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Method of Ultrasonic Cleaning of Internal Combustion Engine Radiator Tubes by Transverse Exposure

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Abstract. This article is dedicated to the study of the ultrasonic cleaning method for vehicle cooling system radiators using transverse exposure to ultrasonic waves. The conducted experiment confirmed the high efficiency of the method based on water cavitation inside the radiator tubes. During the study, key liquid parameters were measured, including density, mass, outflow velocity, and scale content. The results demonstrated that ultrasonic cleaning with transverse exposure effectively removes scale without damaging the radiator structure, thereby improving heat exchange efficiency. An analysis of the dynamic changes in the mass of the removed scale showed that transverse ultrasonic exposure ensures a more uniform energy distribution across the entire radiator surface, increasing the degree of cleaning compared to the longitudinal method. This approach enhances the operational characteristics of the cooling system, extends its service life, and reduces maintenance costs, while also providing an additional environmental benefit by eliminating the need for aggressive chemical reagents.

Keywords: Transport machinery, radiator, cavitation, ultrasound, dispersing, ultrasonic generator, emitter.

Introduction

Contamination of the radiator and cooling system of an internal combustion engine (ICE) significantly affects the performance, durability, environmental impact, and cost-efficiency of vehicle operation. The radiator and cooling system play a crucial role in maintaining the engine's optimal temperature. When these components become contaminated, heat exchange efficiency decreases substantially, leading to engine overheating, accelerated wear of its components, and a reduced service life [1-2].

Engine overheating is one of the most common and dangerous issues caused by cooling system contamination. The primary problem of contamination is the formation of corrosion and scale inside the radiator tubes, thermostat, water pump, and engine channels. These deposits not only obstruct the free flow of coolant but can also damage system components, causing leaks or complete cooling system failure. As a result, the temperature in the combustion chambers rises, negatively affecting all engine processes [3]. The oil used for lubricating moving parts begins to degrade faster, losing its protective properties. This, in turn, increases friction between components, accelerates their wear, and may lead to severe damage, such as cylinder deformation or piston failure [4]. In cases of significant contamination, the engine may overheat to the point where thermal destruction of critical components, including the cylinder head, occurs, necessitating costly repairs or complete engine replacement.

Additionally, overheating leads to increased fuel consumption. When an engine operates under unfavorable temperature conditions, the combustion efficiency of the fuel mixture decreases. Consequently, more unburned hydrocarbons are released into the atmosphere. These substances, along with carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxides (NO_x), significantly contribute to environmental pollution. A vehicle with a contaminated cooling system becomes a major source of harmful emissions, negatively impacting the environment and reducing air quality in urban areas [5-8].

The economic losses associated with radiator and cooling system contamination cannot be ignored. Increased fuel consumption, frequent overheating, and the need for more frequent repairs or component replacements lead to significant operational costs. Furthermore, coolant leaks, which often contain toxic chemicals, can contaminate soil and water bodies, creating additional environmental risks [9-10].

From a reliability and safety perspective, cooling system contamination increases the likelihood of sudden failures while driving. This can lead to hazardous situations, especially if engine overheating occurs in heavy traffic or far from service centers.

To prevent these issues, regular diagnostics, maintenance, and repairs of the cooling system are recommended, as they play a key role in extending engine life and reducing environmental impact. Flushing the radiator, using high-quality coolants, and following maintenance schedules help keep the system in optimal condition [11].

Regular maintenance not only protects the engine from overheating and extends its lifespan but also helps save fuel, reduce harmful emissions, and lower operational costs. Thus, maintaining the cleanliness of the radiator and cooling system not only prolongs the vehicle’s lifespan but also improves environmental conditions, making transportation safer and more cost-effective.

In modern conditions, two main methods are used to clean radiator tubes—mechanical and chemical. The mechanical method involves inserting a probe into the radiator tubes to remove contaminants. However, this method can damage the radiator, leaving scratches and chips on its surface, which weaken the structure and promote future corrosion. Chemical cleaning, on the other hand, involves using alkalis for copper radiators and acids for aluminum ones. Despite the high efficiency of this method, it also carries certain risks. Chemical agents can cause corrosion of other materials in the radiator structure and lead to the formation of microcracks and leaks, negatively impacting the device's durability [12].

Modern engineering technologies are focused on developing safer and more effective cleaning methods, including those for diagnostics, geographic studies, and gas and liquid purification. One promising technology is ultrasonic cleaning, which is already widely used in various industries, including exhaust gas purification [13-15]. Ultrasonic waves can break down contaminant particles, significantly reducing harmful emissions into the atmosphere and improving overall environmental conditions [16-21]. The advantages of the ultrasonic method include its high efficiency and safety, as it does not cause material damage and does not require aggressive chemicals [22-23].

Given the increasing environmental and safety requirements in the automotive industry, we propose a new method for cleaning radiator scale using ultrasonic exposure to the water inside the radiator tubes. This method offers significant advantages over traditional mechanical and chemical cleaning methods. It eliminates the risk of radiator structure damage and minimizes the need for chemical reagents, making it safer and more environmentally friendly.

The goal of our experiment was to confirm the effectiveness of the transverse ultrasonic wave exposure method for radiator cleaning and to demonstrate its practical value.

The scientific novelty of this study lies in the development of dependencies that determine the effectiveness of radiator cleaning using transverse ultrasonic exposure.

1. Materials and methods

The ultrasonic radiator cleaning method is based on the phenomenon of water cavitation inside the radiator tubes under the influence of ultrasonic waves. Cavitation is the process of forming and subsequently collapsing microscopic gas bubbles in a liquid, releasing a significant amount of energy. This leads to a localized increase in temperature and pressure, which has a destructive effect on deposits such as scale and other contaminants. This process effectively cleans the internal surface of radiator tubes without the need for mechanical or chemical agents, eliminating the risk of material damage and preserving the structural integrity of the radiator. Thus, ultrasonic cleaning is an innovative and promising technology that ensures high cleaning efficiency while maintaining environmental safety [24-25].

Preliminary research included experimental studies that confirmed the feasibility of using ultrasound for cleaning vehicle radiators. The results demonstrated the high efficiency of the ultrasonic radiator cleaning method [26]. Special attention in the experiment was given to the direction of ultrasonic waves relative to the radiator tubes. Longitudinal ultrasonic wave exposure was examined, where the wave propagates along the axis of the tubes, minimizing energy losses at medium boundaries. In the preliminary experiment, a low-viscosity liquid was used. The choice of this liquid was based on theoretical and practical considerations: low viscosity promotes more intense cavitation bubble formation under ultrasound exposure, enhancing the destruction of deposits [27-28]. The research results showed that ultrasonic cavitation significantly increases cleaning efficiency without negatively affecting the radiator structure, ensuring high process safety.

The authors also considered transverse ultrasonic wave exposure, where waves must pass through the tube walls twice, causing significant energy attenuation and reducing overall cleaning efficiency. However, in this case, the ultrasonic emitter was installed in a fixed position without movement across the radiator surface [29-30].

Transverse ultrasonic wave exposure for radiator cleaning was conducted with the emitter moving across the radiator surface. The experimental study on cleaning the cooling system radiator was performed on an Opel Vectra B 1.6-liter engine cooling radiator, as shown in Figures 1 and 2.

Fig. 1 – Opel Vectra B car

Fig. 2 – Opel Vectra B radiator

The setup for heating, supplying, and filtering the liquid was manufactured based on preliminary studies and is shown in Figure 3.

Fig. 3 – Assembled setup for radiator cleaning

Ultrasonic exposure was applied transversely with the movement of the ultrasonic emitter across the entire surface of the radiator, as shown in Figures 4 and 5.

Fig. 4 – Installation of the ultrasonic emitter on the radiator

Fig. 5 – Ultrasonic impact on the radiator

During the experiment, key liquid characteristics were measured, including its density, volume, and mass, to assess the influence of these parameters on the efficiency of ultrasonic radiator cleaning. High-precision equipment was used for the measurements, ensuring maximum accuracy and reliability of the obtained data.

To determine the liquid mass, MH-500 electronic precision scales with a measurement accuracy of up to 0.01 grams were used. The liquid volume was measured using two types of measuring containers: a 100 ml graduated cylinder for precise measurements of small volumes and a 1000 ml measuring jug for handling larger quantities of liquid [31]. This approach allowed for flexibility in adapting to different experimental requirements and ensured the necessary data accuracy.

2. Experiment

In the experiment, distilled water was used as the flushing liquid due to its lowest dynamic viscosity. The water was heated to a temperature of 60°C. The selected liquid parameters provided optimal conditions for the rapid and effective manifestation of cavitation processes and scale dispersion in the radiator.

The experimental study was conducted as follows: distilled water was poured into the assembled setup and heated to a specified temperature, followed by the determination of mass, volume, density, and outflow velocity of the water through the radiator, as shown in Figures 6–8.

Fig. 6 – Determination of liquid temperature

Fig. 7 – Determination of liquid volume

Fig. 8 – Determination of liquid mass

In the first stage, the ultrasonic generator was activated for 60 seconds at each point, and the ultrasonic emitter was moved across the radiator surface, as shown in Figure 9.

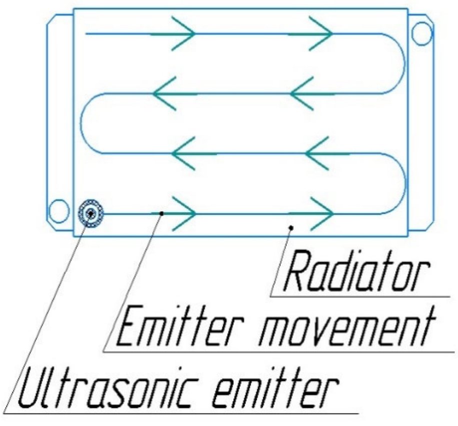

Fig. 9 – Ultrasonic impact scheme on the radiator

The total duration of the first stage was 1200 seconds, and the experiment consisted of three stages. After each stage, the liquid parameters were determined, and the liquid was weighed to obtain precise quantitative data on its mass and density. The mass of scale was determined by subtracting the mass of clean water from the total mass of the resulting pulp, allowing for an accurate measurement of the removed scale.

The pulp is a mixture of liquid and solid scale particles that detached from the radiator tubes due to ultrasonic exposure during the cleaning process. Scale, in turn, consists of solid mineral deposits that form on the surfaces of heat exchange elements due to the heating or cooling of the liquid. Over time, these deposits significantly reduce the efficiency of the cooling system by obstructing normal heat exchange.

During the experiment, the pulp was used as an indicator of cleaning efficiency. Key parameters were measured, such as the mass of removed scale, its concentration in the liquid, and the volume of removed contaminants. The collected data allowed for an assessment of the effectiveness of ultrasonic exposure. The difference between the mass of the pulp before and after cleaning was used for the quantitative determination of the method's efficiency.

3. Results and discussion

An analysis of the collected data was conducted, revealing key patterns and establishing dependencies between the different measured parameters. Based on these dependencies, graphs were constructed to visually represent and better understand the research results.

Measured parameters, including the mass of removed scale, concentration of solid particles in the liquid, pulp density, outflow velocity of the liquid from the tubes, and temperature changes, were presented in Table 1.

Table 1. Measured parameters under ultrasonic exposure

№	Ultrasonic exposure time (seconds)	| Liquid mass (grams)	Liquid density (g/cm³)	Liquid outflow time (seconds)	Liquid temperature (°C)	Liquid outflow velocity (ml/s)
1	0	99,13	0,9913	5,64	60	177,30
2	1200	99,47	0,9947	5,31	60	188,32
3	2400	99,98	0,9998	5,02	60	199,20
4	3600	100,21	1,0021	4,78	60	209,21

The analysis of the obtained experimental data revealed a correlation between the liquid density and its outflow velocity through the radiator tubes, depending on the duration of ultrasonic exposure. These dependencies were visualized in the form of graphs, presented in Figure 6, which allowed for a clear representation of the dynamic changes and a deeper understanding of the cleaning process characteristics.

Thanks to the identified relationships, it became possible to determine the most effective operating modes of the ultrasonic equipment, enabling the maximum intensity of radiator tube cleaning. These results not only provide a theoretical understanding of the ultrasonic mechanism but also offer valuable recommendations for the practical application of the method.

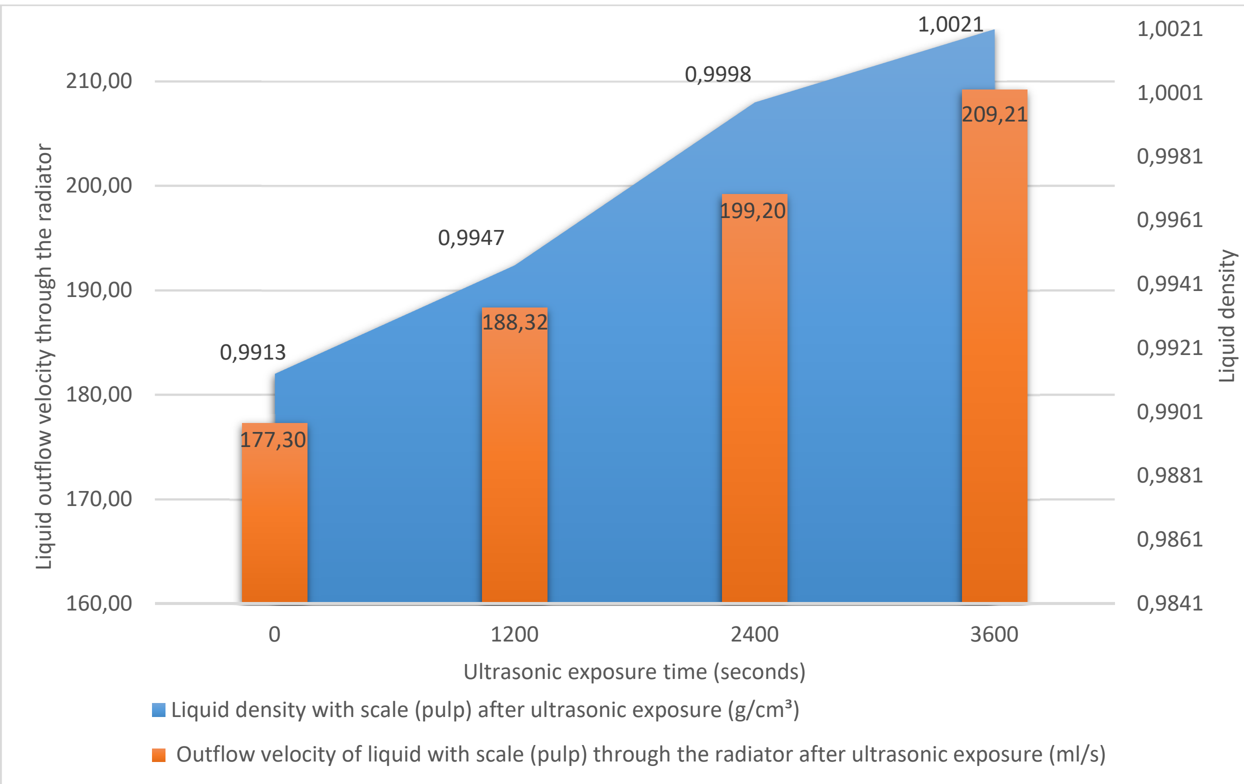

Fig. 10 – Changes in liquid density and outflow velocity through the radiator depending on ultrasonic exposure time

The obtained graphical dependencies demonstrate how the intensity of ultrasonic wave exposure affects the efficiency of contamination removal. Increasing the processing time gradually led to an increase in liquid density due to the washing out of solid scale particles, which, in turn, influenced the outflow velocity. This indicates that ultrasonic exposure has a more pronounced effect on pulp outflow compared to clean water as processing time increases.

Table 2 presents the dynamic changes in pulp mass depending on the ultrasonic treatment duration, with corresponding graphs shown in Figure 11. These data reflect the weight of the pulp and scale content over time during ultrasonic exposure. By subtracting the mass of clean water from the total pulp mass, the mass of removed scale was determined.

This approach provides a quantitative assessment of the efficiency of the ultrasonic cleaning process and highlights the impact of ultrasonic exposure on the removal of scale from the internal cavities of the radiator.

Table 2. Mass of liquid and scale after exposure

Ultrasonic wave exposure time on the radiator (seconds)	Liquid mass (grams)	Scale mass after ultrasonic exposure (grams)
0	99,13	0
1200	99,47	0,34
2400	99,98	0,85
3600	100,21	1,08

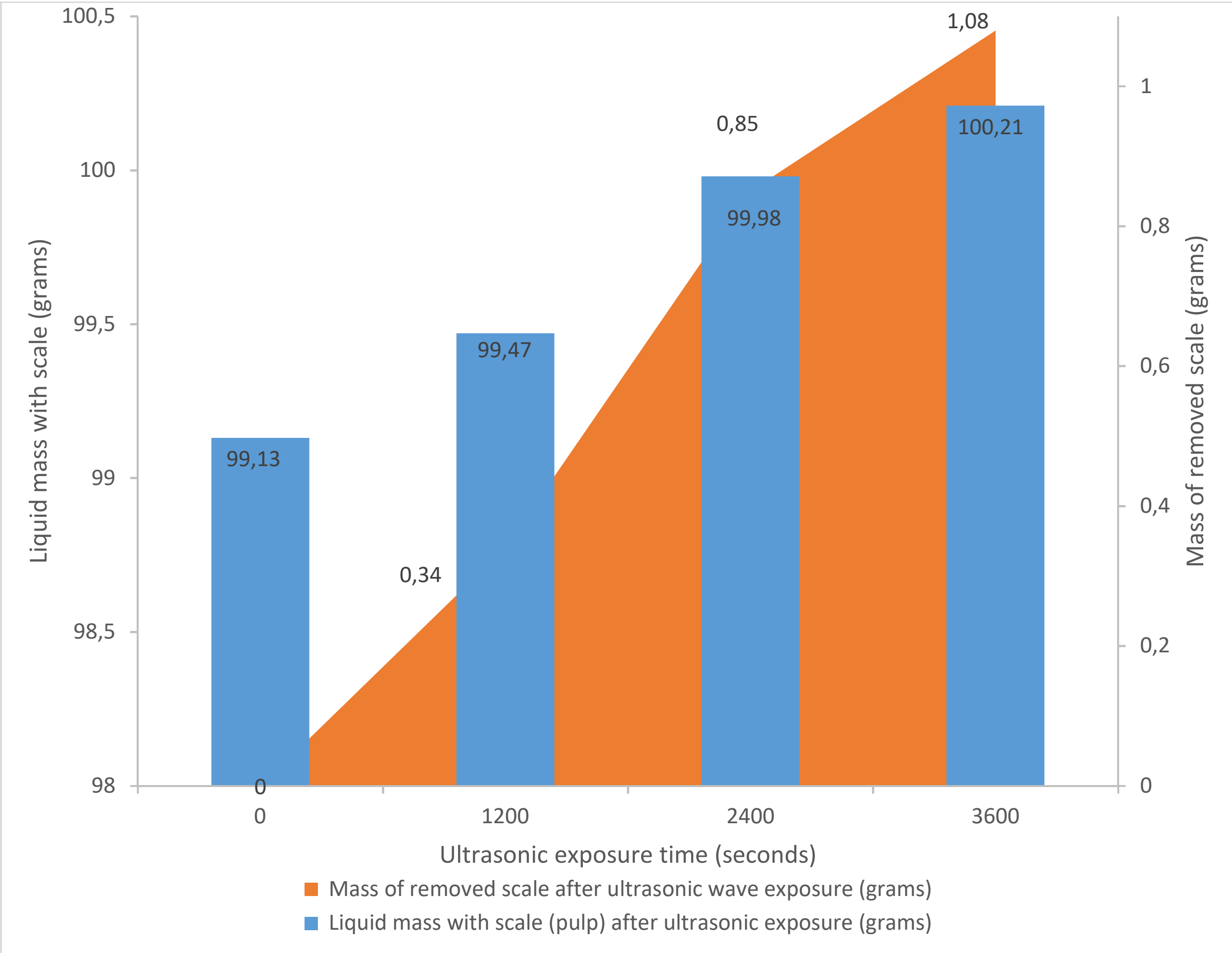

Fig. 11 – Obtained pulp and scale mass depending on ultrasonic exposure time

The analysis of these changes allows us to track the dynamics of the scale removal process from the radiator. As the ultrasonic exposure time on the vehicle radiator increases, the concentration of scale in the liquid rises. The obtained data confirm the impact of ultrasonic cleaning on the efficiency of deposit removal, supporting the initial assumption about the effectiveness of this method in the maintenance of vehicle cooling systems.

Conclusions

The conducted study confirmed that transverse ultrasonic wave exposure is an effective and safe method for removing contaminants compared to longitudinal exposure. The obtained results demonstrated that the use of transverse ultrasonic waves outperforms longitudinal exposure. Unlike longitudinal exposure, the transverse method ensures an even distribution of cavitation processes across the entire radiator surface, contributing to a more intensive scale removal process.

Experimental data confirmed that an increase in transverse ultrasonic exposure time leads to a significant increase in the mass of removed scale. The analysis of dynamic liquid parameters showed an improvement in outflow velocity, indicating an effective restoration of the radiator tube's flow capacity.

The transverse ultrasonic exposure technology is based on the principle of cavitation, which occurs inside the liquid contained within the radiator. During the experiment, the ultrasonic emitter was moved across the entire radiator surface, ensuring a uniform distribution of waves and active breakdown of deposits. This approach minimized energy losses at medium boundaries, which are characteristic of the longitudinal method, where ultrasonic waves propagate along the tube axis and partially dissipate.

Thus, the proposed method not only enables the elimination of contaminants without the risk of damaging the structure but also significantly increases the lifespan of the cooling system. This makes ultrasonic cleaning a promising technology for integration into vehicle maintenance practices, providing both economic and environmental benefits.

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