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Modeling of Thermal Preparation of Shock Absorbers of Trucks

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Abstract

The use of modern materials and technical fluids allows you to operate cars at negative temperatures, but in some regions of the world (for example, in Siberia), the ambient air temperature can fall below 243 K for several weeks or even months. The operation of trucks at such a temperature refers to extreme conditions that force the special preparation of equipment. This preparation consists not only of special maintenance, but also of carrying out some activities that are carried out immediately before starting the engine and driving. The essence of these measures is, among other things, the thermal preparation of the components and assemblies of the vehicle before departure.

This work is devoted to the thermal preparation of truck shock absorbers. It is revealed that the use of oils, the kinematic viscosity of which significantly depends on the ambient temperature, is a limiting factor in the winter operation of shock absorbers. The simulation of the operation of electric flexible heaters for shock absorbers in the SolidWorks Flow Simulation environment was carried out and the preheating efficiency was evaluated. It is established that the temperature distribution of the shock absorber fluid during heating of two-pipe shock absorbers occurs unevenly, but despite this, preheating significantly improves the characteristics of shock absorbers and contributes to the safe and long-lasting operation of trucks.

Keywords

shock absorber, kinematic viscosity, modeling, thermal preparation

1 Introduction

Modern trucks are high-tech products that, in addition to mechanical systems, incorporate electronic management and control systems. The introduction of technical developments evolved in recent years has significantly improved the reliability, safety and environmental friendliness of vehicles. For example, the paper (Droździel and Wrona, 2018) notes that the road accidents are caused less by the technical malfunctions and the main causes of accidents are non-compliance with traffic rules, low qualifications of drivers, non-compliance with the work and rest periods of drivers. Nevertheless, the problem of increasing reliability does not cease to be relevant (Mohd and Srivastava, 2021; Poussot-Vassal et al., 2008), especially when operating machines in extreme conditions, which include low temperatures, among others. When the temperature decreases, the properties of fuels and lubricants, technical liquids, rubber, plastics and metals change, as well as the processes of fuel atomization and combustion in the internal combustion engine (Zöldy, 2021). Thus, when the temperature decreases, the technical characteristics of the vehicles as a whole change, and their resources are also significantly reduced (Bochkaryov and Ishkov, 2020). It is no coincidence that the operating instructions include sections on special preparation of vehicles for winter operation, and manufacturers produce special versions of vehicles for use in Arctic conditions. Special versions of products usually contain devices for preheating the engine, more powerful heating systems and protective screens and covers for saving heat. In addition, the industry produces a number of thermal devices that are installed on equipment outside of manufacturing plants, for example, Webasto preheaters are well known in this field.

The structural elements of the car are extremely sensitive to the effect of low temperatures, the principle of their operation is based on the use of technical fluids, the viscosity of which sometimes significantly changes with a decrease in temperature. Such elements include, for example, shock absorbers. A large number of works related to the research of shock absorbers are devoted to the development of mathematical models (Domnyshev et al., 2019; Hou et al., 2011;

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Mollica and Youcef-Toumi, 1997; Ramos et al., 2005), parameter optimization and structural modernization (Ankitha and Rupa Sri, 2021; Czop et al., 2012; Duym, 2000; Więckowski et al., 2018; Wszołek, 2016), as well as research using CFD and FEM analysis (Chen et al., 2013; Duym, 2000; Herr et al., 1999; Lee, 1997; Shams et al., 2007). It should be noted that a significantly smaller number of works are devoted to the study of the operation of components and assemblies of cars (including shock absorbers) during operation in cold climates (Chernukhin, 2013; Chernukhin et al., 2020; Dolgushin et al., 2019), although this is an actual scientific direction for many regions of the world.

The shock absorber, being a hydraulic damping device according to the principle of operation, consists of parts made of rubber, plastics and non-ferrous metals. Thus, the operational characteristics of this unit are critically dependent on environmental conditions. With a decrease in the ambient temperature, the viscosity of the shock-absorbing fluid increases, which during compression and rebound passes through the throttling holes of the shock absorber and the resulting hydraulic resistance ultimately causes the smoothness of the vehicle and directly affects safe and comfortable operation (Reimpell et al., 2001).

Increased vibration can be the cause of occupational diseases (Bouazara et al., 2006; Karen et al., 2012), and vibration comfort is largely determined as a function of the damping coefficient, which is applied to optimize suspension parameters (Silveira et al., 2014; Tamboli and Joshi, 1999) and depends on the viscosity of the fluid. In addition, the damping coefficient affects the braking distance of the car (Calvo et al., 2008). The physical safety of the cargo also depends on the ability of the vehicle to move on uneven roads without strong vibrations of the body. The results of research in the field of vibrations formed the basis of the international standard ISO/WD 2631-1 "Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration", which describes the requirements that also apply to road transport (ISO/WD 2631-1, 1997). Thus, the ability of shock absorbers to maintain their characteristics in a wide temperature range directly affects the efficiency of the use of vehicles and special equipment, as well as the safety of vehicle operation and the safety of human labor.

2 Methods of ensuring the performance of shock absorbers at low temperatures

The main reason for changing the technical characteristics of shock absorbers is a change in the viscosity of the shock-absorbing fluid, so basically all methods of ensuring operability are reduced to ensuring the constancy of this characteristic. Such methods include the use of modified hydraulic fluids with a low freezing point, or the use of various methods of heating shock absorbers from external sources. During operation the working fluid in the shock absorbers has the property of self-heating due to throttling, however, it is established (Domnyshev et al., 2019) that at temperatures less than 243 K the heating of the shock absorbers is necessary not only at the beginning of the movement, but also afterwards. This is due to the fact that shock absorbers, unlike many other units, do not use heat from the engine for their heating and are constantly exposed to headwinds when the vehicle is moving.

In the works (Makarov and Nikolaev, 2016; Serdyukov, 2010), some methods of thermal preparation of shock absorbers are considered. The heat energy source, which is a flexible heating element, covers the shock absorber housing, or is installed inside the housing (Fig. 1).

With all the external simplicity of this method, there is a problem of powering flexible heaters with energy, since in the practical implementation of such an idea, heating cables or silicone flexible heaters produced by the industry are used as heaters. The operating temperature of such heaters is 453–483 K, and the maximum heating is carried

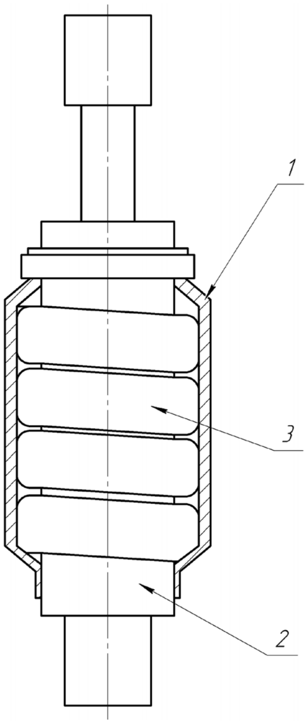


Fig. 1 Design of the shock absorber heating device; 1: thermal insulation casing; 2: shock absorber; 3: heating cable

out up to 523 degrees. When moving, such heaters use the electric power of the on-board network of 12 or 24 V, increasing the load on the electrical system.

Despite the presence of the above methods of heating shock absorbers, there are practically no works on evaluating the effectiveness of such methods based on practical research or at least based on computer modeling of the processes of heating shock absorbers.

The purpose of this work is to evaluate the effectiveness of the use of thermal heaters by computer modeling of the heating of shock absorbers in static conditions at a negative temperature.

3 Initial data for modeling

When modeling, the front shock absorber of the KAMAZ truck was used, which is a double-acting hydraulic telescopic twin-tube shock absorber with the characteristics specified in Table 1.

As a shock-absorbing fluid, these shock absorbers use low-freezing hydraulic oils of the AZH-12T, Lukoil AZH, VMGZ brands or ATF Dexron II/III liquids. When modeling, the characteristics of the AZH-12T fluid were used, as the most common in these shock absorbers (Table 2, Fig. 2).

The viscosity-temperature characteristic used in the shock absorbers of KAMAZ trucks is shown in Fig. 2.

After prolonged parking, the temperature of the shock-absorbing fluid is equal to the air temperature. The initial ambient temperature was assumed to be 243 K.

For the shock absorber resistance forces during compression and rebound (Table 1) the manufacturer has assigned permissible deviations from the nominal value. So, during the rebound, the resistance force should lie in the range from 3,626 to 4,415 N, and during the compression from 1,079 to 1,472 N. Thus, when the values of the resistance forces leave these ranges, we can speak of the loss of the shock absorber's operability.

Table 1 Technical characteristics of the shock absorber used in modeling

Parameter		Value
The length of the shock absorber in the compressed state (mm)		485
Stroke of the piston (mm)		300
Casing diameter (mm)		85
The outer diameter of the pipe D1 (mm)		76
Piston diameter D2 (mm)		40
Stem diameter D3 (mm)		19
Nominal resistance forces at a piston speed of 0.52 m/s (N)	Rebound of nominal resistance forces (N)	4022
	Compression of nominal resistance forces (N)	1226
Weight (kg)		5.92 kg

Table 2 The main characteristics of the shock-absorbing fluid AZH-12T

Parameter	Value
Kinematic viscosity (cSt) at or below 373 K	3.6...3.9
Kinematic viscosity (cSt) at 323 K	12
Kinematic viscosity (cSt) at 313 K	6500
Boiling point (K)	573
Flash point determined in a closed crucible (K)	438
Pour point (K)	491

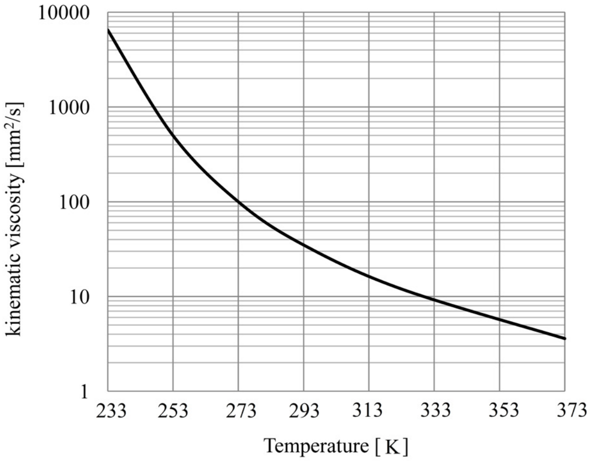


Fig. 2 Viscosity-temperature characteristics of the shock-absorbing fluid AZH-12T

The greatest influence on the resistance forces of shock absorbers is exerted by an increase in the viscosity of the shock-absorbing fluid due to the ambient temperature below 263 K (Domnyshev et al., 2019). Thus, it is advisable to conduct heating during modeling at this temperature.

As a modeling environment, the SolidWorks Flow Simulation software package from Dassault Systems was used, which implements computational fluid dynamics (CFD) algorithms.

4 Theoretical basis

One of the key parameters for evaluating the performance of shock absorbers is the damping coefficient, which is determined from the expression (Dixon, 2008):

$$C_D = \frac{128 \cdot \mu \cdot A_{PA} \cdot L_T}{\pi \cdot D_T^4}, \quad (1)$$

where:

- μ: dynamic viscosity (Pa·s);
- A_{PA}: piston annulus area;
- L_T: tube length;
- D_T: tube inner diameter.

In Eq. (1), when the temperature changes, only one value can change, i.e. – the dynamic viscosity, which is related to the temperature dependence:

$$\mu = \mu_1 \cdot e^{C \cdot \left(\frac{1}{T} - \frac{1}{T_1}\right)}, \tag{2}$$

where:

- μ_1 is the value of the dynamic viscosity at an absolute temperature T_1 (Pa·s);
- T is the absolute temperature (K);
- C is a positive constant coefficient (also known as viscosity sensitivity) (K).

In Eq. (2), the unknown parameter is the viscosity sensitivity C. The paper (Dixon, 2008) presents an empirical expression for determining this parameter, which is typical for non-improved oils:

$$C = 5693 - 304 \cdot \log_{10} \mu_{15} - 646 \cdot \left(\log_{10} \mu_{15}\right)^2 . \tag{3}$$

This expression, however, does not correspond to the characteristics of the AZH-12T shock absorber oil shown in Fig. 2.

We express the dynamic viscosity in terms of the kinematic viscosity v, m^2/s and the density p, kg/m^3:

$$\mu = v \cdot \rho, \tag{4}$$

where:

- v is the kinematic viscosity (m/s^2);
- ρ is the density of the liquid (kg/m^3).

The density of the shock-absorbing fluid also depends on the temperature:

$$\rho = \rho_1 \cdot \left\{1 - \alpha \cdot \left(T - T_1\right)\right\}, \tag{5}$$

where:

- ρ_1 is the density of the liquid at a temperature of 288 K;
- α is the coefficient of thermal expansion (K^{-1}); $\alpha \approx 0.001$, K^{-1}.

The expression for determining the kinematic viscosity can be found by approximating the graph in Fig. 2, using, for example, MatLab (MathWorks, online).

Thus, taking into account Eq. (4) and Eq. (5), the expressions for determining the damping coefficient will take the form:

$$C_D = \frac{128 \cdot v \cdot \rho_1 \cdot \left\{1 - \alpha \cdot \left(T - T_1\right)\right\} \cdot A_{PA} \cdot L_T}{\pi \cdot D_T^4}. \tag{6}$$

Substituting the values of kinematic viscosity in Eq. (6) and setting the real values of other parameters from Table 1, we can calculate the actual values of the damping coefficient.

Considering the graph in Fig. 2, as well as Eq. (6), it is easy to notice that of all the parameters included in it, the kinematic viscosity has the greatest influence on the value of the damping coefficient, the value of which changes significantly with temperature changes.

5 Results and discussion

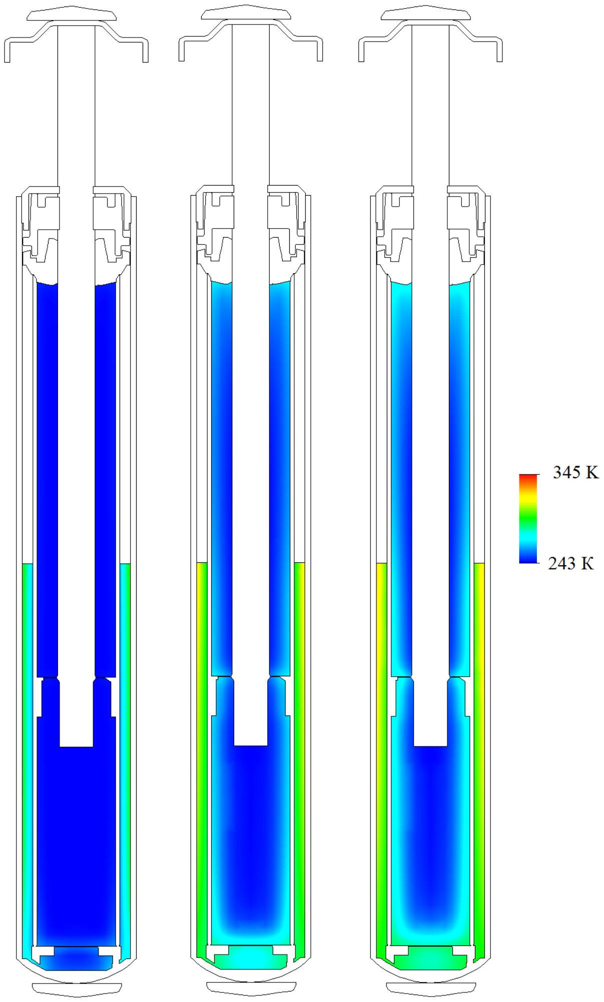
The model constructed from the initial data and its study showed that when exposed to external heat from a heating device, the heating of the liquid located directly near the shock absorber valves occurs rather slowly and extremely unevenly (Fig. 3).

Most of the thermal energy is spent on heating the part of the liquid located outside the piston cavities and valves. There is a "thermos" effect due to the very design of the twin-tube shock absorbers. The heating of the working fluid in the area near the piston occurs quite slowly, provided that the heating is carried out on a stationary shock absorber as a preliminary thermal preparation before starting movement, that is, the flow of liquid through the valves is excluded. The difference in the heating intensity can be estimated by Fig. 4. Thus, the fluid in the outer tube of the shock absorber heats up faster than in the inner one, and this difference increases over time.

In Fig. 5 shows the change in kinematic viscosity during the heating of the shock absorber.

The graph shows that the effective heating is carried out within 500...600 s and the value of the kinematic viscosity drops significantly, which allows you to start driving a vehicle with shock absorbers that have a satisfactory value of damping coefficient.

It should be noted that the time spent on the thermal preparation of shock absorbers can be combined with the



100 s 600 s 900 s

Fig. 3 Temperature distribution after heating for 100 seconds, 600 seconds and 900 seconds

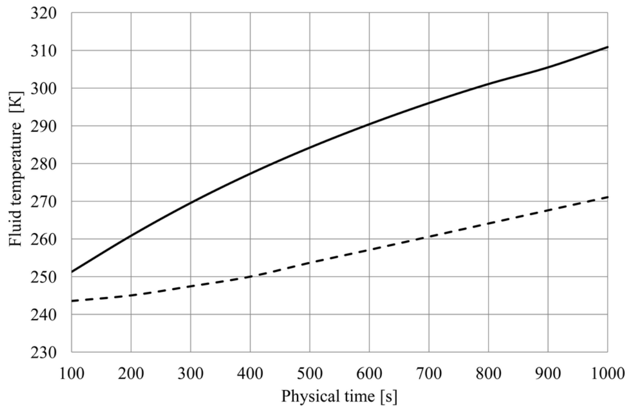


Fig. 4 Change in the temperature of the fluid during heating. The solid line corresponds to the temperature at the point between the shock absorber pipes, the dashed line corresponds to the average temperature in the area near the piston

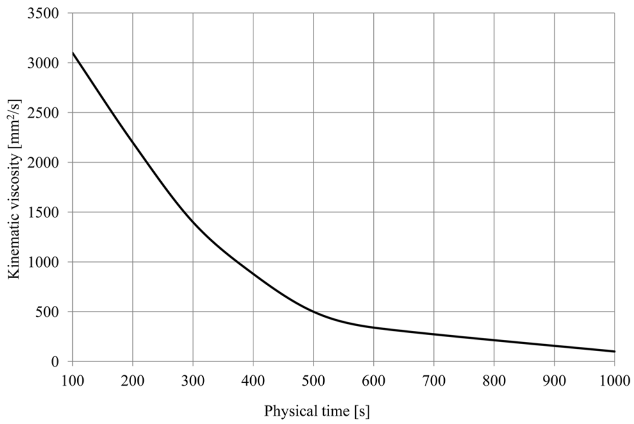


Fig. 5 Change in kinematic viscosity during heating

time that is necessary for the pre-start preparation of the engine and warming it up after starting.

6 Conclusions

Analysis of the expression for determining the damping coefficient shows that its value mainly depends on the viscosity-temperature characteristics of the working fluids used and the use of mineral oils with characteristics similar to Fig. 2 is a deterrent to the operation of vehicles at low temperatures.

Preheating of the shock absorbers before starting the movement has disadvantages associated with the power supply of the heater, which is carried out from the on-board network of the car, as well as associated with uneven heating of the shock absorber fluid. It should be noted that the last drawback will be compensated with the beginning of the movement of the car, when, with the reciprocating movement of the shock absorber piston, active mixing of the liquid will begin and the temperature will "equalize" throughout the filled volume.

Modeling of the operation of the shock absorber heater shows the effectiveness of its application. Preheating allows one to start driving with effectively working shock absorbers after about 500...600 s, since the value of the kinematic viscosity, and hence the damping coefficient, is reduced to a fraction of its initial value and the efficiency of the shock absorber increases.

The shock absorbers can be heated simultaneously with the engine warming up, so there is no need to spend extra time warming up them. In addition, if necessary, it is possible to heat the shock absorbers when the car is moving, but additional experiments are necessary to evaluate the effectiveness of this method.

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