**Development of an Efficient Method for the Regeneration of Used Coolants Based on Multistage Filtration**

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**Abstract.** The article presents an improved method for the regeneration of spent antifreeze based on multistage filtration using filtering elements and a layer of basalt fibers. The design of the experimental laboratory setup is described, and the results of comparative microscopic and physicochemical studies of antifreeze before and after purification are provided. It has been established that the proposed technology ensures the effective removal of mechanical impurities and makes it possible to obtain a purified product with performance characteristics that meet the requirements for fresh antifreeze. Special attention is paid to the analysis of filtration time at various stages of the purification process. In conclusion, the prospects for further research are outlined, including the deep purification of antifreeze from water and the development of a domestic additive package based on local raw materials. The results obtained can be used to optimize technologies for the disposal and reuse of coolants, as well as to reduce environmental impact and save material resources.

**Keywords:** Antifreeze, low-freezing liquids, boiling point, crystallization temperature, engine, cooling system, anticorrosive properties

**INTRODUCTION**

Coolants are widely used to maintain the optimal temperature of vehicle engines and stationary equipment. The most common types worldwide remain traditional “green” antifreezes, which are based on ethylene glycol and special anticorrosive additives containing silicates and phosphates. This formulation effectively protects the metallic components of cooling systems from corrosion and extends their service life [1, 5].

The primary function of a coolant is to absorb excess heat from the operating unit and transfer it to the radiator for subsequent dissipation. The ideal properties of such compositions include high heat capacity, low viscosity, affordability, and chemical stability, all of which help to prevent corrosion within the system [2]. Thanks to these characteristics, antifreeze plays a key role in the reliable operation of engines.

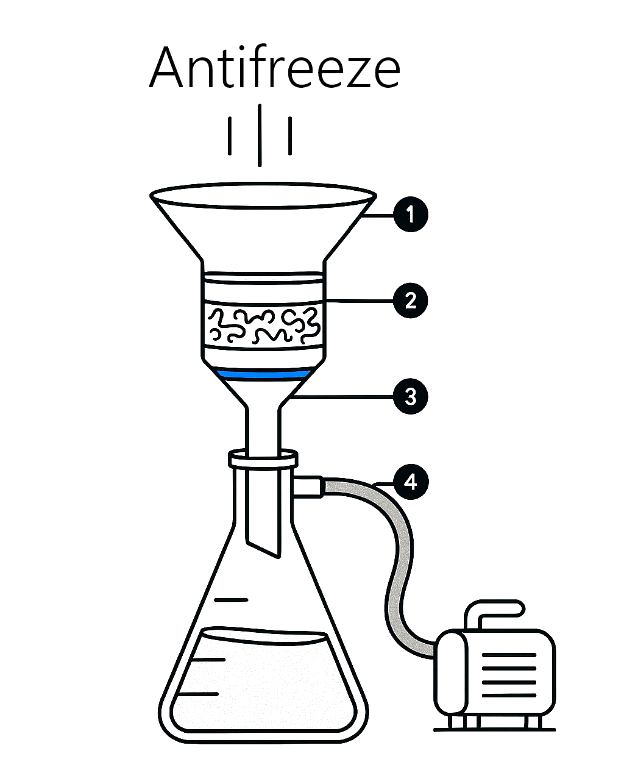
Since the mid-20th century, ethylene glycol has been widely used in antifreeze production worldwide, as it improves reliability during winter operation and reduces production costs. Despite its favorable physicochemical properties, ethylene glycol is highly toxic and poses a risk to both humans and animals, as well as to the environment [3, 4]. According to international studies, ingestion of ethylene glycol can have severe consequences, and improper disposal negatively affects ecosystem health [6, 7].

Issues related to the collection, processing, and regeneration of spent antifreeze are becoming increasingly important from both technical and environmental perspectives. Despite existing legislative restrictions, in many countries-including the USA and European nations—spent antifreeze is often discharged into sewage systems or soil, leading to serious environmental and financial consequences [5, 6, 8, 9, 10]. Ethylene glycol and other components of antifreeze are highly toxic to aquatic organisms and humans [11, 12], which necessitates the development and implementation of effective methods for the purification and reuse of such wastes. International scientific and industrial communities are actively working on the creation of less toxic, biodegradable, and regenerable antifreeze formulations, as well as on improving technologies for the processing and reuse of spent antifreeze, which can significantly reduce environmental impact and mitigate the risks of contamination of natural water bodies [7, 8, 13,14].

**TEXT FORMATTING**

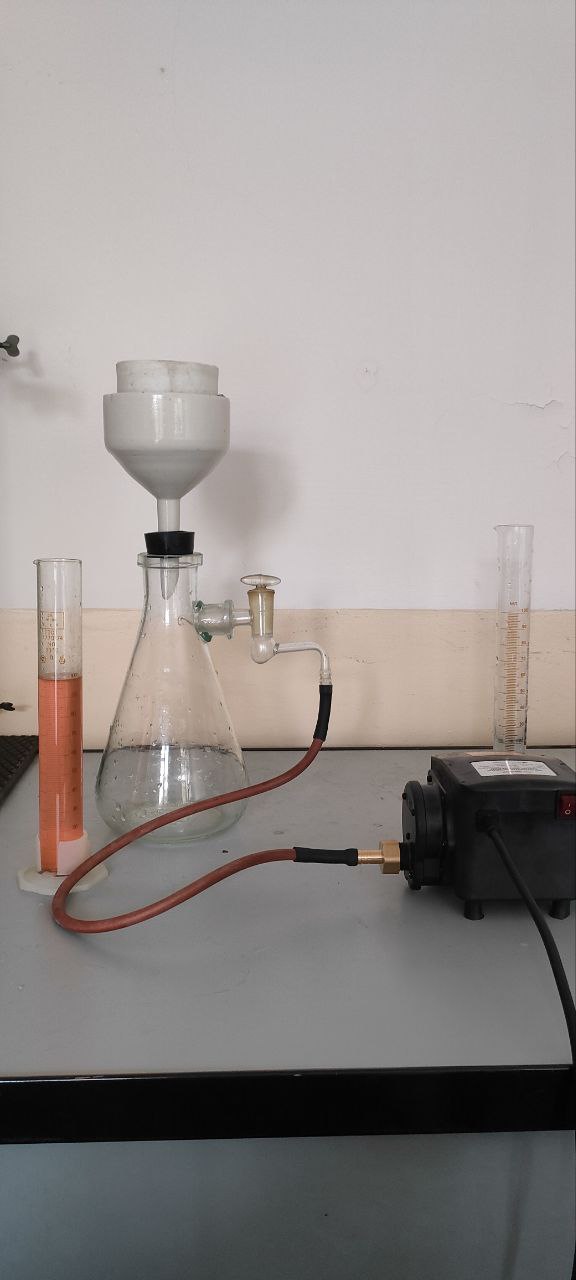
Previously, we proposed our own method for the regeneration of antifreeze, which made it possible to efficiently purify spent coolant fluids for reuse [15]. However, during the operation of this method, certain shortcomings were identified, the main one being the considerable filtration time associated with the use of the employed filter elements [16, 17]. In the present work, we improved the filtration process and developed a new type of filter element, which significantly increased the efficiency and reduced the duration of antifreeze regeneration.

The regeneration process begins by placing the spent antifreeze into a Buchner funnel equipped with a three-stage filtration system. In the first stage, the liquid passes through an upper filtering element-a filter paper with a black marking strip-which serves for the preliminary mechanical removal of large contaminants and particles. The antifreeze then enters the second layer, consisting of basalt fibers that effectively capture smaller impurities and also facilitate the sorption of organic compounds and decomposition products. In the third stage, the liquid passes through a lower filter with a blue marking strip, which ensures fine purification and the removal of the smallest suspended particles. To accelerate the entire filtration process and increase the purification efficiency, a vacuum pump is used to create a vacuum, enabling the antifreeze to pass more quickly through all filter layers. As a result, the implemented scheme provides a high degree of antifreeze purification, making its reuse possible and minimizing negative environmental impact.



**FIGURE 1.** Filtration and regeneration scheme of antifreeze  
1 — filter paper with a black stripe (preliminary purification); 2 — layer of basalt fibers (removal of fine impurities);   
3 — filter paper with a blue stripe (final purification); 4 — vacuum pump (filtration process acceleration)

For a clear demonstration of the proposed method, a laboratory setup was assembled to implement the antifreeze regeneration process according to the developed scheme. The figure shows a photograph of the experimental equipment used during the filtration tests.



**FIGURE 2.** Laboratory setup for antifreeze regeneration

To objectively assess the efficiency of the proposed regeneration method, a comparative analysis of the mechanical impurities in antifreeze before and after filtration was carried out. The comparison was performed using a microscope, which made it possible to visualize and quantitatively evaluate the residual contaminants. The figures below present micrographs of antifreeze samples before purification and after passing through the filtration system.

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**FIGURE 3.** Microstructure of spent antifreeze before filtration

The microscopic image clearly shows both large and small mechanical impurities, as well as bubbles and suspended particles characteristic of spent coolant fluid.

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**FIGURE 4.** Microstructure of antifreeze after filtration through filter paper with a black stripe

The micrographs show a significant reduction in the number of mechanical impurities compared to the original sample; however, some small particles and minor contaminants are still present in the coolant.

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**FIGURE 5.** Microstructure of antifreeze after filtration through filter paper with a blue stripe

After passing through the filter with a blue stripe, the number of mechanical impurities in the antifreeze is minimized. The micrographs show almost no foreign particles, which indicates the high efficiency of this final purification stage.

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**FIGURE 6.** Microstructure of antifreeze after complete purification (filter paper with black and blue stripes, basalt fibers)

The micrographs of the purified antifreeze show virtually no mechanical impurities or foreign inclusions, which demonstrates the high efficiency of the comprehensive filtration system.

During the experimental studies, the filtration time of 100 ml of antifreeze using different purification methods was compared. Filtration through filter paper with a black stripe took 1 minute 26 seconds, while filtration through the filter with a blue stripe took 2 minutes 33 seconds. Comprehensive purification, which involved sequential passage through filter paper with black and blue stripes and a layer of basalt fibers, required only 1 minute 51 seconds. The reduction in filtration time compared to the use of the blue stripe filter alone is explained by the preliminary removal of large and medium particles in the upper layers (black stripe and basalt fibers), which reduces the load on the final filter, promotes a more uniform flow distribution, and prevents rapid clogging. Thus, the comprehensive system not only provides a higher degree of purification but also optimizes the filtration process in terms of time.

**TABLE 1.** Comparative physicochemical characteristics of spent and regenerated antifreeze

| **№** | **Parameter** | **Test Method** | **Antifreeze before regeneration** | **Antifreeze after regeneration** |
| --- | --- | --- | --- | --- |
| 1 | Crystallization onset temperature, °C | GOST 28084 p.4.3 | –33 | –33 |
| 2 | pH | GOST 22567.5 | 7.316 | 7.369 |
| 3 | Alkalinity, mg KOH/g | GOST 28084 p.4.9 | 2.58 | 2.5 |
| 4 | Initial distillation temperature, °C | GOST 28084 | 112 | 112 |
| 5 | Mass fraction of liquid distilled up to 150°C, % | GOST 18995.7 | 41.1 | 40.8 |
| 6 | Density at 20°C, kg/m³ | GOST 18995.1 | 1067 | 1068 |

Based on the analysis results, the following conclusions can be drawn:

1. The crystallization onset temperature remained unchanged (–33 °C), indicating that the frost resistance properties of the antifreeze were preserved after regeneration.
2. The pH value changed insignificantly (from 7.316 to 7.369), with both values corresponding to a neutral environment, suggesting that there were no significant changes in the acid-base balance.
3. Alkalinity decreased from 2.58 to 2.5 mg KOH/g—a minor reduction, but still within acceptable limits, which should not affect the anticorrosive properties.
4. The initial distillation temperature remained constant (112 °C), indicating the retention of the volatility and stability of the antifreeze components.
5. The mass fraction of liquid distilled up to 150 °C changed from 41.1% to 40.8%; this difference is minimal and may be attributed to experimental error.
6. The density at 20 °C changed very little (from 1067 to 1068 kg/m³), indicating that the concentration and homogeneity of the composition were preserved.

Overall, the results of laboratory tests show that after regeneration, the physicochemical properties of the antifreeze practically do not change and meet regulatory requirements. This confirms the effectiveness of the proposed purification method, which enables repeated use of the coolant without deterioration of its performance characteristics.

As a prospect for further research, it is planned to develop and implement methods for the deep purification of antifreeze from water in order to obtain pure ethylene glycol, as well as to create a proprietary additive package based on available local raw materials. The implementation of these directions will not only increase the level of recycling and resource saving but also expand the possibilities for producing import-independent components for coolants. These tasks will be the focus of subsequent stages of scientific work.

**CONCLUSION**

In the course of this work, an improved method for the regeneration of spent antifreeze was developed and experimentally implemented. This method is based on multistage filtration using filter elements and a layer of basalt fibers. Laboratory tests demonstrated that the proposed technology ensures the effective removal of mechanical impurities and enables the production of purified antifreeze with physicochemical properties comparable to the original product.

A comparative analysis of the parameters before and after regeneration confirms the preservation of the main performance characteristics of antifreeze, including crystallization onset temperature, pH, density, and distillation temperature. Microscopic examination confirms the near-complete removal of solid contaminants after comprehensive filtration.

The implementation of this technology can significantly reduce environmental impact, decrease the generation of hazardous waste, and provide cost savings through the multiple reuse of coolant. The results obtained may be used both to improve existing antifreeze disposal technologies and to develop new purification systems for industrial and service applications.

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