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EXPERIMENTAL RESEARCH ON THERMOELECTRIC AUTOMOBILE STARTING PRE-HEATER OPERATED WITH DIESEL FUEL

The results of experimental research on the energy characteristics of 75 – 90 W thermoelectric automobile heater operated with diesel fuel for start heating of engine under low ambient temperatures are presented.

Key words: starting pre-heater, thermoelectric generator.

Introduction

Today the problem of internal combustion engines start-up under low ambient temperatures is solved by using starting pre-heaters commercially produced by a number of companies – Eberspecher, Webasto, Truma (Germany), Ateso (Czeck Republic), Teplostar (Russia), Mikuni (Japan). Such heaters run on different fuels and are used in the cars, trucks, buses, yachts and boats.

Many years' experience of vehicles operation shows that start heating not only assures reliable engine start, but also allows increasing its service life by 50 – 60 thousand kilometers per year and reducing toxic discharge by a factor of 5, while saving 90 – 150 l of fuel during one winter season. Moreover, comfortable conditions provided by start heating eliminate completely the possibility of accident due to cold impact on the driver [1].

However, despite ample opportunities, starting pre-heaters have not found mass application yet. One of the main reasons for this is electric energy requirement for power supply to heater components, namely fuel pump, fan for air delivery to combustion chamber, circulation pump for liquid heat carrier pumping. Preliminary investigations have shown that during operation of liquid heater of thermal power 4 kW and electric power requirement 40 W, a battery of capacity 60 A·hour within 4.5 hours loses 50 % of capacity. This causes battery discharge and creates significant difficulties at engine start. To avoid battery discharge during start heating, it is reasonable to use thermoelectric generator as a source of electricity for such heaters [2 – 4].

In [5], analysis of technical characteristics of starting pre-heaters for various transport means is made and electrical parameters of thermal generators are determined which are necessary for autonomous operation of such heaters and additional power supply to other automobile equipment, including re-charging of batteries.

Based on computer calculations performed in [6], a sample of thermoelectric heater operated with diesel fuel of electric power output 70 – 90 W has been created at the Institute of Thermoelectricity for start heating of transport means with engine displacement up to 4 l.

The purpose of this work is to study thermal and electrical characteristics of the developed heater design and to test its operation in the automobile.

Structure and operating principle of thermoelectric starting pre-heater

Fig. 1 shows a layout of an automobile starting pre-heater with a thermoelectric power supply.

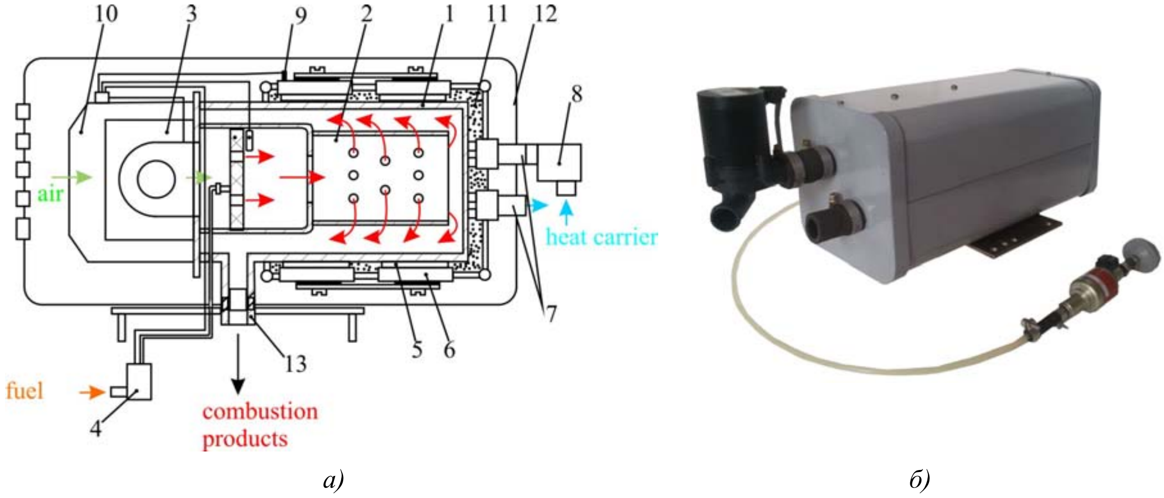


Fig. 1. Layout (a) and exterior view (b) of an automobile starting pre-heater with a thermoelectric power supply: 1 – hot heat exchanger; 2 – source of heat; 3 – fan; 4 – fuel pump; 5 – thermoelectric pile; 6 – cold heat exchanger; 7 – input and output connecting pipes; 8 – circulating pump; 9 – overheat sensor; 10 – electronic unit; 11 – thermal insulation; 12 – case; 13 – exhaust pipe.

This thermoelectric heater is composed of a hot side heat exchanger **1**, which holds the source of heat **2** in its interior space. Fuel and air delivery to the source of heat is carried out by a fan **3** and fuel pump **4**. A thermoelectric pile **5** is located on the exterior surface of the hot heat exchanger the heat from which is removed by heat exchangers **6**.

Cold heat exchangers are combined into one hydraulic loop connected to the engine cooling system by the connecting pipes **7**. Circulation of the liquid heat carrier in the “heater-engine” loop is realized with the circulating pump **8**. An overheat sensor **9** is located on one of the cold heat exchangers to control the temperature of the heat carrier.

The start-up and operation control of all heater devices (fan, fuel and circulating pumps) is done by an electronic unit **10**.

Free space between the hot and cold heat exchangers is filled up with thermal insulation **11**. An automobile heater with a fan, electronic unit, heat exchangers and thermoelectric pile is placed within a case **12**. The end products of the fuel combustion are released by an exhaust pipe **13** into the environment.

A thermoelectric pile is composed of 12 standard generator modules ALTEC-1061 [7] which are electrically connected in series/in parallel. Modules connection was adjusted so that the output voltage of the heater matched the voltage of the automotive storage battery.

A diesel burner Ersatzbrenner D TT-C MB was used as a source of heat in the structure of the heater, pulse pump BTL.DP30.02.12V DAEMPFLER E-TEIL and liquid pump 12V U4847 TT C/E of the starting pre-heater “Thermo Top Evo 4» (Webasto) [8]” were used as fuel and circulating pumps.

The heater works as follows. Thermal energy from fuel combustion heats up the hot heat exchanger, passes through the thermoelectric converter and is diverted by the liquid heat carrier circulating in the heat exchangers of the heater and engine cooling system. Due to the temperature difference between the hot and cold sides, the thermal converter generates electric current. Therefore, thermal energy diverted from the thermal converter is used for the engine warm-up and heating of the car interior, while electric power is used to supply heater components and recharge the automobile storage battery.

Test stand for thermoelectric heater analysis

The analysis of energy characteristics of the designed thermoelectric diesel heater was made on test stands, the layout of which is shown in Fig. 2 and 3.

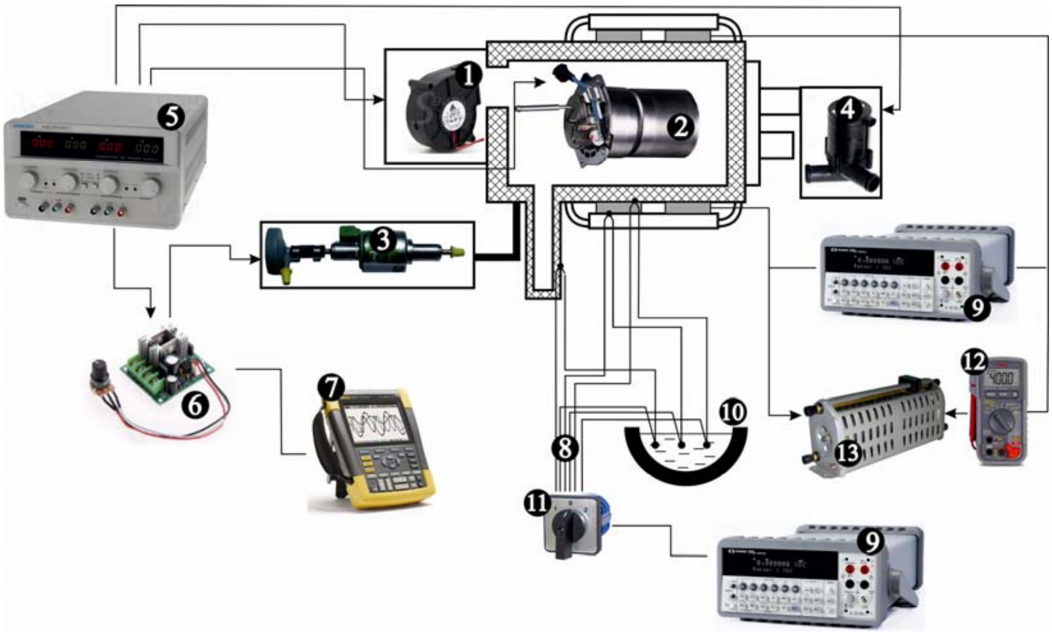


Fig. 2. Layout of test stand №1: 1 – air fan; 2 – diesel burner; 3 – fuel pump; 4 – circulating pump; 5 – electronic control unit; 6 – pulse controller; 7 – oscillograph; 8 – thermocouples; 9 – multimeter; 10 – Dewar flask with ice; 11 – rotary switch; 12 – digital ammeter; 13 – rheostat.

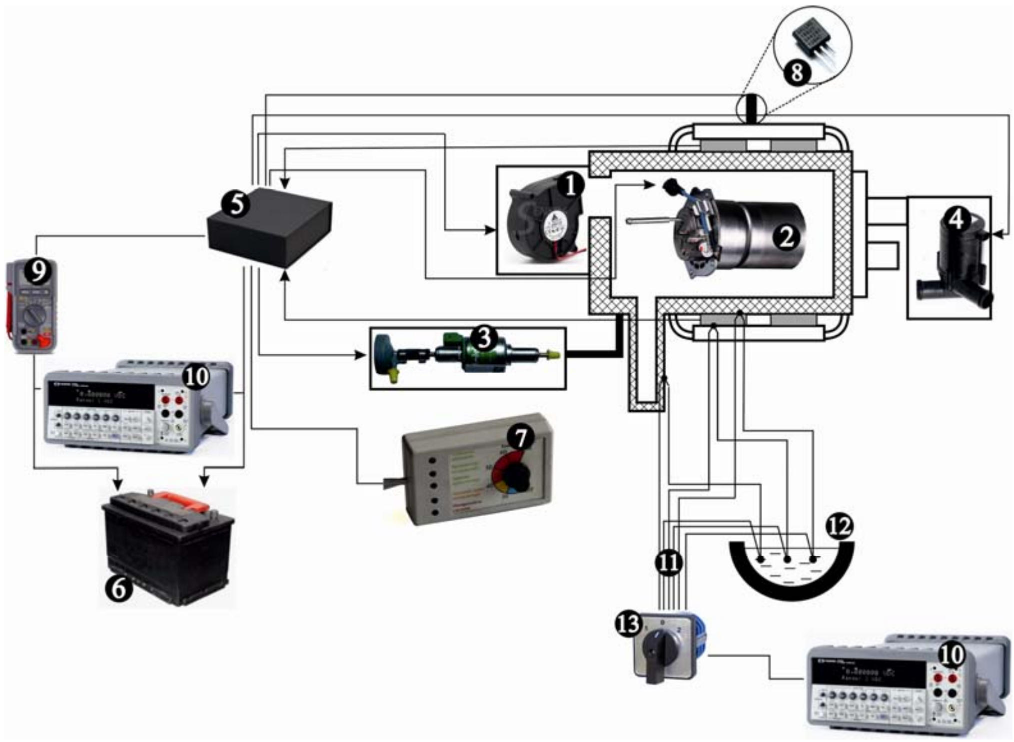


Fig. 3. Layout of the test stand №2: 1 – air fan; 2 – diesel burner; 3 – fuel pump; 4 – circulating pump 5 – electronic control unit; 6 – storage battery; 7 – control panel; 8 – overheat sensor; 9 – digital ammeter; 10 – multimeter; 11 – thermocouples; 12 – Dewar flask with ice; 13 – switch.

Power supply of components (air fan **1**, spark plug of diesel burner **2**, fuel pump **3**, circulating pump **4)** was done from a separate power source to obtain the optimum performance of the heater, improve the algorithm of its start-up and reach the maximum power. Fuel consumption was adjusted by the pulse controller **6** measuring the pulse period with the oscillograph **7**. Temperatures on the hot and cold heat exchangers, as well as the temperature of the gas at the outlet of the exhaust pipe, were measured by differential thermocouples **8**. External load was set by the rheostat **13** removing the voltage and electrical current from thermoelectric modules.

The testing of the thermoelectric heater paired up with the automobile battery was performed on the test stand No.2 (Fig. 3). In this case, the operation of components was not controlled manually by power supply units, but by the electronic control unit **5**.

The storage battery charge level was determined by determining the electric current in the "storage battery - generator" system and the storage battery voltage. The heat carrier temperature was set in the control panel **7** and the set temperature was controlled by the overheat sensor **8**.

The heat removal system of the heater was combined in one hydraulic loop with the thermostat to estimate the heating velocity of the heat carrier.

Test stand results

The research results of the parameters of the automobile starting pre-heater and thermoelectric generator are shown in Fig. 4.

The presented data show that within two hours of the heater operation the cold heat carrier, in this case it is water, is heated to 70 °C (the heat carrier temperature was considered to be equal to the temperature of the cold heat exchanger T_{cold}). In so doing, after 20 minutes of operation the temperatures of the hot heat exchanger T_{hot} and exhaust gases T_{gas} are at 280 °C and 300 °C and do not vary afterwards, therefore the generator reaches the stationary mode. Under such circumstances, the electrical voltage U of the thermoelectric converter under maximum power conditions is within 13 – 12 V at T_{cold} = 30 – 70 °C.

The stationary mode of the heater (mode IV) is sustained when the heat power of the heat source Q is 2.3 kW and the cold heat carrier consumption g_T = 0.3 m^3/hour. However, for the reliable start and steady operation of the heater in the electronic control unit, the gradual increase of heat power of the burner and aerofuel mixture was implemented (Table).

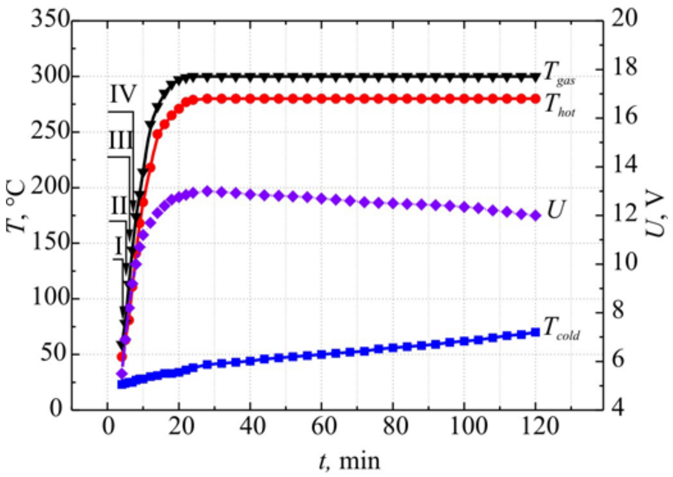


Fig. 4. Temperature dependence of cold T_{cold}, hot heat exchangers T_{hot}, combustion products T_{gas} and output electric voltage U of the heater on the operation time.

Table

Operating mode of thermoelectric starting pre-heater

Mode	Heat power Q, W	Fuel consumption g_n, g/hour	Air consumption g_{air}, m^3/hour	Heat carrier consumption g_T, m^3/hour
I	935	79	3.26	0.3
II	1190	100	3.5	
III	1570	132	3.65	
IV	2330	195	4.57	

Note that further increment of the burner heat power leads to overheating of the hot side of the modules (T_p ~ 350 °C) and therefore such modes are not used for the heater operation.

Fig. 5 shows dependencies of the maximum electric power P and coefficient of efficiency η of the heater on the temperature of the cold heat carrier.

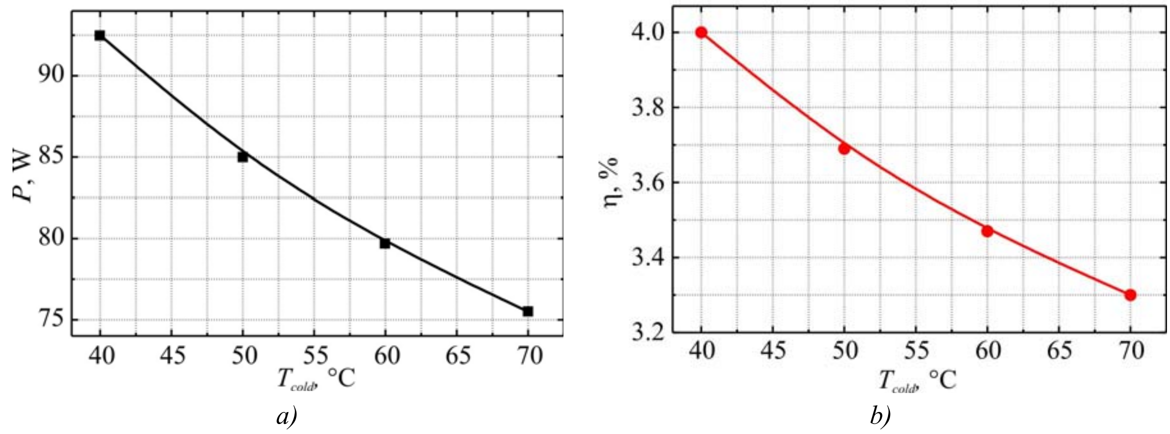


Fig. 5. Dependence of maximum electric power P (a) and coefficient of efficiency η (b) on the temperature of the cold heat carrier.

From Fig. 5 it follows that the output electric power of the thermoelectric starting pre-heater is 90 to75 W within the temperature range of the circulating heat carrier 40 – 70 °C. The efficiency of thermoelectric conversion comes to 4 % at T_{cold} = 40 °C and decreases to 3.3 % at T_{cold} = 70 °C as the heat carrier warms up.

The research results of the operation of the thermoelectric starting pre-heater paired with the automobile storage battery are shown in Fig. 6.

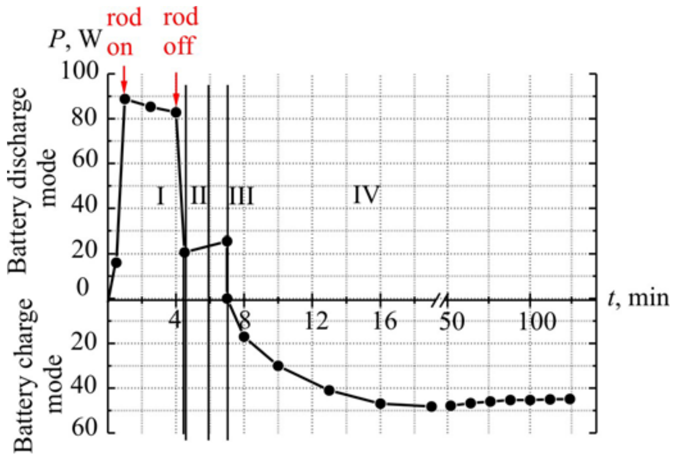


Fig. 6. Dependence of charge and discharge power of storage battery on the time of thermoelectric heater operation. Roman numerals denote the modes of heater operation (Tabl.).

As shown in Fig. 6, after the heater start-up the supply of its components is done with the storage battery (0 – 7 minutes). At the same time, 15 – 25 W is used for the circulating pump, fuel pump and fan depending on the operating mode and 60 – 70 W for the burner spark plug supply. The discharge mode of the storage battery lasts until the time when the output power of the generator is equal to the consumed power of the components. Afterwards, the electronic control unit cuts off supply of the components from the storage battery and the heater switches to off-line mode. With the increase of the output electric power of the generator, the electronic unit reroutes the excess of the electric energy to charge the storage battery (7 – 120 minutes). Data presented in Fig. 6 show that the maximum power used for charging is 50 W and thereafter decreases slightly to 45 W due to the cold heat carrier warming-up.

Observation results made in automobile

The layout of the heater connection to the hydraulic loop of the automobile is shown in Fig. 7.

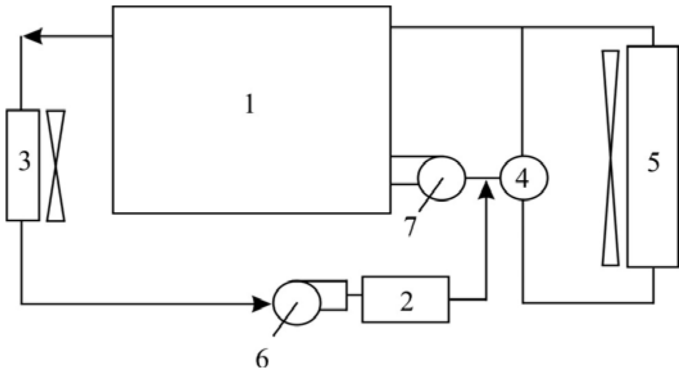


Fig. 7. Layout of the heater connection to the hydraulic loop of the automobile:
1 – engine; 2 – thermoelectric heater; 3 – furnace; 4 – thermostat; 5 – radiator;
6 – circulating pump of heater; 7 – standard pump of automobile.

It is advisable to place the thermoelectric heater **2** in the hydraulic loop of the automobile between the engine **1** and furnace **3** in such a way that the liquid heat carrier which moves along the minor cooling circuit ("engine-furnace-standard pump) reached the engine entry upon exiting the heater.

The operation of the thermoelectric starting pre-heater was analyzed in a "Mercedes" automobile with the engine volume of 2.8 liters (Fig. 8).

Fig. 8. Thermoelectric starting preheater in the
"Mercedes" automobile.

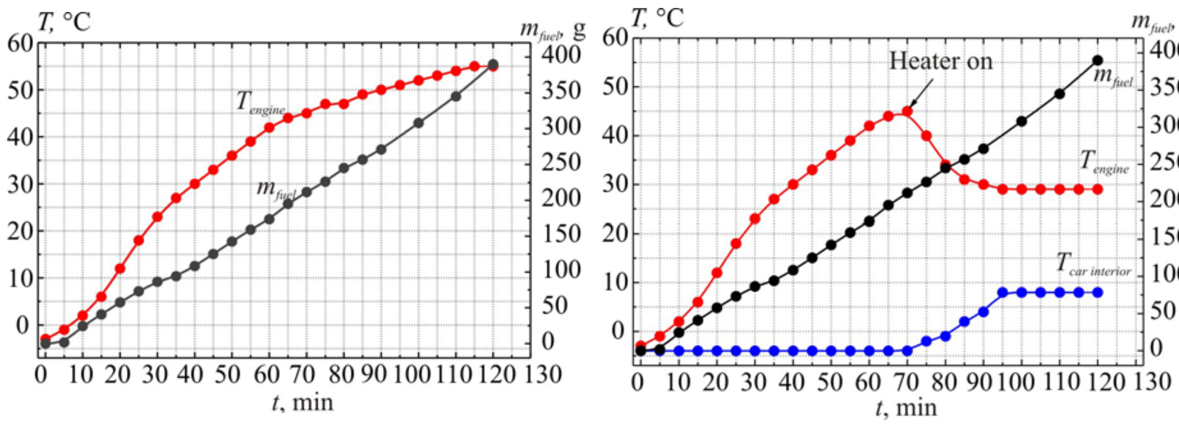
Diesel fuel was delivered to the heater from the separate tank located with the fuel pump in the trunk of the automobile (Fig. 9*a*). The fuel pump was connected to the heater mounted under the automobile hood with the electricity cable and fuel pipe (Fig. 9*b*).

a) *b)*

Fig. 9. Location of fuel tank and fuel pump (a), electricity cables and fuel pipe (b).

The results of the experimental analysis of the starting pre-heater in the automobile are presented in Fig. 10.

The data above show that the thermoelectric heater provides the engine pre-heating up to 50 °C within the time of its operation (Fig. 10*a*), even if the temperature is nonoptimal, it is sufficient for the automobile start-up. Turning on the standard heating system leads to the engine temperature fall T_{engine} down to 30 °C and the car interior temperature rise $T_{car\ interior}$ up to 10 °C (Fig. 10*b*). Under such conditions, the amount of fuel m_{fuel} used by the heater is ~ 400 g in both cases.



a) *б)*

Fig. 10. Results of experimental investigations of thermoelectric heater in the automobile: a) engine preheating; b) engine pre-heating and car interior heating. Ambient temperature T_o = – 5 °C.

The storage battery charging mode (Fig. 11) was turned on on the 7th minute of the heater operation, while the charging rate I reached its peak 1.9 A on the 20th minute of operation and actually did not change afterwards. At the same time, the voltage level of the storage battery $U_{battery}$ was 13 V from the moment the heater reached its off-line operation mode until the fan of the standard heating system turns on, whereupon it declined rapidly to 12 V.

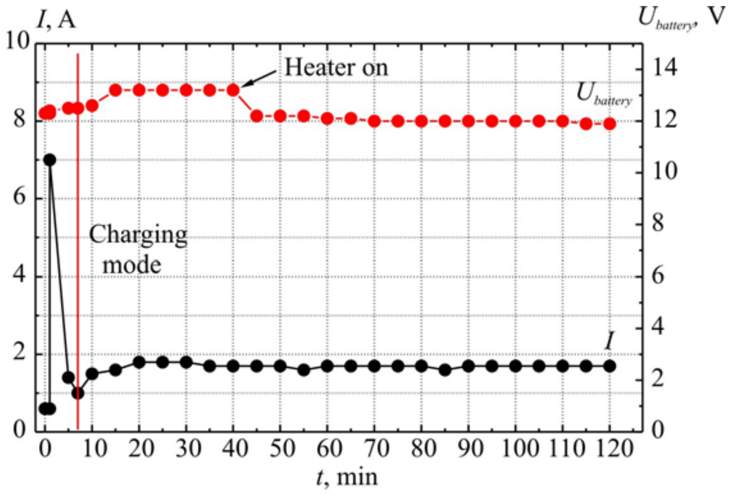


Fig. 11. Dependence of storage battery voltage and charging rate on the time of heater operation.

Thus, within the period of the heater operation in the automobile, the excess of the electric power of the thermal generator used for recharging storage battery is 20 – 25 W.

It should be noted that such discrepancy in the automobile measurement results and test units (Fig. 6) was due to the fact that the storage batteries were charged differently in both cases. Therefore, the charging rate shall be determined first and foremost by the storage battery charge level in each individual case [9].

Similar research aimed at the determination of the fuel consumption, car interior and engine temperatures was performed when the engine was warmed-up at idle. The results of these measurements are shown in Fig. 12.

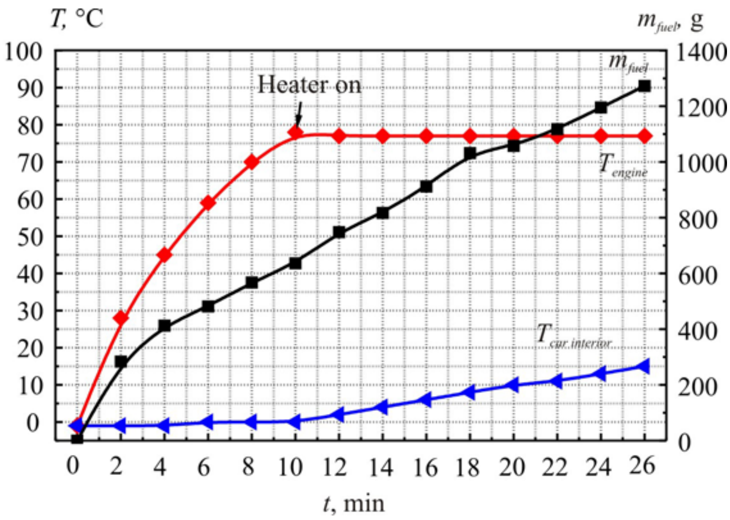


Fig. 12. Results of experimental investigations of automobile warm-up at idle. Ambient temperature T_o = – 5 °C.

As compared with the warming-up by the thermoelectric heater, the idle running provides optimal engine temperature 80 °C for the automobile start-up on the 10^{th} minute of operation and allows the car interior temperature to rise to 15 °C. But in this case, the burned fuel mass m_{fuel} is 700 g at the moment when the standard heating system switches on, which is nearly twice as large as the consumed fuel at the pre-start heating.

Therefore, considering that in average an automobile does 4 cold starts per day during only one winter season (90 – 110 days), the diesel fuel saving for the automobile with the engine volume of 2.8 liters shall be 120 – 150 litres (~ 40 %).

Conclusions

1. It is established that the output electric power of the developed thermoelectric starting pre-heater is 75 – 90 W at the hot heat exchanger temperature 280 °C and cold heat carrier temperature within 70 – 40 °C. The maximum efficiency of the generator is 4 % under such conditions.
2. It is stated that the maximum power mode of the heater is reached when the heat power of the heat source is 2.3 kW, fuel consumption 195 g/hour and air consumption 4.57 m^3/hour. Meanwhile, the cold heat carrier consumption is 0.3 m^3/hour.
3. It is established that nearly 90 W of the storage battery electric power is used to supply the heater components. When the heater switches to off-line mode, the electronic control unit cuts off the supply of the components from the storage battery and with the increase of the output electric power of the generator reroutes the excess of the electric energy to charge the storage battery. Meanwhile, the charging rate is determined by the individual storage battery charge level.
4. It is established that the thermoelectric heater provides the automobile engine pre-heating up to 50 °C within two hours of operation. Switching on the standard heating system of the automobile leads to decrease of the engine temperature to 30 °C, whereas the car interior temperature increases to 10 °C.
5. It is shown that the application of the thermoelectric starting pre-heater in automobiles with engine volume of 2.8 liters allows saving fuel by ~ 40 % during only one winter season as compared with warming-up at idle.

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