The modern concept of thermal preparation of automotive equipment and tools for its implementation

I I Gabitov, A V Negovora, M M Razyapov, A A Kozeev and R J Magafurov
Bashkir State Agrarian University, 34, 50 year Octyabrya Street, Ufa, Russia

E-mail: Mahmut_23@mail.ru

Abstract. The necessity of adjusting the regulatory documentation for the operation of automotive equipment at low temperatures and the development of an “Integrated thermal training system” for it are substantiated. The description of the main components of the heat treatment system and the methods of the heat treatment are given by the example of a hot gas generator. The methods of thermal preparation of ATT, as well as ways to reduce the temperature of the coolant of the generator of hot gases and increase its efficiency, are considered.

1. Introduction
The efficiency of the use of motor vehicles (ATT) in conditions of low temperatures is largely determined by its constructive improvement and the technical readiness of personnel to competently carry out the processes of thermal preparation of ATT to start the engine and maintain its thermal state during the interchangeable time. In turn, these factors depend on the availability and perfection of regulatory and user documentation, which determines the requirements for the equipment of ATT facilities for thermal training. The regulations in force in Russia were developed in the second half of the 20th century, were updated only by small amendments, and are now very outdated [1, 2].

Previously, problems of ATT operation at low temperatures were mainly related to engine start up, as a result of which drivers preferred not to turn off the engine during night stands, lunches and during loading and unloading. Despite the fact that GOST R 54120-2010 “Automobile engines. Starting quality. Technical Requirements” states that when operating vehicles at low temperatures, they should be equipped with tools to facilitate engine start, automobile manufacturers still consider the preheater as additional equipment and do not equip cars with them as a standard.

Since its introduction, tractor and construction equipment has been structurally more complex than automobiles and more demanding in terms of service [3]. Therefore, the standards of thermal equipment in this industry are significantly stricter and more thoroughly worked out. For example, in GOST R 50992-96 “Safety of vehicles when exposed to low ambient temperatures. General technical requirements” regulatory requirements for maintaining vehicle performance at low temperatures are prescribed for such components and assemblies as the engine, steering, cab, electrical equipment. Currently, cars and tractors, as well as construction equipment are structurally approximately similar in their complexity due to the use of various hydraulic systems and hydraulic actuators. In this regard, the equipment that is not properly prepared during operation at low temperatures poses problems associated with increased wear of parts and system failures [4]. The tightening of environmental requirements in the early 90s of the last century and the legislative prohibition of car parking with a running engine lead...
to the need to equip most of the commercial vehicles sold in Russia with heaters. However, they are used only in the preheating of the engine, despite the urgent need for heating other units [5,6].

In a modern car, besides heating the internal combustion engine before starting, other systems and units need to be optimized for thermal conditions, most of which are shown in the diagram (fig.1).

Figure 1. Integrated heat treatment system.

It should be noted that along with the change and complication of the design of ATT, there has been a fundamental reassessment of the design, control algorithm and strategy for the use of heaters. In operation, they perform the role of the main source of heat when the engine is inactive and the auxiliary when it is running [7]. It should be noted that the design of the heaters that are used to equip KAMAZ vehicles (14TS-10 since 2004, produced by ADVERS LLC and since 2013, 16GD-24 produced by Eltra-Thermo OJSC) they are intended for heating the engine coolant, but can also be used for heating the oil in the engine crankcase, either by exhaust gases or by means of a coil mounted in the crankcase. There are examples of external heating of the gearbox, transfer case, battery and other vehicle components [8-11]. However, the use of such methods without clear and uniform requirements leads to a decrease in the effectiveness of these measures, sometimes also to a breakdown of aggregates or accidents.

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2. Materials and methods
To solve this problem, in our opinion, it is necessary to make some changes with the existing Technical Regulations and GOSTs. The most important thing is to consolidate the concept of “Integrated thermal preparation of ATT for taking a load at low temperatures”. In essence, this is a set of measures to attract funds and methods, which allow in low-temperature conditions to increase ATT reliability and readiness for launching and accepting load, as well as bringing them closer to performance under normal operating conditions. These requirements should apply not only to the engine and standard ATT units, but also to its mounted units and cover three interrelated areas: the implementation strategy of the “Integrated Thermal Preparation of ATT”; improvement of the design of the means providing it and the technology of preserving the optimum viscosity of all the oils used, regardless of the ambient temperature.

Integrated thermal preparation (Figure 1) includes a set of measures to ensure the operability of all units and systems of ATT to take the load at low temperatures, which is aimed at automation:
- thermal preparation of the ATT engine for receiving the load with the obligatory reduction of harmful impurities in the exhaust gas and the reduction of starting wear when operating in the engine warm-up mode;
- thermal preparation of transmission units and ATT mounted units for load taking;
- thermal preparation of the power steering, brake system and suspension assemblies;
- thermal preparation of the battery and electrical equipment;
- long-term maintenance of a given thermal state of an inoperative engine, cabin, systems, and mounted units, including exhaust gas after-shift systems;
- coolant temperature of a running engine in case of its reduction below 55 °C (“reheating” mode).

To provide such comprehensive heat treatment, sources of thermal energy are needed that allow this training to be carried out without damage to the heated unit and with the least amount of time. When developing such heaters, it is desirable to take into account a number of mandatory requirements:
- liquid heater should be autonomous and located on the ATT;
- the heat output of the unit must be adjustable (for this, it is preferable to have an evaporative type combustion chamber);
- the design and control algorithm of the heater must provide the necessary and sufficient thermal power for pre-heating the engine coolant to 70 °C at the time set by the State Standard 30 min at temperatures up to minus 450 °C and 45 min at temperatures up to 600 °C and other ATT units according to values.

It is known that the minimum temperature, to which it is necessary to heat up certain ATT aggregates, differs significantly and must be established theoretically with experimental confirmation. For example, according to our research [12,13], to safely receive a load on a ZF 16S 1820 gearbox, the oil temperature in its crankcase should not be below minus 80°C, provided that it is filled with oil recommended by the manufacturer.

The cost effectiveness of battery energy consumption with automatic maintenance of the set coolant temperature, ATT units, mounted units, long-stay cabs or in between-hours with the engine not working depends on the required power of each consumer. In this case, the regulation mode of the heat treatment process should be smooth.

When developing tools for complex heat treatment, it is necessary to envisage the possibility of further reducing the power consumed by the heater in transient conditions due to a proportional decrease in the performance of the circulation pump.

One of the main problems arising in the operation of ATT at low temperatures is an increase in the viscosity of lubricating fluids due to their physical properties [15]. This problem is solved by the manufacturer’s recommendation to use oils of various classes in accordance with the chemmotology cards, however, in operation, the implementation of this item is almost impossible due to the mismatch of the seasonal and the scheduled oil replacement periods.

This is due to the fact that the routine replacement of oil for mileage from cars can be carried out: in the engine - once every two years, in the gearbox - once every four years. The engine and gearbox are assembled at the factory with standard oil: engine oil with SAE 15W viscosity with a lower temperature limit of minus 17 °C, gearbox oil with an SAE 80W viscosity and lower temperature limit of minus 26 °C. At the same time, even in Central Russia, where SAE 10W oil is recommended, the air temperature often drops below minus 30 °C, and the total number of such cold days can reach 23 days a year. [16].

Maintaining the minimum allowable temperature of lubricating oils, taking into account the structural and physical properties of each unit installed on the vehicle is possible only through comprehensive thermal preparation. Heating of such units and components as a driving axle, transfer case, power steering, brake system units, battery compartment, cylinder block of air-cooled engines and fuel equipment is most optimally produced using stationary or portable hot gas generators - air heaters (such as Thermix-15).

Since, in the basic version, the temperature of hot gases at the exit from the air heater reaches 500–700 °C, all units that undergo thermal preparation due to their design features carry the risk of thermal damage. Therefore, to reduce the temperature of hot gases, it is necessary to use additional devices - an ejector or a steam generator nozzle. Figure 2 shows a hot gas generator with an ejector installed [14].
Figure 2. Hot gas generator ThermMix 15D-24 with an ejector: 1 – Air heater, 2 – flame tube with ejector, 3 – handle, 4 – metal sleeve, 5 – false pallet, 6 – heated unit.

The essence of the work of the ejector lies in the fact that during operation of the hot gas generator, the temperature of the flow of hot gases moving at high speed is reduced by cold air drawn through rectangular holes in the walls of the ejector. However, with this method, along with a decrease in temperature, the heating capacity of the heater decreases, which significantly increases the time of thermal preparation. This method of reducing the temperature of the coolant is applicable in places where the permissible temperature is 300 - 400 °C and in cases where the duration of thermal preparation is important. To heat large-sized units with a permissible coolant temperature of up to 130 °C, it is necessary to look for other ways to reduce the temperature with a minimum decrease in thermal power.

For example, a more effective way to reduce the temperature of hot gases is to mix them with water vapor. This is achieved by applying a steam generator nozzle, which is a “pipe-in-pipe” design, in which the outer wall of the small-diameter pipe and the inner wall of the larger-diameter pipe form a vessel, and hot gases pass along the inner side of the small pipe. The nozzle is filled with water, which when heated, the generator of hot gases is heated and evaporates. During evaporation, steam has only one outlet – through a tube into the internal cavity of the nozzle, where it is mixed with a stream of hot gas, which causes a decrease in its temperature. The diagram of the device is shown in Figure 3.

Figure 3. Scheme of a steam generator based on ThermMix -25D-24: 1 – fuel tank, 2 – flame tube, 3 – steam nozzle, 4 – metal sleeve, 5 – guiding device, heated unit with installed thermocouple, 7 – ADC, 8 – computer for data recording.

Experiments were carried out in several stages: at the first stage, we obtained the characteristic of a hot gas generator as standard, then we used an ejector head to reduce the temperature of hot gases, and at the third stage we used a steam generator. To study the work of the proposed steam generator, an
experimental study of the process of vaporization in the nozzle and mixing of steam with the hot gases of the generator was carried out.

3. The results and discussion
The experiments carried out using the nozzle and the hot gas generator as a heat source showed the efficiency and effectiveness of this idea. The experimentally obtained graphs (Figure 4) show that with the same intensity of heating the oil in the engine pan, the temperature of the heat carrier when using the ejector is lower by 55°C, and when installing the steam generator – lower by 268°C.

![Graph showing temperature comparison](image)

**Figure 4.** Comparison of the effectiveness of the three methods of heating the object.

Experimental studies carried out confirmed the possibility of a significant decrease in the temperature of the mixed coolant, as well as the dependence of its thermophysical properties on the ratio of gas-air mixture and water. However, the main reserve for reducing the heat treatment time is the use of an effective coolant, which makes it possible to preserve the thermal power of the generator while lowering the coolant temperature.

The use of steam generator nozzles in hot gas generators allows, without reducing the heating power of the heater, to reduce the temperature of the heat carrier, which determines the efficiency and safety of the thermal preparation of the vehicle units and allows to solve the problem of thermal damage to car parts when heating hot water.

Another significant drawback of modern hot gas generators, autonomous cabin heaters, engine heaters and other heat treatment units is the high energy consumption of the battery. In some cases, despite the autonomy of the applied design solutions, the engine heated to the operating temperature cannot be started due to a decrease in the battery charge. To eliminate this shortcoming, we have proposed a device that allows reducing the energy consumption of a battery by 80%, without reducing its performance. Additional electric power is generated by a thermoelectric generator module (TGM) mounted on the heat pipe of the heater. To increase the efficiency of work, a cooling radiator is installed on the outer side of the TGM.

The proposed device works as follows: the electrical generator nozzle 1 is fixed on the hot gas generator 6 (Figure 5), and the connecting wires are connected to the corresponding battery terminals.
The hot gas generator 4, after reaching its maximum power, creates on different sides of the thermoelectric generator module a temperature differential, which forms a potential difference at the terminals of the TGM. Electricity through the converter goes to the battery, which compensates for the current electricity consumption from it. At the same time, there is no decrease in heat energy, which is used to heat the vehicle’s units.

For theoretical and experimental verification of the use of the developed nozzle, an experimental setup was assembled, consisting of a hot gas generator, an electrical generator nozzle (TGM) and a measuring complex. To control the temperature, chromel-copel thermocouples were used, installed in various places of the TGM.

Through experimental studies, it was determined that TGM could be used to supplement the supply of electricity to a hot gas generator. The magnitude of the voltage received from the unit TGM was 2.1 volts. We have investigated the design of the nozzle with four TGM, which allowed to increase the voltage of the generated energy to 9 volts. The increase in the total potential of the generator set as a function of the temperature difference between the external and internal surfaces of the TGM is shown in Figure 6. It can be seen that at the moment of starting the hot gas generator the temperature of both sides of the TGM does not differ and there is no output voltage. As the inside warms up, after 1-2 minutes, the potential increases and stabilizes after 15 minutes at a value of about 9 volts. At the same time, the total power of the generated electricity reached 50 watts.

The final values of the output voltage and the total power of the source will be determined by the area and number of TGMs, but when installing 6 TGMs or using a voltage converter, it becomes possible to partially replace the energy consumed by the heater from the battery.
Thus, we can conclude that the existing algorithm for the use of pre-start heaters does not provide effective thermal preparation of automotive engineering. A heater that heats only the engine coolant cannot heat the oil and ensure its specified viscosity, therefore it is necessary to use other means of thermal preparation. The choice of the oil to be used must be made not by the pour point, but by viscosity. This allows you to more fully assess the suitability of oil in specific conditions, especially for hydraulic systems with an extensive network.

4. Conclusion
The proposed measures make it possible to form a concept and implement new tools for the integrated thermal preparation of automotive engineering at low temperatures, allowing it to be ready for launch and acceptance of load and reliability in operation. The implementation of the proposals specified in this article is feasible without significant costs. Moreover, most of these measures are already in operation, but due to unclear regulatory requirements or their absence, they are not widely implemented. The introduction of uniform requirements for integrated heat treatment will significantly increase the reliability of systems and components of automotive engineering during operation at low temperatures.

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