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Improvement of diesel injector nozzle test techniques

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Abstract Due to changes in the characteristics of the fuel equipment during operation, a considerable part of the life cycle of locomotive engines operate under increased fuel consumption, and thermal voltage, which often causes degraded environmental performance and reduced engine capacity and, as a result, low efficiency of the locomotive. A reserve for improving the performance of the diesel plant and the diesel locomotive in general is the implementation of measures to prevent changes in the characteristics of the fuel system, for example, the development of clean-in-place technique of fuel systems from carbon deposits. In order to determine the effectiveness of such measures, it is necessary to apply new quality control methods of fuel atomization. The article offers a more informative method for evaluating the quality of fuel atomization, which can be used in locomotive depots during research and development work. The method consists of microphotography of the drops of sprayed fuel followed by microscopic analysis and processing of the results using special software. It is proposed to process the results of injectors testing using a statistical method, taking into account the parameters according to the Rosin-Rammler dependence for the relative total curve. As a result of the work, it became possible to develop requirements and implement technical improvements to the test stands for fuel equipment of diesel locomotives.

1. Introduction

In accordance with the target program and the National Transport Strategy of Ukraine until 2030, approved by the Decree of Cabinet of Ministers of Ukraine No. 430-p of May 30, 2018 [1], one of the main directions of scientific and technical development of Ukrzaliznytsya JSC is to increase the economy and the service life of its technical means.

Better reliability and service life of locomotives can be achieved through the introduction of new control methods of the technical condition and detection of faults or failures of the injector nozzles of diesel locomotives, as well as the angle of advance of fuel injection from changing the course of the spray needle. Therefore, the improvement of the test technique of diesel injector nozzles is an important component of technical measures aimed at improving the efficiency and longevity of locomotives.

This problem should be solved through comprehensive measures that include a wide range of issues related to the durability of traction rolling stock. The efficiency of locomotives operation largely depends on the reliability and durability of the fuel equipment. It is determined by the accuracy

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of diagnosis and the quality of maintenance and repair. The share of failures of locomotives on the railway network due to failure of diesel plants reaches 41 % of the total number of failures of the main locomotive assemblies, including 12-13 % of the total number of failures of diesel because of failure of the fuel system. Some elements of the fuel system operate under high thermal and mechanical load. This, together with the structural and regulatory factors, as well as the physical and chemical properties of the fuel, leads to a significant formation and accumulation of carbon deposits [2, 3, 4]. This leads to the maldistribution of fuel on the cylinders and inside the combustion chamber, which degrades the performance of the diesel. This condition of the locomotive fleet and the fuel equipment of diesel locomotives is due to the low quality of current repairs and inaccurate diagnosis, which indicates the need for further work in this area and the relevance of this topic.

Therefore, improving diesel injector nozzle test techniques subject to the conditions and modes of operation of locomotives is a relevant scientific problem.

2. Literature review and problem statement

The objective of this research is to improve both an important stage of the technological process of testing fuel equipment, and the reliability and economy of diesel locomotives.

The fuel spraying process in the combustion chamber of the internal combustion engine was considered in the works by AS. Lyshevskyi, V.A. Kutovyi; then, the proposed approaches were modified by N.F. Razleitsev and other authors [2-10]. As the processes of fuel spraying have been studied, requirements were made for the fuel equipment of the internal combustion engine, the authors used some simplifications and assumptions that lead to distortion of the object and the results of the research, but made a significant contribution necessary for the construction of the physical picture and understanding of the essence of the phenomena and establishing their relationships. Experimental studies show that a sprayed jet of fluid consists of a very large number of droplets whose sizes vary within fairly wide limits. Spray characteristics are used to evaluate the dispersion of the sprayed liquid or the spray quality. The review of the works showed that the definition of the quality of spraying is relevant in current research to test alternative fuels and new and promising fuel systems.

Obtaining a reliable analytical expression is very important because it allows calculating the number of droplets, their volume and surface, choosing reasonably the average dispersion of the sprayed liquid, and making calculations related to the evaporation of the droplets and the torch combustion in general.

3. Objective and tasks

The objective of this research is to improve diesel injector nozzle test techniques by improving the quality assessment method of fuel spraying. This will increase the efficiency and reliability of the fuel equipment and reduce the cost of their maintenance and repair.

To achieve the set objective, the below-mentioned task had to be solved:

- to develop a control method for the dispersed composition of the sprayed fuel jet;
- to search for and identify statistically conditioned interrelations of the controlled parameters obtained at the spraying quality control bench using high-speed shooting and image processing of fuel jets;
- to develop recommendations for further improvement of test stands in the characteristics of the fuel spraying flow.

4. Main part

The assessment of the impact of resource-saving measures and means (for example, the impact of in-place cleaning on the technical condition of the fuel equipment) was carried out by testing the injectors of diesel locomotive on A106 bench before and after in-place cleaning. The tests checked injection pressure, hydraulic density of the nozzles, tightness, as well as visual inspection of the fuel spraying quality by nozzles. In-place cleaning did not affect the injection pressure and the hydraulic density. During the nozzle tests on A106 bench, the spray quality was visually assessed, which allowed detecting only serious malfunctions of the nozzle. Therefore, to assess the impact of the use of in-place cleaning on the quality of fuel spraying, a more accurate and reliable method of assessment was required.

Dispersion composition is a mandatory method of controlling the quality of fuel spraying [11]. The application of dispersion analysis methods is necessary for scientific research, for the development of new and promising fuel supply systems.

Experimental studies show that the torch of sprayed fuel consists of a very large number of droplets whose sizes vary within wide enough limits. Spraying characteristics are used to estimate the dispersion of the sprayed fuel or the quality of the spray. When estimating the dispersion of sprayed fuel, in calculations of motion, evaporation and combustion of droplets in the torch we have to use average data on the size of droplets. The average size of the droplets gives a simplified summary of the degree of fuel fineness; it serves as one of the characteristics of the dispersed composition of the droplets in the torch and allows simplifying mathematical operations in the analysis of the composition of the droplets: perform calculations related to the change of the torch of the sprayed liquid in relation to the number of droplets and their magnitude during evaporation; approximately determine the path of the torch vertex; calculate the time required to burn the torch of the sprayed fuel of a certain dispersed composition, etc. Studying fuel spraying, and especially the size and quantity of droplets, is a difficult and time-consuming task. There are various methods for its solution: micro-filming of drops in a torch, photometric method, injection into molten paraffin with subsequent freezing of drops and their screening, sedimentometric method, etc. All of these methods require sophisticated equipment and considerable cost and may not always be applicable in locomotive research. To determine the effect of indiscriminate cleaning technology on the quality of fuel spraying, the test method used was glycerol droplet trapping, followed by microscopic analysis and processing of results on special software [12-14]. The layout of the automated plant for determining the dispersion composition and size of the droplets is shown in Figure 1.

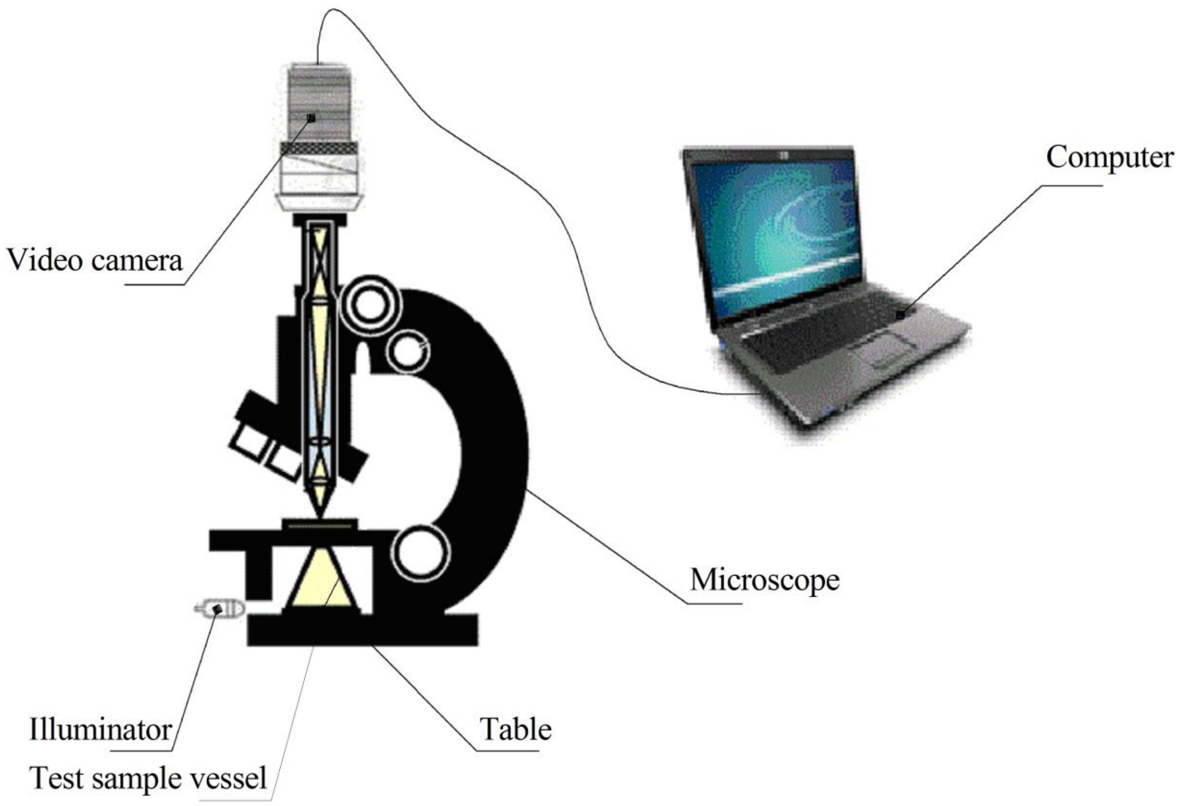


Figure 1. The automated dispersed composition determination plant layout.

The image through the microscope lens gets is converted into digital video signal in the video camera. This signal is sent to the computer and converted into a bitmap. Obtaining and further processing of the graphic image is carried out by means of the special software which allows for:

- calibration and entering of the scale factor;
- image filtering;
- image conversion to negative;
- horizontal and vertical image display;
- image splitting by shades;
- binary image conversion (black and white);
- processing of the edges of the image (removal of unwanted objects along the edges of the image);
- manual linear measurements;
- manual measurements of areas;
- automatic image analysis (calculation of linear sizes and areas);
- grouping of the data obtained from image analysis.

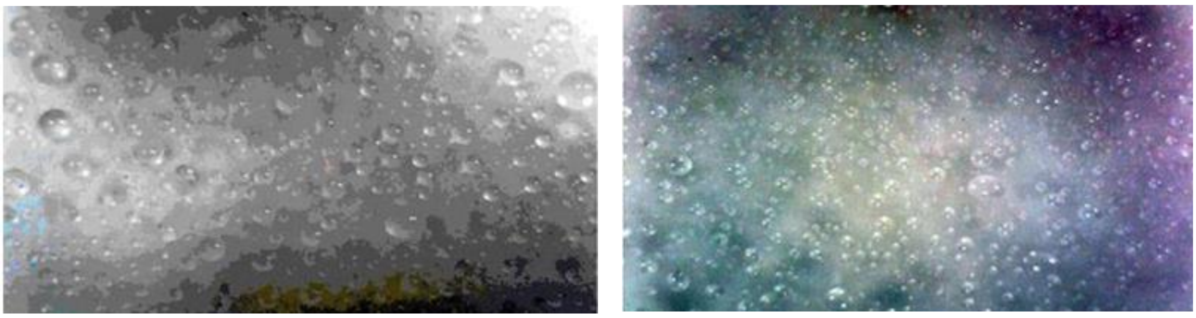
Statistical analysis of the nozzle test results was performed, taking the Rosin-Rammler relation parameters for a relative total curve:

$$S(z) = 1 - \exp\left[-\left(\frac{z}{B}\right)^A\right], \tag{1}$$

where A and B are constants determined from experimental data.

The parameter B is also called the size constant. It is the size of a droplet that divides the relative total curve so that 63.2% of all the sprayed fuel consists of smaller droplets, and 36.8% - of larger droplets.

Parameter A characterizes the width of the distribution, i.e. the degree of uniformity of the droplets of size z. Images of sprayed nozzle droplets after a 300-day period both with and without application of the proposed technique are presented in Figure 2.



(a) (b)

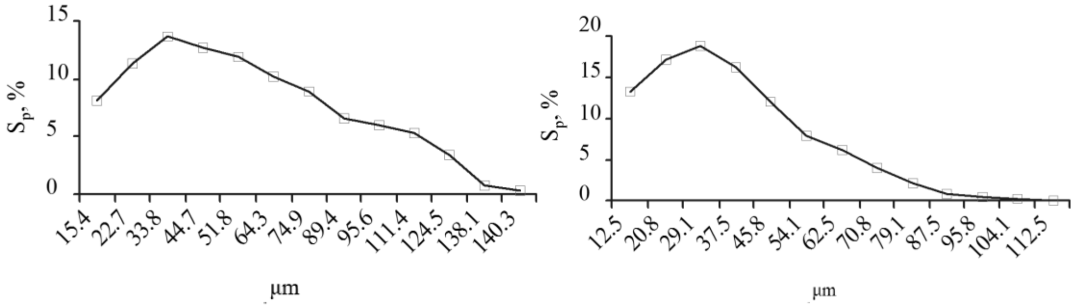
Figure 2. An image of sprayed fuel droplets from a nozzle, (a) an image of sprayed fuel droplets from a nozzle with service hours $T = 300$ days (150× magnified), (b) an image of sprayed fuel droplets from a nozzle with service hours $T = 300$ days after in-place cleaning of the fuel system (150× magnified).

In addition, to determine the effect of in-place cleaning on the quality of fuel spraying, a high-speed image shooting of the sprayed fuel torch was performed (Figure 3).

As a result of the experimental studies, the differential and integral curves of the size distribution of droplets were obtained, which are shown in Figure 4 and Figure 5 respectively.

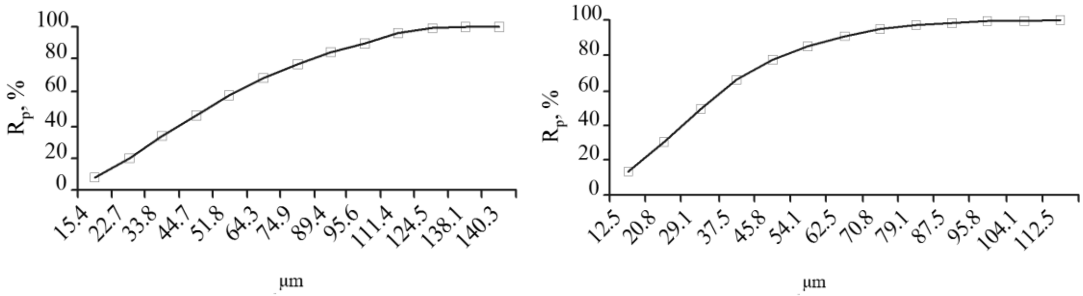
(a) (b)

Figure 3. Spraying of fuel with K6S310DR diesel nozzle, (a) spraying of fuel with a nozzle with service hours $T = 300$ days, (b)s of fuel with a nozzle with service hours $T = 300$ days after in-place cleaning of the fuel system.



(a) (b)

Figure 4. Differential distribution curves of droplets by size, (a) nozzle service hours $T = 300$ days, (b) nozzle service hours $T = 300$ days after in-place cleaning of the fuel system.



(a) (b)

Figure 5. Integral distribution curves of droplets by size, (a) nozzle service hours $T = 300$ days, (b) nozzle service hours $T = 300$ days after in-place cleaning of the fuel system.

The distribution parameters of droplets by size based on the Rosin-Rammler relation with the nozzle service hours $T = 300$ days, were: $A = 31.06$; $B = 85.21$ µm, after removal of carbon deposits: $A = 3.62$; $B = 66.06$ µm.

Thus, while maintaining the fuel supply pressure, the use of in-place cleaning reduces the size of the sprayed fuel droplets. This increases the specific surface area, accelerates fuel evaporation of the fuel, and, as a consequence, improves the quality of blending and, as a result, the combustion process and the technical and economic performance of the locomotives [15, 16].

Summary

The article presents scientifically grounded technical solutions in the development of quality control methods of fuel spaying by nozzles. The implementation of these solutions will increase the efficiency of control over the operation of fuel equipment during their maintenance and repair, as well as during research and development activities.

To estimate the dispersed composition of the sprayed fuel, glycerol droplet trapping with subsequent software-based analysis was proposed. Spraying quality was evaluated using the Rosin-Rammler equation, which helps estimate the dispersed composition of the fuel sprayed with the nozzle.

The developed guidelines for the production of a test bench based on the proposed method of determining the fuel spraying quality of nozzles were developed.

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