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ANALYSIS OF THE AUTOMOBILE ENGINE COOLING SYSTEM CALCULATIONS

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Abstract

This article presents an analysis of the automobile engine cooling system. It discusses the calculation of the cooling system radiator, the operating principle of the thermostat, and the methodology for determining the calculated performance of the engine cooling system. The paper also provides guidelines for evaluating the efficiency and performance of the cooling system through engineering calculations.

Keywords

Types of cooling systems, cooling system structure, operating principle, thermostat and its types, open and closed cooling systems, radiator and its types, water pump.

Function of the cooling system. The function of the cooling system is to remove heat from the heated engine components and dissipate it into the surrounding environment, thereby ensuring that the engine operates within the required temperature range. During operation, the average temperature of the engine working cycle is 1070–1200 K (800–1000°C). At such temperatures, the components of the crankshaft-connecting rod mechanism and the gas distribution mechanism become overheated, while the lubricating oil between the friction surfaces burns, causing excessive friction. As a result, the piston expands due to heat and may seize inside the cylinder, whereas the bearings may melt. Therefore, it is necessary to continuously remove heat from the heated engine components and transfer it to the surrounding environment. However, excessive cooling of the engine is also undesirable because heat energy is wasted, the lubricating oil becomes more viscous, and the power required to overcome friction increases. In addition, part of the combustible mixture condenses into liquid droplets, washing away the lubricating oil from the cylinder walls, which results in increased wear of the cylinder-piston group components. Thus, both engine overheating and excessive cooling reduce the engine's effective power and fuel economy. The

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cooling system maintains the engine at the optimum operating temperature required for efficient performance.

Liquid Cooling System. According to the method of coolant circulation, liquid cooling systems are classified into **thermosiphon**, **mixed**, and **forced circulation** systems.

In a **thermosiphon cooling system**, the coolant circulates naturally due to the difference in density between the hot and cold liquid.

In a **mixed cooling system**, the coolant cooled in the radiator is pumped by a water pump to the upper part of the engine cylinders, while it flows naturally to the lower part under the influence of gravity.

In a **forced circulation cooling system**, the coolant is continuously circulated throughout the system by a water pump. When calculating the performance of an engine cooling system, the properties of the coolant, particularly antifreeze, play a significant role. Based on its heat transfer characteristics and its ability to absorb heat from engine components, Table 1 has been prepared and is used in the subsequent calculations. When antifreeze is used instead of water in the radiator, the heat absorption capacity decreases by approximately 8–12%.

Table 1. Physical properties of engine coolants

Substance	Temperature, °C		Density ρ, kg/m3	Heat absorption, kDj/(kg·K)
	Freezing	Boiling		
Water	0	100	1000	4,2
Air	- 213	- 193	0,95…1,2	1,0
Antifreeze	- 65 …- 45	102…117	1100…1112	2,5…3,8

Methodology for determining the design performance of the cooling system

When calculating the cooling system, the initial parameter is the amount of heat that must be removed from the engine and dissipated into the surrounding environment. The calculations are performed for the engine operating at its rated power, N_{en} (kW). According to the results of experimental studies conducted on various types of engines, the specific amount of heat, q_{oxl}, has the following values:

Gasoline engines: 2840–5700 kJ/(kW·h)

Diesel engines: 2270–2900 kJ/(kW·h)

If the engine oil is also cooled by the cooling system components, the value of q_{oxl} should be increased by 2–4.5 %.

$$Q_J = \frac{1}{3,6} q_{oxl} N_{en}\,, \quad Dj/s$$

The coolant circulation rate through the cooling system per second is determined by the following equation:

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$$V_j = \frac{Q_j}{C_j \cdot \rho_j \cdot \Delta T_j}, \quad m^3/s$$

Where: Q_j – specific isobaric heat capacity of the coolant, *J/(kg·K)*; the value is taken from Table 1. ΔT_j – temperature difference between the coolant inlet and outlet of the system (i.e., the radiator inlet and outlet). For closed-circulation cooling systems, this value is assumed to be 6–15 K. ρ_j– density of the coolant, kg/m³; the value is selected according to Table 1.

Cooling System Radiators

Radiators designed for air cooling may be installed either together with the main liquid-cooling radiator or as independent units, depending on the system design. In most cases, air-cooled radiators are mounted in front of the engine coolant and engine oil radiators, in the direction of the incoming airflow. This arrangement allows the main cooling fan to direct airflow efficiently through all heat exchangers, thereby improving cooling performance. Such a configuration is intentionally adopted to overcome increased hydraulic resistance, simplify the overall cooling system, and enhance operational efficiency. An example of this design can be found in automatic transmission variants of the Chevrolet Cobalt, where an auxiliary transmission oil cooler is installed ahead of the main radiator.

Radiator Design Calculation

The radiator design calculation is generally completed by determining its effective heat transfer surface area, F_p. First, the amount of heat generated by the engine that must be dissipated during operation is determined. Subsequently, several modifications are introduced to the previously presented equation to account for the radiator's operating conditions. The radiator heat transfer surface area is calculated using the following equation:

$$F_P = \frac{Qj}{k_p \cdot \Delta T_{jl}}, \quad m^2$$

$T_{v\ sr} = 0.5 \cdot (Tv\ vx + Tv\ vyx)$ – average temperature of the air passing through the radiator.

Where: k_p – heat transfer coefficient of the radiator heat exchange surface (from the coolant to the air):

for gasoline engines, kp = 140…180 W/(m²·°C);

for diesel engines, kp = 80…100 W/(m²·°C).

$DT_{j\cdot v} = T_{jsr} - T_{v\ sr}$ – difference between the average temperatures of the coolant and the air passing through the radiator.

$T_j\ sr = Tv\ jx - 0.5 \cdot DT_j = 86…91$ °C – average coolant temperature in the radiator.

DT_j coolant temperature rise (7…9 °C).

T_j – coolant temperature at the radiator outlet, 90…95 °C.

T_v sr = 0.5 ·(Tv vx + Tv vyx) – average air temperature passing through the radiator.

Tv vx = T_0 + DTv.vx – air temperature at the radiator inlet. The atmospheric air temperature at the water radiator inlet is T_0. As the air passes through the radiator grille and the oil radiator, its temperature increases by DTv.vx = 3…5 °C.

If there is no oil radiator, Tvx = T_0 may be assumed. For an ambient temperature of T_0 = 20 °C, the air temperature at the radiator inlet is Tv = 23…25 °C. Tv = Tv vx + 0.5·DT – air temperature at the water radiator outlet. DTv.vx = 20…30 °C – temperature increase of the air across the liquid radiator core. At an ambient temperature of T_0 = 20 °C, the air temperature at the radiator outlet is Tv vyx = 33…40 °C.

Cooling system circulation pumps

In most automobiles, centrifugal water pumps are used to ensure coolant circulation.

The pump shaft is driven by the engine crankshaft through V-belts. In some cases, the cooling system fan is also mounted on the same shaft. More commonly, however, the pump drive is designed separately from the fan drive. Pumps that provide coolant circulation in automotive engine cooling systems must ensure a coolant flow at a pressure of 0.06…0.12 MPa.

The circulation pump is calculated to determine its main geometric parameters and the power it consumes.

The pump capacity is calculated by taking into account the leakage coefficient *hn (hn = 0.8…0.9)* of the coolant flowing between the pressure side and the suction side through the clearance between the pump casing and the impeller.

$$\boldsymbol{Vjr} = \frac{\boldsymbol{Vj}}{\boldsymbol{hn}} \quad or \quad \boldsymbol{Vjr} = \frac{\boldsymbol{Q_j}}{\boldsymbol{\mu_j \cdot C_j \cdot \rho_j \cdot \Delta T_j'}}, \quad (\mathbf{m^3/s})\ (\mathbf{2-a})$$

Where: μj – pump delivery coefficient; μj = 0.8…0.9. The pump inlet opening must ensure the delivery of the required coolant flow rate. This requirement is satisfied when the following condition is met:

Vjr /s1 = π ·(r1– r2), where s1 – coolant velocity at the pump inlet, m/s; s1 = 1…2 m/s; r1 and r0 – respectively, the radius of the impeller inlet opening and the impeller hub radius, m; The impeller hub radius is taken as one-half of the pump shaft diameter and is approximately r0 = 0.01…0.015 m. The radius of the impeller inlet opening is determined using the above equation, which can be rearranged as follows:

$$r_1 = \sqrt{\frac{V_{jr}}{\pi \cdot c_1} + r_0^2}$$

The outlet radius of the impeller is determined as follows:

r2 = kr · r1, m; where kr = r2 / r1 – the ratio of the impeller inlet and outlet radii of the pump. This value can be taken approximately as kr = 1.5.

Cooling system fan.

The dimensions and performance of the fan must be sufficient to ensure proper cooling of the coolant in the radiator. To allow rapid engine warm-up and improve energy efficiency, fan drives are designed with automatically adjustable performance or are arranged to remain inactive when the engine is cold. For this purpose, automatic clutches and thermosensitive sensors are installed in the cooling system. The characteristic parameter describing fan operation is pressure, which for simple axial fans is 0.07.

The calculation of fan performance is determined using the design formula that ensures heat removal from the radiator by means of cooling air.

Qj = qoxl Nen,   Dj/s.

Air flow rate provided by the fan.

$$Vv = \frac{Qj}{\rho v \cdot \Delta Tv \cdot cv}, \quad (\mathrm{m}^3/\mathrm{s})$$

Cv – specific heat capacity of air, J/(kg·K); Cv = 1000 J/(kg·K).

ρv – air density at the average radiator temperature, kg/m³;

ρv = 1.05…1.12 kg/m³.

ΔT – air temperature rise across the radiator core: (ΔTv = Tv.vx – Tv.Vx.); ΔTv = 20…30 °C.

Power required to drive the fan:

$$Nv = \frac{V_v \cdot \Delta P}{\mu_v}, \quad (Vt)$$

μv – fan efficiency (η); μv = 0.32…0.4 for riveted fans;

η_v = 0.55…0.65 for cast fans;

Δrv – air path resistance (aerodynamic losses);

Δrv = 600…1000 Pa.

Note: The fan may have an independent electric drive, and its operation is activated by a thermosensitive sensor installed in the cooling system.

Liquid cooling system calculation.

We consider the calculation for a cooling system of a gasoline engine with a rated power of 90 kWt.

This engine cooling system is a liquid-type, closed system that ensures forced circulation of the coolant.

During engine operation, the heated coolant is directed through a thermostat via an outlet pipe and hoses to the radiator. When the temperature of the coolant passing through the thermostat is below 70 °C, the valve remains closed. As a result, the coolant does not flow into the radiator and circulates only within the cylinder block cooling jacket. As the temperature increases, the valve begins to open, and the heated coolant gradually flows into the radiator. When the temperature reaches 80…85 °C, the valve is fully open, and the coolant starts to flow entirely into the radiator. When the coolant temperature reaches 95 °C, the fan is activated, creating an additional forced airflow that accelerates heat dissipation from the radiator tubes to the environment. The cooled coolant in the radiator is then drawn by the pump and delivered back into the cooling jacket.

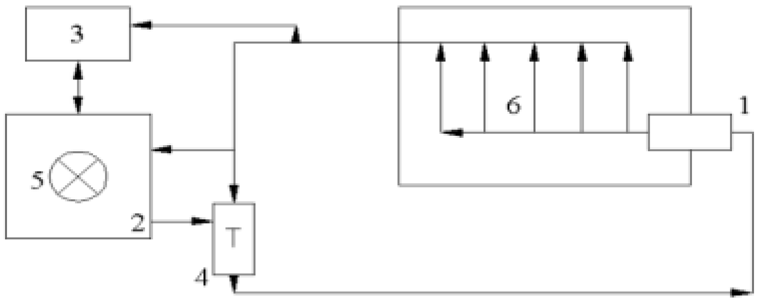

Figure 1. Functional diagram of the engine cooling system

The cooling system consists of the following components:

1. Centrifugal circulation pump
2. Radiator
3. Expansion tank
4. Thermostat
5. Fan
6. Engine cooling jacket

Radiator. The amount of heat removed from the engine per unit time by the cooling system.

Qj = qoxl Nen,= ·3780 ·90 = 94500 Dj/s.

Where: q_{oxl} – relative heat transfer coefficient with respect to water; q_{oxl} = 3780 kJ/(kW ·h).

N_{en} = 90 kWt – engine rated power.

Radiator cooling surface

$$\boldsymbol{Fp = \frac{Q_j}{k_p \cdot \Delta T_p} = \frac{94500}{100 \cdot 35} = 27m^2}$$

Where: *k_r = 100 Wt/(m² ·K)* – heat transfer coefficient from the coolant to air.

$\Delta T_r = Tj - Tv$ ΔT_r = 35 K – average temperature difference between the coolant and air across the cooling radiator.

Circulation Pump.

Calculated capacity of the circulation pump.

$$Vjr = \frac{Q_j}{\mu_n \cdot C_j \cdot \rho_j \cdot \Delta T_j} = \frac{94500}{0.82 \cdot 3800 \cdot 1000 \cdot 9} = 0{,}0031\ m^3/sek$$

$$= 186l/min,$$

(antifreeze) h_n = 0.82 – pump delivery coefficient;

ρj = 1000 kg/m³ – coolant density;

ΔTj = Tj vx. – Tj vx. = 9 K – temperature change of the coolant in the radiator.

Power consumed by the circulation pump

$$Nn = \frac{Vj \cdot Rn}{\mu g \cdot \mu mex} = \frac{0{,}0031 \cdot 1 \cdot 100000}{0.7 \cdot 0{,}9} = 378vt = 0{,}378kvt$$

Where: *Rn* = *0.1 MPa* = *1* $\cdot 10^5$ *Pa* – pressure generated by the pump;

μ_g = 0.7 – hydraulic efficiency of the circulation pump;

μ_{mex} = 0.9 – mechanical efficiency of the circulation pump.

Thus, the power consumed by the circulation pump in the engine cooling system, N_n, constitutes 0.42% of the engine rated power N_e.

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