Colour Measurement as a Tool for Monitoring Oil Quality

- Changes in colour indicate quality deviations

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It is a fact that different chemical and physical factors affect the quality of oil and thus its performance in various uses. The number of factors contributing to the deterioration of quality increases over time and with use, and at times the quality of oil can drop quite suddenly. The first sign of quality change is often a change in the oil colour. Although oil colour alone is not necessarily a direct indication of the oil being damaged, the colour change is nevertheless a good indicator that the properties have changed and a more detailed analysis of the situation is required. Online colour measurement can be used to immediately detect changes in quality and take corrective measures before any damage occurs.

Introduction

Many factors are known to have a direct or indirect impact on the quality of oil. These factors may be associated with the oil manufacturing process or with changes in quality during use. Such factors include [1], [2] the degree of refining, natural ageing of the oil, additives and their degradation and reactions, polymerisation, water, oxidisation, temperature, external chemical substances, metal and other particles detached from the system, dissolved gases, etc.

The quality of oil and the changes in the quality have a key effect on oil performance in its intended use. In a worst-case scenario, oil of the wrong quality, or which has deteriorated, can cause expensive mechanical breakdowns and even bodily injury. That is why monitoring of oil quality and condition has become an important factor in nearly every branch of industry. A very diverse range of different measurement devices have been developed for this purpose, such as [3] relative humidity and absolute water content indicators, particle calculators, dielectric sensors, oxidisation indicators (TAN value), viscosity meters and colour analysers. The operating principles of these devices are executed by many different technical solutions and the measurement methods range from the online type to laboratory equipment. Some of the devices are intended for measuring a specific and very limited property affecting quality, while others can indicate quality changes caused by several factors. One of these measurement device categories is colour analysers.

Colour

As such, colour is not a physical property or quantity but a very subjective concept [4]. The colour of an object is always affected by the lighting conditions (light source properties), the reflection and transmittance properties of the object at different wavelengths of light and, finally, the ability of the viewer's eye receptors and brain's vision areas to process the arriving signal and the viewer's learned conceptions of colour. In particular, the sensitivity of the retinal cones that produce colour vision to different wavelengths plays an important role in the concept of colour. Thus a very broad-ranging branch of science has developed around colours and perception of them.

[4] By the beginning of the 1800s, it was ascertained that there are three types of retinal cones that produce colour vision: they can be roughly divided into red (R), green (G) and blue (B). It was also observed that light stimuli of two different spectra could produce the same colour (metamerism). Around 1930, Wright and Guild performed independent visual experiments that led to so-called colour-matching functions using the three primary colours (monochromatic): red, green and blue. In standardised conditions, the people participating in the experiment were asked to adjust the amounts (ratios) of these primary colours so that the results would correspond to the monochromatic colour samples provided. This made it possible to examine the sensitivity of a person's colour vision to certain wavelengths and metamerism phenomena. In 1931, the CIE (Commission Internationale de l'Eclairage) adopted these results as standardised RGB colour-matching functions [*Figure 1*]. This can be considered as the starting point for development work of numerous other types of colour spaces.

The ambiguity of the concept of colour has led to the situation in which several different organisations have developed a wide variety of simplified, standardised and purpose-dependent scales for colour measurement and numeric expression. For example, specific colour scales exist [5] for oil, beer, honey, latex, whiskey, milk, blood urea content and many other uses.

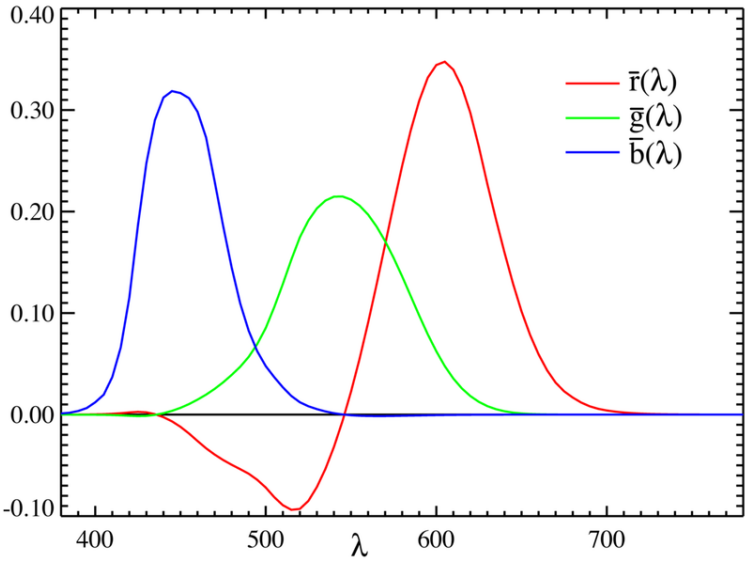

Figure 1[6]*: RGB colour-matching functions.*

ASTM D 1500 Colour Scale

One of the most commonly used colour scales specifically intended for oil is ASTM D 1500 [7]. This scale is widely used, particularly in the oil refining industry, for indicating the degree of refining and the uniform quality of colour observed by customers. As well it is also commonly used to show changes in quality when monitoring the condition of the oil in use.

ASTM D 1500 is a two-digit, one-dimensional number ranging from 0.5 to 8.0 with 16 values in steps of 0.5. The value 0.5 corresponds to a very pale "straw shade" while 8.0 is a deep red (nearly black) [*Figure 2*].

According to the ASTM D 1500 testing method, the colour of an oil sample is assessed by comparing it to the standardised (ASTM D 1500) coloured glass disks in standardised conditions. Traditionally performed, at its worst (in a case of 1:20), the testing method provides a value with an accuracy of one (1.0) colour units.

The scale is suitable for colour definition for many petroleum products, such as [7] lubricating, heating and diesel oil and even for petroleum waxes. The scale is not suitable for kerosene, gasoline and other very pale-coloured (colour lighter than 0.5 on the ASTM D 1500 scale) petroleum products. One option in such cases is the ASTM D 156 (Saybolt) scale and testing method [8].

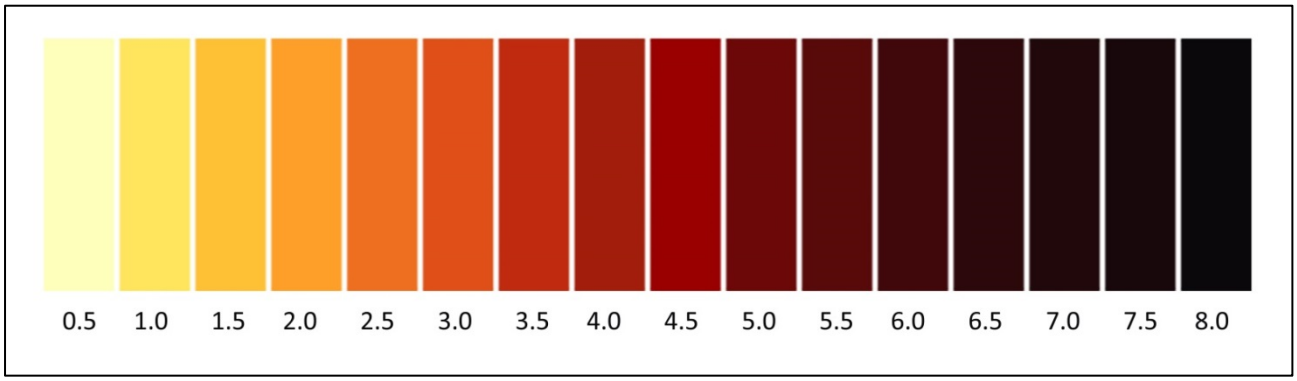

Figure 2: *A schematic figure of the ASTM D 1500 colour scale (the colours may differ from actual ones as a result of the colour accuracies of screens, image processing programs, printers, etc.).*

The Importance of Colour Measurement

Many factors, affecting the quality of oil, such as [1], [2], [7] degree of refining, oxidisation, particles, ageing, etc. also have a direct impact on the colour of oil. Generally speaking, oil darkens as it ages due to changes in the state of these (among other) factors. Measuring the colour of oil provides a good general picture of possible quality variation or oil ageing. Although colour on its own may not necessarily always indicate anything absolute about oil quality or its functional properties, the change in the colour is at least a clear indication that some property has changed. Thus, this can serve as an advance warning of, for example, early damage in a lubrication system, an approaching need for an oil change, or that something has changed in the refining process. A colour change that exceeds (for example, empirically) set limits, makes it possible to take proactive measures and, if necessary, perform a more detailed analysis of the oil in use or processed.

Oxidisation Changes Colour

Oxidisation is one of the most important factors that change oil colour and reduce oil quality as it ages [1]. As oil oxidises, its hydrocarbon releases electrons to oxygen. At the same time oxygen is reduced as it accepts the electrons. This reaction is accelerated by high temperature and catalytic substances possibly contained in the oil, such as copper and lead. Among other things, the oxidisation reaction produces alcohols, which further oxidise into aldehydes and ketones. These aldehydes then oxidise to form carboxylic acids [*Figure 3*], while ketones no longer oxidise. Carboxylic acids easily corrode metals containing lead. On the other hand, a small-molecule acid water mixture can even corrode parts located above the surface as it evaporates from oil.

The hydrocarbon chains lengthen as the oxidisation reaction progresses. These polymerisation products settle easily and cause sludge in the oil system, which in the worst cases can clog the system. Furthermore, when oxidised oil touches a hot surface, it tends to form a lacquer-like layer on that surface. This reduces clearances and thus causes a rise in temperature, which in turn further accelerates the oxidisation reaction.

The oxidisation phenomena are most easily observed as a change in oil colour [1]. The colour becomes darker as oxidisation progresses, eventually turning nearly black. The ASTM D 1500 colour scale described earlier is the best way to examine this colour change. A commonly used measure of oxidisation level is the so-called Total Acid Number (TAN), which is specified using the ASTM D 664 method [9]. However, TAN is a measure that reacts rather slowly to the oxidisation phenomena and its results can be slightly distorted by the original additive compositions of oil. Furthermore, since measurements by the means of the ASTM D 644 method are performed by titration in a laboratory, on-line colour measurement provides significantly faster feedback on a change in the degree of oil oxidisation.

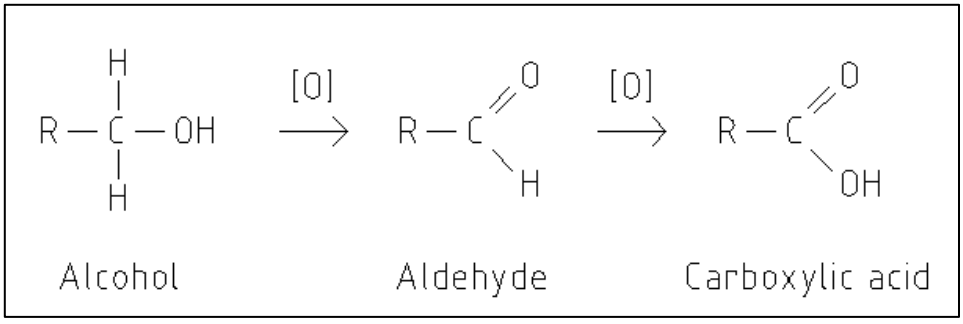

***Figure 3**: Oxidisation of alcohol into aldehyde and subsequently into carboxylic acid.*

Online Colour Measurement

Automatic online colour measurement devices have joined traditional colour testing performed in a laboratory according to the ASTM D 1500 [7] standard. These devices can be calibrated by either using equipment that complies with the above-mentioned standard and system or by means of liquid ASTM D 1500 standard reference colours suitable for the purpose of calibration.

The clear benefit of automatic devices in comparison to the traditional analysis method is better accuracy, which is due to the missing human factor. The accuracy of an analysis performed according to ASTM D 1500 is, at worst, 1.0 units in a case of 1:20 [7], while the automatic devices can provide measurements with accuracy clearly better than 0.5 units and much more reproducible. In fact, since these types of devices can be adjusted to show results to an accuracy of several decimals, they can in theory be more accurate than actually required or specified by the standard. Especially using online measurement, the reaction to changes in colour takes place immediately, and the results are obtained in real time. Thus, oil samples don't have to be collected and sent to a laboratory, there's no need to wait for laboratory results or invest in such services. Quick real-time information about changes in oil colour helps to anticipate the need for service, oil changes or refining process changes and thus to avoid possible major damage.

Kytola OILCOL Oil Colour Analyser

Based on the starting points presented above and customer needs, Kytola Instruments Oy and its partners (including VTT) began development to create a reliable online ASTM D 1500 oil colour analyser. The device was also intended to supplement the company's family of oil lubrication system monitoring products, which includes rotameters, oval gear meters and the OILAN (oil water content analyser) device that has been popular over a longer period of time.

The key challenge for product development involved combining mechanics and electronics to optimise optics in order to achieve the required accuracy and feasibility. Following numerous intermediate phases, test versions, studies and experiments, a device that met the company's high quality criteria and suitability to the most demanding customer needs was launched in 2013.

The device named the OILCOL – Oil Color Analyzer [*Figure 4*] measures the colour of oil according to a scale that complies with the ASTM D 1500 standard and provides a reading with an accuracy of 0.1. This online device, which can also be used as a portable analyser, provides real-time information about the colour of oil. The sturdy device has an aluminium frame and is easy to install and set-up. Its electrical connection options include a serial interface (Modbus) and a milliampere output (4 - 20 mA). The device can be used with nearly all petroleum products for which the ASTM D 1500 scale is suitable, such as [7] lubricating, heating, diesel and mineral oils. Furthermore, its structure and tolerance for environmental conditions (-20 °C – +70 °C) make installation possible in a wide variety of user environments, such as paper, mining and petrochemical or offshore operations.

Figure 4: *OILCOL – Oil Color Analyzer (Kytola Instruments Oy).*

Conclusions

Since the quality changes of oil, caused by many different factors, can often be detected as changes in the oil colour, the measurement of colour is very useful tool for oil quality surveillance. Furthermore, if an on-line device is used, the feed-back on quality changes is immediate, thus enabling to take corrective actions even before any damage occurs. We believe the OILCOL (oil colour analyser) device by Kytola Instruments Oy is an excellent, compact solution to bring oil quality monitoring systems to a new level.

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Sources

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[7]: ASTM D 1500 –standard, “Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)”.

[8]: ASTM D 156 –standard, “Standard Test Method for Saybolt Color of Petroleum Products (Saybolt Chromometer Method)”.

[9]: ASTM D 664 –standard, “Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration”.