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REGULAR ARTICLE

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# Relevant issues on quality evaluation of petroleum pipeline preparation for oil product transportation

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**Abstract.** This article discusses the issue of assessment of the quality of petroleum pipeline preparation for light oil product transportation. The need to implement appropriate measures is conditioned by the requirement to maintain the quality of oil products during their transportation. We identified vulnerable indicators, which are most prone to change if oil products contact with asphaltene-resin-paraffin deposits remaining in the pipeline, as well as estimated probability of failures and emergencies if off-spec oil products are used in automotive and aviation equipment. The scope of the article includes considering variants of technical solutions for the cleanup of the line part of petroleum pipelines and process pipelines of oil pumping stations from asphaltene-resin-paraffin deposits using specially selected chemical reagents and the methodology for assessing the quality of their preparation for oil product transportation. We considered the order of estimation of the possible volume of off-spec oil products formed as a result of the oil product's contact with residues of the cleanup products and chemical reagents located in the cavity of the pipeline and provided the results of the implementation of technical solutions to ensure the quality of petroleum pipeline cleanup at the facilities of *PJSC Transneft* repurposed for oil product transportation in 2014–2017.

## 1 Introduction

The increased demand in the domestic market of Russia and the competitiveness of domestic-made motor fuels at foreign trading European platforms have led to an increase in the output of oil products and the volume of their transportation.

The growth in the transportation volumes of oil products (Fig. 1) Joint-Stock Company Transneft in 2016 amounted to 13.4% compared to 2011. By 2021, the transportation volumes are projected to increase to 56.1 million tons [1, 2].

The main constraining factors for increasing the volumes of oil product transportation in the modern conditions are:

- The absence in some regions of Russia of main oil product pipelines required to connect the existing oil refineries to the pipeline system.
- The insufficient flow capacity of the existing oil product pipelines.
- The significant cost and duration of works to design and build new oil product pipelines.

One of the ways to increase the acceptance of oil products for transportation with the least time and financial costs is to repurpose a part of the excess capacity of the main petroleum pipelines to the transportation of oil products. At the same time, one of the main tasks that had to be solved when preparing pipelines for pumping oil products was to maintain the quality of oil products during the transportation from the producer to the final delivery points to consumers [3, 4].

To resolve the above mentioned issue, new engineering solutions, combining a set of oil pipeline preparation and quality verification activities, have been developed and implemented. The feature of these engineering solutions is that required volumes and the time of solvent contact with asphaltene-resin-paraffin deposits are calculated at pipeline lengths of 250–500 km and pump station process oil piping volumes of 500–1500 $m^3$.

## 2 Methodology

### 2.1 The necessity of the preparation of petroleum pipelines for the transportation of oil products

According to our estimates, a direct replacement of oil with oil products by the displacement method would result in the formation of a large amount of substandard oil products as

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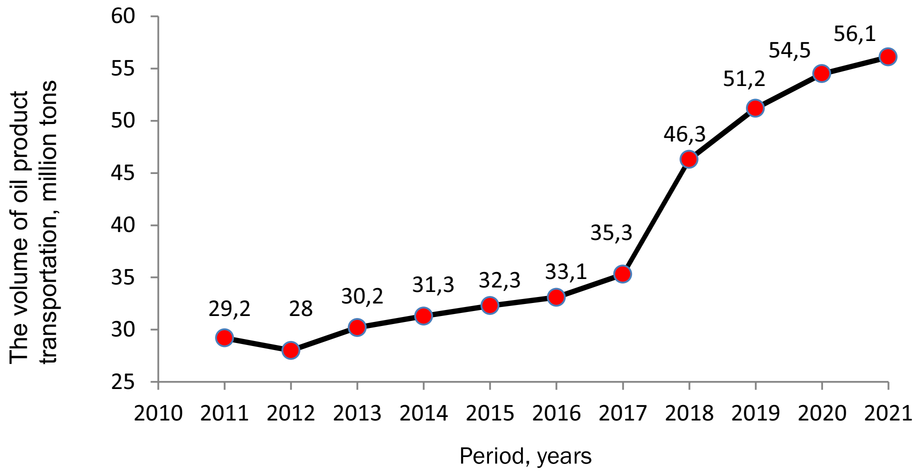


**Fig. 1.** Schedule of changes in the volumes of oil product transportation by pipeline transport.

**Fig. 2.** Asphaltene-resin-paraffin deposits on the inner surface of the pipeline sample.

a result of their mixing with oil in the contact zone. Zones of oil residues accumulation can form in the lower geodetic points of the pipeline route profile. Such oil residues would change the qualitative characteristics of oil product in case of a long-term contact with them, before they are completely removed. In addition, in the course of oil transportation, asphaltene-resin-paraffin deposits are formed on the inner walls of pipelines, pumping equipment, and shut-off valves (Fig. 2); and the contact of oil products with them can also lead to a change in their quality.

An analysis of asphaltene-resin-paraffin deposits, taken from the inner walls of pipelines, showed that their composition is significantly different in different petroleum pipelines and directly depends on the characteristics of the transported oil. The composition of asphaltene-resin-paraffin deposits mainly varies within the following range: 3–12% (wt.) of asphaltenes, 5–20% (wt.) of resinous substances, and 20–45% (wt.) of paraffins. In addition, asphaltene-resin-paraffin deposits contain 30–80% (wt.) of mechanical impurities, including metal corrosion products and foreign substances [5]. Due to the fact that the group composition of asphaltene-resin-paraffin deposits for each pipeline is individual, and the extent and ways of changes in the quality characteristics of oil products will also differ [6]. In turn, when using chemical reagents for the removal of asphaltene-resin-paraffin deposits, their residues in the pipeline cavity together with the residues of the cleanup products will also contribute to the change in the oil product quality (Tab. 1).

In accordance with the classical provisions of chemmotology [7, 8], a change in the qualitative characteristics of oil products means a change in their operational properties, which in turn can lead to failures and emergency situations in the equipment operation [9–11]. Various oil products can be accepted for the transportation along main product pipelines [12]. At the present time, the main volume of it is fuels for aviation and automotive equipment, including up to 87% of diesel fuel, up to 6% of gasoline motor fuel, and 7% of fuel for jet engines transported by *Joint-Stock Company Transneft* [13].

**Table 1.** Ways of changes in the oil product quality characteristics in their interaction with oil, asphaltene-resin-paraffin deposits, and chemical reagents.

| Sq. No. | Oil product type | The change in the standardized indicators | |
|---|---|---|---|
| | | Decrease | Increase |
| 1 | 2 | 3 | 4 |
| 1 | Diesel fuel | Cetane rating | Content of polycyclic aromatic hydrocarbons |
| | | Flash point in a closed crucible | Content of sulfur |
| | | Oxidative stability | Temperature of distillation of 95% of fractions |
| | | | Cold filter plugging point |
| | | | Cloud point |
| | | | Pour point |
| | | | Acidity |
| | | | Filterability factor |
| | | | Content of water-soluble acids and alkalis |
| 2 | Gasoline motor fuel | Antiknock rating (the octane number by the motor method, the octane number by the research method) | The content of sulfur, the volume fraction of benzene, olefinic and aromatic hydrocarbons, alcohols (methanol, ethanol, isopropyl, isobutyl, and tert-butyl), esters |
| | | bubble point | Saturated vapor pressure |
| | | Temperature of distillation of 10% of fractions | Acidity |
| | | | Temperature of distillation of 90% of fractions |
| | | | End boiling point |
| | | | Content of water-soluble acids and alkalis |
| 3 | Aviation kerosene | Net heating value | The distillation temperature of 90% and 98% of fractions |
| | | Acidity | Chilling point |
| | | Flash point in a closed crucible | Thermal oxidation stability |
| | | | The volumetric fraction of aromatic hydrocarbons |
| | | | Content of sulfur |
| | | | Content of water-soluble acids and alkalis |
| 4 | All types of fuels for aviation and automotive equipment (FAAE) | After the contact with the residuals of chemical reagents in the stagnant areas of a pipeline that are a mixture of the solvent and the substances contained in the removed asphaltene-resin-paraffin deposits, the quality deterioration by the following indicators is predicted: water content, general contamination, soluble gum content, mass fraction of mercaptan sulfur, 10% residue coking ability, ash content. In addition, when contacting chemical reagents produced on the basis of acids or alkalis, the quality of fuels for aviation and automotive equipment can deteriorate due to the increasing corrosive aggressiveness, as measured by the "copper plate test." | |

We analyzed properties and chemical composition of petroleum products, oils, asphaltene-resin-paraffin deposits and various types of chemical reagents, and also conducted experimental studies. Based on these data, we identified key areas of changes in quality characteristics of aviation and motor fuels, contacting with oil, asphaltene-resin-paraffin deposits and chemical reagents, as well as the probability of equipment failures and malfunctions if off-spec oil products are used (Figs. 3–5).

Taking into account the risks of the consequences of the use of off-spec oil products in the equipment, one of the main tasks for preparing petroleum pipelines for the

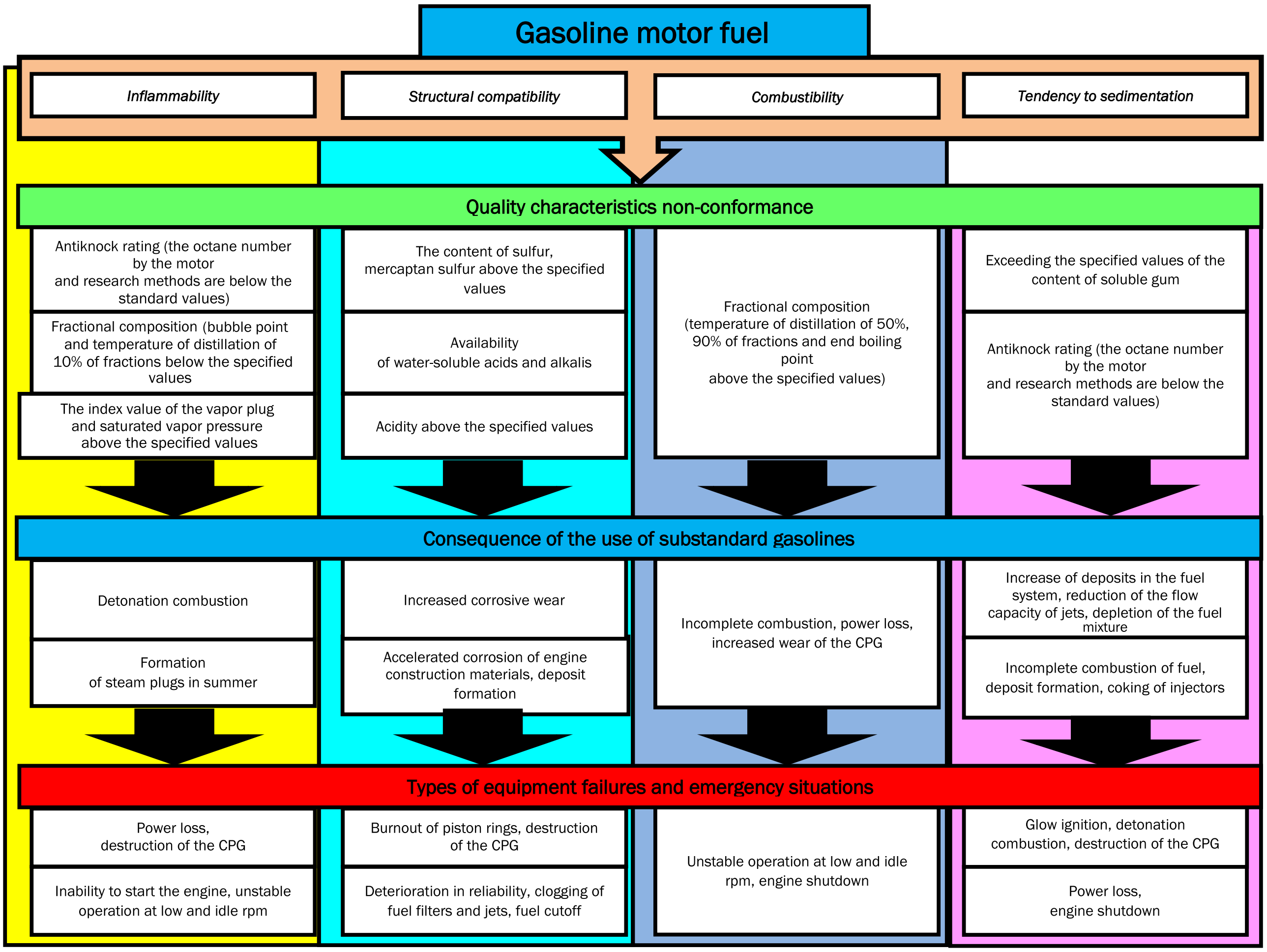


**Fig. 3.** The effect of changing the quality characteristics of gasoline motor fuels on the reliability of the equipment operation.

transportation of fuels for aviation and automotive equipment is the pipeline's internal cavity cleanup from oil residues and asphaltene-resin-paraffin deposits.

## 2.2 Preparation of petroleum pipelines for oil product transportation

The process of oil transportation includes the asphaltene-resin-paraffin deposit removal, which is conducted in two main directions: deposit prevention and removal of formed deposits. The methods used for the asphaltene-resin-paraffin deposit removal and their efficiency depend on the hydrocarbon composition of oil, its physical and rheological properties, pumping temperature modes, service life, pipeline structural features, etc. The most effective methods for the asphaltene-resin-paraffin deposit removal include: mechanical, physical, and chemical methods [14, 15].

Mechanical methods assume the removal of the formed asphaltene-resin-paraffin deposits by introducing a cleaning unit (pistons and scrapers of various types and design) into the pipeline, which moves along with the oil flow while destroying the asphaltene-resin-paraffin deposit layer on the inner surface of the pipeline with its cleaning elements. The deposits removed during the cleanup process from the walls of the pipeline are taken out by the cleaning devices into pig trap stations (Fig. 6).

The drawbacks of this method are as follows: the limited application capacity of the cleaning units, restricted by the geometric parameters of the pipeline; the insufficient efficiency of cleaning compacted deposits and deposits located in hard-to-reach places, for example, near welded joints [16]. As an alternative cleaning unit, the so-called "ice scrapers" can be used [17]. This method allows cleaning hard-to-reach places, but the process of forming "ice plugs" is rather complicated and requires disposing of large volumes of water-oil emulsion formed during the process.

The physical methods are based on the effects of mechanical and ultrasonic vibrations (vibration methods), as well as electrical, magnetic, and electromagnetic fields, on the produced and transported products. The vibration methods allow creating ultrasonic vibrations in the paraffin formation region, which act on the paraffin crystals, causing their micro-movement that prevents the deposition of paraffin on the pipeline walls [18].

Physical methods also include the "steaming" method, whose implementation allows asphaltene-resin-paraffin

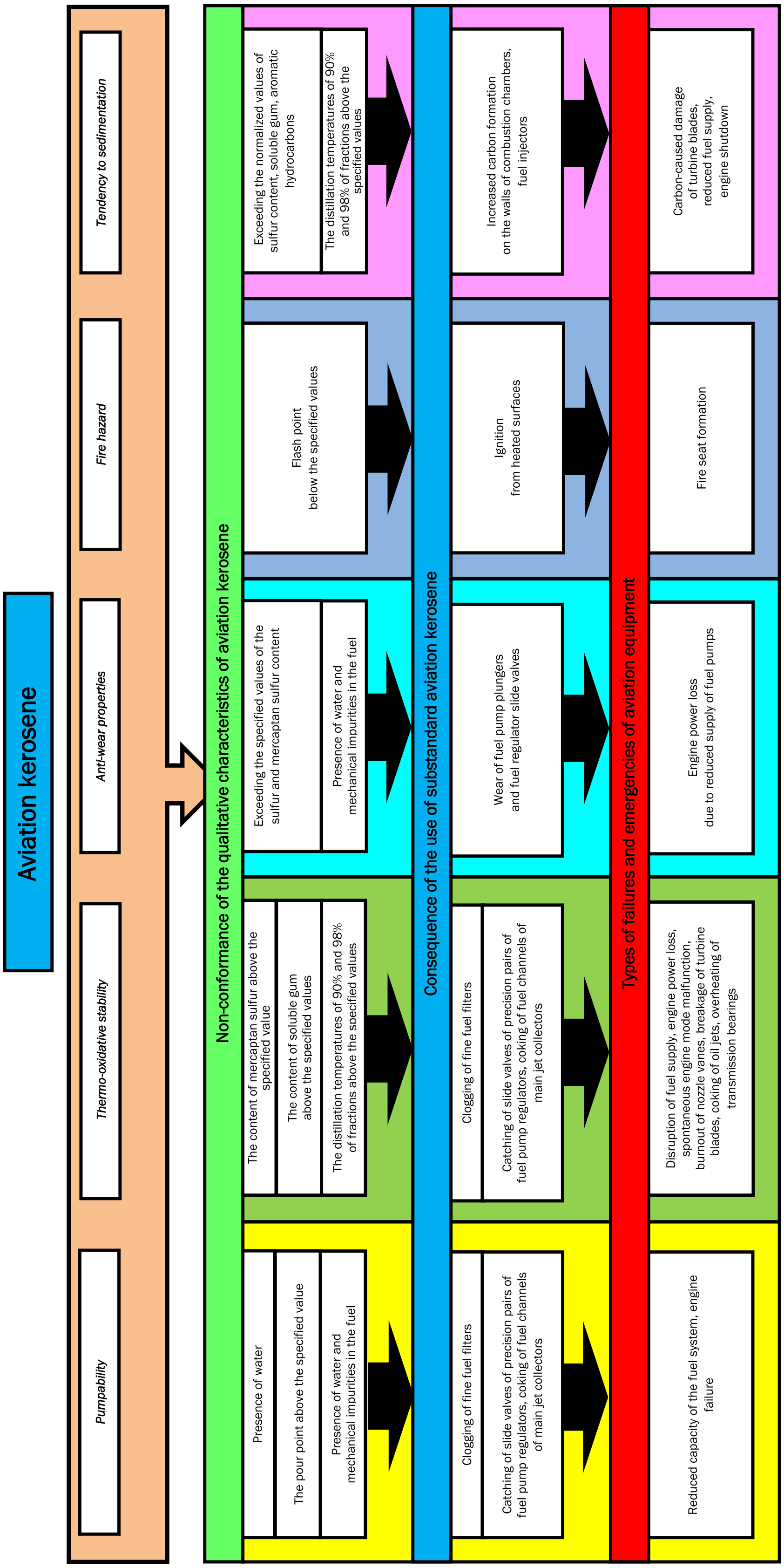


**Fig. 4.** The influence of changes in the qualitative characteristics of aviation kerosene on the reliability of aviation equipment operation.

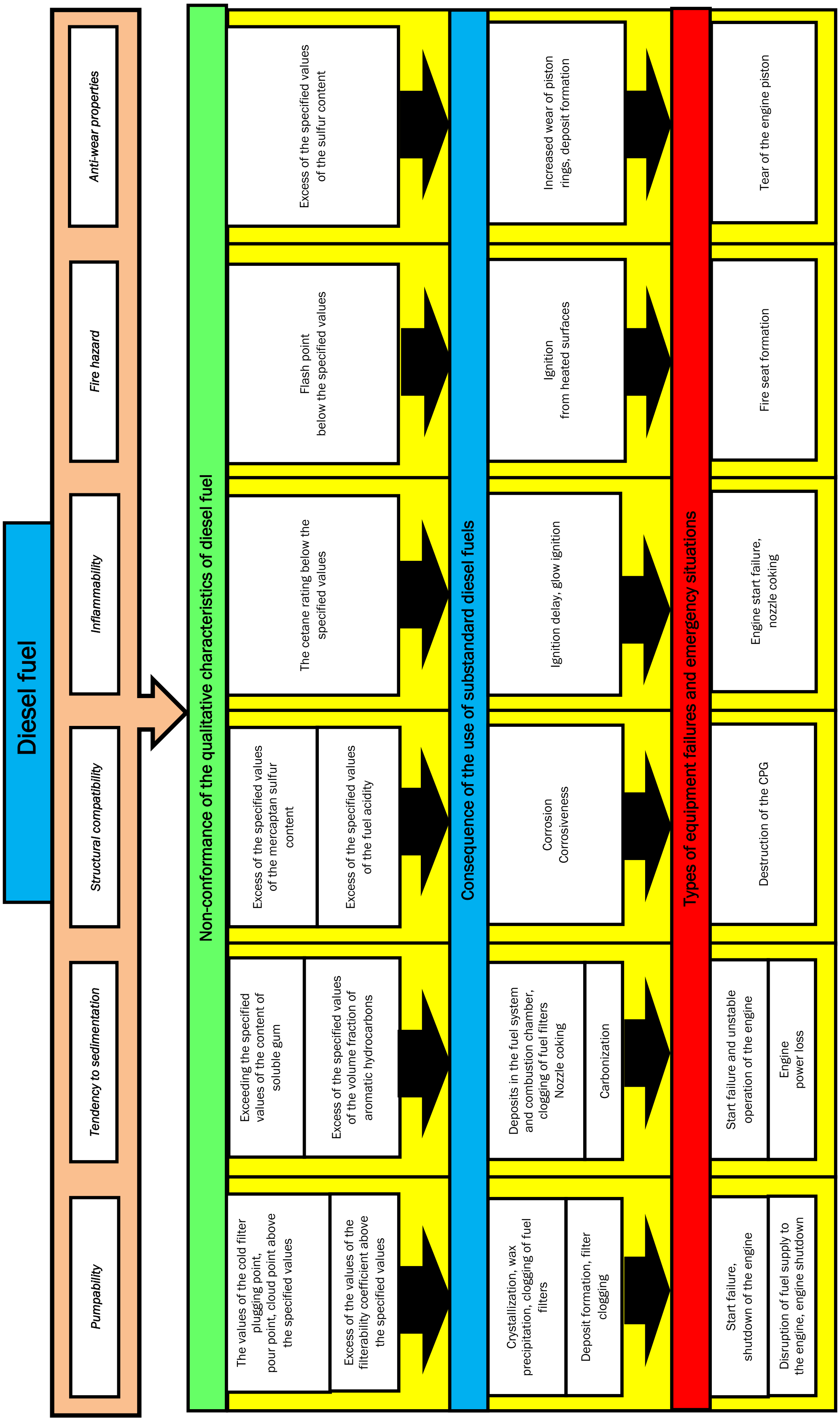


**Fig. 5.** Influence of the changes in the qualitative characteristics of diesel fuels on the reliability of the equipment operation.

**Fig. 6.** Asphaltene-resin-paraffin deposit removal with mechanical cleaning units.

deposits to be removed by hot steam supplied to the pipeline section that is being cleaned [15]. This process involves melting and separation of asphaltene-resin-paraffin deposits from pipeline walls, with a subsequent evacuation of water-oil emulsion produced. The drawbacks of the method include the insignificant length of the sections to be cleaned and the need to supply large volumes of water and steam, as well as dispose of the formed water-oil emulsion. The method is mainly used for cleaning process pipelines and equipment of oil pumping stations.

The chemical cleanup methods include the use of chemical reagents based on organic or inorganic compounds (solutions of acids, alkalis) [19]. The use of reagents based on inorganic chemical compounds is not widely used due to their aggressive impact on pipelines, pumps, shut-off valves, etc., as well as in connection with the formation of a significant amount of waste requiring disposing of and neutralize chemically active compounds.

To solve the problem of efficient petroleum pipeline cleaning from asphaltene-resin-paraffin deposits during the preparation of petroleum pipelines for the transportation of fuels for aviation and automotive equipment, experts of *LLC NII Transneft* developed and implemented technical solutions for cleaning the line part of main petroleum pipelines [20] and process pipelines of oil pumping stations. The novelty of technical solutions has been confirmed by the following patents of the Russian Federation: RU 2609786 "Preparation method of oil-trunk pipeline for transportation of light petroleum products" and RU 2637328 "Method for cleaning inner surface of industrial pipelines of oil-pumping stations during preparation for pumping of light oil products". For the line part of the main pipelines, a comprehensive purification method was implemented, which involves the joint application of mechanical cleaning units and chemical reagents based on organic compounds. The comprehensive method enabled simultaneous destruction of the structure of asphaltene-resin-paraffin deposits by mechanical cleaning and with chemical reagents.

The technical solutions for the preparation of the pipeline for the transportation of fuels for aviation and automotive equipment provide for:

- oil displacement and petroleum pipeline division into separate sections;
- selection of effective chemical reagents for the removal of asphaltene-resin-paraffin deposits;
- avoiding the use of mechanical cleaning devices in the chemical reagent environment on certain sites;
- removal of cleaning products and residues of chemical reagents from the pipeline cavity;
- cleanup quality control.

An oil pipeline is divided into separate cleaned areas, and their length should on the average be 45–55 km (depending on the profile of the main pipeline route, the convenience of access roads), to ensure the necessary speed of the cleaning units and the solvent.

The cleaning units are moved by the pressure of the inert gas mixture produced by nitrogen units at the initial (final) points of the section. The uniform motion of the cleanup units is provided by a second nitrogen unit, which creates back pressure in the section to be cleaned and is located at the final (initial) point of the section.

The chemical cleaning of the inner surface of the main pipeline is performed by forming a plug of the asphaltene-resin-paraffin deposit solvent (Fig. 7) [20].

The effective solvent is selected depending on the asphaltene-resin-paraffin deposit type, based on preliminary laboratory tests [21, 22]. The solvent is chosen with account of the available knowledge about the reagent and its constituents, sanitary and ecological properties, its effectiveness, economic reasoning, as well as the effect of reagents and products of their interaction with asphaltene-resin-paraffin deposits on the quality of oil products.

The efficiency of solvents is assessed by the level of their dissolving power, maximum concentration of the saturation, asphaltene-resin-paraffin deposit dissolution rate, corrosiveness, and the effect on the quality of the fuels for aviation and automotive equipment to be transported.

Figure 8 is an example of a comparative assessment of the efficiency of solvents based on the results of experimental determination of the indicators. Efficiency is evaluated for each new pipeline section.

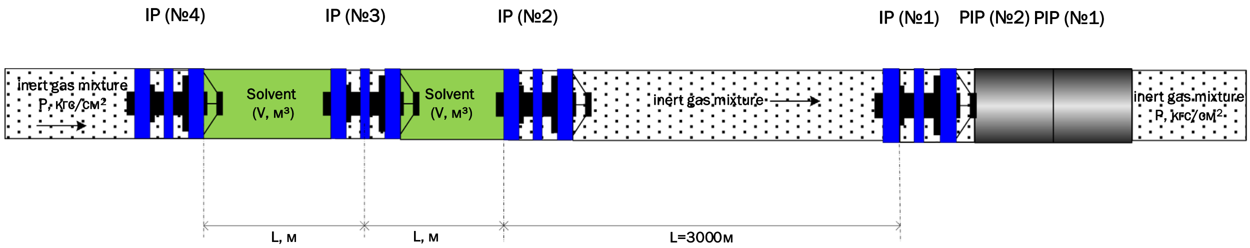


**Fig. 7.** Formation of the asphaltene-resin-paraffin deposit solvent plug (IP-isolation plug, PIP-polyurethane isolation plug).

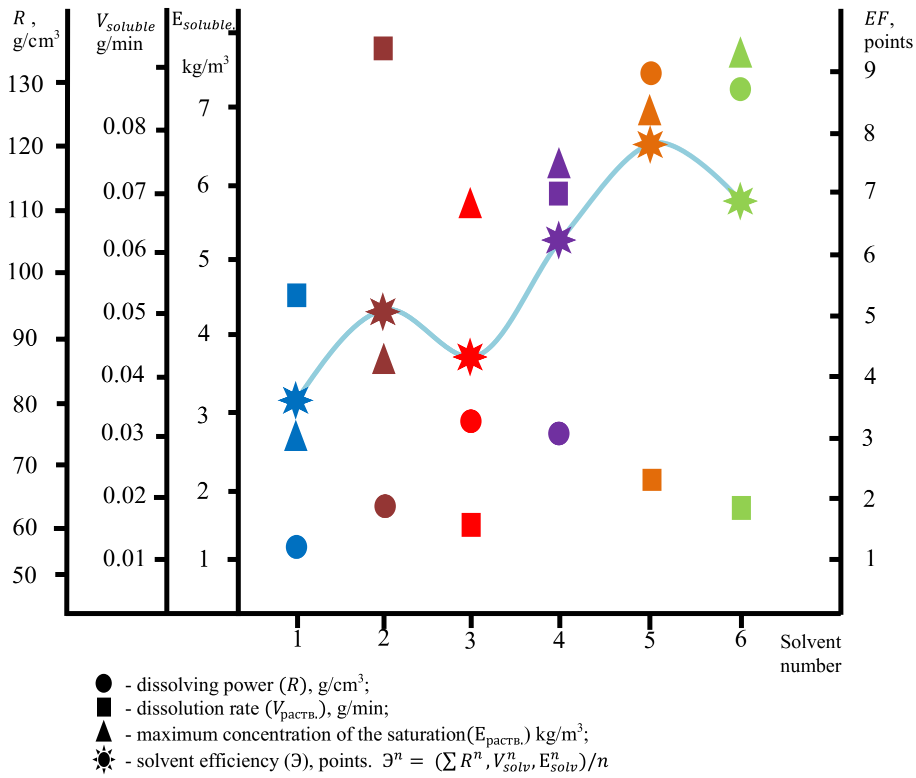


**Fig. 8.** Solvent efficiency evaluation chart.

The comparative evaluation of the effectiveness of asphaltene-resin-paraffin deposit solvents uses a score system, in which the points are awarded differentially from 1.0 to 10.0, with an increment of 0.1 points for each of the indicators being evaluated. The maximum number of points corresponds to the best possible values.

The values of the measured indicators obtained during the laboratory studies are used to calculate the required volume of the solvent ($V'_{\text{soluble}}$, m$^3$) and the speed of movement of the solvent plug ($\vartheta_{\text{soluble}}$, km/h), as well as to monitor the residual solvent service life during the cleanup.

The required volume of the solvent is calculated by the following formula:

$$V'_{\text{soluble}} = \frac{m_{\text{ARPD}} \cdot L_{\text{pp}}}{E_{\text{soluble}}} \cdot 1.1, \tag{1}$$

where:

$m_{\text{ARPD}}$ is the weight of asphaltene-resin-paraffin deposits in the running meter of the pipeline, kg/m;
$L_{\text{pp}}$ is the total length of the pipeline to be cleaned, m;
$E_{\text{soluble}}$ is the maximum concentration of the solvent saturation, kg/m$^3$;
1.1 is the correction factor that takes into account possible solvent overflows through the isolation plug due to the elevation differences in the profile of the main pipeline route and the uneven movement of the solvent plug.

The rate of the solvent plug movement is calculated based on the available volume of the solvent $V_{\text{pacme}}$ and the time required to dissolve asphaltene-resin-paraffin deposits, by the following formula:

**Table 2.** The list of the quality indicators of fuels for aviation and automotive equipment, determined when assessing the readiness of pipelines for oil product transportation.

| Sq. No. | Description of the quality indicators of fuels for aviation and automotive equipment | | |
|---|---|---|---|
| | Gasoline motor fuel | Diesel fuel | Aviation kerosene |
| 1 | 2 | 3 | 4 |
| 1 | Appearance, color, transparency | | |
| 2 | Density | | |
| 3 | Mass fraction of sulfur | | |
| 4 | Content of water-soluble acids and alkalis | | |
| 5 | Resistance to oxidation | Acidity | |
| 6 | Fractional composition | | |
| 7 | – | Ash content | |
| 8 | Concentration of soluble resins | | |
| 9 | Volume fraction of benzene | Coking ability 10% of the residues | The content of mechanical impurities and water |
| 10 | – | Filterability factor | Kinematic viscosity at 20 °C |
| 11 | – | Mass fraction of mechanical impurities | Flash point in a closed crucible |
| 12 | – | Flash point in a closed crucible | Mass fraction of hydrogen sulphide |
| 13 | – | – | Thermo-oxidative stability |
| 14 | – | Specific electrical conductivity | |

$$\vartheta_{\text{pr.soluble}} = \frac{V_{\text{soluble}} \cdot 4}{\pi \cdot d^2 \cdot t_{\text{soluble}}} \cdot 0.06, \quad (2)$$

where:

$t_{\text{soluble}}$ is the time required to dissolve asphaltene-resin-paraffin deposits, min;
$V_{\text{soluble}}$ is the required volume of the solvent, m$^3$;
$d$ is the pipeline diameter, m.

To clean process pipelines of the oil pumping station, it was decided to use successively steaming and asphaltene-resin-paraffin deposit dissolving with chemical reagents. For this purpose, the process pipelines, after being emptied from oil, are divided into small sections of 50–150 m$^3$ and steamed with a mobile steaming unit. In this case, the deposits partially pass into the liquid water-oil phase and are removed through the drain points at the lowest points of the sections. Then the sections are filled full of the selected chemical reagent, which is kept in the pipe cavity for the time required to dissolve the asphaltene-resin-paraffin deposits. To improve the cleaning efficiency, the sections are looped and the solvent is circulated. When the value of the "saturation coefficient" parameter is reached, the cleaning is stopped and the solvent is pumped out.

The residues of chemical reagents and cleaning products from cleared areas are removed with adsorption plugs formed from oil products of similar quality to the oil products to be transported through the pipeline. At this stage, the quality of its purification is preliminarily assessed by the change of the quality indicators of adsorption fuel samples taken before the beginning and at the end of the adsorption batch that is run through the section. In process pipelines, adsorption batches of fuels are circulated through the section to be cleaned up.

### 2.3 The quality assessment of the preparation of oil pipelines for oil product transportation

The assessment of the readiness of oil pipelines for oil product transportation was proposed to be carried out based on the analysis of the quality of the control oil product batches. The control batches are made up of oil products, similar in quality to oil products to be transported through the pipeline. The quality analysis is carried out at the initial point of the controlled section based on the analysis of the sample taken before the formation of the control batch and at the end point of the section based on the results of the analysis of the samples taken in the head, middle, and tail parts of the control batch. The cleanup quality is judged based on the change dynamics of the qualitative characteristics of the fuel along the length of the control batch. The change in the quality characteristics of the fuels for aviation and automotive equipment is assessed by the quality indicators that are most prone to changing as a result of contact with oil, asphaltene-resin-paraffin deposits, and chemical reagents [23, 24]. At the same time, a number of indicators that are not included in the requirements of the standards are determined additionally.

As a result, the indicators, which allow a reliable assessment of that fuel is not contaminated with chemical reagent, cleaning product and solvent residues, were selected (Tab. 2).

Upon the completion of the cleanup of pipeline sections, process pipeline sections at oil pumping stations, and subject to positive conclusions on the cleanup quality in each section, the cleaned sections are connected with each other. After the interconnection of the cleaned sections into a single pipeline, a check plug is also run with a volume of at least 0.4% of the total internal volume of the pipeline in order to determine the volume of estimated off-spec oil products formed while filling the pipeline.

The experience in the preparation of oil pipelines for oil product transportation showed that the maximum amount of substandard product formation ($V_{\text{substd}}^{\max}$, m$^3$) can reach up to 15% of the total volume, provided the entire volume of the pipeline is continuously filled up:

$$V_{\text{substd}}^{\max} = \frac{(\pi D^2)}{4} \cdot L \cdot 15\%, \tag{3}$$

where:

$D$ is the pipeline diameter, m;
$L$ is the total length of the pipeline (taking into account the standby pipeline runs), m.

At the same time, the estimated volume of substandard products ($V_{\text{substd}}$, m$^3$), for the quality indicators that change additively, can be calculated by the following formula:

$$V_{\text{substd}} = V_{\text{final.plug}} \cdot K_{\text{mix}} \cdot K_{\text{R}} \cdot K_{S_{\text{st.value}}}, \tag{4}$$

where:

$V_{\text{final.plug}}$ is the total volume of the final gasoline motor fuel plug, m$^3$;
$K_{\text{mix}}$ is the mixing ratio, calculated by the following formula:

$$K_{\text{mix}} = \frac{G_{\text{avg}}^i}{G_{\max}^i}, \tag{5}$$

where:

$G_{\text{avg}}^i$ is the average value of the $i$-indicator in the samples of the final control batch;
$G_{\max}^i$ is the maximum value of the $i$-indicator in the samples of the final control batch;
$K_{\text{R}}$ is the factor that takes into account the dissolving power of gasoline motor fuel;
$K_{S_{\text{st.value}}}$ is the factor that considers indicators that change additively.

It is necessary to determine the estimated volume of substandard products in order to develop measures for the acceptance of off-spec fuels and take decisions on their further application.

## 3 Conclusion

1. We have established the relevance of the quality assessment of the preparation of petroleum pipelines for oil product transportation.
2. As a result, we have suggested a list of quality indicators that are most prone to change when (FAAE) is mixed with solvents and asphaltene-resin-paraffin deposits.
3. We have also considered the technical solutions aimed at ensuring the quality of petroleum pipeline cleanup, within a limited time frame, with minimal costs, while preserving the quality of transported oil products.
4. The technology of preparing petroleum pipelines for oil product transportation was implemented in 2014–2017 in the course of repurposing 252 km of the Tyumen – Turgamysh petroleum pipeline, 258.6 km of the Kirishi – Primorsk petroleum pipeline and 525.4 km of the Yaroslavl – Kirishi-2 petroleum pipeline for the transportation of diesel fuel, 395 km of the Gorky – Ryazan-2 main petroleum pipeline and 198 km of the Ryazan – Moscow petroleum pipeline for gasoline motor fuel transportation, as well as ten oil pumping stations.

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