A NOVEL ULTRASONIC TECHNIQUE FOR THE INSPECTION OF A PLATE HEAT EXCHANGER.

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1 Introduction

Heat exchangers play a vital role in various industries such as food processing, power generation, and water treatment, serving as crucial heat-transfer mechanisms. However, heat exchanging fluids circulating through these systems often contain suspended or dissolved particles, leading to the accumulation of deposits on the surface of the device. This process is commonly referred to as fouling. Biofouling represents a particularly severe form of fouling arising from the accumulation of microorganisms, including bacteria, algae, and other organisms, on the surface of a plate heat exchanger. Consequently, it poses a significant challenge for heat transfer devices, diminishing their efficiency and operational effectiveness. Therefore, a real time tool to monitor the amount of deposit becomes essential.

Only a few studies have been presented, till date, to use ultrasound as a detection tool for heat exchangers. The majority of studies utilize linear ultrasonic transmission and pulse-echo configuration techniques to obtain material properties and assess plate quality. However, numerous investigations encounter limitations in employing guided acoustic waves on pipelines due to the challenges associated with implementing guided sensors on the surface of heat exchanger plates [1, 2].

However, based on the fundamental knowledge of non-linear wave propagation, it can be anticipated that the propagation of high-amplitude ultrasonic waves is highly medium-dependent. Thus, non-linear propagation through the medium can be easily linked to fouling growth in the heat exchanger plates. Thus, this research aims to explore the nonlinear ultrasonic parameters using the second harmonic generation technique as a real-time tool for monitoring biofilms in plate of an heat exchanger device.

2 Method

The strength of non-linearity in material is described by the coefficient of non-linearity β. In terms of the pressure of the fundamental P_1, and the second harmonic, $P_2(x)$, at a distance x from the source, β can be expressed as Eq 1 [3]

$$\beta = \frac{B}{A} + 2 = \frac{2\rho_0 c_0^3}{\pi f}\frac{P_2(x)}{xP_1^2(0)} \tag{1}$$

Based on the existing literature [4], an approach involving relative measurement can be used to avoid absolute pressure measurement and transducer calibration expressed as Eq. 2.

$$\beta \propto \frac{A_2(x)}{xA_1^2(x)} \tag{2}$$

Accordingly, a relative ratio measurement of the amplitudes helps to determine the relative non-linearity parameter β', plotted as a function of axial distance between the transducers (x). By varying the propagation distance, any initial instrumentation non-linearity will decrease with increasing propagation distance, while intrinsic material non-linearity will cause an increase in A_2.

3 Experimental Setup

A linear investigation is first applied to a specimen of heat exchanger plate made up of titan with a grove thickness of 4 mm in a through transmission mode as shown in Fig. 1. A small area of 80 mm x 10 mm is considered for the investigation. The efficiency of indicator is tested to verify its applicability in existing ultrasonic heat assisted devices.

Nonlinear analysis is conducted on an aluminum plate sample with a thickness of 0.5mm, upon which layers of biofilm-mimicking material of varying thicknesses are deposited and submerged in water. The RITEC Advanced Measurement System (RAM-5000) generates high-amplitude ultrasonic sinusoidal burst of 810 V_{p-p} to the transmitter transducer operating at a frequency of 1 MHz. The polar c-scan system is employed for data acquisition and for controlling the mechanical motion of the robotic arm linked to the receiver.The received signal is then processed by signal processing software and the harmonic ratio A_2/A_1^2 with the axial distance from 0mm to 100 mm is computed. The slope of the linear region of this curve is then related with the relative non-linearity parameter β' which serves as an indicator of film thickness.

4 Results and Discussion

Using linear ultrasound, an approximation of the position of the deposition can easily be determined as evident from the Fig. 2 and Fig. 3. However, the technique is less sensitive to the small variation in thickness of the biofilm.

Based on the investigation on various thickness of the biofilm mimicking material, it is inferred that the presence of a biofilm along the sound propagation path impacts non-linearity. Fig. 4 depicts a comparison of the non-linear ratios for two distinct biofilm thicknesses, each exhibiting varying slopes corresponding to β' values. The results demonstrate a decrease in β' values with increasing deposition thickness.

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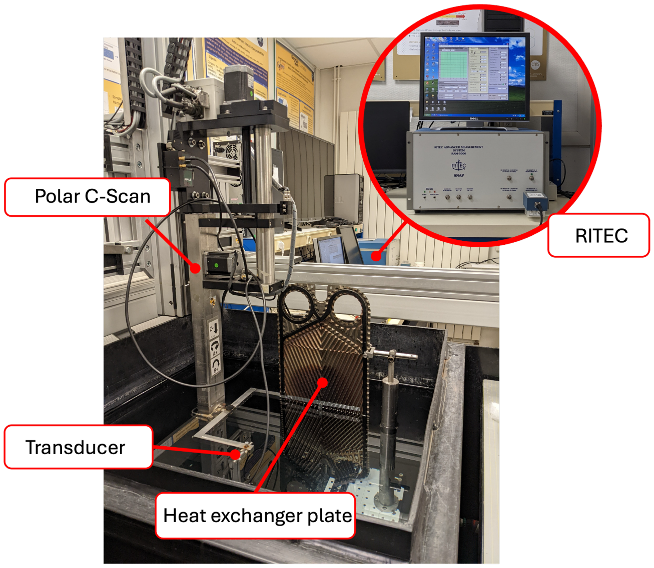

FIGURE 1 – Experimental setup of investigation on biofilm deposition on plate of heat exchanger.

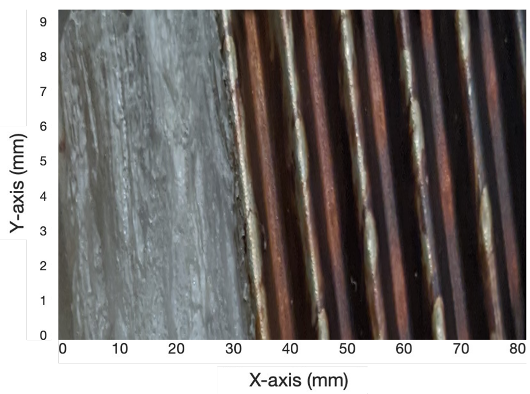

FIGURE 2 – Optical image of the sample.

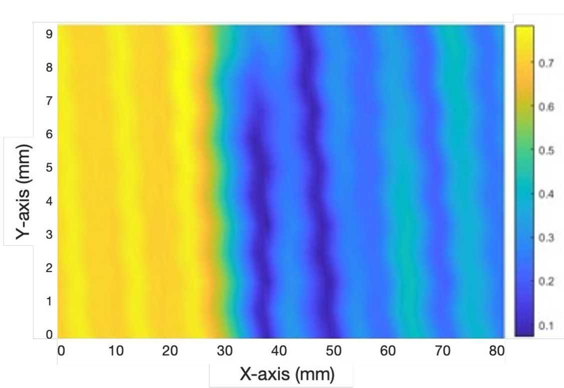

FIGURE 3 – Maximum amplitude plot of acquired time signal for the sample shown in Fig.2.

5 Conclusions

The suggested approach, utilizing nonlinear ultrasonic, has demonstrated efficacy as a tool for inspecting biofilm deposits on heat exchanger devices. This study underscores the effectiveness of physical acoustics in advancing practical acoustic applications to aid existing devices.

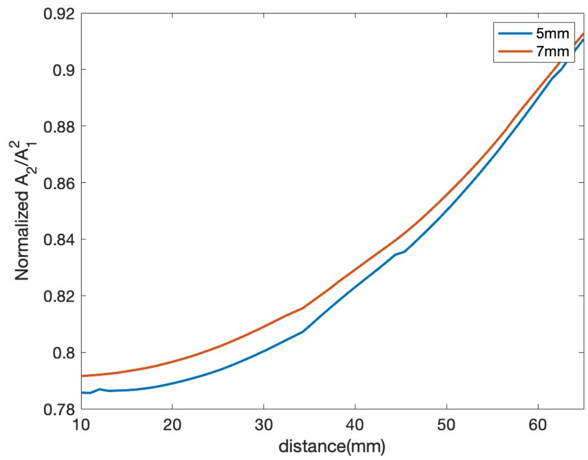

FIGURE 4 – Non-linearity ratio plotted for biofilm thickness of 5mm (in blue) and 7mm (in red) with respect to propagation distance.

TABLE 1 – Relative non-linearity parameter for various thicknesses of biofilm deposit on aluminium plate.

Biofilm thickness $[mm]$	β'
0	0.351
1	0.314
2	0.282
5	0.157
7	0.122

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