ABSTRACT

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DEVELOPMENT AND STUDY OF A METHOD AND EQUIPMENT FOR ULTRASONIC CLEANING OF VEHICLE RADIATORS

Around the world, the environmental burden from automobiles is steadily increasing, and the proper functioning of all vehicle systems, including the cooling system, plays an important role in reducing this harm. Malfunctions in the cooling system can lead to engine overheating, reduced efficiency, increased emissions of harmful substances, and ultimately, severe engine damage and failure. It is therefore crucial that the cooling system operates efficiently, and that one of its most important components — the radiator tubes — remains in good condition. Currently, mechanical and chemical methods are used for cleaning radiators, each with its own advantages but also significant drawbacks. Chemical cleaning involves the use of reagents that can cause corrosion in the radiator and cooling system components, leading to the formation of microcracks and leaks, which reduces their durability and reliability. Mechanical cleaning, on the other hand, risks damaging the radiator surface — scratches, dents, and chips that weaken the structure and accelerate corrosion. An alternative and promising method is ultrasonic cleaning of radiator tubes, which relies on the cavitation effect in liquids. In the dissertation by K.A. Sinelnikov, the effectiveness of ultrasonic cleaning of radiator tubes was proven. Compared to mechanical and chemical methods, ultrasonic cleaning has clear advantages. It does not damage the radiator or cooling system components, as it avoids both aggressive chemical exposure and physical wear typical of mechanical treatment. Ultrasonics provide gentle yet effective removal of contaminants, making it a safe and promising maintenance method.

Despite the successful results in cleaning, the developed method is difficult to apply in practice, since the question of cleaning efficiency depending on the amplitude of the ultrasonic wave and its direction relative to the deposits on the tubes — whether along or across — as well as the duration of exposure, has not been resolved.

In addition, there is no developed methodology for calculating equipment for cleaning that would be valid for radiators of different sizes and would account for the necessary amplitude of sound wave oscillations and exposure time. Therefore, research aimed at developing a methodology for calculating equipment for cleaning radiator tubes is relevant and necessary.

The hypothesis of the study is that optimizing the placement of emitters and the amplitude of oscillations can increase the efficiency of ultrasonic radiator cleaning.

The aim of the study is to develop a methodology for calculating equipment for ultrasonic cleaning of radiator tubes.

To achieve this goal, **the following tasks have been set**:

- analyze the designs of engine cooling systems, their malfunctions, and methods of eliminating them;
- analyze the physical nature of cavitation processes and methods for calculating the cleaning of radiator tubes using cavitation;
- develop a theoretical model of the process based on the similarity theory, derive similarity criteria, and explain their physical meaning;
- conduct experimental studies with variable ultrasonic amplitude and wave direction (transverse and longitudinal) on radiator tubes;
- analyze the obtained results and compare them with analytical results;
- analyze the regression equation of the washed-out slag mass depending on oscillation amplitude and exposure time;
- develop a calculation methodology and carry out the research.

Research Methods:

The following methods were used in the study: analytical literature review; theory of similarity and dimensional analysis; mathematical analysis; regression analysis.

Scientific novelty of the research lies in the following:

- experimental determination of the dependence of the density of washed-out liquid on oscillation amplitude and exposure time;
- derivation of a regression equation linking the mass of removed scale to oscillation amplitude and exposure time;
- using the theory of similarity and dimensional analysis, a system of similarity criteria was obtained, describing the radiator tube cleaning process — including tube geometry, energy input, mass of removed scale, and oscillation amplitude;
- the developed regression model reveals a strong correlation between wave oscillation amplitude, exposure time, emitter placement, and the mass of washed-out liquid;
- analysis of the obtained equation for extremum showed that the mass function behaves differently: it increases with longer exposure time and decreases with increasing amplitude;
- scaling relative to a reference model provided scale coefficients for geometric, physical, ultrasonic, energetic, and cleaning parameters;
- the coefficient of acoustic energy utilization and erosion efficiency was confirmed and calculated experimentally.

Scientific contributions submitted for defense:

- the theoretical model based on similarity theory accurately describes the process of cleaning radiator tubes, as confirmed by experimental results;

- for specific radiators, there are optimal cleaning solutions defined by the ratio of ultrasonic wave amplitude, exposure time, and emitter position;

- analysis of the physics of ultrasonic cavitation and cleaning of radiator tubes confirmed its effectiveness. The collapse of cavitation bubbles effectively cleans the inner walls of the tubes.

The author defends:

- the proposed method for cleaning radiator tubes using ultrasonic cavitation;
- the obtained similarity criteria;
- the experimental results and the regression equation;
- the developed calculation methodology;
- the derived scaling coefficients.

Object of the study: ultrasonic cavitation.

Subject of the study: cleaning of radiator tubes.

Practical significance lies in the development of a method for cleaning radiators.

The results of the scientific research and developments were implemented at Gradient Project Institute LLP and in the educational process of the Abylkas Saginov Karaganda Technical University for students of the educational program 6B07106 – "Transport, Transport Equipment and Technologies" as part of the discipline "Service and Branded Maintenance of Transport Equipment."

Summary:

Chapter One provides a literature and patent-based analysis of internal combustion engine systems, considers engine cooling methods, and designs of vehicle radiators. An analytical review of ultrasonic cleaning methods is conducted. The state of the problem is analyzed, ending with the formulation of research objectives.

Chapter Two presents the theoretical study of the process of cleaning automobile radiator tubes. The physical essence of cavitation is examined, similarity criteria describing the ultrasonic cleaning process of radiator tubes are established, and conclusions are drawn from the theoretical study.

Chapter Three is devoted to experimental research on ultrasonic cavitation-based cleaning of radiator tubes. The goals and objectives of the experiments are defined by the author, along with the plan and methodology for conducting experiments on test benches. Results of experiments carried out on a modernized ultrasonic cleaning stand and on brand mew stand are analyzed, and the main parameters are calculated.

Chapter Four presents the implementation of the research results. The author proposes a methodology for calculating optimal parameters for ultrasonic cavitation cleaning of radiator tubes, develops scaling coefficients for extrapolating results to various radiators, and evaluates the economic efficiency of this ultrasonic-based maintenance method for cooling system radiators.

The conclusion contains a summary of the main findings of the dissertation research.

Personal contribution of the doctoral candidate:

The work was carried out entirely by the author. The author conducted an analysis of methods for cleaning radiators of internal combustion engine cooling systems in automobiles. He identified the similarity criteria describing the process of cleaning radiator tubes using ultrasound.

The author designed and built an experimental stand for cleaning radiator tubes using transverse ultrasonic exposure to validate analytically obtained results. He obtained and compared analytical and experimental dependencies that describe the ultrasonic cleaning process of automobile radiator tubes.

Publications and approbation of the work:

The main provisions of the dissertation were published in 4 scientific papers, including 2 articles indexed in the Scopus database with a non-zero impact factor, and 2 articles recommended by the Committee for Quality Assurance in the Sphere of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

In the article "Justification of the Method of Vehicle Engine Radiator Ultrasonic Cleaning" published in Communications - Scientific Letters of the University of Zilina (Scopus, Q3, Transport percentile: 29, https://doi.org/10.26552/com.C.2025.015), the author conducted theoretical and experimental studies on ultrasonic cleaning of radiators in internal combustion engine cooling systems. Theoretical dependencies were derived and confirmed experimentally. The results confirm the feasibility of using the ultrasonic cleaning method in vehicle radiators.

In the article "Determination of optimal parameters for ultrasonic cleaning of vehicle radiators", also published in the same journal (https://doi.org/10.26552/com.C.2025.031), the author developed a methodology accounting for the influence of ultrasonic vibration amplitude and exposure time on the contaminant removal process. The experimental results presented by the author confirm that increasing the exposure time leads to greater removal of scale mass and shorter liquid outflow duration.

In the article «Автомобиль радиаторларын тазалау әдістерін талдау» published in the national journal «Труды Университета», the cooling system of automobile engines was reviewed. The author analyzed methods for cleaning vehicle radiators, the use of ultrasonic vibrations for cleaning radiator tubes, and described the experimental stand for ultrasonic cleaning.

In the article "Theoretical and Experimental Analysis of Ultrasonic Cleaning of Internal Combustion Engine Radiators wit the Development of Practical Recommendations", published in Material and mechanical engineering technology, the author identified critical relationships between ultrasonic energy, the kinetic energy of liquid, and shock wave energy. These allow assessment of the energy efficiency of the cavitation process and the effectiveness of ultrasonic cleaning of radiators. The obtained results confirm the applicability of the method.

Structure and volume of the dissertation:

The dissertation consists of an introduction, four chapters, and a conclusion. It is presented on 126 pages of printed text, includes 67 figures, 23 tables, and a list of 147 references.

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Research results and key findings:

1. The hypothesis regarding increased efficiency of ultrasonic radiator tube cleaning through optimization of emitter placement and oscillation amplitude has been confirmed.

2. The necessity of placing emitters transversely to radiator tubes with calculated ultrasonic wave amplitude for radiators of various volumes and designs has been substantiated.

3. The design of radiators, cooling systems, their faults, and cleaning methods have been analyzed.

4. The physical nature of liquid cavitation has been described, parameters influencing the process substantiated, and research results on cavitation energy, cavitation number, and erosive activity presented.

5. A theoretical model of the cavitation process was developed using similarity theory, allowing the definition of dimensionless criteria describing the process.

6. The derived dimensionless criteria allow analysis and calculation of cavitation and ultrasonic parameters for radiators of different sizes and volumes.

7. A full-scale experimental stand was developed, experiments conducted, and regression equations derived relating washed mass to oscillation amplitude, exposure time, and emitter placement.

8. Regression analysis showed that exposure time positively affects cleaning efficiency and that careful selection of amplitude is necessary.

9. Based on the experiment, similarity coefficients were calculated:

- the mass change coefficient reflected mass variation based on time and amplitude;
- the cavitational acoustic energy utilization coefficient determined the degree of conversion of acoustic energy into cavitational effects;
- the efficiency coefficient emphasized the need for parameter tuning;
- transverse ultrasonic action proved more effective and easier to maintain than longitudinal.

10. A methodology for calculating radiator cleaning modes and equipment parameters was developed.

The proposed cleaning method allows for the removal of contaminants without risk of damage or disassembly of structures, making it applicable in vehicle maintenance.