MEASUREMENT OF NON-ELECTRIC QUANTITIES

PREDICTIVE ASSESSMENT OF DIESEL FUEL QUALITY BASED ON WAVELET TRANSFORMATIONS

Oksana Shpak, Ph. D., Assistant,
Lviv Polytechnic National University, Ukraine
Nazariy Velykiy, Ph. D student
Lviv State University of Life Safety, Ukraine
e-mail: oksana.i.shpak@lpnu.ua

https://doi.org/10.23939/istcmtm2023.02.005

Abstract. The principle of device operation for determining the quality control of diesel fuel is considered, which helps to investigate the spectral characteristics of diesel fuel. Basic wavelet transformations are given. IR spectroscopy of diesel fuel from different producing countries was carried out, and determination of the cetane number through wavelet coefficients and determining conclusion diesel fuel quality were performed.

Key words: Diesel fuel; quality control; spectral characteristics; cetane number; wavelet conver.

1. Introduction

The fuel market, in particular diesel fuel, has reformatted over the months of the war and withstood the crisis of changes in supply channels and resource shortages. During the war, the item of diesel fuel (DF) quality is of strategic importance, since not only transport infrastructure, but also the Armed Forces of Ukraine work on it. In addition, many businesses and critical infrastructure are dependent on diesel generators that operate during power outages. During the war, it is necessary to provide agricultural equipment with high-quality fuel for sowing and the existence of life in the country. Fuel quality up to determine its performance by express methods and provide appropriate characteristics. Methods of DF parameters determination using measuring methods of quality control are widely interesting. Since standardized laboratory of quality control measurement methods is long-term, it makes sense to refer to express methods. Spectrum analysis of signals can provide consumers with diagnostic information about fuel quality. It is characterized by high accuracy and resolution. Wavelet transformations of the signal are a summary of spectral analysis. They are a convenient and effective tool for solving scientific and engineering problems. Modern usage of wavelet transformations in various fields of science and technology is one of the important items of the present.

Therefore, the quality of DF determination through the prism of wavelet transformations is an innovative task of science and the fuel industry. They are well localized in the frequency domain, big set of basic functions, and have the ability to choose and match between the basis and measured signals.

2. Disadvantages

Determination of DF quality is performed by definition of quality indicators by using standardized methods. Therefore, the usage of laboratory methods for determining diesel fuel quality indicators is outdated, and long-term and worthwhile in the period of computerization.

3. Goal

Determination of diesel fuel quality index with different cetane numbers based on analysis of spectral characteristics DF by using wavelet transformations in the frequency domain.

4. Block diagram of the diesel fuel quality control device

To determine the quality, spectral scanning of DF samples from manufacturers of different countries was carried out. The cetane number (CN) was selected for the quality of the study. The cetane number characterizes the self-ignition of DF and is the main indicator in determining the quality of DF. Higher the cetane number allows the engine to start easier. Also, a high cetane number indicates a lower amount of harmful aromatic hydrocarbons in its composition for the environment. The optimal value of the cetane number is in the range of 40–60 units. At these values, the maximum “saturation” of the fuel is achieved, which means, the higher value of the cetane number, the better quality of the DF. Indirect methods for determining the cetane number rely on component composition analysis. These are infrared spectrometers, which must be recalibrated with any change in the composition of DF (for example, when it is mixed with biodiesel).

This study exploits a device to determine the quality indicator of DF [11] by computer methods with the application of a sensor that calculates the quality indicator of DF by using the IR spectrum and transmits it to the control board, where a comparison with the value of this indicator according to the standard [8] (Fig. 1) is provided.

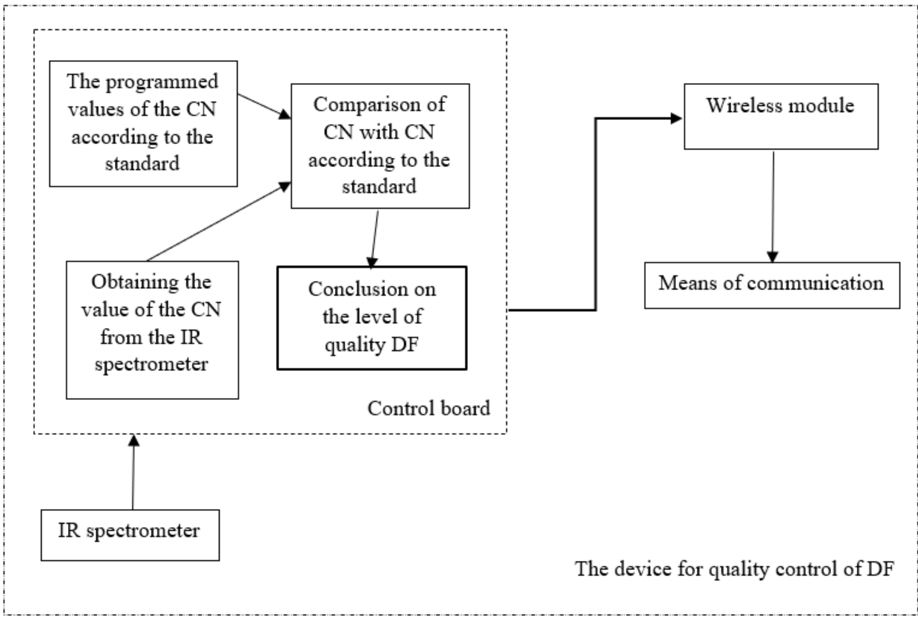

Fig. 1. Structural diagram of the device

This device is applied to research the spectral characteristics of the DF in the frequency range of 750–1550 nm. Each spectral range corresponds to a certain value of cetane number. That is, if the wavelength corresponds to the frequency range of 750–1000 nm, then the cetane number is within 40–47 units which characterizes a low-quality of fuel. If the frequency range is 1000–1250 nm, then the cetane number is 47–54 units; this is an average quality. For wavelength 1250–1550 nm and the estimated cetane number equal to 54–60 units characterizes the high level. The level of quality is divided into three components: satisfactory quality, good quality, and excellent fuel quality [1] depending on the value of the cetane number and its corresponding spectral characteristics. Due to this, the quality of DF is evaluated depending on the value of the cetane number.

The DF quality control device contains a control board, which is a microcontroller, an infrared spectrometer, a wireless module, and means of communication.

The IR spectrometer, presented as a quality indicator, determines the value of the cetane number of DF by wavelength and transmits an analog signal to the microcontroller. The Atmel ATmega168 or ATmega328 microcontroller contains the programmed values of the cetane number of DF according to the standard for a specific spectrum, which is fixed in the data buffer, compares this value with the measured value of the indicator, forms a conclusion about the level of DF quality, converts an analog signal into a digital signal, forms and outputs quality information DF through a wireless module to a means of communication. The wireless module represents the over-the-air BLE (Bluetooth Low Energy) data transmission protocol, which transmits information about the quality of the fuel in the car tank to the consumer's communication device. The nRF Connect for Mobile application is used to connect the communication tool to the device. To install BLE, you need to: scan all available devices; select the appropriate device according to its parameters; connect to the desired device using the "connect" button. Data on the quality level of the DF on the consumer's means of communication are displayed after connection in the device's services. A message about the quality of the DF is displayed on the screen of the communication device – gadget. Thus, the consumer evaluates the fuel quality at the gas station based on the message on the screen of his communication device.

Studies of such control make it possible to establish the dependence of the electrical parameters of the DF on its chemical nature.

5. Study of diesel fuel

To establish the possibility of determining the cetane numbers of fuels by the method of near-wave IR spectroscopy, the spectra of various DFs were recorded

[9]. Infrared radiation spectrum data form the dependence of the light intensity on the cetane number and fractional composition of the fuel [2]. The acquisition of DF absorption spectra was carried out on the device “Nicolet iS10” [10], which is designed for quality control of chemicals with various fields of application. The principle of operation of the device is based on measuring the absorption spectra of the studied fuels in the near-infrared region. The method is based on the microscopic interaction of infrared light with a chemical substance using the absorption process. As a result, a set of spectral ranges is obtained and a spectral library is formed. These spectral ranges serve as the “molecular fingerprint” of substances. Fourier transform infrared spectroscopy is based on the analysis of chemical properties. A spectral library mapping approach rapidly identifies a chemical with a unique “molecular fingerprint”. Fig. 2 shows some results of studies of DF with different percentages of cetane number. It can be seen from the conducted studies that the spectral characteristics of DF with different values of cetane number significantly differ in the region of 850–950 nm, which are due to the different ratio of cetane and alpha-methylnaphthalene A.

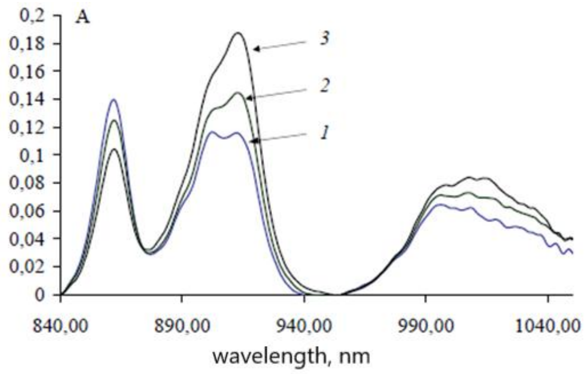

Fig. 2. Spectra of reference fuels with different cetane numbers: 1–32 % cetane; 2–40 % cetane; 3–52 % cetane

That is, IR spectrometry is useful for the determination of the CN of DF by spectrum. The study of the possibilities of the IR spectrometer has confirmed its effectiveness in the assessment of DF quality. To obtain specific values of CN, it would be expedient to apply wavelet transformations. Based on their basic functions, we can quickly determine the CN values. Such a device can be programmed powered by appropriate software. It can compare the measured and stored value of the CN and then produce the conclusion on the DF quality level.

Advantages of wavelet analysis.

Wavelet analysis is a variety of spectral analysis, in which the role of simple oscillations is played by functions of a special kind, which are called wavelets. The basic function of a wavelet is some “short” oscillation. Wavelet transformation of a signal is its representation in the form of a general series or a Fourier integral according to the basic functions constructed from a mother wavelet with certain properties, considering in such a manner impacts of time shift.

After obtaining the spectral characteristics of the DF, a signal is processed, transformed, and analyzed. Measurement of amplitudes of oscillations at the corresponding harmonic corresponds to the capabilities of Fourier analysis. The representation of signals based on harmonic functions is considered in the theory of oscillations. The choice of harmonic functions as basic functions is explained by the presence of periodic action with pronounced spectra. Harmonic functions of the form $u(t)$ were obtained in the analysis and synthesis of signals $u(t) = A\sin(\omega t + \varphi)$, where A is the amplitude of harmonic oscillations; ω is angular frequency; t is the time; φ is an initial phase of the oscillatory process.

For the transformation of non-stationary signals that change over time, the application of basic functions does not give the desired result. Therefore, the wavelet transformation is the most relevant for the transformation of non-stationary signals, considering its adaptability for the analysis of local features of the signal. With the help of wavelet transformation of digital signals of technical systems, it becomes possible to determine their dynamic characteristics [12].

Depending on the needed signal data, the mother wavelet is selected. The properties of separate wavelets are considered since different wavelets can reflect the properties of the signal in different ways. This is because each wavelet has its characteristics in the time and frequency domains. The mother wavelet plays the role of an adaptive window, the width of which is large for small frequencies v and small for large ones. The forward wavelet transform contains the combined information of signal analysis and wavelet analysis. The most effective and acceptable approach in the analysis of complex signals $s(t)$ is the decomposition of signals in the form of a set of simple components – basic functions $\psi_k(t)$, multiplied by some coefficients C_k: $s(t) = \sum C_k \Psi_k(t)$. Since the basic functions do not change their appearance for different signals, we can conclude that only the coefficients contain information about the tested signal.

By analogy with the basic functions, not all properties of the wavelet transform depend on the selected parent wavelet, based on which the wavelet transform is performed. It is customary to classify wavelets by the type and features of the generating function and by the name of the scientist who first proposed this or that wavelet. The classification of wavelets is presented in the Table.

Table 1. Classification of wavelet transformations

Name	Features	Advantages and disadvantages	Type
Rough Wavelets	The small number of properties for signal analysis	Advantages: symmetry, the possibility of continuous decomposition of the signal	Gauss Wavelets, Morleta, "Mexican Hat"
Unlimited regular wavelets	Has no fast algorithm conversion	Advantages: symmetry and regularity in limitlessness, the ability to determine the details of the signal	Meyer's Wavelets
Orthogonal wavelets with compact support	Presence of orthogonal analysis, the possibility of a fast transformation algorithm, insufficient periodicity	Disadvantages: Dobeshi – not symmetric, Simplet – close to symmetric, Coiflets – no symmetry	Wavelets of Dobeshi, Simpleta, Coiflets
Biorthogonal paired wavelets with compact support	Presence of biorthogonal analysis, good localization in space, insufficient periodicity	Advantages: symmetry with filters. Disadvantages: lack of orthogonality	B-spline biorthogonal wavelets
Complex wavelets	No fast algorithm for signal conversion and reconstruction	Advantages: symmetry	Gauss, Morlet, Chenon wavelets, and B-spline frequency wavelets

The wavelet spectrogram carries detailed information about the investigated signal, namely about the local characteristics of the signal, which are understood as spikes or dips in the signal of the object. Considering the features, of the presented wavelet transforms, it is advisable to choose orthogonal wavelets with a compact carrier. Namely, the Dobeshi wavelet, which is characterized by a fast transformation algorithm, has an orthogonal analysis and a clear space localization of functions. So, we can determine and select the frequency-suitable wavelet function and produce an appropriate conclusion about the similarity of the signals. The application of the selected wavelet permits to obtain of a graphical representation of the wavelet transformations for the DF signal, where the characteristic areas are convenient for analysis at different values of the cetane number. Therefore, the spectral characteristics of the DF and the characteristics of the wavelet transformation coincide in the shape of the signal and apply to identify the fuel by cetane number.

6. Assessment of diesel fuel quality

To evaluate the quality of fuels, DFs from different producing countries were studied while researching at Lviv oil depots with their quality certificates. There, the specified cetane number was previously determined in a traditional laboratory, where according to [8] the cetane number is equal to the volume concentration of cetane in the mixture.

The procedure for evaluating the quality of the DF consists in determining the spectral characteristics with different values of the cetane number, selecting the wavelet transform, comparing it with the standard deviation, and transferring this data to the information device. The received spectrogram is processed by the program code of the applied software. That is, to the received spectral characteristics, the program selects the appropriate wavelet transformation from the database, compares it with the standard value and, on this basis, issues a result about the appropriate level of quality of the DF.

The study of DFs from different producer countries (Poland, Romania, Sweden, Bulgaria, the Baltic States, and Italy) consists of the following algorithm:

1. Obtaining a signal spectrogram with an IR spectrometer.
2. Setting the cetane number according to a specific value of the spectrum.
3. Selection of the type of wavelet from the database to identify the accuracy of the selection of the CG of the DP.
4. Comparison with the programmed value.
5. Formation of a diagnostic conclusion.

50 measurements of DF samples from different producing countries were carried out. Spectral data were collected at an ambient temperature of 10 °C to 18 °C and in the range of 750 nm to 1550 nm with 2 nm intervals. Each spectrum was recorded as the average of 10 spectra with an integration time of 10 ms. Some of them are given in Table 2.

The average error between the measured value and the value according to the quality certificate is 0.3 %. After the calculations, the wavelengths were selected for the correlation dependence between the cetane number determined by an IR spectrometer and the cetane number according to the Certificate. Results are presented in Fig. 3.

Table 2. Measurement data

Measurement number of DP from different countries (Poland, Romania, Sweden, Bulgaria, Baltic States, Italy)	Cetane number, units		Error, %
	Certificate	Results of study	
1	52	52.4	0.4
2	46	45.8	0.2
3	50	49.4	0.6
4	48	47.7	0.3
5	42	41.6	0.4
6	53	52.6	0.4
7	49	48.8	0.2
8	48	47.5	0.5
9	47	47.1	0.1
10	50	49.6	0.4
11	51	51.4	0.4
12	50	49.9	0.1
13	49	48.7	0.3
14	51	50.8	0.2
15	50	50.1	0.1

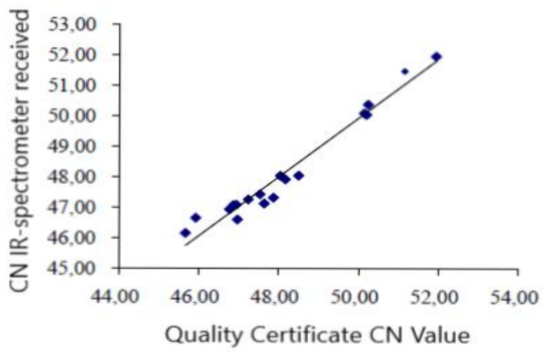

Fig. 3. Correlation dependence of cetane number when determined by an IR spectrometer and cetane number according to the quality certificate

As the measurement data prove, the determination of the cetane number by an IR spectrometer is inherent in a certain error regarding the value of the quality certificate. So, it is possible on the measurement of spectral characteristics basis to define the DF quality. That is, after determining the spectral characteristic of the DF and selecting the appropriate wavelet transformation with the help of the software, and comparing it with the standard value, a conclusion can be proposed on the DF quality.

7. Conclusion

The device for monitoring the quality of diesel fuel directly at a gas station is studied. Its operation is based on the infrared radiation application. It is demonstrated the possibility to define the DF quality based on the measurement of spectral characteristics applying the wavelet transformation.

8. Gratitude

The authors thank the Editorial Board of the Scientific journal "Measuring Equipment and Metrology" for their support.

9. Mutual claims of authors

The authors have no claims against each other.

References

[1] The method of controlling the quality of diesel fuel: Pat No.77043. Ukraine. IPC G1N 33/22 / O. I. Shpak. No. u 2012 08725; Application 16.07.2011; Publ. 25.01.2013. Bul. No. 2. 6 p.

[2] P. Djahani, J. Kahn Analysis of infrared wireless links employing multi-beam transmitters and imaging diversity receivers Global Telecom. Conf. GLOBECOM'99 (Cat. No. 99CH37042) 5–9 Dec. 1999. DOI: 10.1109/GLOCOM.1999.

[3] V. W. Vermehren, H. M. de Oliveira. Close expressions for Meyer Wavelet and Scale Functional DOI: https://doi.org/ 10.48550/arXiv.1502.00161.

[4] Xuyin Zhang; Kaixia Deng; Yao Han. The image space of Meyer wavelet transform Proceedings of 2013 2nd International Conference on Measurement, Information, and Control Aug. 16–18. 2013, Vol. 2. DOI: 10.1109/MIC. 2013.6758159.

[5] M. Misiti, Y. Misiti, G. Oppenheim, J.-M. Poggi. Wavelet Toolbox. URL: https://courses.washington.edu/me333afe/ Wavelet_Toolbox_Misiti_Ch1.pdf.

[6] Hui Li. Complex Morlet wavelet amplitude and phase map, based bearing fault diagnosis 8th World Congress on Intelligent Control and Automation (WCICA), 7–9 July 2010. DOI: 10.1109/WCICA.2010.5554232.

[7] S. E. N. Correia; J. M. de Carvalho Optimizing the recognition rates of unconstrained handwritten numerals using

biorthogonal spline wavelets Proceedings 15th International Conference on Pattern Recognition. ICPR-2000, 3–7 Sept. 2000, Vol. 4. DOI: 10.1109/ICPR.2000.906060.

[8] DSTU 7688-2015 “Diesel fuel Euro. Technical conditions” [Effective from 2016-01-01]. Kyiv: UkrNDNC, 2015. 15 p. (National Standard of Ukraine). URL: http://online.budstandart.com/ua/catalog/doc-page?id_doc=62099.

[9] István Péter Kondor, Máté Zöldy, Dénes Mihály Experimental Investigation on the Performance and Emission Characteristics of a Compression Ignition Engine Using Waste-Based Tire Pyrolysis Fuel and Diesel Fuel Blends Energies 2021, 14(23), 7903. DOI: https://doi.org/10.3390/ en14237903.

[10] Thermo Scientific Nicolet iS10 FT-IR Spectrometer. URL: https://www.tecnofrom.com/moduloProductos/noti_114/file.pdf

[11] Device for determining diesel fuel quality control: patent application No. C-2255, Ukraine / O. I. Shpak, 09/29/2022. Ukraine. Lviv, 2022.

[12] S. Glushkov, V. Zhidkikh. The choice of a wavelet-forming function for the analysis of the dynamic characteristics of the internal combustion engine signal. URL: https://cyberleninka.ru/article/n/vybor-veyvlet-obrazuyuschey-funktsii-dlya-analiza-dinamicheskih-harakteristik-signala-dvigatelya-vnutrennego-sgoraniya /viewer.