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A new approach involving a multi transducer ultrasonic system for cleaning turbine engines' oil filters under practical conditions

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The purpose of this paper is to provide a green technology that can clean turbine engine oil filters effectively in ships using ultrasound, with ultrasonic devices having a frequency of 25 kHz and different powers of 300 W and 600 W, respectively. The effects of temperature, ultrasonic cleaning times, pressure losses through the oil filter, solvent washing, and ultrasonic power devices were investigated. In addition, the cleaning efficiency of three modes (hand washing, preliminary washing and ultrasonic washing) were compared to assess their relative effectiveness. Experimental results revealed that the necessary ultrasonic time varied significantly depending on which solvent was used for washing. For instance, the optimum ultrasonic cleaning time was 50–60 min when the oil filter was cleaned in a solvent of kerosene oil (KO) and over 80 min when in a solvent of diesel oil (DO) using the same ultrasonic generator device (25 kHz, 600 W) and experimental conditions. Furthermore, microscopic examination did not reveal any damage or breakdown on or within the structure of the filter after ultrasonic cleaning, even in the filter's surfaces at a constantly low frequency of 25 kHz and power specific capacity (100 W/gal). Overall, it may be concluded that ultrasound-assisted oil filter washing is effective, requiring a significantly shorter time than manual washing. This ultrasonic method also shows promise as a green technology for washing oil filters in turbine engines in general and Vietnamese navy ships in particular, because of its high cleaning efficiency, operational simplicity and savings.

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1. Introduction

A turbine engine is a type of internal combustion engine used widely in factories, power plants, planes, ships, tanks, trains, etc. Engines are composed of very complex, detailed mechanical elements requiring high performance accuracy. Therefore, lubricating oil, hydraulic oil and fuel oil in turbine engines must always be of high quality and filtered through a small metal filter system to ensure all impurities arising during operations are eliminated [1–3].

In recent years, the Vietnamese naval forces have been progressively equipped with modern facilities to improve sea defenses and combat training; the majority of these modern ships use turbine engines. One of the factors affecting the sustainability and productivity of turbine engines is the quality of fuel oil, lubricant oil, hydraulic oil, etc. When a turbine engine is running, fuel oil, lubricating oil and hydraulic oil are sent continuously through the oil filter system to ensure all impurities arising in the course of work are removed, so the engine can continue functioning normally.

Over time, the oil filter is clogged by impurities (oversized particulates or products) that have been filtered out of the oil and by a wide variety of foulants, even the activities of micro-organisms [3,4]. In general, these impurities significantly reduce the productivity of the filter device. Thus, in order to stabilise the productivity of the device, it is necessary to replace or clean the soiled oil filter at regular intervals. To clean the oil filter, either of these two common methods is generally applied: (1) cleaning with solvent combined with manual washing or (2) cleaning with solvent combined with ultrasound waves.

The process of conventional manual cleaning with solvent often uses strongly polarized solvents such as those containing halogen atoms, for example methyl halide compounds [3,5]. Utilising these compounds is not only corrosive to filters and detrimental to the

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surrounding environment, and for the mechanic, but conventional manual cleaning also wastes a large quantity of solvent. Thus from this perspective, ultrasonic cleaning – which uses smaller quantities of less-corrosive solvent – would be a more suitable method than conventional manual cleaning.

In recent years, research applications of ultrasonic waves to clean surface materials (in industry, medicine, and laboratory fields) are attracting the attention of many scientists around the world as an innovative technology and a priority for further research and development [6–9]. The ultrasonic process generates numerous advantageous physical and chemical phenomena, like shear forces, micro-jets, micro-streamings, shock waves, and free radical species (·OH, ·H, ·O, etc.) [10–14], and in particular creates a series of tiny and transient cavitation bubbles with a diameter of less than 100 μm [11]; these tiny bubbles penetrate nearly every corner and crevice of the filter which conventional cleaning methods cannot reach or easily access [9]. These cavitation bubbles exist for an extremely short (transient supercritical) time, then are violently collapsed during the compressional phase, so that they emit shock waves [10,15] with high temperatures (up to 5000 K) and pressures (up to 1000 atm) [7,12,16]. This microscopic process acts with sufficient energy on the dirt surfaces (soluble contaminants and insoluble particles), that they gradually separate and dissolve into the solvent solution from the filter, leading to complete filter cleaning. Conversely, manual cleaning such as by air spray and brush cannot achieve such complete cleaning [9]. Essentially, the main benefits of the ultrasonic cleaning method include better efficiency, shortened filter cleaning time, safety, easy installation, simple operation and maintenance, and reduced labour costs, despite the slightly higher electrical power consumption.

Several studies have been conducted on the application of ultrasonic waves to clean the surface of materials, such as cleaning the surface of solar cell panels [17,18], cleaning the membranes in water treatment [6,12,19], and cleaning motor and sailing boats at the ferry terminal [20]. All this research has achieved excellent results at a very reasonable cost. To minimise harm to the environment, to protect personnel from the health risks of manual washing, and especially to achieve highly efficient cleaning, ultrasonic cleaning devices have generated much interest and are worth investigating for oil filter cleaning.

To date the most common filter cleaning work on navy ships in Vietnam is still done manually. Overall, the traditional and current filter cleaning procedure is quite complicated, costly and time-consuming, resulting in poor efficiency and uneven results. (Technicians remove the filter, place it in clean kerosene oil (KO) or diesel oil (DO) as a solvent, and brush with a soft brush over the filter surface; then the filter is rinsed off with new KO or DO, followed by the technicians using compressed air to spray the filter after every scouring in new KO or DO. This work is repeated until the KO or DO that is rinsed out is no longer dirt-stained, then the filter is considered clean and reassembled.) This method may cause oil filter damage and consume large quantities of solvent. In addition, manual scouring with uneven force may damage the filter, clean only the surfaces, or cause secondary contaminations.

In recent years only very few Vietnam navy ships were equipped with ultrasonic filter cleaning equipment, but there are still many shortcomings in the operation and optimal efficiency of the devices according to local conditions. It is suggested that the cleaning of fouled oil filters by ultrasound in association with solvent oils (KO or DO) is a novel method that can clean turbine engine oil filters at a reasonable cost.

Currently, Vietnam is carrying out renovations and building new navy ships, using turbine engines, which are equipped with ultrasonic oil filter cleaning system. Studying the ultrasonic cleaning process as micro-level cleaning, designing the right equipment, and improving cleanliness in washing procedures as well as inspection procedures are imperative to significantly reduce the foulants doing damage to the turbine engine's efficiency.

Therefore, the present study was conducted to determine the following: (1) the procedure and method of cleaning the oil filter using ultrasound equipment, (2) the better solvent for ultrasonic cleaning, (3) the ideal duration, intensity, and frequency (kHz) of ultrasound exposure, (4) the parameters for evaluating oil filter cleanliness in turbine engines, and (5) any possible changes in the solvent oils after ultrasonic irradiation.

2. Materials and methods

2.1. Experimental design and set-up

2.1.1. Subject of the study

The experiments in this study were conducted on two types of oil filters (lubricant oil filter and fuel oil filter) used in navy ships' turbine engines (Fig. 1), and on oil filters used in anti-submarine ships of Brigade 171, Navy Region X, Vietnam. The fine-scale filters were micro filters with pore sizes ranging from 10 to 16 μm, made of copper or stainless steel in circular disc-shapes, with 25 mm inside diameter, 70 mm outside diameter, and thickness 5 mm (Fig. 1).

2.1.2. Experimental apparatus

Ultrasonic wave experiments were conducted with two ultrasonic systems (a bath-type sonoreactor model). Both ultrasound devices had an oscillated frequency of 25 kHz; the Model MU-300 had a power of 300 W, and the Model MU-600 had a power of 600 W (Mirae Ultrasonic Tech. Co. Ltd., South Korea) (Fig. 2a). The models MU-300 and MU-600 were equipped with 6 transducers and 12 transducers, respectively, and were arranged and fixed under the bottom and two sides of the reactor. The transducer diameter was 60 mm (Mirae Ultrasonic Tech. Co. Ltd., South Korea).

The air velocity and degree of pressure loss through the filters (before and after each test) of the experiments were measured by VITTEP 01, which had a power of 0.5HP (VITTEP, Vietnam) (Fig. 2c), and by Testo 350 XL (Ashtead Technology Co., Ltd.) in order to determine the effectiveness of the cleaning procedure.

2.1.3. Solvents and sampling

The solvents used in these experiments to fill the cleaner tank were industrial kerosene oil (KO), and diesel oil (DO), which are widely used in various industries today. The main properties of KO and DO are summarised in Tables 1 and 2.

2.2. Cleaning experiments

2.2.1. Experimental procedure

The schematic block diagram (Fig. 3) represents the experimental procedure used to compare and optimise the oil filter cleaning process by means of ultrasound.

2.2.2. Experiment description

The used and clogged oil filters of marine turbine engines (ship HQ-9X and ship HQ-17X) were removed from the filter housing; each filter housing contains 40 disc filters. The experiment was conducted on two groups, each with 20 disc filters. The filters were put into equipment measuring pressure losses, to determine the original overall pressure losses (Fig. 4).

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