Device for measuring the moisture content of diesel fuel

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Abstract: *The relevance of the study is conditioned by the wide occurrence of situations in which diesel fuel, during its storage and transportation, reacts with the environment, resulting in its oversaturation with moisture and a decrease in a number of characteristics that are of fundamental importance in the process of practical use, which necessitates the development and practical implementation of a special device that allows determining the moisture content in diesel fuel before its use. The purpose of this study is a theoretical assessment of the prospects for the development of such a device and its practical use, including an assessment of its main technical characteristics that are essential from the standpoint of practical use for measuring the moisture content of diesel fuel in various branches of its application. The leading approach is a combination of a theoretical investigation of the prospects for the development and technical improvement of a device for measuring the moisture content of diesel fuel with a systematic analysis of the main aspects of the effectiveness of its practical application. The results obtained indicate the significant importance of qualitative measurement of the parameters of the moisture content of diesel fuel and the need to use special devices to ensure the high quality of such control. The results and conclusions of this study are of significant importance for developers of special devices designed to measure the moisture content of diesel fuel and for employees of technical services whose duties include monitoring the condition of diesel fuel before its direct use and evaluating its parameters that are of fundamental importance from the standpoint of the safety of its further use.*

Key Words: *measurement of the moisture content of diesel fuel, analysis of the quality of petroleum products, characteristics of diesel fuel*

1. INTRODUCTION

A timely analysis of the quality indicators of petroleum products is essential from the standpoint of safety of their subsequent use in various branches of technology. The parameters of the ambient temperature and pressure in the places of storage of petroleum products and the directions of their transportation can have a significant impact on the change in the moisture content in them, often towards a significant increase in this indicator [1]. If the permissible value of the moisture content of petroleum products, and in particular, diesel fuel, is exceeded, it cannot be used for its intended purpose without carrying out its preliminary dehumidification. In the case of using commercial-type petroleum products, this refers to a critical level of moisture content in them, if this indicator is at the level of hundredths or even

thousandths of a percent. Modern oil-filled equipment with its direct practical application in the field of thermal power engineering, in air transport engines, in particular, in conditions of moisture dissolution in tanks and reservoirs can become very unsafe, which would result in emergency situations [2], [3].

Currently, diesel fuel is widely used in aviation as the main fuel for helicopter engines [4]. In general, aviation diesel engines are still widely used in aviation, and the beginning of their practical use dates back to the 1920s. Reciprocating diesel engines in small target aviation have greater practical efficiency compared to gas turbine engines, and the most important requirement that is imposed on them should be considered trouble-free operation in combination with significant fuel economy. To date, the design and development of multi-purpose aircraft piston engines that have the property of working effectively on various types of fuel, including kerosene and diesel fuel, is a very urgent task in the field of aviation engine construction. In this context, the quality control of the level of moisture content in diesel fuel intended for practical use in aircraft engines is of fundamental importance from the standpoint of ensuring the quality control of diesel fuel in particular and guaranteeing the safety of aviation traffic in general [5], [6].

Modern devices designed for quality control of diesel fuel provide effective control of a number of its parameters that are of fundamental importance from the standpoint of the safety of its subsequent operation, among which the humidity indicator occupies a special place. To date, a significant number of devices have been developed and successfully tested in practice, guaranteeing high quality measurement of the moisture content of diesel fuel [7]. Among them are electronic moisture meters of petroleum products (moisture meter Neft-2), (moisture meter IVN 3003), the quality analyser of petroleum products SHATOX SX-300, as well as other devices. If there are differences in the principles of operation of these and other devices designed to measure the moisture content of diesel fuel, they have a general similarity, which is expressed in the ability to accurately determine the percentage of moisture content in the total volume of diesel fuel in a given time unit. All these meters have been successfully used for a long time in various fields of modern technology for measuring these values [8], [9].

The presence of moisture in diesel fuel is one of the most common problems, not only for motorists, but also for representatives of other areas of diesel fuel use, including aviation [10], [11], [12]. The reasons for the appearance of moisture in the fuel or fuel tank can be different, the consequences of such a situation remain unchanged, which can be expressed in different ways, up to the failure of the engine or the fuel system as a whole. Therefore, the issues of using a device for measuring the moisture content of diesel fuel are of significant practical importance from the standpoint of ensuring the quality of diesel fuel at any stages of its storage and practical use.

2. MATERIALS AND METHODS

The methodology of this study is based on a combination of theoretical research of the prospects for the development and technical improvement of a device for measuring the moisture content of diesel fuel with a systematic analysis of the main aspects of the effectiveness of its practical application in various fields of science and technology. Theoretical studies were carried out taking into account the experience of the practical application of such devices and the practical consideration of the main features of their use. The chosen combination of theoretical and practical methods of research provides a high quality of disclosure of the subject matter in the context of forming a qualitative assessment of the effectiveness of the device for measuring the moisture content parameter in diesel fuel,

which is of significant practical importance for various areas of use of this type of fuel. The theoretical basis of this study were research papers by Russian and foreign researchers investigating the development and practical application of a device designed to determine the parameter of the moisture content of diesel fuel. The theoretical and practical studies by other authors were selected in strict accordance with the stated topic of research in order to provide it with the most complete and objective coverage. To facilitate the perception of the submitted information and create the highest quality picture of scientific research, all the information given in the order of citation in this paper has been translated into English [13], [14], [15].

This study was carried out in three stages.

1. At the first stage, a theoretical study was carried out on the prospects for the development and technical improvement of a device for measuring the moisture content of diesel fuel, in relation to the prospects of its practical application in aircraft engines. In general, this contributes to the establishment of a high-quality theoretical basis for this study, which in the future will serve as a reliable basis for the formulation of the results of this research work and the conclusions obtained on this basis.

2. At the second stage, a systematic analysis of the main aspects of the effectiveness of the practical application of the device for measuring the moisture content of diesel fuel was carried out based on the previous theoretical study. At the same time, at this stage of study, the preliminary results were formulated, as well as their comparison with the results of other researchers of the declared and related topics was carried out.

3. At the final stage of this research, the final conclusions were formulated based on the previously obtained results, summarising all the studies carried out, reflecting the main aspects of the development and practical application of a device for measuring the moisture content of diesel fuel. The results and conclusions of this research will be of significant practical importance for the developers of the devices under consideration and for employees of technical services who are faced with the need for their practical application by the nature of their occupation.

3. RESULTS AND DISCUSSIONS

Today, there are numerous varieties of devices for measuring the moisture content of diesel fuel, the practical use of which provides sufficient accuracy, which is decisive from the standpoint of the quality of operation of such devices. An accurate determination of the total amount of moisture in diesel fuel is necessary to understand the degree of suitability of the fuel for use, since the presence of moisture in the fuel leads to a significant change in its characteristics, which leads to unstable operation of the aircraft engine and uneven speed. When severe frosts occur, moisture may freeze, which, if it enters the fuel line, leads to partial or complete blocking of fuel access to the engine [16]. The timely use of a device for determining the moisture content in diesel fuel removes all these problems and makes the use of diesel fuel completely safe [17].

As an example of the principle of operation of the device in question, this study suggests considering the IVN-3003 moisture meter, designed to determine the volume of moisture in petroleum products in general and in a diesel engine in particular. The principle of operation of this device for measuring the moisture content of diesel fuel is based on the presence of a functional dependence of the permittivity indicators of a mixture of two components on their total volume content. The permittivity indicators of diesel fuel are in the range of 1.7-2.6, similar indicators for water are in the range of 70-80, which means a significant increase in the permittivity index of the mixture even with a slight concentration of moisture in the fuel.

The graph in Figure 1 shows the dependence of the permittivity index of a mixture of fuel and water on the volume of moisture in diesel fuel.

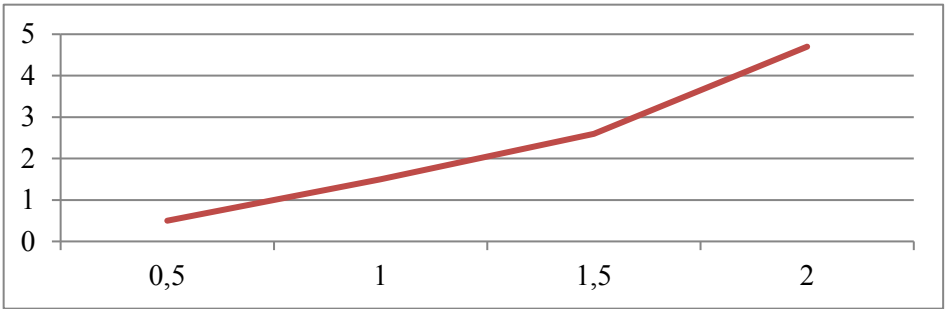

Fig. 1 – Dependence of the permittivity index of a mixture of fuel and water on the volume of moisture in diesel fuel

As can be seen from the data presented in Figure 1, an increase in the volume of moisture in diesel fuel (x-axis indicator, mg/l) leads to a significant increase in the permittivity of the mixture of diesel fuel and liquid (y-axis indicator). Understanding this dependence allows the study to determine the exact value of the volume moisture content in a mixture of liquid and diesel fuel, based on knowledge of the value of the dielectric constant of the mixture.

Table 1 shows the main technical characteristics of the device for measuring the moisture content of diesel fuel used in aircraft engines.

Table 1 – The main technical characteristics of the device for measuring the moisture content of diesel fuel used in aircraft engines

Ambient air temperature during operation	From +5°C to +55°C
Air humidity during operation	Up to 75% at +27°C
Normal pressure during operation	From 80 to 106.7 kPa
Product permittivity range	1.5-5.5
Error range	0.3%-0.7%
Device performance	0.5 mst/sec
Operating mode setting time	≤30 seconds
Duration of operation without recharging	≤72 hours
Measuring range	0.5%-25%
Weight	Less than 1 kg

The range of the dielectric constant of the studied mixture of diesel fuel and water is the main criterion by which the moisture parameter in the fuel is determined. In addition, the operating time of the device without additional recharging is essential, since it is not always possible to perform it in practical operation.

For aircraft engines, in some cases, a high moisture content in diesel fuel is characteristic, therefore, when determining the proportion of moisture in diesel fuel intended for practical use in aircraft engines, it is recommended to use the method of distilling moisture from the mixture of the tested fuel, using a device for quantifying the moisture proportion. The essence of the method is to use a special device containing a receiver for distilling fuel and a moisture solvent. The distillation process is carried out until the moisture level in the receiver becomes unchanged, and the upper layer of the solvent is transparent, after which the solvent is cooled. The volume of moisture in a unit of diesel fuel is determined using the equation:

$$\mathrm{Wp} = 100\mathrm{V}/\mathrm{M},\mathrm{Wp}, \quad (1)$$

where: V – volume of moisture in the receiver; M – weight of fuel taken for the study.

In addition, the Clifford method is used in devices for determining the moisture content of diesel fuel intended for use in aircraft engines, the essence of which is to fix the colour change of the mixture of fuel and liquid, and the turbidity of such a mixture in the presence of potassium permanganate. About 100 ml of diesel fuel from a high-quality prepared sample is poured into a glass container. Soaking takes place for 10 minutes. Then crystals of potassium permanganate are added to the fuel tank and thorough mixing is performed. If the volume of moisture in diesel fuel does not exceed the concentration parameter critical for the subsequent use of this fuel in the engine, its colour does not change in the presence of potassium crystals. If moisture in the specified concentration is present in the fuel, potassium permanganate gives a pink colour, which gradually turns into a purple hue. Subsequently, potassium permanganate dissolved in a mixture of diesel fuel and water gives areas of intense colouring, having the form of characteristic flakes, in the contact zones of moisture present in the mixture with fuel.

For diesel fuel used in aircraft engines, the method of analysing the moisture content in the fuel based on the principle of evaluating thermal properties has become widely used. Figure 2 shows the change in temperature parameters for diesel fuel that does not contain moisture and has an increased moisture content exceeding the permissible concentration norms, depending on the duration of heating of the mixtures.

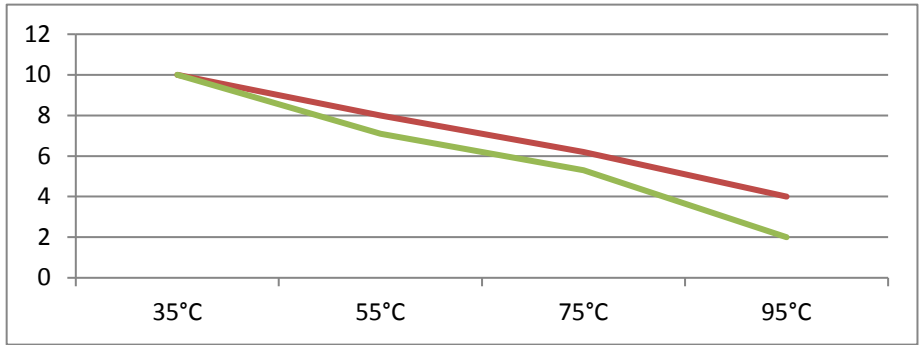

Fig. 2 – Changes in temperature parameters for diesel fuel that does not contain moisture (green) and has an increased moisture content (red), exceeding the permissible concentration norms, depending on the heating duration

As follows from the data presented in Figure 2, diesel fuel with a high moisture content imposes a significantly lower ability to ignite from compression in the cylinder of an aircraft engine, which significantly reduces the efficiency of its use and makes it unsafe in general. The use of a device for determining the moisture content of diesel fuel intended for use in an aircraft piston engine contributes to the early detection of excess moisture in the fuel and preventing its further use for its intended purpose. In addition, the assessment of changes in the composition of the liquid-fuel mixture under significant temperature exposure involves a comprehensive assessment using the boiling point of the mixture and the ignition temperature of the fuel [18].

Comprehensive monitoring of the level of moisture content in diesel fuel immediately before its use in internal combustion engines of aviation equipment involves the use of electronic moisture meters in combination with laboratory research methods. Such a combination of research methods significantly complicates the process, while increasing the accuracy of measurements. If excessive moisture content in diesel fuel is detected during the research, a set of measures should be taken to remove moisture. They usually include the use of additional devices, such as filters with settling tanks, in which the removal of moisture from diesel fuel can be performed automatically or manually [19]. In addition, in practice, it is

allowed to use separation filters, which are installed directly before the fuel purification filters and involve additional heating of diesel fuel in order to evaporate the moisture that has got into it, which prevents the development of freezing processes of the fuel and water mixture in this particular node. Somewhat less often, the use of electric fuel heaters connected to the on-board electrical network of an aircraft or helicopter is allowed in aviation equipment. Fuel overheating is not allowed in any case. The device's ability to self-regulate allows it to be used in the cold season without switching off.

Modern aircraft engines are developed and applied in practice with the expectation of using various types of fuel, one of the varieties of which is diesel. To date, aircraft engine manufacturers from Western Europe have accumulated and successfully implemented a rich practical experience in the development of aircraft engines running on diesel fuel on the principle of compression ignition. The control of the volume of moisture content in the fuel for such engines is of fundamental importance, since the presence of excess moisture in the fuel significantly reduces the flammability of diesel fuel, up to its complete unsuitability for practical use [20].

The existing practice of periodic monitoring of the humidity of technological media using laboratory chemical analysis does not meet the current trends of continuous monitoring of critical equipment parameters. It is known that the thermophysical characteristics of hydrogen-water mixtures depend on the volume of moisture content. The development of technologically suitable devices for high-quality monitoring of the residual moisture level in petroleum products can be successfully implemented using a fundamentally new method of pulsed thermal control, built taking into account the long-term history of the development of the method of pulsed heating of a wire probe. The idea of the method is based on the results of the study of the phenomenon of achievable overheating of systems with limited mutual solubility of components in the processes of their pulsed heating [21].

Modern methods for determining the moisture content of diesel fuel suggest the possibility of quickly determining this value without conducting a chemical analysis of the composition of the fuel and water mixture. The theoretical possibility of developing a device that allows determining the amount of moisture in the fuel based on the available indicators of the dielectric permittivity of the composition under study allows creating an electronic moisture meter for subsequent wide application in various fields of technology to solve these problems [22]. In favour of devices of this kind, the relative simplicity and compactness of their design, the possibility of repeated use for a limited period of time and a sufficiently high measurement accuracy, which is the defining characteristic of their work, testify to the relative simplicity of their design. In the future, electronic moisture meters for determining the moisture content of diesel fuel would find more and more widespread use in aviation, automobile and railway transport.

Aviation diesel engines are used in almost all branches of aviation, while the durability of their practical operation is largely determined by the quality of the fuel on which they operate. The percentage of moisture content in diesel fuel largely determines the quality of the fuel mixture and its ability to ignite under compression pressure.

This explains the urgent need to avoid the ingress of moisture into the fuel for aircraft engines and fuel tanks, which is successfully resolved by the use of special devices for measuring the moisture content of diesel fuel. Such devices can be recommended for use at airfields, oil and fuel storage facilities and wherever it is theoretically possible for moisture to enter diesel fuel, which reduces its quality [23].

The moisture content of diesel fuel is one of the most important criteria for assessing its quality. The presence of water in diesel fuel leads to significant economic losses, expressed in

the impossibility of its practical use and the need for a set of measures to reduce the level of moisture in the fuel. At the same time, the cost of transporting fuel increases, provided that its operating characteristics are significantly reduced. In addition, if water is present in diesel fuel together with salts dissolved in it, it can cause accelerated corrosion of the structural elements of the fuel tank and other components [24]. The calorific value of diesel fuel decreases when water is added, which can cause blockage of the engine spray nozzles. In the cold season, crystals of water frozen in diesel fuel can clog filters, prematurely disabling them, which also destabilises the operation of internal combustion engines and can lead to serious accidents.

Laboratory methods for determining the volume of water content in diesel fuel require mandatory sampling for subsequent studies. In addition, laboratory research requires the use of expensive equipment and takes quite a long time [25]. Notably, a laboratory sample, when delivered to the test site, can significantly change its properties, under the influence of changes in ambient temperature, pressure, as a result of direct contact with atmospheric air, etc. Therefore, it is simply impossible to quickly and accurately determine the parameters of the moisture content in laboratory conditions when it is required to determine the exact indicators of the moisture content in diesel fuel in a short time, in order to determine the admissibility of using this fuel in principle in an internal combustion engine.

In modern conditions, with the achieved level of diesel fuel production and the distillation of petroleum products, periodically measuring the parameters of the moisture content in diesel fuel may not be sufficient to reliably determine the quality of diesel fuel and its suitability for use. This necessitates the development and practical implementation of a complex of control and measuring devices, either operating continuously or in short time intervals, providing information about the current state of diesel fuel in terms of moisture ingress into it.

Automatic analysers are able to provide high-quality flow control, with the processing of data coming from sensors, which forms a complete picture of changes in the state of the diesel fuel under study, which would greatly facilitate the management of all processes associated with its use [26].

Automation of the process of measuring moisture indicators in diesel fuel is essential from the standpoint of the frequency and regularity of checking the quality of diesel fuel during its storage and preparation for use in aircraft engines. Automatic measurement of the moisture content of diesel fuel using special devices involves the creation of a system for active monitoring of this parameter, consisting of several measuring devices, the operation of which is regulated from one centre, where the data of the measurement results are received. If a deviation of the parameter under consideration from the permissible possible value is detected, work is required to eliminate the increased moisture content in diesel fuel [27]. The main advantage of such a system is a significant reduction in the time for checking the fuel moisture content indicator due to the automation of the process and the rapid elimination of detected inconsistencies in the quality of diesel fuel.

An important aspect in the operation of the measuring device is its measurement error, which should not exceed a certain indicator, which, as a rule, should not exceed several tenths of a percent. In case of exceeding the permissible possible indicator of measurement error, the permissible accuracy of the device is neglected, which negatively affects the results obtained. In such cases, it is necessary to use other, more advanced devices and control methods that can provide a complete and qualitative picture of the research [28].

Methods of monitoring the moisture content of diesel fuel can vary significantly, depending on the condition of the fuel, the storage period in warehouses, and the industry of the intended use. In aviation technology, the use of electronic moisture meters should be considered preferable, as the most compact devices that allow numerous measurements of

diesel fuel parameters at different stages of its storage and transportation to the place of use. These devices allow measuring the moisture content of diesel fuel within the permissible error, which should not exceed the established value.

The measurement of the parameters of the moisture content of diesel fuel is performed at different stages of its storage and transportation, which implies the need for periodic repetition of measurements, due to changes in the storage conditions of diesel fuel, after its transportation and movement to various containers for subsequent use. Timely and high-quality measurement of the specified value of the moisture content of diesel fuel contributes to the preservation of its characteristics that are important from the standpoint of its subsequent safe use [29].

Devices for measuring the moisture content of diesel fuel should ensure high quality control of this indicator with a relatively short measurement time, without the need to take a sample for laboratory studies. Portable devices, due to their small size, are available for use on a large scale.

The speed of measuring the parameter of the moisture content of diesel fuel is of significant importance from the standpoint of the frequency of using moisture meters for quality control of petroleum products. Devices for measuring the moisture content of diesel fuel allow quickly and effectively monitoring the moisture content in the fuel and preventing the excessive water concentration in diesel fuel at any stage of its storage and transportation. These devices are not intended for determining other additional parameters related to the quality of fuel or fuel mixture.

The current practice of periodic monitoring of the state of process fluids and media, involving the use of chemical analysis methods in laboratory conditions, does not always meet the needs of the aviation industry and trends in tracking the most significant parameters of equipment and materials [30]. Modern developers regularly put forward alternative monitoring methods, such as the method of pulsed thermal control, which involves heating the volume of fuel to determine its physicochemical properties and the method of pulsed heating of a wire probe placed in a given volume of fuel. Nevertheless, the use of electronic moisture meters is a priority in this area, because, despite the relatively lower accuracy of measuring the parameters of the moisture content of diesel fuel compared to the methods given as examples, it has a number of other advantages, such as a higher frequency of possible measurement operations, which implies the possibility of performing more measurements per unit of time, the comparative simplicity of the design of moisture meters and their convenience in practical operation also matters.

Modern electronic moisture meters for measuring the moisture content of petroleum products and, in particular, diesel fuel, are distinguished by the ability to quickly perform analysis, as a rule, they have a convenient graphical interface, a system of built-in sensors for monitoring the temperature of the studied petroleum product, a lightweight and durable aluminium housing and the ability to calibrate several samples of petroleum products with different moisture content indicators [31]. The warranty period of such devices, as a rule, does not exceed two years, provided that all mandatory operating requirements are met it can be from five to seven years, without carrying out any significant repairs.

Such devices have been constantly being improved in recent years, taking into account the changing needs of the aviation industry for high-quality parameters of diesel fuel used in engines, dictated by the introduction of technological improvements in the design of modern aircraft engines. In the future, there is no tendency to reduce the demand for such devices, both in the aviation industry and in other fields of science and technology, in which diesel fuel is used as the main fuel for various types of engines, which is associated with the need to track fuel quality indicators for them.

4. CONCLUSIONS

A study of the technological features of the device for measuring the moisture content of diesel fuel has led to the following conclusions. The presence of moisture in diesel fuel significantly reduces its quality and makes its use unsafe in general. For this reason, the practical use of the device for determining the level of moisture content of diesel fuel should be considered fully justified, from the standpoint of timely assessment of the quality of the fuel mixture and preventing its further use in the presence of significant deviations in the level of moisture concentration from the normative indicators.

The principle of operation of the most modern and advanced devices for determining the level of moisture concentration in diesel fuel intended for practical use in aircraft piston engines is based on the principle of evaluating the permittivity index of a mixture of fuel and liquid, with the identification of critical indicators by which the parameters of the moisture content of diesel fuel are calculated. This technique should be considered the most effective today, taking into account the compactness of such devices, their small weight and the ability to perform a large number of operations to measure the parameters under study per unit of time. At the same time, monitoring the moisture level in diesel fuel involves determining critical parameters, the achievement of which allows using the fuel mixture for safety reasons. Electronic moisture meters can determine the actual moisture concentration in diesel fuel intended for practical use in aircraft engines with a minimum error, which determines their preference over other types of devices.

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