The impact of the quality of diesel fuel on the efficiency of engines

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Abstract. High-quality diesel fuel is the guarantee of work of an internal combustion engine. Low ambient temperature has an influence on the physical and chemical properties of diesel fuel. It becomes a reason for failure of details of a high pressure fuel pump system. This issue is more acute in the Republic of Sakha (Yakutia) where the surrounding air temperature can reach up to -60°C and where the essential goods are delivered to the regions of the Far North by winter roads. The article illustrates the results of experimental study of the quality of arctic diesel fuel taken from different filling stations of the Republic of Sakha (Yakutia). It also suggests a way of increase of fuel efficiency for equipment operated in the North. The article also presents a mathematical model of fuel cost during winter time. The main operational properties of arctic diesel fuel are studied. The work was carried out in the laboratory of “General, analytical and physical chemistry” department. The samples of diesel fuel were divided into three categories according to their geographic locations: central, northern and riverside. Three samples of arctic diesel fuel from different filling stations were taken in each of the regions. The study revealed that the chosen main properties of diesel fuel, such as: density, viscosity, fractional structure and low-temperature properties differ from standard values.

1. Introduction
The severe natural and climatic conditions of cold regions (such as the Republic of Sakha (Yakutia)) impose many requirements for vehicles. The tendency of vehicle development in the North is the increasing use of diesel engines that spend by 30-35% less fuel in comparison to carburetor engines and have low toxicity exhaust gas. The overall efficiency of work of a car is defined by joint influence of all its operational properties. The indicators of fuel efficiency characterize the consumer properties of a car.

The fuel cost is about 20-30% of all transortation fees; that is why the fuel efficiency has a significant impact on the road transport performance. The diesel fuel must possess proper features to provide a safer and more economical function of the diesel engine.

Some of the main disadvantages of diesel fuel are a number of its features that impedes starting diesel engines in wintertime [1]. Therefore, regular studies should be held in Yakutia to define operating properties of diesel fuel imported to the region.

2. Materials and methods
The test samples of the arctic diesel fuel were taken from different filling stations of central, northern and riverside regions of the Republic of Sakha (Yakutia). All the samples were divided into three groups, and three samples of arctic diesel fuel were taken from every group. Central group I contained regions (CGR), northern group II - regions (NGR), riverside group III regions (RGR). Diesel fuel was taken
from three major motor fuel suppliers: JSC “Yakut Fuel and Energy Company” (fuel No.1 for all regions), JSC “Sakhaneftegazsbyt” (fuel No.2 for all regions), JSC “Tuymaada-neft” (fuel No. 3 for all regions). Arctic diesel fuel samples of central group of regions (CGR) were taken from the town of Pokrovsk of Khangalas district (fuel No. 1 of CGR), Namtsi village of Namski district (fuel No. 2 of CGR), and from village Maya of Megino-Khangalas district (fuel No.3 of CGR). Arctic diesel fuel samples of the northern group of regions (NGR) were taken from the urban-type settlement Batagay of Verkhoyansky district (fuel No.1 of NGR), village Saskylakh of Anabarsky district (fuel No.2 of NGR), urban-type settlement Tiksi of Bulunsky district (fuel No.3). Arctic diesel fuel samples of the riverside regions were taken from the village Ytyk-Kyuel of the Taattinsky district (fuel No.1 of RGR), village Churapcha of Churapchinsky district (fuel No.2 of RGR), and village Borogontsy of Ust-Aldansky district (fuel No.3 RGR). There were 9 samples of fuel in total:

* Fuel No. 1 CGR
* Fuel No. 2 CGR
* Fuel No. 3 CGR
* Fuel No. 1 NGR
* Fuel No. 2 NGR
* Fuel No. 3 NGR
* Fuel No. 1 RGR
* Fuel No. 2 RGR
* Fuel No. 3 RGR

The following major quality indicators were chosen for the experimental research: density, viscosity, fractional structure, cetane number, low-temperature properties (cloud point, pour point, and cold filtering plugging point).

The research program suggested to study methods of defining operational properties of arctic diesel fuel. The study results are presented in the histogram - distribution of values of quality indicators.

3. Results

The density of the diesel fuel samples is not the same. The fuel density indicates the predominance of different (aromatic, paraffinic and naphthenic) groups of hydrocarbons. For instance, paraffinic hydrocarbons have the least density while the aromatic hydrocarbons are of more density than the paraffinic ones. Naphthenic hydrocarbons have average density. During the injection the diesel fuel is dosed by the pump according to its volume. Consequently, the increase of the fuel density leads to the increase of injection and the fuel mixture enriches [3-5]. The diesel fuel density for high-speed diesels is about 820-840 km/m³ at 20°C. The study showed that the majority of the presented samples of arctic diesel fuel have density of about 820km/m³. These results completely meet the requirements of state standard specifications. However, the samples of fuel No. 1 of CGR, the samples No. 1 of NGR and No. 3 of NGR have the highest density with the interval 830-840km/m³. This means that the fuel contains a lot of paraffinic hydrocarbons (Figure 1).

Viscosity indicates the fuel flow rate [2]. A high viscosity level reduces the atomization rate, and lower viscosity causes increased fuel line wear. Viscosity of the presented samples is in the interval of 1.6-2.9 mm²/s (cS) which meets the requirements of state standard specifications 305-82 (Figure 2).

The fractional composition of diesel fuel also has a great influence on the speed of its evaporation and formation of mix with air after injection. Nevertheless, fractional composition simplification weakens flammable properties of diesel fuel [3-5].

According to the state standard specifications, the optimal distillation of 50% of fuel volume must evaporate at temperature not higher than 225 °C. Arctic diesel fuel samples used during the study meet the requirements of the state standard specifications. However, sample №1 of NGR has an extremely light composition which shows that the diesel fuel was probably mixed with gasoline fractions (Figure 3). Evaporation interval of 96% of fuel lies between 280-330 °C (Figure 4).
Figure 1. Arctic diesel fuel density distribution at 20°C.

Figure 2. Distribution of values of arctic diesel fuel kinematic viscosity at 20 °C mm²/c (cS).

Figure 3. Distribution of values of arctic diesel fuel kinematic viscosity at 20°C mm²/c (cS).
Figure 4. Distribution of fractional composition value of 96% of arctic diesel fuel distillation.

State standard specifications 305-82 regulate only one temperature (diesel freezing point) out of all low temperature properties.

The diesel freezing point determined by a standard technique is considered to be quite an approximate indicator and does not correspond to the temperature of fuel mobility loss during its practical use. However, this technique is considered to be simple and is used for the quality control of oil products. Oil product freezing is connected with the presence of a firm phase in it (crystallized at low temperature of solid hydrocarbons) [8-10]. Fuel No.1 of NGR has the lowest freezing point out of all the studied samples, while No.2 of CGR and fuel No.2 of NGR have the highest freezing point (Figure 5).

Figure 5. Value of arctic diesel fuel freezing point, °C.

The diesel cloud point and the start point of crystallization indicate the presence of water and paraffin in fuel, the lower the cloud point, the less the concentration of water and paraffin in fuel [5-7]. Cloud point intervals of the studied samples are from -28°C (sample No.1 of CGR has the lowest temperature) and up to -32°C (samples No.2 of CGR and No.3 of CGR have the highest temperature) (Figure 6).
Cold filtering plugging point (CFPP) is a fuel feature that indicates the lowest temperature at which it can still run through the filter or loses this function (or when 20 cm³ is filtered for more than a minute) [6]. The results of the study show that sample No. 2 of NGR has the highest CFPP (minus °C), and sample No. 1 of NGR has the lowest CFPP.

Standard fuel consumption value for heavy-duty trucks and tractor-trailers is calculated according to the formula [11]:

$$Q_{H} = 0.01 \cdot (H_{san} \cdot S + H_{w} \cdot W) \cdot (1+0.01 \cdot D)$$  \hspace{1cm} (1)

where:
- $Q_{H}$ – standard fuel consumption, l/100 km;
- $S$ – truck or trailer mileage, km;
- $H_{san}$ – standard fuel consumption rate of equipped automobile or trailer mileage without freight, l/100 km;
- $H_{w}$ – fuel consumption rate on transportation, l/100 t·km;
- $D$ – rate correction factor (total relative extra charge or reduction), %;
- $W$ – transportation volume, t·km.

Mathematical models of fuel consumption can be received by equation of vehicle and different features with engine operation modes.

$Q_{m}$ model of fuel consumption was chosen as a mathematical model, l/100 km from the subsystem of technical and economical indicators of vehicles, with input parameters [3]:

$$Q_{t} = \left( \frac{l}{100 \beta} B_{km} + \frac{l \cdot q \cdot \gamma}{100} B_{tkm} \right) \alpha_{T} + 1.7 \cdot \frac{t_{pr} \cdot t_{z}}{t_{l} + t_{z}}$$  \hspace{1cm} (4)

where:
- $l$ – mileage distance;
- $\beta$ – mileage utilization rate; $B_{km}$ – fuel consumption rate for 100km, l/100km;
- $q$ – vehicle carrying capacity, t;
- $\gamma$ – loud capacity; $B_{tkm}$ – fuel consumption capacity for transportation 100 t/km; $\alpha_{T}$ – rate of increase of amortization expenses in the Northern regions; $t_{pr}$ – loading and unloading time, $t_{z}$ – number of winter days per year, $t_{l}$ – number of summer days per year.

At the same time fuel consumption influences on the fuel expenses, rub/t.

$$Z_{t} = \frac{Q_{t} \cdot C_{f} \cdot \gamma_{t}}{1000 \cdot q \cdot \gamma}$$  \hspace{1cm} (5)

where:
- $\gamma_{t}$ – fuel density kg/m³;
- $C_{f}$ – diesel fuel cost for Yakutia.
4. Conclusion
The 5th model points out that fuel expenses depend on the density of the fuel. The study results show that:
• fuel No. 1 of NGR has the most density, while fuel No. 3 of RG has the least density;
• fuel No. 2 NGR is the most viscous, and fuel No. 2 NGR is the least viscous;
• fuel No. 1 NGR has the highest evaporation point;
• fuel No. 2 CGR and No. 2 NGR have the lowest freezing point, equal to −52 °C;
• fuel No. 2 CGR and No. 3 CGR have the lowest cloud point, equal to −32°C;
• fuel No. 1 NGR has the lowest CFPP, equal to −36 °C.
The study of the arctic diesel fuel shows that the received arctic diesel fuel does not have proper qualities regulated by state standards.

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