Improving the Operational Efficiency of Diesel Locomotive Engines by Enhancing Their Cooling Systems

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**Abstract.** This article presents an analysis of the main malfunctions of diesel locomotive engines, water analysis in various regions of the republic, requirements for cooling water, and statistical data on unscheduled repairs of diesel locomotives due to malfunctions in the cooling system and cooling equipment. It also discusses the dependence of diesel locomotive engine efficiency on the water system, as well as the possibilities of improving heat exchange by enhancing the cooling system of the TE10M locomotive's diesel engine. This improvement aims to reduce overheating of engine parts, decrease unscheduled repairs, and lower excess fuel consumption. According to the research results, it was established that contamination in the locomotive's cooling system leads to a decrease in heat exchange efficiency, an increase in fan load, and consequently, an increase in fuel consumption. Statistical data also shows that radiator sections and diesel engines are subjected to unscheduled repairs due to contamination of internal water channels. By introducing a three-stage filter into the locomotive's water system, solid particles and corrosion products in the water system are effectively captured, increasing the system's efficiency. As a result, the diesel engine operates at normal temperature, fuel consumption decreases, and engine reliability improves.

# Introduction

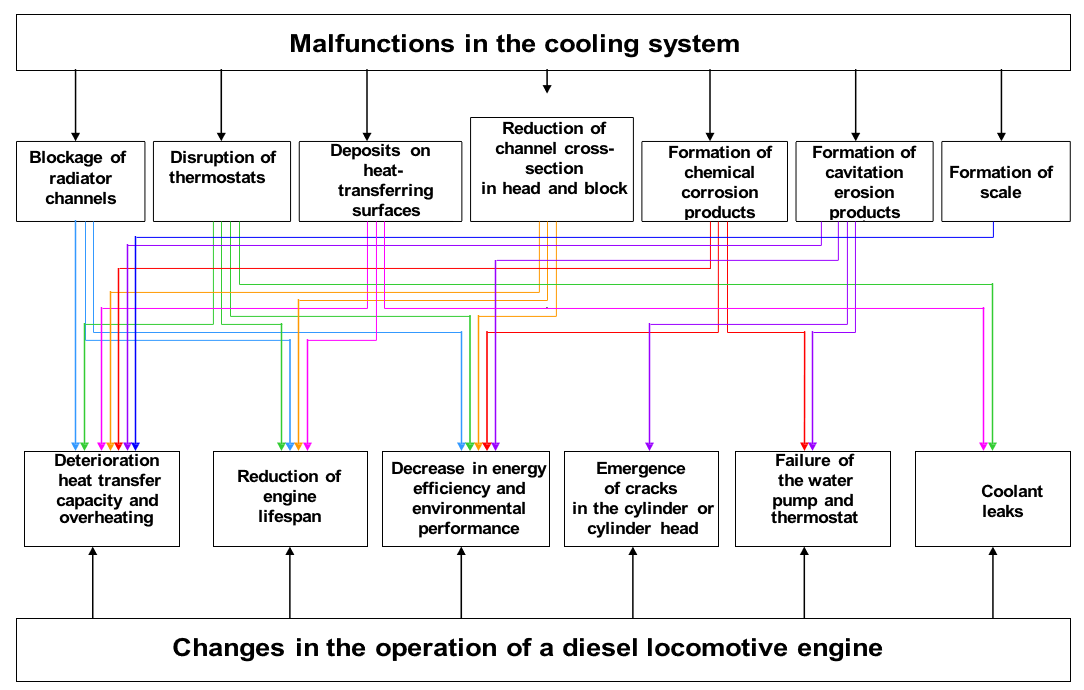
The efficiency of a diesel locomotive engine is dependent on its technical condition, and malfunctions and excessive fuel consumption occurring during the operation of locomotives are considered one of the economically significant issues. The cooling system of the TE10M locomotive directly influences its performance and the service life of the diesel engine [1].

The cooling system of a locomotive is one of its most critical components, operating under the heaviest load and prone to failure. Malfunctions in this system not only increase the complexity of maintenance but also lead to significant economic losses. During operation, due to external and internal factors, the heat exchange efficiency of the cooling system gradually decreases. Scientific and practical analyses show that the heat dissipation capacity of the cooling system reaches the permissible limit - a decrease of up to 15% - indicating that parameters which should be restored during routine repairs according to current maintenance regulations are deteriorating much earlier. This necessitates the improvement of the existing repair system.

# Related Work

The decrease in cooling system efficiency or the occurrence of malfunctions is associated with several technical reasons. Primarily, when the diesel engine temperature exceeds the norm, its power output decreases, and in some cases, complete failure may occur. Such instances are usually linked to the inconsistent operation of cooling system control mechanisms in relation to engine load and ambient temperature. Additionally, the discharge pressure of water pumps decreases, which is attributed to wear in the pump's internal components. This includes increased radial clearances between the housing and the impeller, wear or deformation of bearings due to friction, as well as cavitation erosion of the impellers. Furthermore, heat transfer in heat exchange units, particularly on the inner surfaces of radiator pipes, significantly decreases due to the formation of a mineral deposit layer. Ultimately, the cooling surfaces, namely the plates and pipes, become clogged, restricting the unimpeded flow of air through the radiator sections. This substantially reduces the effective transfer of heat from the cooler to the external environment [2].

Based on the analysis presented above, it can be concluded that any technological malfunctions occurring in the water-cooling system directly affect the engine's operation, leading to a decrease in its performance indicators, loss of stability in operating modes, and in severe cases, complete breakdown. Practical observations demonstrate that there is a direct functional relationship between thermohydraulic changes in the cooling system and the engine's operational efficiency. The logical and technical description of this relationship is illustrated in Figure 1.



**FIGURE 1.** Effect of cooling system malfunctions on diesel engine performance

The diesel locomotive's cooling system consists of hot and cold circuits. The hot circuit ensures the heat exchange process in the diesel engine components, while the cold circuit facilitates heat exchange in the air cooler and water-oil heat exchanger. The TE10M locomotive's cooling system lacks a water filter, which leads to the accumulation of salt deposits and rust particles in very small water channels of the cylinder head, between the cylinder liner and jacket, and in radiator sections. This accumulation decreases heat exchange efficiency, resulting in several serious technical issues. Notably, cracks appear in the engine's cylinder head and cylinder liners (Figure 2). This significantly reduces the engine's operational efficiency. Furthermore, high temperatures decrease oil viscosity, increasing dry friction between the engine's moving parts. This increased friction leads to component wear and a drastic reduction in their service life [3, 4].

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**FIGURE 2.** Malfunctions caused by contamination of the cooling system: a) scale accumulation in radiator water pipelines; b) rupture of the cylinder cover; c) breakage of the cylinder bushing

One of the main causes of malfunctions in the water-cooling system is the high hardness of water. The quality of cooling water is constantly monitored by depots or industrial laboratories. If the amount of chlorides in the water exceeds 50 mg/l, and the hardness level exceeds 0.3 mg-eq/l, it is removed from the system and replaced with fresh clean water.

For analysis, water samples were taken from locomotive depots located in various regions of the republic. The conducted analyses (Table 1) showed that the hardness of groundwater in the territories of the republic is high and varies by region [5].

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| --- | --- |
| **TABLE 1.** Groundwater hardness in all regions of the republic | |
| Areas of groundwater sampling | Total hardness, mg-eq/l |
| Bukhara | 11.2-23.5 |
| Navoi | 11.5-35.7 |
| Surkhandarya | 15.3-21.0 |
| Khorezm | 12.0-20.0 |

Water for cooling diesel engines of locomotives operating in the republic is prepared in the locomotive depot or laboratory according to the technology specified in the water preparation instructions. Requirements for the physicochemical properties of water (Table 2) vary depending on the diesel unit used [6].

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| --- | --- | --- |
| **TABLE 2.** Requirements for the physicochemical properties of water | | |
| Indicators | Diesel engines | |
| Cast iron | Cast iron |
| Total hardness, not more than mg-eq/l | 0.2 | 0.2 |
| Chloride content (chlorine), not more than mg/l | 30 | 30 |
| Alkalinity:  for phenolphthalein  for pH | 1.5-2.5  10.8-11.2 | unauthorized  7-8 |
| Phosphate anhydride content, P2O5, mg/l | 15-25 | 15-25 |
| Chromate anhydride content, CrO3, mg/l | unauthorized | 800-1000 |
| Sodium nitrite content, NaNO2, mg/l | 2500-3000 | unauthorized |

# Results and Discussion

Currently, TEM2, ChME3, UzTE16M, TEP70BS, and TE10M locomotives are being utilized in the operational process in the Republic of Uzbekistan. Since the TE10M locomotive is the main freight hauler in the republic, implementing an effective filtration system to improve the heat exchange process in the diesel engine of this locomotive is considered a pressing issue.

The cooling system is one of the most problematic components in the process of locomotive operation, and its malfunction can lead to significant economic losses. Under the influence of various factors, the heat exchange capacity of the system gradually decreases, which negatively affects the overall efficiency of the locomotive. Although the locomotive repair system is based on a planned schedule, it has been observed that due to malfunctions, locomotives are entering unscheduled repairs 15% earlier than the established timeframe.

Modern methods for monitoring the condition of the cooling system are divided into two categories: the first only allows determining the emergency condition of the locomotive; the second requires temporarily taking the locomotive out of service, and such control methods are costly and labor-intensive. As a result, the task of preventing unscheduled repairs of locomotives due to malfunctions in their cooling systems is relevant and important, as this is one of the ways to reduce operating costs.

Based on research on the technical condition of locomotives, it was revealed that approximately 19% of all repairs at JSC "Uzbekistan Railways" in 2022 were related to cooling system failures, as shown in Figure 3. This indicator continues to increase according to the fault registration system.

**FIGURE 3.** Statistical data on cases of unscheduled locomotive repairs due to malfunctions in the cooling system and cooling equipment for the period from 2019 to 2024

The majority of malfunctions occur due to the accumulation of sedimentary salt particles in the water-air radiator, between the cylinder and cylinder jacket, and in the water channels of the cylinder head, which accounts for 97% of all unscheduled repairs of the cooling system. Thus, the proportion of unscheduled repairs continues to grow due to the failure of cooling system components.

Contamination of the internal cavities of radiator sections reduces the flow of coolant, which leads to an extended operation time of the fan unit. Under such conditions, the disruption of the heat exchange process increases the fuel consumption of the locomotive.

Studies show that before scheduled maintenance, contamination of the cooling system can reach 80%, which increases the energy consumption of the fan unit by 50%. A sharp decrease in heat exchange increases the likelihood of the locomotive's cooling system losing its ability to operate normally and even requiring unscheduled repairs.

At the turnaround section of the locomotive depot of the Navoi Mining and Metallurgical Combine, the relationship between the rate of decrease in relative heat dissipation capacity of the cooling units of TE10M locomotives №2223, operating under operational conditions from 2023 to 2024, was determined. As a result, a regression equation was obtained [7].

(1)

where - diesel locomotive operating time, days; - rate of decrease in heat dissipation capacity, days-1; - the average value of the relative heat dissipation capacity at the initial state after reduction at .

The results of assessing the heat dissipation capacity of the cooling unit of TE10M locomotive № 2223 are presented in fig. 2.

The values of the coefficients were determined using the least squares method. The results are presented in Table 3.

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| --- | --- | --- | --- | --- | --- |
| **TABLE 3.** Coefficients of the analytical expression for determining the heat dissipation capacity of a refrigeration unit | | | | | |
| Parameter name | Designation | Parameter values | | | |
| Locomotive |  | TE10M № 2223 A, B | | | |
| Cooling period |  | hot circuit | | cold circuit | |
| A | B | A | B |
| Rate of decrease in thermal conductivity, days-1 |  | 0.00084 | 0.00138 | 0.00023 | 0.00218 |
| Initial state value |  | 0.88 | 0.71 | 0.55 | 0.54 |

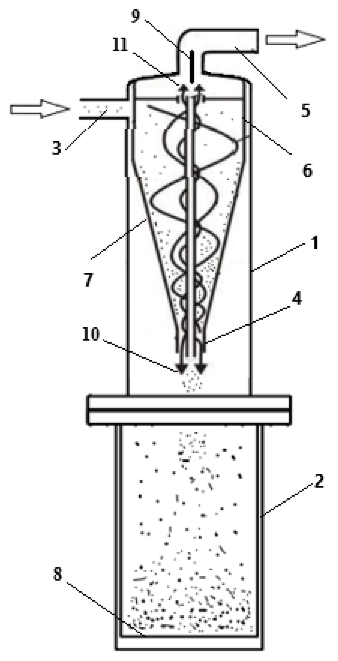
The curves reflecting the decrease in the relative heat dissipation capacity of the locomotive's cooling system after overhaul are shown in Figure 4.

**FIGURE 4.** Decrease in the relative heat dissipation capacity of the locomotive cooling unit during various periods of operation: HC - results for the hot circuit; CC - results for the cold circuit; CR - capital repair

It was established that the restoration work carried out according to the existing methods in the depots does not guarantee the full restoration of the heat dissipation capacity of the refrigeration unit, and does not even ensure the restoration of this parameter within the lower permissible limit ( 0,85).

Furthermore, heat exchange deteriorates due to the accumulation of various solid particles - rust, sand, salt, and metal residues - in the cooling channels of the diesel engine. To prevent these issues and ensure the normal operation of the system, it is crucial to implement an effective filtration system.

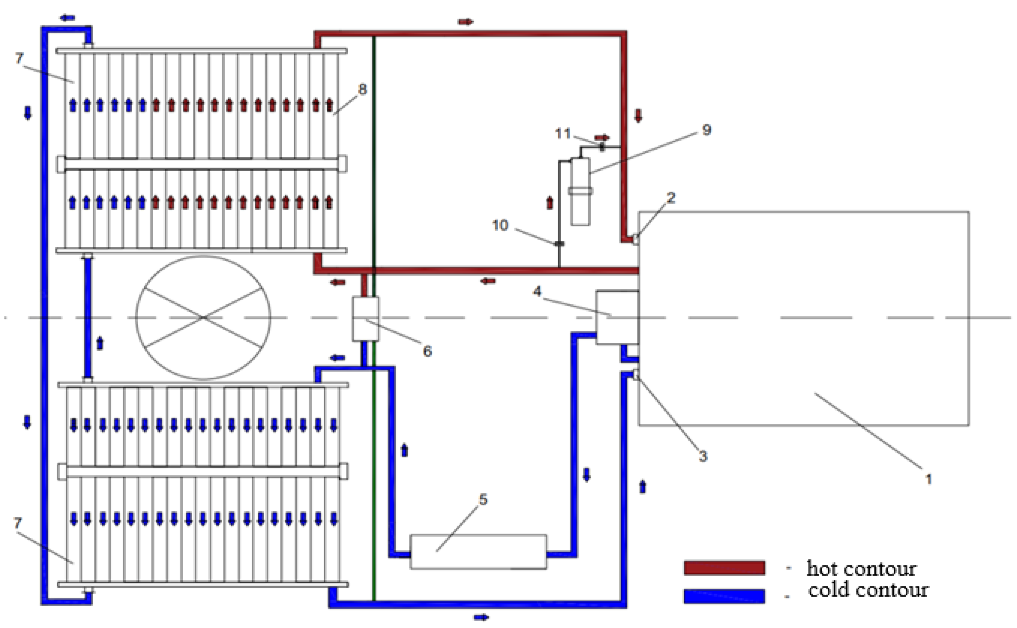
By implementing a three-stage filter and maintaining clean cooling water in the locomotive, it is possible to increase the energy efficiency of the diesel engine and achieve optimal heat exchange (Fig. 5). Once installed on the locomotive, this filter operates continuously and only requires cleaning or replacement of damaged elements during scheduled maintenance. As a result, using a filter in the cooling system of a locomotive diesel engine serves to reduce maintenance costs, optimize fuel consumption, improve heat exchange, and increase operational efficiency.



**FIGURE 5.** Schematic diagram of the main elements of the water filter and the liquid flow movement principle: 1-filter housing; 2-sediment chamber housing; 3-supply pipe, 4-sludge outlet pipe; 5-purified water outlet pipe, 6-cylindrical part of the hydro cyclone, 7-conical part of the hydro cyclone, 8-fabric bag; 9-magnetic rod; 10-downward flow, 11-upward flow

The filtering elements of the proposed three-stage water filter consist of three parts: a magnetic rod, a hydro cyclone, and a special fabric element. On the non-electrified railways of our republic, the main load-bearing locomotive is the TE10M. Implementing a water filter in the cooling system of this locomotive reduces the number of unscheduled repairs.

The proposed cooling system for the TE10M locomotive engine is shown in Figure 6 and consists of two circuits: hot and cold. The circulation of cooling water in the hot circuit is provided by a centrifugal pump, which feeds water to the air intake manifold, cylinder liner, cylinder head, exhaust manifold, and turbocharger. Hot water is cooled in the radiator sections located on the left side of the cooling chamber and enters the suction part of the water pump. The water tank is designed to prevent water pressure increase in the water supply system and to replenish water lost through leaks at pipe joints and evaporation [8].



**FIGURE 6.** Proposed cooling system for the TE10M locomotive: 1 - diesel engine; 2,3 - water pump; 4 - air cooler; 5 - heat exchanger; 6 - water tank; 7,8 - radiator sections; 9 - proposed three-stage water filter; 10,11 – valve

The circulation of cooling water in the cold circuit is also provided by a centrifugal pump, which feeds water to air coolers and a heat exchanger through a pipe connected behind the diesel engine to cool the diesel oil. Hot water is cooled in the radiator sections located on the right and partially on the left side of the cooling radiators and then enters the suction part of the water pump.

The inlet pipe of the proposed three-stage water filter in the cooling system of the TE10M locomotive is installed in the hot water circuit after the diesel engine, before the hot water enters the radiator. The outlet pipe is designed to be installed in the hot water circuit after the cooled water exits the radiator and before the diesel engine. The valves and filtration device allow for servicing without draining water from the system (figure 7).



**FIGURE 7.** Three-stage water filter installed on a TE10M locomotive

The introduction of a three-stage water filter into the locomotive engine cooling system enables effective retention of solid salt particles, corroded metal residues, and other contaminants in the cooling system. As a result, heat exchange is improved, premature failure of engine components is prevented, and the likelihood of unscheduled repairs is significantly reduced. This approach serves to increase the reliability of locomotive operation.

By implementing a filter in the cooling system of the TE10M locomotive, restoration work carried out according to existing depot methods ensured the heat dissipation capacity of the cooling unit at a value of 0.91. Consequently, the heat exchange capacity was optimized, and costs associated with reduced fuel consumption were calculated.

**FIGURE 8.** Fuel consumption of the fan drive over time: 1-Fuel consumption of the cooling system without a three-stage filter; 2-Fuel consumption of the proposed system

Calculations for determining excess fuel consumption (the difference between curves 1 and 2 in figure 8) show that the additional diesel fuel consumption due to radiator contamination and reduced heat dissipation efficiency during 1 year of operation of TE10M series locomotives amounts to 20 tons.

# Conclusions

The research results indicate that the introduction of a three-stage water filter into the cooling system of the TE10M locomotive improves heat exchange by effectively capturing solid particles and corrosion products in the cooling system, reduces premature contamination of radiator sections, decreases fan load, and consequently optimizes fuel consumption. Additionally, by ensuring uninterrupted operation of the locomotive's cooling system, it prevents unscheduled repairs and significantly reduces operating costs through minimizing malfunctions in the engine cooling system. Overall, the use of a three-stage water filter serves to increase the operational reliability of the TE10M locomotive and ensure its efficiency throughout its service life.

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