Experiment of using thermal insulating materials for accumulation of heat in the transmission

A A Dolgushin, D M Voronin and A P Syrbakov
Novosibirsk State Agrarian University, 160, Dobrolyubova Street, 630039, Novosibirsk, Russia
E-mail: sirbakovap@yandex.ru

Abstract. Operation of production vehicles in conditions of negative temperatures is related to certain difficulties. One of the main problems is the intensive heat extraction from the unit surface in the environment. As a result of heat exchange, the thermal mode of the unit work is broken. It leads to the change of viscosity-temperature characteristics of lubricating oil. Operation of transmission units in such conditions results in the decrease of vehicle fuel efficiency, diminution of service life of the main units and parts and deterioration of ecological efficiency of their work. This article is devoted to the experiment of using thermal insulating materials aimed at reducing heat loss in the transmission. The method of calculation of thickness of a thermal insulation layer is proposed. The necessity of the employment of infrared thermal imaging to detect areas subject to insulation is substantiated. It is revealed that the area of insulation on the unit under study makes up 1.45 m². The intensity of transmission cooling with the use of liquid insulation is studied. It is established that the insulation of the unit casing allows reducing heat removal rate and increasing cooling-off time from 360 to 540 minutes. The process of heating of the thermally insulated unit is studied. It is determined that the use of liquid insulation allows intensifying the unit heating. The time to stabilization mode decreases by 35% to 45 minutes, and the stabilized temperature increases by 8 K.

1. Introduction
Transportation of goods in northern parts of Russia is carried out in severe climatic conditions. According to the data [1], cargo’s proportion, transported in months with negative temperatures, can be from 20 to 40% of the overall annual volume. Severe service conditions are characterized by cold temperatures, wind speed and air humidity. Combined influence of stated factors intensifies heat exchange between the vehicle and the environment when moving and stopping or parking.

Intense heat removal from the surface of vehicle units leads to the violation of the temperature condition during their work. The decrease of temperature of motive fluids in units deteriorates their viscosity-temperature characteristics. Particularly, increase in viscosity of lubricating oils results in considerable fuel consumption because of friction in nodes and mechanisms. According to data [2], to overcome friction force in units, one vehicle consumes on average 340 litres of motor fuel per year. Taking into account the number of vehicles in the world, about 208000 million litres of petrol and diesel are used to overcome friction. According to data [3], when air temperature goes down to 20 °C below zero, CO₂ emissions increase by 5% when the vehicle moves. To save fuel and decrease pollutant emissions, it is proposed to preheat the engine and other vehicle units [4].

Transmission units contribute significantly to the deterioration of engine fuel economy. Test of a track KAMAZ at 30 °C below zero shows that the temperature of transmission is about 30-35 °C, and
the temperature of front and back axles, in most cases, is negative [5]. The work of transmission at such oil temperatures increases wear intensity of gears 3 times [6], and decreases performance efficiency by 30\%, as well [7].

Research on losses of engine power during friction in transmission units at positive temperatures shows that losses on mechanical friction in geared transmission constitute 52\% of general losses, losses on mixing oil – 40\%, respectively [8]. In negative temperature conditions the proportion of losses on oil mixing and spraying grows considerably due to the augment of its viscosity.

On this basis, we can conclude that maintenance of temperature rate of units at a certain level is the resource of increase of fuel economy and ecological properties of vehicles during the operation in severe climate conditions. For this purpose, under production conditions, vehicles use external sources of thermal energy, using gas vapour mixture [9] or the heat of exhaust gas [10, 11] as heat carriers.

One of the ways of achieving this goal is to use modern insulating materials to diminish the intensity of heat exchange between units and environment, while operation and storage. Positive experience of the employment of thermal insulation for accumulation of heat in engine is stated in works [12, 13]. According to information [14], the use of polyethylene film for thermal insulation of engine area, while parking, allows to diminish heat emissions intensity by 39\% from 0.260 C/min to 0.160 C/min. In the work [15], the use of polyurethane foam cover for thermal insulation of transmission units allows to increase its adaptability to operate at low temperature. The appearance of new types of thermal insulation, like liquid paste and paint, makes it interesting to insulate transmission units by covering their surface by liquid thermal insulation.

As a result of math modeling of cooling of heat-storage device, it is stated that the main factors, influencing heat losses, are thickness of thermal insulating material, heat dissipation area, unit temperature and environment temperature [16]. Therefore, it is necessary to know temperature difference of examined objects and unit surface area, participating into heat exchange, to substantiate characteristics of thermal insulation. In works [17, 18], it is proposed to use infrared thermal imaging to detect unit surface areas, where significant heat losses occur. The employment of thermal imager for such tasks allows to detect areas to be insulated from the environment.

The aim of the work is to diminish the intensity of cooling of vehicle transmission via insulation of heat-stressed areas on the surface of its case from open air with the help of liquid insulating materials, and, on this basis, to increase temperature mode of the transmission work.

2. Research Methods

Experimental plant on the basis of KAMAZ vehicle transmission is made for the research. The plant drive is carried out via chain gearing with a capacity of 7500 W. The measuring complex, based on PC, is used to register the transmission oil temperature. The measuring complex includes five temperature sensors (resistive temperature transducers), an eight-channel unit of temperature registration, an interface converter and a PC with proper software.

Experimental design includes measuring transmission oil temperature, while the transmission works and cools after stop. The temperature and air humidity during experiment change slightly and reache 23-25 °C (248-250 K) and 75-80\%, respectively. Wind speed has values close to zero.

Four temperature sensors are installed in transmission gear case: sensor No.1, installed in the area of drain hole; sensor No.2 in the top layer of the oil, close to gears of the 5th speed; sensor No.3 in the top layer of the oil, next to gears of the 3rd speed; sensor No.4 in the lower layer of gears of the 1st speed and reverse gear. The fifth sensor fixes air temperature. The temperature is registered at 2-second intervals. Obtained data processing is carried out, using the standard application program package.

Infrared thermal imaging of the transmission surface is conducted by a thermal imager with resolution of 320×240 pixels.
3. Study Results
The intensity of cooling of the transmission in the process of long stop or off season storage is studied at the first stage of the research. The environment temperature is 250 K. Measuring results are introduced in figure 1.

Analysis of dependency in image 1 shows that cooling of the oil in the transmission gear case is carried out logarithmically. Cooling of a warm unit starts from the temperature 280 K, which corresponds to the temperature of lubricating oil stabilization under predetermined conditions. Oil layers, located in direct contact with body sides, cool more intensively (sensors No. 1, No. 4). Top oil layers cool more slowly, as they contact with gears (sensors No. 2 and No. 3). Due to some temperature variation in layers of the oil bath, we will consider average dynamic temperature of lubricating oil or of the whole unit as case oil temperature.

![Figure 1. Dynamics of cooling of lubricating oil in transmission gear case.](image)

At the beginning, high intensity of cooling is determined by a large temperature difference between the unit and the environment. After 120-150 min of parking, the intensity of cooling starts to decline. The duration of total cooling of the unit to the environment temperature is about 330 min, depending on the sensor.

Speed dynamics of cooling of the oil in transmission gear case is represented in figure 2. At the beginning, oil cools down by 1 K within 2.5 min, which corresponds to the speed of 0.4 K/min. Then cooling speed starts to decrease sharply and declines 4 times in 90 minutes. After 120-150 min of parking, oil temperature is close to the environment temperature, and cooling speed is close to zero.

One of the ways of the reduction of resource expenditure during vehicle operation in conditions of negative temperatures is the decrease of intensity of heat elimination from units to the environment. The use of different types of thermal insulating materials for transmission units, due to different thermotechnical characteristics, is connected with minimal thickness of the used material. Thus, the insulation of gearbox is possible both with the help of special movable insulating jacket and by covering the case surface with liquid thermal insulation.

The main purpose of thermal insulation of units is to reduce the intensity of heat emission in environment that will provide predetermined (optimal) temperature level, combined with other measures. Thereby, the key factor at substantiation of a choice and thickness of necessary thermal
insulation is maximum allowable heat flow $q_{T_{\text{max}}}$ through gearbox casing in the environment under the conditions.

Figure 2. Relation of oil cooling speed with parking time.

Knowing heat content of the studied gearbox and the duration of the heat exchange, maximum allowable heat flow can be determined:

$$q_{T_{\text{max}}} = \bar{c}_A \bar{M}_a (\bar{T}_{RAB} - \bar{T}_{SR}) / t_T$$

where $\bar{c}_A$ – average weighted specific heat of gear box, J/(kg K); $\bar{M}_a$ – gear box mass, kg; $\bar{T}_{RAB}$ – average weighted temperature of the examined gear box, K; $\bar{T}_{SR}$ – average weighted environment temperature, K; $t_T$ – heat exchange duration.

It should be noted that, when determining the value $q_{T_{\text{max}}}$, the amount of extra heat, transferred to the gear box from external sources, if they are used, should be taken into account.

The process of molecular heat transfer from gear box to the environment can be referred, with some assumptions, to thermal conductivity through multi-layered flat wall, where every layer is in thermal contact with each other. At the beginning, the heat is transmitted through cast-iron wall of the case of transmission gear box, and at second stage, through the layer of thermal insulation. We consider that all heat, transferred on the external surface of thermal insulation layer, is withdrawn in the environment by means of convection.

The following values will be initial data for the substantiation of thermal insulation layer thickness:

1. Coefficient of thermal conductivity of the case of transmission gear box $\lambda_1$, W/(m K);
2. Coefficient of thermal conductivity of thermal insulation $\lambda_2$, W/(m K);
3. Average temperature of internal surface of the wall of gear box case (equal to average temperature of oil in case), $\bar{T}_{K}$, K;
4. Average temperature of external layer of thermal insulation (equal to environment temperature), $\bar{T}_{I}$, K;
5. Area of gear box surface participating in thermal exchange, $S_T$, m²;
6. Average thickness of the wall of gear box case, $L_T$, m.
Due to the fact that coefficients of thermal conductivity of the walls in studied temperature span can be considered as constant, the amount of transmitted heat will be determined by heat drop and the thickness of walls. Therefore, heat losses from the surface of transmission units can be regulated by changing the thickness of thermal insulation layer.

For multi-layer wall made from two layers, being in ideal thermal contact, heat flow is expressed with the formula:

$$q_T = \frac{t_k - t_l}{\frac{L_2}{\lambda_2 S_T} + \frac{L_2}{\lambda_2 S_T}}, \text{W.}$$  \hspace{1cm} (2)

In terms of the examined task, heat flow is limited by the value $q_{T_{\text{max}}}$. Thus, the formula (2) can be written like:

$$q_{T_{\text{max}}} = \frac{t_k - t_l}{\frac{L_2}{\lambda_2 S_T} + \frac{L_2}{\lambda_2 S_T}}, \text{W.}$$  \hspace{1cm} (3)

Having expressed the value $L_2$ from the formula (3), we obtain the expression for the determination of minimal thickness of thermal insulation layer:

$$L_2 \geq \frac{(t_k - t_l)}{q_{T_{\text{max}}} \frac{L_2}{\lambda_2 S_T} \frac{L_2}{\lambda_2 S_T}} \text{m.}$$  \hspace{1cm} (4)

The use of formulas (4) is based on knowing the area of unit surface, which should be insulated.

Preliminary experiments show that maximum heat losses via thermal conductivity in transmission gearboxes are observed in areas of contact of lubricating oil with case walls. For rational use of thermal insulating materials, it is reasonable to insulate only surfaces of units with maximum heat losses.

It is possible to detect surfaces of gearboxes with intense heat emissions by means of thermal imaging diagnostics using special devices. Thermographic image of warm transmission (side-view) is presented in figure 3.

The analysis of series of thermographic images of the examined transmission allows detecting number of peculiarities of thermal exchange with environment. It is discovered that side and bottom parts of oil case heat more intensively than other surfaces and have temperature from 7 °C to 12 °C below zero. Therefore, intensive thermal exchange and convective heat removal occur through these walls. It can be explained by direct contact of indicated surfaces with warm oil and proximity of heat sources in the form of gearings.

Transmission cap and its frontal surfaces warm slightly and have temperature close to the temperature of ambient air. Slight drop of temperature minimizes heat losses in specified areas that allows not insulating them.

The flange of transmission output shaft should be mentioned because it has temperature 10 °C higher than the back side. In this case, heat transfer is carried out from warm gears through drive shaft to the
flange by means of thermal conductivity. For reduction of heat losses, it is reasonable to insulate transmission flange.

As a result of thermal imaging energy audit, the area of surface of transmission body, which should be insulated to diminish heat losses, is determined. The desired area makes up 1.45 m², including 0.8 m² of front walls, 0.45 m² of case bottom and 0.2 m² of back side, which makes up 36% from total surface area of the unit.

According to the experiment conditions, it is necessary to decrease cooling rate of the oil in transmission case with the help of insulation by 25% from 0.08 to 0.06 K/min. Theoretical calculations show that, for this purpose, a 2 mm layer of thermal insulation is required. Liquid thermal insulation with 0.0011 W/m °C coefficient of heat conductivity is used to insulate the walls.

Experiment results on cooling of insulated transmission are shown in figure 4.

![Figure 4](image)

**Figure 4.** The intensity of cooling of thermally insulated transmission.

Comparison of cooling rates of non-insulated and insulated transmission shows that covering the body with liquid thermal insulation allows to diminish considerably the intensity of heat removal in the environment. For example, thermal transfer at first 30 min of parking decreases 2 times which results in the increase of oil temperature in case by 5 K, compared with standard transmission. The employment of thermal insulation allows to accumulate the heat inside the unit and to enhance its thermal potential. In the course of the experiment, the duration of cooling of examined unit grows from 360 to 540 min. This is achieved by diminution of thermal conductivity of insulated wall and decrease of the conductive thermal transfer.

Accumulation of heat inside units can influence established temperature of lubricating oil, in particular, and of a unit, in whole. Diminution of specific heat losses from the surface changes thermal balance of the unit. Provided that the amount of heat generated by the unit at a certain time is constant, and heat losses in environment reduce, thermal balance can set in at higher values of oil temperature. The dynamics of heating of working thermally insulated transmission is studied to prove the hypothesis. The measurement results are shown in figure 5.
Analysis of the graphic data shows that the heating of transmission is less intensive without insulation. The unit reaches stabilization mode only in 65-70 minutes of the work. Thus, established temperature of the oil is 276 K. Insulation of heat-stressed surfaces helps to intensify the heating process. The time to stabilization mode decreases by 31% to 45 minutes, and established temperature increases by 8 K.

To sum everything up, we can conclude that the employment of thermal insulating materials leads to positive results both at long stopping and parking of vehicle and when operating in negative temperature conditions. However, thermal insulation itself does not solve the problem of provision of thermal modes of the work of vehicle units and should be used in combination with devices for extra heating.

4. Conclusion
1. One of the ways to increase the efficiency of the work of transmission units is the employment of thermal insulating materials. The research is conducted by the example of the use of liquid thermal insulation applied directly on the external surface of the transmission case.
2. The method is proposed to substantiate the thickness of the thermal insulating layer. Theoretical calculations show that to decrease oil-cooling rate in the gearbox case by 25%, a 2 mm layer of thermal insulation is required.
3. The necessity to employ infrared thermal imaging to detect surfaces subject to insulation is established. It is determined that the area of insulation on the unit under study makes up 1.45 m².
4. The intensity of cooling of transmission with the use of liquid thermal insulation is studied. It is established that insulation of the unit case allows to reduce the speed of heat removal and to increase cooling time from 360 to 540 minutes.
5. The process of heating of thermally insulated unit is studied. It is determined that the use of liquid thermal insulation allows intensifying the unit heating. The time, required to reach stabilization mode, decreases by 31% to 45 minutes, and the established temperature increases by 8 K.

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