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Improving The Efficiency Of Air Filters In Dusty Environments

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ABSTRACT

This scientific article examines the issue of improving the efficiency of air filters in vehicles operating under dusty climate and road conditions. The impact of dust and fine particles in the intake air on engine power, fuel consumption, and maintenance intervals was analyzed. Practical recommendations for optimizing air filter design were developed based on the local dust composition, particle size, and density. The effects of filter element material, layer thickness, and filtration surface geometry on efficiency were investigated through experimental results.

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INTRODUCTION

The stable and efficient operation of automobile engines primarily depends on the quality and quantity of clean air supplied to them. For an internal combustion engine to perform normal combustion, the chemical composition of the air, particle concentration, and airflow rate are of critical importance. Under operating conditions, especially in areas with high dust levels, the quality of the air entering the engine significantly decreases. This directly affects the engine's overall lifespan, power output, fuel consumption, and maintenance intervals. A large part of Uzbekistan is located in arid climate zones, where fine dust particles sharply increase in the air during high-temperature seasons[1]. This situation is particularly hazardous for vehicles operating in agricultural lands, construction areas, open quarries, deserts, and semi-desert regions. According to statistical data, 70–75% of dust particles are within the 10–60 micron range, which cannot be fully captured by standard air filters. As a result, engine components such as piston rings, cylinder walls, valves, and other parts of the valve timing mechanism wear out more rapidly. The direct or partial entry of dusty air into the engine disrupts the combustion process, i.e., it alters the optimal air-fuel mixture ratio[2]. This leads to reduced engine power, increased fuel consumption, higher emissions of harmful gases, and disturbance of the engine's thermal regime. In addition, the accumulation of dust causes the air filter to clog quickly, which reduces the amount of air the engine can intake.

Figure 1. Installation of the air filter in the engine

Therefore, improving the efficiency of automobile air filters in dusty regions is currently one of the most pressing issues. Experience from the global automotive industry shows that modernizing filter materials and designs, using additional pre-separation devices, and implementing two-stage filtration systems significantly extend engine service life. The main objective of this study is to develop constructive and technological recommendations for enhancing the efficiency of air filters in vehicles operating under dusty climate conditions, to scientifically analyze the filtration performance of different filter types, and to propose optimal solutions based on experimental results[3].

LITERATURE REVIEW

The analysis of literature related to improving the efficiency of automobile air filters in dusty regions indicates that existing sources address the topic from various perspectives. Bosch's *Automotive Handbook* (10th Edition, 2020) provides a detailed explanation of the types of air filters, their operating principles, efficiency characteristics, and suitability under different operating conditions. While this manual is useful for technical guidance, it does not sufficiently address the conditions and challenges specific to local dusty regions. Heywood's *Internal Combustion Engine Fundamentals* explains, from a theoretical perspective, the sensitivity of engines to airborne particles, the air-fuel mixture, and the efficiency of the combustion process[4]. This book serves as a valuable scientific resource for analyzing the effect of filters on engine performance; however, it lacks practical recommendations regarding filter materials and construction. In the context of Uzbekistan, Miftahov's *Vehicle Operation and Maintenance* (2018) provides statistical data on dusty roads, maintenance intervals, and filter wear rates. This source considers local climate conditions and addresses vehicle operation issues, but it offers limited scientific recommendations for modernizing filter materials and design. Overall, the literature analysis shows that while the topic is well-covered theoretically and international experience exists, the influence of local conditions, dust composition, and particle characteristics on the filtration efficiency of engine intake air has not been sufficiently studied. Therefore, this study incorporates experimental research aimed at optimizing filters and improving their efficiency under local climate and road conditions, highlighting its scientific novelty and practical significance[5].

RESEARCH METHODOLOGY

The aim of this study is to identify constructive and technological solutions for improving the efficiency of automobile air filters in dusty regions and to develop practical recommendations. The research methodology incorporates a scientifically grounded approach and experimental methods. The object of the study comprises vehicles operating in dusty environments and their air filtration systems. The subject of the study includes the filter's design, material, layer thickness, surface area, aerodynamic characteristics, and their influence on engine performance.

Figure 2. Vehicle movement in a dusty environment

Several methods were employed in this study. Firstly, a theoretical analysis was conducted to examine the types of air filters, their operating principles, and efficiency characteristics. In parallel, scientific literature and international standards were reviewed. Subsequently, an experimental approach was applied, testing various types of filters (dry, oiled, and two-stage) under laboratory conditions simulating local dust composition[6]. The effects of filter clogging and service life were observed. In addition, mathematical modeling and calculation methods were utilized. The relationship between filter surface area, airflow rate, and particle density was analyzed using mathematical formulas, and computer simulation tools (MATLAB, SolidWorks Flow Simulation) were employed to optimize aerodynamic properties and improve filter efficiency. A comparative analysis was also performed during the study. Differences in filtration efficiency and service life among different filter types and designs were identified, and the experimental results were compared with international data presented in the literature. The main stages of the study included: theoretical preparation and literature review; conducting laboratory experiments; mathematical and computer modeling; and analyzing results and developing recommendations for filter optimization. The research instruments and equipment used comprised a laboratory airflow stand, particle sensors, filter measurement and analysis tools, and software such as MATLAB and SolidWorks Flow Simulation. Evaluation criteria included filter efficiency, service life, engine power, fuel consumption, and the economic effectiveness of filter design. This methodology ensures a comprehensive theoretical, experimental, and practical study, providing the basis for optimizing air filtration systems in vehicles operating in dusty environments[7].

ANALYSIS AND RESULTS

Experimental research and mathematical modeling results indicate significant differences in efficiency and service life among various types of filters used in vehicles operating in dusty regions. Three types of filters were tested: a standard dry filter, an oiled filter, and an upgraded two-stage filter. **Filtration Efficiency.** The experimental results show that the standard dry filter captures 93% of dust particles in the air. The oiled filter achieves 97% efficiency, while the two-stage filter captures up to 99% of particles. These efficiency levels are directly related to the filter's material, layer thickness, and surface area. High efficiency can also increase airflow resistance through the filter; however, the two-stage filter design minimizes this issue. **Service Life and Clogging Time.** The standard dry filter becomes clogged after approximately 2,000 km, leading to reduced efficiency. The oiled filter remains effective up to 3,500 km, while the two-stage filter maintains its efficiency for 5,000–6,000 km. These data allow for practical recommendations to optimize filter design and extend service life. When filtration efficiency is low, the amount of dust entering the engine increases, resulting in a 10–15% decrease in engine power, an 8–12% increase in fuel consumption, and accelerated wear of internal components. Experimental results show that using a two-stage filter maintains optimal engine power and fuel consumption. Coating the filter material with microfibrous polyester or nanomembrane improves efficiency and captures fine particles in the 0.3–1 micron range. Expanding the filter layer surface increases service life by 25–30%. Experimental and mathematical modeling results indicate that, in dusty environments, the optimal solution is a two-stage filter design with a pre-filter, providing high efficiency, long service life, and minimal engine damage. Furthermore, aerodynamic optimization and airflow monitoring can further enhance filter performance.

CONCLUSION AND RECOMMENDATIONS

The results of the study indicate that improving the efficiency of air filters in vehicles operating in dusty regions significantly enhances engine power, fuel consumption, and service life. Experimental and mathematical modeling results revealed differences in efficiency and service life among various types of filters. While standard dry filters capture up to 93% of dust, their service life is relatively short, leading to an increased amount of particles entering the engine. Oiled filters achieve 97% efficiency with a longer service life. The most optimal performance was observed in the upgraded two-stage filter, which achieves 99% efficiency and maintains effectiveness over a distance of 5,000–6,000 km. Filter material, layer thickness, surface area, and aerodynamic design directly influence filtration efficiency.

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