STUDYING THE NONLINEARITY EFFECTS IN ULTRASOUND-ASSISTED WATER PURIFICATION AND TREATMENT SYSTEMS

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1 Introduction

Water pollution is a critical environmental issue characterized by the introduction of harmful substances into aquatic ecosystems, adversely affecting their quality and integrity. One of the significant and potential cause of increasingly pollution is the presence of oil in wastewater streams from food processing industries, oil extraction process and domestic waste. It creates an indispensable effect on the ecosystem and destruct the marine and human life. It presents a pressing challenge for treatment facilities, as the hydrophobic nature of oil makes it difficult to remove using conventional methods.

Effective treatment strategies such as Membrane-based techniques therefore plays a significant role in treatment of oily wastewater. It generate potable water of superior quality through the selective separation of water molecules from impurities [1–3]. However, fouling is a severe problem with these kinds of filtration devices. The word 'fouling' here refers to the deposition of unwanted substances on the surface of the treatment devices, resulting in a loss of efficiency. Therefore, in this study, the emphasis on water treatment devices is solely directed towards membrane filtration devices.

Ultrasound-enhanced membrane filtration devices present an appealing solution for mitigating deposit accumulation, facilitating cleaning processes, and reducing fouling. This integration enhances process performance and augments device efficiency [4, 5]. Besides its cleaning capabilities, ultrasound-enhanced water treatment systems can serve as tools for monitoring system functionality by analyzing impurities present in the treated water. In an ideal case, the treated water is pure, whereas in real operation residual impurities persist, which can cause influences on the propagation of sound through it. In terms of ultrasound, the aspects that may be influenced are speed of sound, attenuation, or nonlinear effects.

In a preliminary study, we discovered that sound speed and attenuation may work for highly contaminated water samples or water streams, but are insensitive to small contamination. One of the parameters in oily wastewater treatment applications is the fat content still present in the treated water. The objective of this work is to investigate the fat content present in the form of oil-in-water emulsion, specifically focusing on case involving minuscule droplets present in extremely low volume fractions. This investigation is particularly pertinent for understanding the dynamics of emulsions in water purification systems, as it reflects conditions most relevant to their operation.

The final step in this work, addresses the effect of presence of biofilm on the measurements conducted along the sound propagation path. Conceptually, considering a scenario where a biofilm covers either the transducer itself or covering a plate positioned between the emitter and receiver acknowledging its integration into the operational framework of the system under investigation.

2 Method

2.1 Linear Analysis

To conduct linear analysis, straightforward through transmission experiment with a fixed distance between transducers is used. The received signal is then utilized to compute linear parameters such as speed of sound and attenuation measurements.

2.2 Non-linear Analysis

The strength of non-linearity in a material is quantified by the coefficient of non-linearity, denoted as β The exact measurement of this coefficient, is expressed as Eq. 1, which relates the pressure of the fundamental wave P_1 and the second harmonic wave $P_2(x)$ at a distance x from the source. [6]

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

However, to avoid absolute pressure measurement and transducer calibration, the relative method is used to measure β'. The relative acoustic nonlinearity parameter β' for the longitudinal wave in the liquid is defined as Eq. 2

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

Therefore, to determine the non-linearity parameter β', a relation between the non-linearity ratio $(A_2(x)/A_1^2(0))$ is plotted for the axial distance between the transducers (x) for different kinds of fluids. 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. This allows the separation and effectual removal of the instrumentation non-linearity in the measured A_2, leaving only the material non-linearity contribution.

For the non-linear analysis, the generation of high amplitude ultrasonic waves is provided by RITEC Advanced Measurement System (RAM-5000) as shown in Fig. 1. The high voltage output the RITEC generates is first passed through a 50 Ω load and then to the transmitter transducer of 1 MHz. Thus, an input voltage of 810 V_{p-p} for a sinusoidal burst of 10 cycles at a frequency of 1MHz is generated for the

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experiment. The polar c-scan system is used for acquisition as well as in controlling the mechanical movement of robotic arm connected to the receiver. The acoustic wave passing through the liquid was intercepted by a submerged 2.25 MHz receiver. The output is processed to obtain changes in the amplitude harmonic ratio A_2/A_1^2 with the axial distance from 0mm to 100mm. The slope of the linear region of this curve is then related with the relative non-linearity parameter β'.

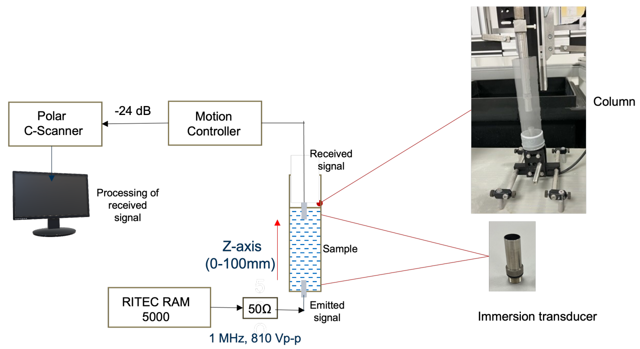

Figure 1 – Schematic diagram of the non-linear ultrasonic investigation setup.

3 Results and Discussion

3.1 As monitoring tool

Linear results

The computed ultrasonic velocities of all the samples representing the oil in water emulsion are presented in the Table. 1. Although there is an identifiable decreasing trend in the average speed of sound with increasing fat content in sample, it is hard to distinguish between unknown samples due to high tolerance bounds in the measurement. Therefore, the linear measurement does not provide an accurate differentiation based on fat content.

Table 1 – Speed of sound for a range of sample with different fat content.

Fat content $[g/l]$	speed of sound $[m/s]$	Volume fraction of fat $[\%]$
5	1451.1±6.0387	0.56
16	1448.8±4.6596	1.80
36	1443.5±4.5523	4.05

Non-Linear results

Based on the analysis, a decreasing trend in β' is observed with the increase in the fat content. It helps to conclude that the non-linearity decreases with the increase in the volume fraction of oil. In addition, by using a sample with the lowest fat content 1 [g/l] as a reference, a significant variation in the non-linearity indicator is obtained among various samples as shown in Fig. 2. A high sensitivity of 6.62 % in relative β' is achieved for 1% variation in volume fraction in the sample.

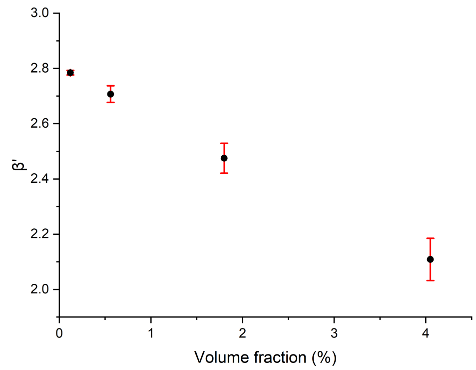

Figure 2 – Relative non-linearity parameter for various volume fraction of fat in form of emulsion.

3.2 The effect of a biofilm on the proposed research method

It is observed that the presence of a biofilm along the path of sound propagation influences non-linearity. It has been demonstrated that the values of β' decrease with increasing thickness of deposition.

4 Conclusions

The proposed method, based on nonlinear ultrasonic, is highly efficient in distinguishing low-fat in an oil-in-water emulsion. This work highlights efficiency of physical acoustics for development of practical acoustic applications within the realm of water purification.

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