Research on the phenomena of warming up and free cooling down the car engine

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Abstract. The average cold start temperature in Europe is 9 degrees C. However, not the average is the most important for the composition of exhaust gases and associated air pollution. The most onerous for the environment are the winter starts when automotive emissions of harmful gases add up in cities with those of home heating systems. The paper presents preliminary studies of warming up and cooling down processes in various environmental conditions. It was pointed out that thermal insulation of engines could be required.

1. Aim of work

The aim of the presented work is to learn about the phenomena of heating and cooling the car engine in real road conditions. Determining the dependence of the temperature rise on heating and cooling down is a prelude to the selection of engine heat shields and the design of control of the new generation of cooling systems.

2. Car engine warm up process

The thermal condition of the engine is defined as the set of temperatures of selected parts of the engine or its circulating liquids. The proposed temperatures often result from the possibility of mounting measuring transducers at selected locations. Traditionally, for the assessment of the thermal condition, the authors of the publication use the temperature of the cooling liquid leaving the head. In road measurement conditions, this is sufficient. For laboratory tests, this approach is too narrow - not including fast-changing processes. When carrying out measurements in this work, the authors benefited to a large extent from simplified measurement of engine coolant temperature.

Road tests covered the warming process in winter conditions. The temperature of the coolant as a function of time against the background of the speed of driving at an external temperature of -12 ºC (ride 2) and -13 ºC (ride 3) is shown in Figure 1. The Ford Fiesta 1.3 was used. The engine was started leaving the garage at +18 and +20 ºC. In this way, the start-up occurred in conditions similar to those used in laboratory tests on chassis dynamometer. Due to different speed profiles - higher acceleration and maximum speed when ride No. 2 - the cooling liquid reached a constant temperature in 670 s, and in the No. 1 ride only in 1180 s. In both rides, in negative temperatures, heating lasted from 2 to 4 times longer than at high ambient temperatures + 20 ºC. During driving No. 1, the start was at a temperature of 12 and 10 degrees lower than in the first two rides. This constant difference persisted at the beginning of the test. In the four-second test, the cab heating blower was turned on. At the increased air velocity through the heater, this caused the suppression of the liquid heating process and even a slight decrease in temperature. Until the end of ride 1, the liquid did not reach the temperature stabilization system, heating up to 73 ºC at 690 s at the end of the journey. Thus, reducing the load on the engine when it warms up (fig. 1), whether the inclusion of the interior heating fan (drive No. 1 figure 1) interrupt the engine warm-up process.
For various passenger car engines their warm-up processes have a different course. In Figure 2, the heating of 2 engines: Honda Accord 2.0 and Ford Fiesta 1.3 (table 1) were compared. The test was carried out on the same route in the city at an external temperature of -3°C.

Table 1. Selected technical data of cars used in the road warm up test of engines

| Car            | Honda Accord 2.0 | Ford Fiesta 1.3 | Honda CRV 2.0 |
|----------------|------------------|-----------------|---------------|
| Engine type    | K20A6            | A9JA            |               |
| Euro standard fulfilled | IV               | III             |               |
| Stroke volume [dm³] | 1998            | 1299            |               |
| Power per unit of the engine stroke volume [kW/dm³] | 57,1             | 43,4            |               |
| The volume of liquid in the cooling system [dm³] | 6,6              | 5               |               |
| Weight of the car with the load in the test [kg] | 1390             | 1110            |               |
Figure 2. Comparison of engine warm up of various cars on the same city route; T - temperature of the cooling liquid; v - driving speed; ambient temperature -3°C Ford Fiesta (top graph) and Honda Accord (bottom graph).

The change in driving speed was similar, as it was driven the same way with similar traffic conditions (stop at traffic lights when driving in a column). The cooling liquid in the Ford engine warmed up over 672 seconds, which is slower than in the Honda engine, for which this time until the thermostat fully opened was 500 s. The liquid in the Ford engine got higher temperature due to a different thermostat setting. The faster warm-up rate of a Honda car is the result of higher energy consumption for a heavier car and a smaller volume of coolant inside the block and head.

Subsequent tests concerned driving at low temperatures at start-up also in the state of thermal equilibrium with the surroundings. Figure 3 shows 3 consecutive rides on the same route with heavier car (Honda CRV car - K20A6 engine - engine data in table 1). The cooling liquid temperature lowering is easy visible when the cab heating blower was turned on.
Figure 3. Coolant temperature as a function of time at outside temperature: -10 °C; -7 °C; -5 °C; starting at ambient temperature; Honda CRV 2,0 dm³

Figure 4 shows two drives at low ambient temperatures when starting the engine at the same temperature as driving. The power of the engine was recorded during a slow urban driving. Such driving conditions results in a slow heating of the engine. Short-term power gains will not cause a change in engine coolant temperature, while a longer standstill results in a coolant temperature drop which then heats the passenger cabin.
Figure 4. The temperature of the engine cooling liquid on the background of the engine power during two city drives on the same route. Commissioning at -5 and -7 °C.

During short urban rides at low temperature starts, the heating rate of the engine depends to a large extent on the unit energy consumption on the route, which in turn depends mainly on the car's inertia resistance. Slow cycling is a frequent overcoming of inertia resistance. The energy intensity factor defined in [2] is:

$$\Phi = \frac{E}{L_n m}$$  \hspace{1cm} (1)

where:
- \( E \) – Energy consumed
- \( L_n \) – length of ride
- \( m \) – mas of vehicle

Energy consumption for a specific car depends on the resistance of traffic but also the distance traveled. For both trips shown in Figure 3, the energy intensity factor differs slightly (0.23 for the initial temperature of -5 °C and 0.21 for the initial temperature of -7 °C). These are typical values \( \Phi \) for driving in a traffic jam [2].

From 01/09/2017, in the vehicle emission tests, a new speed profile is applied in the European Union during tests on a chassis dynamometer. It is presented in Fig. 5.
Figure 5. Profile of the winter driving speed in the city against the WLTP test speed profile. Thin red line shows real driving conditions.

Against the background of this profile one of the test drives in winter conditions was shown. Despite the different course of the speed profile, the acceleration values are close and the maximum speeds in the low and medium phases are the same. Similar approximation factors $\Phi$ and warm-up times of the engine can be expected. The test currently in force better reflects the actual operating conditions of cars.

3. Cooling processes of passenger car engines

During the operation of passenger cars in the cities, their engines cool down between subsequent rides. Engine stop periods have different durations. For commercial cars, stops are usually short. However, stops of private cars often last many hours.

To determine after which standstill time the coolant temperature will drop to the assumed temperature limit of 30 $^\circ$C, at which the engine is considered cold by the program controlling its operation. the temperature of the coolant was recorded with natural cooling, at different ambient temperatures.

At a standstill lasting car over an hour, the temperature of the cooling liquid decreases initially to about 3.5 hours exponentially and then linearly (Fig. 6). The speed of temperature change in the first hour of $0.5 \div 0.6 ^\circ$ / min, after 4, 5 hours of parking was only $0.04 ^\circ$ / min in the tested engine.
Conclusions
The presented experimental research indicates the imperfection of the internal combustion engine when used to drive the car in urban traffic. During short trips in winter conditions, the temperature of the coolant stabilizes after 400 s and thus 100 s later than during the approval tests. This leads to increased emissions of toxic compounds in the exhaust and increased fuel consumption. Activation of the passenger compartment heating prolongs the heating of the engine and causes the coolant temperature to drop sharply by 5 degrees for a period of about 40 seconds. Commonly used start / stop systems [2] also contribute to the slowdown of engine heating.

The engine cooling is fast in the first hour around 0.5 °C / min in the third, fourth hour ten times slower. The authors propose research on thermal insulation of engines to slow down the cooling process. This would require increasing the efficiency of the cooling system operating in the heated engine.
New chemical substances would need to be changed to change the state of focus to use their latent heat. Currently, they are manufactured for a low density of thermal energy storage or are dangerous to the environment.

The works on the use of high-temperature heat sources such as exhaust gases, especially for the production of electricity, are also ongoing [4].

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