarizations rotating in opposite directions. The electric field of a wave traveling through a medium polarizes the electrical charges of the atoms of the medium in the direction of the wave's oscillations. The electric polarization of the material is then in the direction of polarization of the wave. Because of different speeds, two circularly polarized waves forming a linearly polarized light traversing optically active specimen must be out of phase and the resultant wave would appear to have rotated. When a certain thickness of optically active material is inserted between the Analyser and a Polariser, the condition of extinction no longer exists, because the E-vector of the light is rotated by the active medium (Brown, 1981; Mucunguzi-Rugwebe, 2000). Each type of optically active molecules causes different optical rotation. This is the reason for using this technique to measure purities of transparent liquids. The optical rotation is found to be linearly dependent on the path length traversed by the light through the sample.

The exact angle of rotation can be measured by rotating the analyzer until the extinction re-occurs. The rotation measured depends on the wavelength of light, thickness traversed by light, temperature and concentration of the optically active substance in the solution. This relationship is given by:

$$\theta \text{ [degrees]} = L \text{ [cm]} \times \omega \times d \text{ [kgm}^{-3}\text{]} \quad (1)$$

where,

- ω = The specific rotation and in liquids defined as the rotation due to a 0.1 m column length of the active liquid
- θ = The net rotation
- L = The path length through which light traverses in the liquid
- d = The concentration expressed as kilograms of active substance per cubic metre

The relation in Eq. (1) holds for one optically active substance. If N types of optically active substances are involved in the sample under test then (Kawamura, 1996).

$$\theta = L\ x\ (\omega_1\ x\ d_1 + \omega_2\ x\ d_2 + \cdots + \omega_N\ x\ d_N) \quad (2)$$

The relation in (2) is valid for static situation, if a mixture is in dynamic state, for example sea water and oil is flowing, then (2) becomes:

$$\theta = [L\ x\ [\omega_{sw}\ x\ d_{sw} + \omega_{oil} + d_{oil}] + L\ x\ (\delta_{sw}\ x\ d_{sw} + \delta_{oil}\ x\ d_{oil}) \quad (3)$$

where, $\delta_{sw}, \delta_{oil}$ = The specific rotation of sea water flow and oil flow respectively. Let ϕ be the angle of rotation caused by oil intrinsic and flow birefringence, then from (3):

$$\phi = L\ x\ (\omega_{oil}\ x\ d_{oil} + \delta_{oil}\ x\ d_{oil}) \quad (4)$$

$$\phi = \theta - \varphi_{fsw} \quad (5)$$

where, φ_{fsw} = L x$[\omega_{sw}\ x\ d_{sw} + \delta_{sw}\ x\ d_{sw}]$ the contribution towards rotation from intrinsic and flow birefringence of sea water.

Three preliminary experiments were done in order to investigate the effect of the rate of water flow and air fraction component on light intensity, I and monochromatic defects as great agents of depolarization.

The effect of water-flow rate on light intensity, I: In order to investigate the intensity attenuation caused by water flow alone, a two inches two component air-water closed loop was used. A laser beam was directed almost along the diameter of the empty pipe in the loop.

Light intensity, I, was observed with help of laser power meter and a digital display multimeter. Afterwards, the loop was filled with water which was left for over a night to allow air creep out. Then the intensity, I, was determined for the static water. The flow rate was controlled by the regulator pump and the required value of rate in cubic meter per hour was monitored by turbine digital meter. At a set value of the rate of flow (Q), the light intensity, I, was measured. The values of intensity, I, were recorded with their corresponding values of Q as the rate of flow was increased from Q = 0 to Q = 27.2 $m^{3/}$h. A graph of intensity, I, against the rate flow, Q, was plotted and the results are shown in Fig. 1.

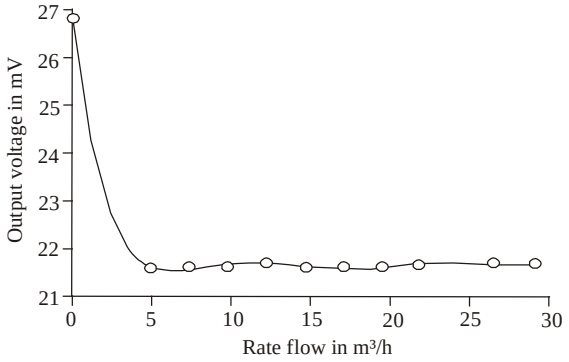

Fig. 1: Output Voltage versus the rate flow, Q, in m^3h

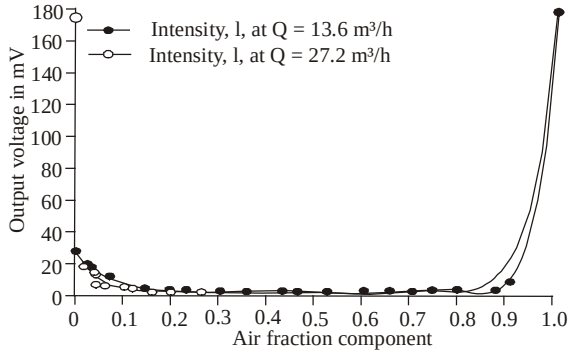

Fig. 2: The Output voltage versus air fraction component, α

The effect of air-fraction component, α on light intensity, I: The flow-rate was set at a constant value of Q = 13.6 $m^{3/}$h i.e., at $\frac{1}{3}Q_{max}$, then values of air fractions with the corresponding values of light intensity, I, were recorded. The experiment was repeated with Q = Q_{max} = 27.2 m^3/h. A graph of intensity, I, against air fraction component, α, was plotted and the results are shown in Fig. 2. This study was done by a team of three researchers based the University of Bergen in Norway. It was documented and the data were reviewed this year 2011 from the initial 2010 documented results.

The impact of monochromatic defects on polarization: Monochromatic defects arise due to the fact that monochromatic rays originating from an axial object point and intersecting the spherical refracting surface at different heights do not meet at a single point after refraction. Pipe walls have two spherical refracting surfaces and the width of the laser beam used is two millimeters. The beam of laser therefore may not be regarded as a point source as the marginal rays from beam are at 1mm from optical axis. It was observed that when the beam was directed through the pipe a combination of monochromatic defects occurred although the beam was directed almost along the diameter of the pipe. Because of this, the beam can be regarded as an oblique ray making a small angle,θ, with the diameter which in this case is considered as the principal axis so that by Maclaurin's expansion (Jenkins and White, 1976):

$$Sin\theta = \theta - \frac{1}{3!}\theta^3 + \frac{1}{5!}\theta^5 - \frac{1}{7!}\theta^7 + \ldots\ldots\ldots\ldots \quad (6)$$

If, θ, is small then sin θ≈ θ and the first term is used, then we have the first order or Gaussian and this gives accurate results for paraxial rays. In our case, it is necessary to consider higher-order terms which express five Seidel sums (Brown, 1981). These five monochromatic defects are spherical aberration, coma, astigmatism, curvature of the field and distortion. Because of these defects, the beam was depolarized and therefore, it was impossible to get the extinction point when the Analyser was rotated. In order to eliminate refraction at the curved surfaces of the pipe, windows were dexterously grafted in the sides of the pipes.

Detection of small oil fractions in sea water flow: In order to determine small fractions in sea water flow (process water), the experimental setup shown in Fig. 3 above was used.

The continuous wave (cw) He-laser model 1676 (1997) provided a randomly polarized light of 543.5 nm and produced light energy of 2mW. A Polariser, P, was for improving the quality of polarization of the beam, a green laser was preferred because:

- Green gives suitable rotation and higher penetration than red laser
- Economically cheaper than a blue laser

The pipe that contained the flow was designed with two windows, W_1 and W_2 directly opposite each other along its diameter. This made it possible to direct the beam normally on W_1, the first window and have it emerge normally through the second window, W_2, thereby minimizing refraction that contributes greatly towards depolarization. Depolarization makes it impossible to get extinction when the Analyser is rotated to obtain cut-off angle. The shields T_1 and T_2 in which the windows were fixed, were painted black to minimize reflection which is another agent of depolarization. A is the Analyser which is rotated to cause cut-off or minimum irradiance, I_{min}, T is a tube intended to cut off ambient light (light from the surroundings) and its blackened inside to reduce reflection.

Since flowing water attenuates light intensity, I, the laser power meter, M, was put in its sensitive mode in order to pick and amplify weak light intensities through the pipe and the output was displayed by the digital meter. The rig was carefully filled wit sea water so that there were very few air bubbles in the system because

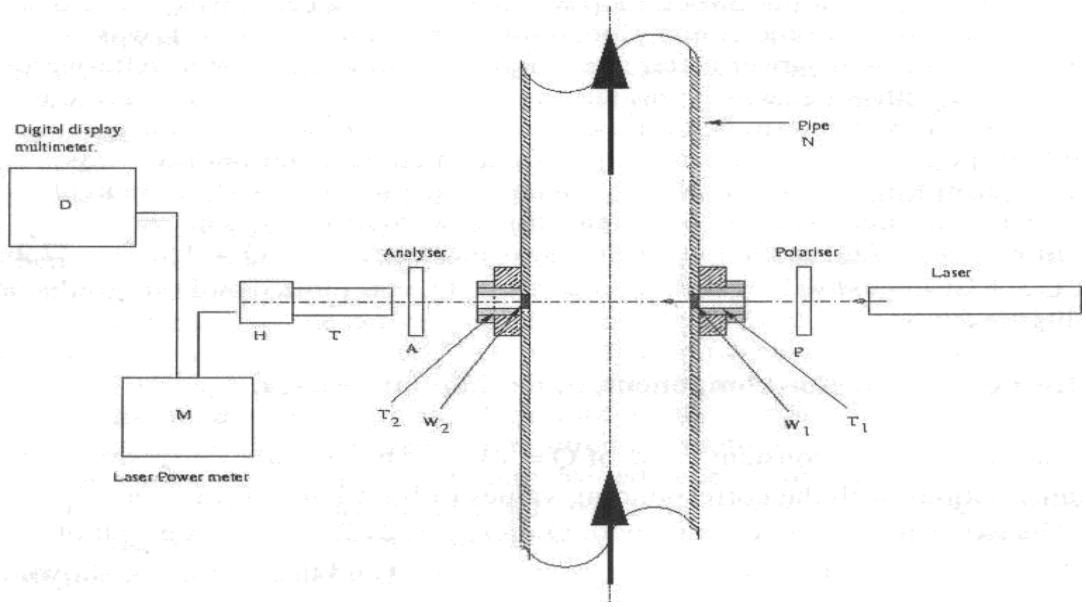

Fig. 3: Experimental layout for determining small oil fractions in process water

air bubbles make the medium optically dense. The pump acts as a mixer which causes water to flow at 5m/s. The angle, φ_{fsw}, at which the minimum, I_{min}, occurred was noted when only sea-water was flowing in the rig. This, I_{min}, obtained with only sea-water flow was taken as the irradiance reference in determining extinction point for all measurements.

The volume of the rig was determined and found to be 35.0 L. A syringe graduated in millitres ranging from 0.0 up to 1ml was used to measure the volume of oil. The volume of 0.18 mL was measured and mixed with sea-water in the rig i.e., the volume of crude oil, γ, was approximately 5 ppm. Profound care was taken to have a mixture of oil and sea-water only in the rig. This was practically impossible because very few air bubbles remained in the mixture particularly with Heidrun crude oil. Oil was thoroughly mixed with sea-water by using the pump which caused the mixture to flow thereby achieving thorough mixing. The angle of rotation, θ ,caused by this mixture-flow was determined and, φ due to oil fraction was calculated using equation (5). The procedure was repeated for other oil fractions up to 70 ppm beyond which the medium was optically too dense for that laser. When 40 ppm oil fraction component was mixed with sea-water, ten values of rotation angle were measured, an average was calculated and the S.D was determined for each of the two samples using the equation (Mucunguzi-Rugwebe, 2000):

$$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}} \quad (7)$$

where,

x_i = The value of the i^{th} observable

$\bar{x}$ = The mean value of n observables

RESULTS

Results indicate that the variation of light intensity, I, with change in the rate of flow, Q is shown in Fig. 1 below. It can be observed that the laser power meter output decreases from 26.8 mV to 21.6 mV at Q = 5m^3/h. These results show that once the flow has started, then light intensity, I, is independent of the flow rate.

The variation of light intensity, I, with change in air fraction component, α, was investigated and the results are shown in Fig. 2. For the flow rate, Q = 13.6 m^3/h the air fraction which reduces the voltage output to a constant value of 2.1mV starts at a critical value, α_c = 0.18 or 18% whereas for Q = 27.2 m^3/h, this critical value occurs at α_c = 0.12 or 12% After these two critical values the light intensity is independent of rate of flow and air fraction component until an increase in intensity, I, is observed at α = 0.87 or 87% for Q = 13.6m^3/h and at α = 0.78 or 78% with Q = 27.2m^3/h. From these results it should be noted that intensity, I, is independent of flow and air fraction component in the regions 0.15 to 0.87 and 0.12 to 0.78 for Q = 13.6 m^3h^{-1} and Q = 27.2 m^3h^{-1}, respectively. It was also observed that monochromatic defects can be another source for intensity attenuation. When there was refraction, in static sea-water μ_{static} = 0.38, and in running water μ_{flow} = 0.42. When refraction was eliminated by grafting windows in the pipe, μ_{static} = 0, μ_{flow} = 0.11 and in both cases μ_{flow} was independent of the flow rate.

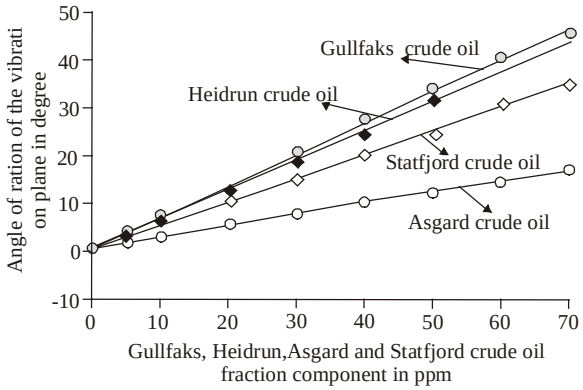

Fig. 4: Angle of rotation of the vibration plane versus Gullfaks, Heidrun, Statfjord and $\overset{o}{A}sg\overset{o}{a}rd$ crude oil fraction components, γ, in ppm in sea water at 23.7°C

Table 1: Shows the angle of rotation at 40 ppm of various crude oils

40 ppm oil fraction component	ϕ in degrees	S.D.
Gullfaks crude oil	27.0°	0.2°
Heidrun crude oil	23.9°	0.2°
Statfjord crude oil	20.0°	0.2°
Asgard crude oil	10.0°	0.1°

Small fractions of °Asg°ard crude oil were mixed with sea-water at a time to investigate the relationship between rotation angle, ϕ and dynamic oil fraction component as given in equation (5). The experiment was repeated with Heidrun, Statfjord and Gullfaks crude oil and the results are shown in Fig. 4. At 40ppm, the rotation was as follows: Gullfaks $\phi = 27.0^o \pm 0.2^o$, Heidrun $\phi = 23.9^o \pm 0.2^o$, Statfjord $\phi = 20.0^o \pm 0.2^o$, and $\overset{o}{A}sg\overset{o}{a}rd$ $\phi = 10.0^o + 0.1^o$. The greatest rotation was observed in Gullfaks crude oil, followed by Heidrun and the rotation in Statjord was less than that in Heidrun but higher than one in °Asg°ard whose rotation was the least. Gullfaks and Heidrun each contains a molecule with more loosely bound electrons than that of °Asg°ard crude (Barth, 2001). Since loosely bound electrons contribute greatly towards optical rotation the results in Fig. 4 are in line with the theory. It can be observed that the rotation due to Gullfaks is almost twice that of $\overset{o}{A}sg\overset{o}{a}rd$ (Table 1).

DISCUSSION

Monochromatic defects such as, spherical aberration, coma, astigmatism, curvature of the field and distortion can cause depolarization thereby making it difficult to obtain cut-off angle. Since loosely bound electrons are responsible for rotation of the vibration plane, the more loosely bound electrons the medium has, the greater the angle of rotation that medium produces when a plane polarized beam is directed through it. °Asg°ard crude oil contains unstable aromatic compounds which have low atomic weight and therefore have few loosely bound electrons. Because of fewer loosely bound electrons, $\overset{o}{A}sg\overset{o}{a}rd$ crude oil rotates the vibration plane less than those oils like Heidrun oil components with higher atomic weight and therefore with more loosely bound electrons.

Although, static sea water is somehow transparent as one can see through the sample of 10.0 cm, nevertheless, when flowing, it is not as transparent as in the static situation. In flowing water therefore, the absorption of light is higher than that in static water. The intensity, I, was observed to reduce with the increase of oil fraction component in running water. In other words the more the oil fraction component in sea-water, the more optically dense the medium became and the less intensity reaches the detector. Because of low light intensity, it was difficult to detect fractions beyond 70ppm with that laser whose power output was 2.omW.

CONCLUSION

This method has been proved to study very well when small fraction of oil (5.0-70.0 ppm) are in sea water. Therefore this technique can be used as an environmental monitor where it is required that the amount of oil in process water must not exceed 40mg/litre (40 ppm).If, however, a laser producing a strong beam grater than 2.0mW say 20.0 W is used, higher oil fractions can be detected. Then this method can be used to control the re-injected process water and this in line with the recommendation by Abro and Mortensen (2001).

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