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MONITORING FUEL QUALITY IN THE TRANSPORT INDUSTRY

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Purpose: The aim of the article is to check whether there are indications that light waves can be used to monitor fuel quality.
Design/methodology/approach: Tests of deposits released in fuels during long-term storage were carried out. The research involved observing with the unaided eye illuminated samples of fuels stored in glass vials. The research was qualitative in nature. Samples of diesel oil, gasoline were tested. The phenomena occurring in materials under the influence of aging processes were determined and the relationships between the tested material, its quality and the impact of light rays on the sample were explained using physic-chemical phenomena.
Findings: The novelty of the article is to show that fuels after the storage process can significantly differ in quality from the starting material and that it is possible to monitor fuel quality using spectroscopic methods.
Research limitations/implications: The research conducted is qualitative and not quantitative.
Practical implications: It is suggested to use methods of continuous monitoring of stored fuels using light spectroscopy methods.
Originality/value: It is to show that fuels from one manufacturer and stored in the same tank age at different times. Fuels have different properties and significantly differ in quality compared to the input material. Therefore, there is a real need for continuous monitoring of fuel quality.
Keywords: automotive, fuel, quality of gas, quality of oil.
Category of the paper: Research paper.

1. Introduction

Fuel quality testing based on standardized measurement procedures enable the determination of the quality of fuels only in specialized testing laboratories according to appropriate standards (PN-EN 15442:2011, PN-EN 15413:2011, PN-EN 15443:2011). In accordance with the standards, tests of transport fuels require taking samples of material from tanks located at service stations, transporting appropriately secured samples to a laboratory and then performing tests (UOKIK Report). The information obtained on the quality of the fuel, in accordance with the presented test procedure, is time-consuming and does not give the possibility of an immediate decision on the release of the fuel on the market or its withdrawal (Vasileiadou et al., 2021). Stored fuels undergo ageing processes, which results in a change in their physic-chemical properties and translates into deterioration of their functional properties (He et al, 2021; Matijošius, Sokolovskij, 2009; Stepien, 2015). As a result of chemical reactions taking place in stored fuels, resin deposits or acids are formed (He et al., 2018; Correia et al., 2018; Debe, 2012; Blaabjerg, Teodorescu, Liserre, Timbus, 2006). Improper storage can even accelerate these reactions (Jiang et al., 2024; Jeon et al., 2017; Stępień, 2015; Ukhanov et al., 2022; Sacha, 2020; Silva et al., 2021). Therefore, an important element in the fuel supply chain to the consumer is to check its quality. Due to the lengthy laboratory procedures, new methods are being sought to improve the process of fuel quality assessment (Kalwas, Bukrejewski, 2016).

The article proposes to conduct research and indicate the direction of development of methods for monitoring the quality of fuels in real time.

2. Investigation methods

Visual tests were carried out in accordance with the PB/AS-91 standard as preliminary tests. They consisted of visual inspection of fuel samples placed in glass vials with the naked eye. The tested liquids were characterized by different degrees of degradation related to the changes occurring in them, resulting from the aging process during their long-term storage. Samples for testing non-stored and stored fuels were illuminated from one side. They observed whether individual materials exhibited changes in color and clarity, which could form the basis for inferences about their quality. The aim of the study was also to determine whether the light wave passing through the sample could be used in research on the quality of liquid fuels in order to monitor them. The presented research is preliminary research carried out as part of a broader research project related to the monitoring of the quality of liquid fuels, including biofuels.

3. Results of investigation

Examples of tested samples of liquid fuels are presented in Fig. 1-2. In the case of illumination of unarmed samples, some subtle differences can be observed between individual fuel samples. The differences are in the color and turbidity of the liquid. The analysis of the test results allows us to conclude that the material, purchased directly from the manufacturer without the long-term storage process, has a light color and is clear (Fig. 1 a-b). With the naked eye, it is difficult to see significant differences between the starting sample of gasoline and diesel oil, both fuels are characterized by light coloration and volume uniformity. If you move the vial, you will notice that diesel has poorer flow properties, which is due to its higher density and viscosity compared to gasoline. As a result of storage, noticeable changes occur in the observed fuel samples. The samples undergo degradation, which is initially manifested by a slight, but unambiguous and observable change in color.

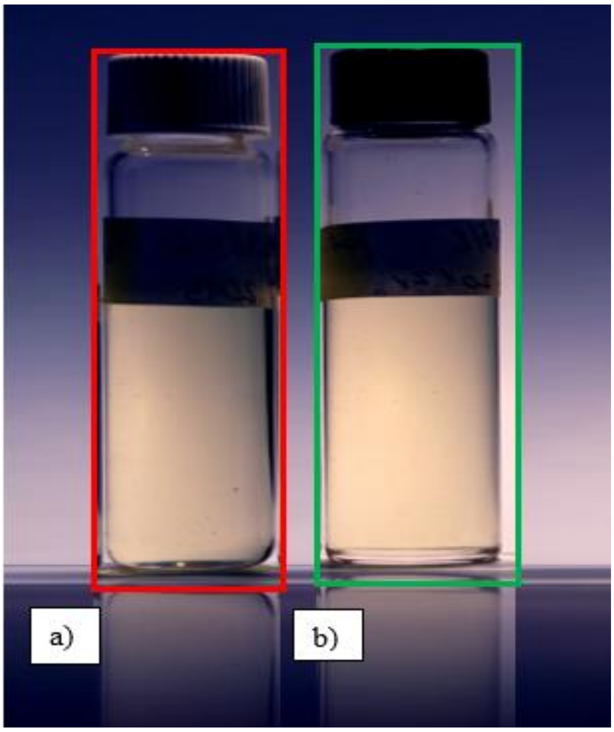


Figure 1. Starting samples: (a) diesel fuel; (b) petrol Pb 95.

First of all, this change is recorded in samples of diesel fuels, which, according to the literature, is related to the process of resin release. As a result of the aging process, the samples acquire a colour of varying intensity of yellow, as shown in Figure 2 – sample (1) and (3). In the initial storage period, the colour is heterogeneous in volume. It is possible to observe the spread of an area of liquid with a more intense color in the test tube with the passage of time and the aging processes taking place. Figure 2a shows samples after two months of storage. In sample (1) – diesel fuel, darker and lighter areas can be clearly distinguished in the tested material. According to the literature analysis, it can be concluded that during the aging process, small fractions of resins are initially released, which are coagulated over time. The process of combining particles of the dispersed phase of the colloid (resins) into larger aggregates forming a continuous phase with an irregular structure (sample 1, 3 – Fig. 3) results in an increase in the absorbance of light and thus a decrease in its transmittance (which will be explained in more detail later in the article).

Further observations of the sample indicate that the sediments formed as a result of coagulation increase in mass and fall freely to the bottom of the tube. The described phenomena make it possible to observe changes in the form of darker and lighter areas in the tested sample of liquid material. The liquid becomes heterogeneous in its volume.

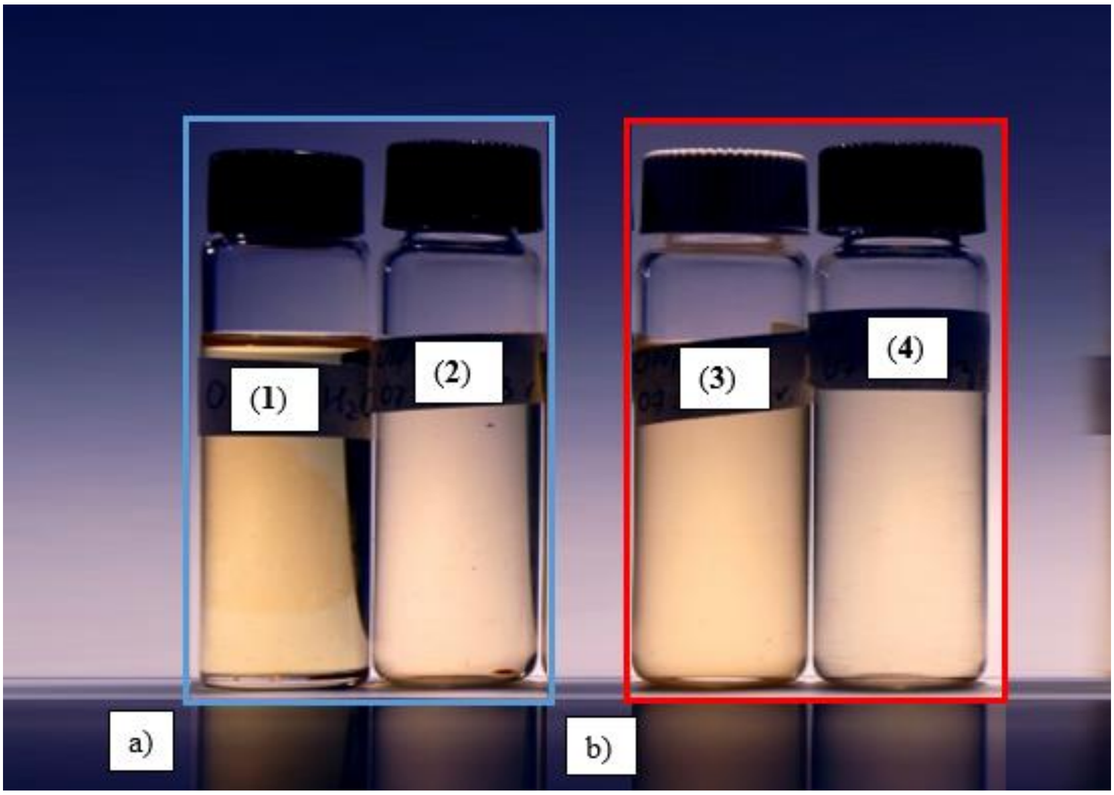


Figure 2. Samples of stored diesel fuel (1) and (3) and unleaded petrol (2) and (4) with different quality parameters (a) samples after 2 months of storage (b) samples after 4 months of storage.

Slightly subtle changes take place in gasoline. During the four-month study, no color changes were observed. The observed changes in the test relate only to the clarity of the fuel. Sample 4 is cloudier compared to the starting material. Although the change is not as characteristic as in the case of the tested diesel fuel, it undoubtedly indicates the beginning of degradation processes in the fuel.

The obtained test results and their analysis allow to clearly state that there is a relationship between the intensity of light falling on the fuel sample, the amount of light intensity passing through the material and the quality of the fuel, its degree of degradation as a result of the aging processes taking place in it. The observed differences in the color and turbidity of liquids between the original and stored samples result from both changes in the chemical structure of the tested liquids and the laws of physics. First of all, it should be noted that the light falling on the material sample interacts with it. Molecules have different types of energies, m.in kinetic, rotational, oscillatory and electron. Kinetic energy – called translational energy is related to the free movement of the molecule in gases and liquids, while in solids it is the energy of vibration in the crystal lattice. A slow-moving molecule can perform rotational motions, which is a rotational component. On the other hand, the oscillatory part is related to the mutual attraction and repulsion between the atoms of a given molecule. Electron energy is due to the electronic and nuclear structure of the molecule. Atoms combining into molecules lower the total energy of the system. The reduction of this energy depends on the type of bond formed, the distance between the nuclei of atoms, and the degree of electron relocation. A molecule can change its rotational, oscillatory or electronic energy only in certain portions characteristic of its structure – called quanta, which is the basis of spectroscopy. The energy of photons of optical radiation depending on the wavelength is determined with the equation (Cygański, 1993; Paszyc, 1983):

$$E = h\nu = hc / \lambda \qquad (1)$$

where:

$h = 6.6256 * 10^{-34}$ [J*s] – means Planck's constant.

n – frequency of light wave.

c = 2.9979*108 [m/s] – the speed of light in a vacuum.

L – wavelength of radiation.

Thus, light carries different portions of energy depending on the wavelength. The transition of electrons between individual energy levels requires a strictly defined portion of energy. Infrared radiation is too low energy and does not induce any change in electronic energy. Radiation from the visible range is able to cause 3D- >4p transitions and such photons will absorb atoms. Further passages require radiation in the far UV range, or X-rays. Electron transitions between molecular orbitals in molecules require ultraviolet photon energy, which is used in absorption spectroscopy and photochemistry of organic compounds. Infrared radiation is sufficient to induce oscillatory and rotational transitions (Cygański, 1993; Paszyc, 1983).

On this basis, it should be concluded that light passing through the sample changes its intensity as a result of interaction with it. Samples of the same fuel, with a different degree of material degradation, are characterized by a different concentration of undesirable components (e.g. resins, microorganisms, etc.), which constitute an additional barrier to the light wave. Hence, it should be concluded that the observed subtle differences between the tested materials are related, m.in, to the intensity of the incident light and the light passing through the sample. According to the literature data, the ratio of the passing intensity I to the incident intensity I_0 is called the transmittance T:

$$T = I/I_0 \qquad (3)$$

On the other hand, the absorbance A of the sample is defined as:

$$A = \log(1/T) = \log(I_0/I) \qquad (4)$$

The Lambert-Beer law determines the relationship between the change in the intensity of radiation passing through the tested sample, by optical route, and the concentration of absorption centers:

$$\log(I_0/I) = e*c*l \tag{5}$$

where:

I_0 – intensity of incident radiation.

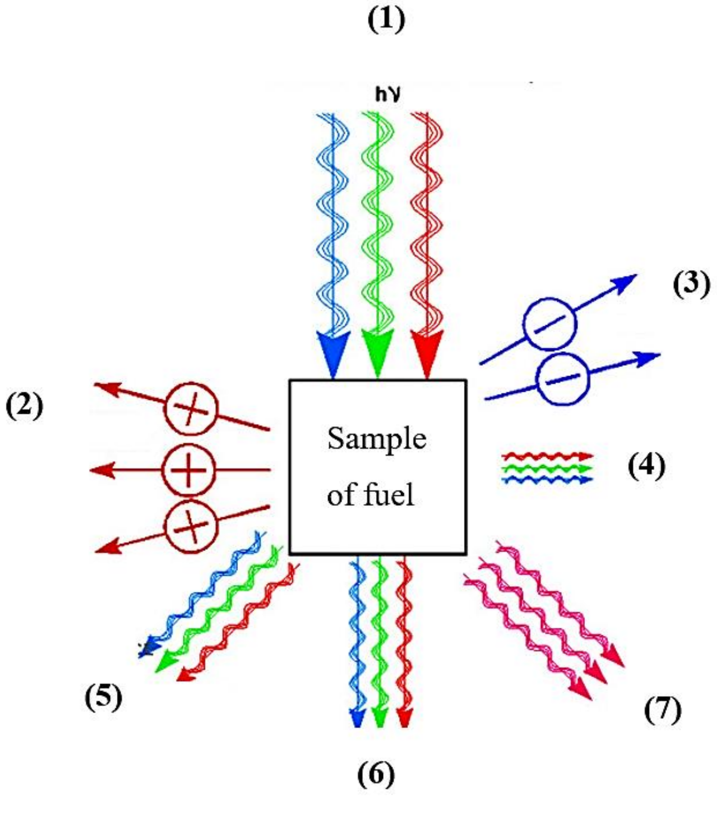
I – the incoming current after passing through the sample.

e – proportionality constant [$l*mol^{-1}*cm^{-1}$].

c – concentration of the substance in the solution.

L – optical path [cm].

Based on the above formulas, the observed differences between the samples with the tested fuels can be explained by the mechanism of interaction of light (waves coming from the illumination source of the sample – Figure 3) with the test material placed in the sample, according to Figure 2.



(1) - incident radiation
(2) - positive ion emission, MSI mass spectroscopy
(3) - Electron emission, photoelectron spectroscopy
(4) - scattered radiation and Raman spectroscopy
(5) - transmitted radiation with changed polarization, optical rotation dispersion
(6) - transmitted radiation, UV-VIS absorption spectroscopy, IR, MW, EPR spectroscopy, NMR
(7) - emission of radiation other than excitation radiation, UV/VIS spectrofluorometric

Figure 3. Mechanisms of light-sample interaction.

Source: own study.

Therefore, it should be concluded that the selection of the right light source, its power and intensity, as well as proper measurements of the intensity of light passing through the tested fuel sample may enable observations to be made, giving the basis for conclusions about the occurring stages of fuel aging. The results of the research indicate that it is possible to develop fuel quality monitoring based on the methods of well-known analytical techniques involving the generation and interpretation of spectra, e.g. spectrophotometry, in order to identify undesirable components in the fuel, e.g. the presence of resins in oils. The interpretation of the research results enabled a qualitative analysis of the fuels, providing the basis for conclusions about the degradation processes taking place in them.

4. Summary and Conclusion

On the basis of the results of the tests presented in Figure 1-2 and their detailed analysis, taking into account the mechanisms of light interaction with the samples, it can be concluded that:

1. light passing through the sample changes its intensity as a result of interaction with it,
2. the amount of radiation passing through the sample depends on its physic-chemical parameters,
3. samples of the same materials, after a different storage time, showed a change in color, so the light reacting with the medium through which it passes changes depending on the mechanisms and processes occurring in the samples during their storage.

On the basis of the results obtained, it can be concluded that it is possible to develop a new method of fuel quality control using spectrometric methods. Due to the fact that the intensity and colour of light changed both when testing samples of different types of fuels and materials after different storage times. It cannot be stated unequivocally that it will be possible to set specific parameters specified in the standards. The obtained results and the recorded changes between the samples of the "fresh" starting fuel and after several months of storage indicate that the observed changes can be related to the ageing processes occurring in the fuel determining the functional properties of the fuels. Therefore, it can be concluded that spectroscopic methods can be used to apply simplified methods for the assessment of the functional quality of fuels.

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