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# High-Power Ultrasound Cleaning for Printed Circuit Heat Exchangers

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**Abstract:** Printed Circuit Heat Exchangers (PCHEs) are prone to clogging and difficult to clean using conventional methods. This study investigates high-intensity ultrasound as an effective alternative, applying Langevin transducers to a real PCHE. Ultrasonic vibrations enhanced deposit removal without the need for disassembly. The method is more sustainable, reduces downtime and costs, and offers on-site cleaning.

**Keywords:** Ultrasound Cleaning, Printed Circuit Heat Exchangers, PCHEs, High Power Transducer.

## Introduction

Printed Circuit Heat Exchangers (PCHEs) represent an advanced category of compact heat exchangers, distinguished by their exceptional thermal performance and mechanical robustness [1], [2]. The core of a PCHE consists of thin metal plates, where channels for fluid passage are chemically etched. These plates are then bonded by diffusion, forming a solid block with intricate channels for heat exchange, as shown in Figure 1 (a). Their ability to operate under high-pressure and high-temperature conditions makes them particularly well-suited for demanding industrial environments, such as solar thermal energy systems [3]. Owing to these characteristics, PCHEs have emerged as a compelling option for sectors such as petrochemical processing, where both efficiency and durability in heat exchange are critical. On offshore oil platforms, for example, they are employed during primary processing to cool natural gas using seawater. However, these exchangers are susceptible to clogging, as fouling caused by oily sludge and calcium carbonate that can accumulate in their channels over time, compromising performance and requiring pump overloads or maintenance shutdowns. This incrustation on the channel walls also reduces heat transfer efficiency due to its low thermal conductivity [4].

Cleaning PCHE-type heat exchangers presents a significant challenge due to the small dimensions of the channels through which fluids pass and their intricate internal architecture, which are generally arranged in a zigzag pattern. These channels have a semicircular geometry with dimensions of approximately 2 mm, as shown in Figure 1 (b). These structural characteristics limit the effectiveness of conventional mechanical or chemical cleaning methods, particularly in reaching and removing deposits from deep or narrow passages.

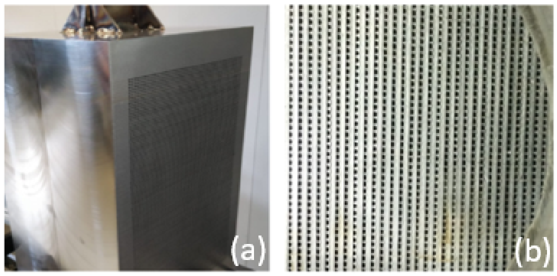


*Fig. 1: (a) Core of a Printed Circuit Heat Exchanger (PCHE) ; (b) cross-sectional view highlighting the internal flow passages within the PCHE.*

One promising technique for cleaning PCHEs in industry is the application of high-intensity ultrasound waves to produce cavitation in the regions that need to be cleaned. The use of ultrasound for cleaning materials and equipment is a well-established technique, with numerous companies offering cleaning services and the commercial sale of ultrasonic cleaning equipment [5], [6]. However, the mechanical structures of PCHE-type heat exchangers are very complex due to the large number of fluid flow channels with small dimensions and the overall size of the units. This makes cleaning in ultrasonic tanks unsuitable, as cavitation is unlikely to occur uniformly in all areas that require cleaning.

The method presented in this study is a non-invasive strategy for cleaning the internal channels of the PCHE through the application of ultrasonic energy.

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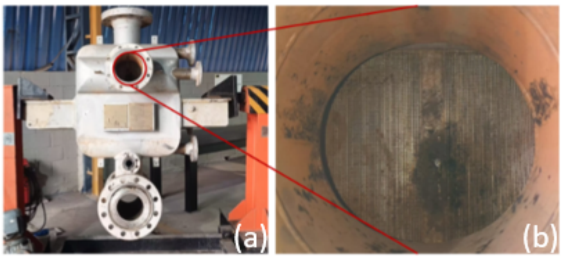


*Fig. 2: (a) External view of a Printed Circuit Heat Exchanger (PCHE), showing the main inlet and outlet nozzles; (b) Internal view through the inlet nozzle.*

This approach employs high-intensity ultrasonic transducers attached to the outer surface of the equipment. When driven at their resonance frequency, these transducers induce acoustic waves that propagate through the structure, generating localized mechanical stresses and high pressure in the cleaning fluid that fills the channels, causing cavitation that disrupts the adhesion of scale deposits. These dynamic effects promote the detachment of existing scale. Thus, this work proposes to experimentally evaluate the power ultrasound technique applied to the cleaning of the channels of a compact heat exchanger

## Materials and Methods

Figure 2 shows the PCHE employed in the tests conducted for cleaning and unclogging its channels using high-power ultrasound. Figure 2 (a) displays a PCHE unit, highlighting its compact and densely packed design, which underscores the practical difficulties associated with maintenance and fouling mitigation. Figure 2 (b) presents an internal view through the inlet nozzle, displaying the small channels of the PCHE, which are designed for high-efficiency heat transfer and operation under extreme thermal and pressure conditions.

Acoustic cavitation enhances the action of detergent/degreaser in cleaning mechanical parts. For acoustic cavitation to occur, the pressure of the ultrasonic wave must reach approximately 100 kPa at frequencies around 20 kHz.

In a complex structure such as cavitation penetration into small orifices, relative to the wavelength, is very limited and thus would not reach the interior of the PCHE. To overcome this limitation, Langevin-type ultrasonic transducers were designed to be directly coupled to the PCHE surface. These transducers were constructed with four rings of piezoelectric ceramic sandwiched between front and rear masses, optimizing acoustic output by promoting longitudinal vibrations in the thickness-extensional mode, at a resonance frequency near 20kHz.

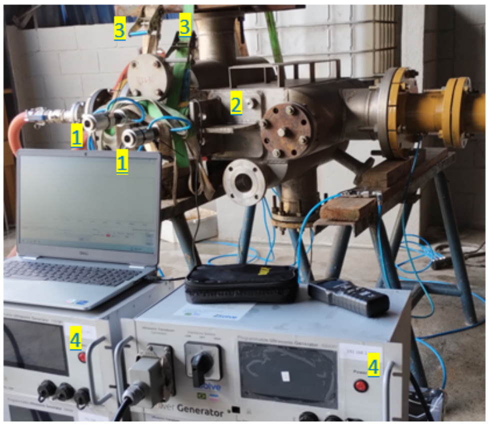


*Fig. 3: Experimental setup for applying high-power Langevin transducers to the body of a PCHE-type heat exchanger, where (1) indicates the transducers, (2) the PCHE body, (3) the ratchet straps, and (4) the ultrasonic generators.*

The experimental setup for applying ultrasound in the PCHE cleaning process is illustrated in Figure 3. Two high-power Langevin-type ultrasonic transducers (1) were firmly attached to one side of the external surface of the PCHE (2) using ratchet straps (3). Two additional high-power transducers were mounted on the opposite side of the PCHE. The mechanical contact achieved through pressure is enhanced by applying Araldite adhesive to ensure proper acoustic coupling between the flat interfaces formed by the lateral surface of the PCHE block and the tip surface of the transducer's extension rod. The transducers (1) are powered by individual high-power ultrasonic generators (4), with each transducer driven by a dedicated generator. A frequency sweep is performed for each transducer to ensure tuning within its resonance band during operation. This direct coupling is critical for the efficient transmission of ultrasonic waves into the exchanger structure, thereby maximizing the cleaning effect through mechanical vibrations and acoustic cavitation.

Finally, two comparative tests were conducted under identical conditions, using the same water-diluted detergent: one with the application of ultrasonic waves and the other without. These two tests were only performed after circulating the water-detergent mixture for one hour to remove the initial fouling through the conventional cleaning process. This approach was employed to verify the effectiveness of ultrasonic-assisted cleaning through a qualitative visual assessment of the removal of scale and other impurities from within the PCHE channels.

In the first test, without ultrasound—repeating the conventional cleaning process—a sample of the freshly

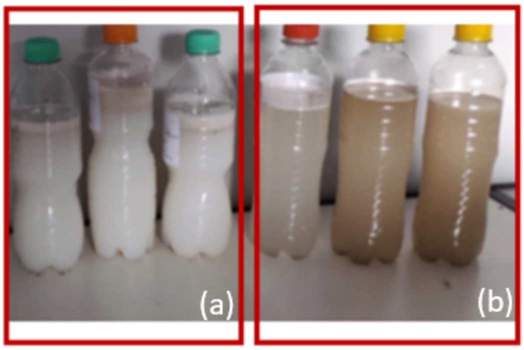


*Fig. 4: Comparison of cleaning effectiveness for a PCHE-type heat exchanger: (a) without ultrasonic assistance and (b) with ultrasonic application. The samples collected at the beginning of the process, after 30 minutes, and after 1 hour of operation are positioned from left to right.*

circulated mixture inside the PCHE's channels was collected and stored in a labeled PET bottle for later analysis. After 30 minutes of recirculation, another sample was collected and stored, and finally, after 1 hour of recirculation, a third sample was bottled. In the second test, with ultrasound—i.e., with the transducers directly coupled to the surface of PCHE and activated—samples were also collected at the beginning, after 30 minutes, and after 1 hour of recirculation. In both tests, a freshly prepared detergent solution (diluted in water at the same mass ratio) was used to ensure consistency in the cleaning conditions.

## Results

As a form of qualitative assessment, the collected samples were subjected to visual inspection following a one-week settling period. Figure 4 presents the appearance of the samples after being left undisturbed on a laboratory bench, allowing for the evaluation of sedimentation behavior and overall cleaning effectiveness.

In Figure 4(a), corresponding to the test without ultrasonic assistance, the cleaning solution appeared more homogeneous and turbid, indicating limited particle separation and less effective scale removal. In contrast, Figure 4(b), representing the sample collected after applying ultrasound during the cleaning process, qualitatively shows more pronounced stratification and increased sediment deposition at the bottom of the containers. This suggests enhanced detachment of impurities and particulates from the internal surfaces of the PCHE channels due to ultrasonic agitation. The visual difference clearly demonstrates the efficacy of ultrasonic waves in improving contaminant dislodgement and suspension, thus validating the positive impact of ultrasonic-assisted cleaning on PCHE performance.

## Conclusions

High-intensity ultrasound, applied via Langevin transducers, is an effective and sustainable method for cleaning Printed Circuit Heat Exchangers (PCHEs) without requiring disassembly. The experimental results qualitatively demonstrate that ultrasonic vibrations significantly enhance the removal of deposits, leading to a more effective cleaning process compared to conventional methods. This approach offers benefits such as reduced downtime and costs, and enables on-site cleaning, making it a promising alternative for maintaining PCHE efficiency in industrial applications.

## Acklowledgements

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## References

[1] C. Huang et al. "Review on the characteristics of flow and heat transfer in printed circuit heat exchangers". In: *Applied Thermal Engineering* 153 (2019), pp. 190–205.

[2] J. E. Hesselgreaves, R. Law, and D. Reay. *Compact heat exchangers: selection, design and operation*. Butterworth-Heinemann, 2016.

[3] Y. Ma, G. Xie, and K. Hooman. "Review of printed circuit heat exchangers and its applications in solar thermal energy". In: *Renewable and Sustainable Energy Reviews* 155 (2022), p. 111933.

[4] H. Nasiri et al. "Cleaning of Printed Circuit Heat Exchangers (PCHE) Using High-Power Ultrasonic Transducers". In: *2024 IEEE UFFC Latin America Ultrasonics Symposium (LAUS)*. IEEE. 2024, pp. 1–2.

[5] K. L. Mittal and R. Kohli. *Developments in Surface Contamination and Cleaning: Particle Deposition, Control and Removal*. Elsevier, 2010.

[6] M. O. Lamminen, H. W. Walker, and L. K. Weavers. "Mechanisms and factors influencing the ultrasonic cleaning of particle-fouled ceramic membranes". In: *Journal of membrane science* 237.1-2 (2004), pp. 213–223.