Automation of laboratory studies in the determination of the mass of mechanical impurities in petroleum

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Abstract. The article solves the problem of automated control of laboratory research process in determining the mass of mechanical impurities in petroleum. The research analyzed the features of the test and identified the need for an automated control system of this test. The developed automated system controls the filtering process of the sample and pump power, allows simultaneous parallel studies on independent suction lines, while optimizing the pump motor power, depending on the number of used lines. The article provides a block diagram describing the basic system algorithm and scheme of the laboratory tests automated installation in determining the mass of mechanical impurities in petroleum. The result is a reduction in the complexity of the study, optimization of laboratory research.

1. Introduction
Natural combustible minerals, such as oil and gas, are the main energy carriers. They play a significant role in the economy of any state. [1]

Due to the rapid global development of the chemical and petrochemical industry, the need for oil is rising not only to increase the production of fuels and oils, but also as a source of valuable raw materials for the production of synthetic rubbers and fibers, plastics, surfactants, detergents, plasticizers, additives, dyes, etc. (more than 8% of the world production) [2, 3]. Oil is unique in its combination of qualities: high energy density (thirty percent higher than that of the highest quality coal), oil is easy to transport (compared to gas or coal, for example). Finally, it is easy to get a lot of the above-mentioned products from oil [4, 5].

The oil produced in the fields contains many impurities (water, sand, gas, pieces of rock, etc.) [6]. In order to submit this raw material to the system of trunk oil pipelines for further transportation to refineries or for export, first, it must be brought to the required level of quality [7, 8].

The presence in the produced oil of a large number of mechanical impurities complicates the operation of well bores, increases equipment wear, complicates well bore maintenance, and operating costs increase [9, 10].

The impurities contained in the pumped liquid are different in qualitative and quantitative composition: these can be products of reservoir destruction or cement ring or particles of different
composition brought from the surface [11]. However, their effect on all equipment is identical: they clog up the filters of the pumps, first reducing, then completely stopping the flow of fluid into the pump, or acting as an abrasive, accelerating the process of wearing out items of equipment or seizing them [12]. In addition, mechanical impurities cause erosion of the inner surface of pipes during transportation, form deposits in the equipment, which leads to a decrease in heat transfer coefficient, increase the ash content of distillation residues (fuel oils, tars), promote the formation of stable emulsions [13]. In accordance with the requirements of existing regulations mechanical impurities should be absent in the commodity oil [14].

It is important to control such an indicator as the amount of mechanical impurities in oil at all stages of oil production, transportation, and preparation [15, 16]. Proceeding from the flow rate of the wells currently in operation and the volumes of oil on the market, there is a need to modernize existing methods, namely the automation of laboratory monitoring of the oil quality: the amount of mechanical impurities in the oil [17, 18].

2. Material and Methods
The existing method for determining the mechanical impurities in oil includes filtering the test samples with preliminary dissolution in a solvent and washing the filter cake with a solvent followed by drying and weighing. For the test, a porcelain funnel (1), a glass flask (2) and an air vent (3), which is connected to a vacuum pump (assembly scheme in Figure 1a), are used, then a prepared paper filter is installed (4, Figure 1b).

![Figure 1. Installation assembly diagram.](image)

After assembling the installation, the test sample is mixed, poured into a measuring cup, diluted with solvent and filtered through a paper filter. The laboratory technician ensures that the filtrate (5) does not exceed the critical level and does not get into the pump for air exhaust. At the end of the test, the paper filter with the mechanical impurities remaining on it is dried and weighed.

The mass fraction of mechanical impurities ($X$) in percent is calculated by the formula (1).

$$X = \frac{(m_1-m_2)}{m_3} \cdot 100$$  

where $m_1$—the mass of the glass for weighing with a paper filter and mechanical impurities, g.;

$m_2$—the mass of the weighing cup with a clean prepared paper filter, g.;

$m_3$—the mass of the sample, g.

The result of the analysis is the arithmetic average of the two parallel measurements results.

The amount of time spent on the analysis depends on:

- Quality of bringing the filters to constant weight (re-drying the filters in a drying cabinet takes 30 minutes, and after that the dried filter is kept for another 30 minutes in a desiccator).
- Pump suction capacity (when there is a large amount of mechanical impurities, the filter becomes clogged and complicates the filtration process).
The method complexity for determining the content of mechanical impurities by the existing method is 2.20 man-hours. At one installation it is possible to conduct only one test at a time. During the test, the laboratory technician must be directly located near the installation, which eliminates its multitasking.

3. Results and Discussion
Technique automation consists of incorporating the following elements into the existing funnel-bulb-pump chain: silicone hose, tripod, valve, strain gauge sensor, power regulator, wire, data acquisition board, personal computer (PC). The principle of collecting the installation is shown in Figure 2.

![Figure 2](image)

Figure 2. Automated installation for determination of mechanical impurities: 1 – engine, 2 – valve, 3 – vacuum pump, 4 – engine power regulator, 5 – bulb mass detection sensor, 6 – computer, 7 – suction line, 8 – data acquisition board, 9 – wire, 10 – tripod.

Principle of operation: a flask with a funnel joins the hose, a filter is inserted into it, and the whole system is installed on the base of the tripod. The mass sensor, located on the base of the tripod, is calibrated to the volume of the used flask. When the flask is installed on the sensor, the data acquisition board receives a signal, processes it and transfers it to the PC; the response signal comes in two directions: the valve opens the corresponding suction line, the power regulator transmits the optimum power to the pump motor. With a critical volume of filtrate in the flask, the mass sensor transmits the corresponding information to the PC, and the corresponding line stops participating in the work until the laboratory technician changes the flask upon receiving the message of its necessity.

The algorithm of operation of this installation is presented in Figure 3.

An option of solving the task of the determination of mechanical impurities is based on the ability to filter three samples at once, using one pump and an extensive suction line, and in the event of one or two samples being excluded from the process while the pump is running (or conducting the experiment initially with 1 or 2 samples), with the possibility of automatic shutdown of an unused suction line, and, therefore, with the ability to control the pump power in accordance with the number of participating suction lines in the filter process.
Before starting the test, the density of the tested oil is measured, this information is needed to calibrate the mass sensor and determine the critical mass. The critical mass is determined by calculation, as the product of volume and density.

4. Conclusion
In the process, an automated system for determining the mass fraction of mechanical impurities in petroleum was developed. The developed system has the following main functions:

- Automated control of the filtering process.
- Pump power control.
- Detection of inactive suction lines and their automatic shutdown.
- Laboratory study process visualization.

As a result of this work, the algorithm for automated laboratory research software for determining the mass of mechanical impurities in oil was developed. The development improves the quality of testing and minimizes the human factor.

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