

The Effect of Fabric Position to the Distribution of Acoustic Pressure Field in Ultrasonic Bath

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Abstract. Nowadays, the use of ultrasonic energy in textile wet processes at industrial-scale is limited. It is largely due to the lack of understanding about design, operational and performance characteristics of the ultrasonic bath, suitable for textile treatments. In the context of this study, the effect of fabric position, as one of the design parameter, to the distribution of acoustic pressure field in ultrasonic bath was investigated. The ultrasonic bath in the size 20×30 cm² with one transducer at frequency 40 kHz was used in experiments. The cotton fabric with 1 mm thickness was moved along vertical and horizontal directions of the ultrasonic bath. The acoustic field and cavitation volume density in the bath is analyzed by COMSOL Multiphysic. The cavitation volume density is calculated by comparing the pressure points in the bath with cavitation threshold pressure. Consequently, it was found that the position of the textile material in the ultrasonic bath is one of the most important factors to achieve the uniform and maximum acoustic cavitation field. So, it should be taken into consideration during the design of industrial-scale ultrasonic bath used in textile wet processes.

1. Introduction

Ultrasonic is the application of acoustic fields above audible frequency region. Ultrasonic fields have a broad range of application areas like medical imaging, welding, cutting, surface treatment, material synthesis and textile engineering [1]. The two fundamental effects of ultrasonic in fluidic environments are used in textile treatment baths. One of them is the sonochemistry which is alteration of chemical reactions by ultrasonic fields. And the other and widely used effect of ultrasound is the acoustic cavitation. Fluid molecules are effected by compression and tension forces which induce peak negative and positive pressure regions in MPa range due to the applied acoustic field [2]. This alternating pressure field changes fluid molecules state to gas locally. These micro bubbles grow as the pressure reduces and collapse.

Acoustic cavitation is a complex transition phenomenon and acoustic cavitation field which is map of the local points of micro bubbles in the fluid depends on various parameters as density and speed of sound in the fluid, surface tension of fluid, temperature of fluid, and geometry [3, 4].

In this paper, the dependence of cavitation to the place of the fabric is studied with the Finite Element Modelling. The acoustic field and cavitation volume density in the bath is analyzed by COMSOL Multiphysics. The cavitation volume density is calculated by comparing the pressure points in the bath with cavitation threshold pressure [5].



2. Simulation Method

The ultrasonic bath with one transducer at frequency 40 kHz was modelled in 2 dimensions in COMSOL Multiphysics 3.5a software (Figure 1). The size of the bath was $20 \times 30 \text{ cm}^2$. The centre of transducer was placed at nearly 0.1 cm in the x-axis in the light of our previous studies. Fabric was modelled as cotton subdomain with a 1 mm thickness. It was assumed that ultrasonic bath was full with water at 25°C . Two different sets of simulations were done for the position of fabric at different vertical and horizontal directions (Table 1). Time – harmonic analyses are done with frequencies of 40 kHz.

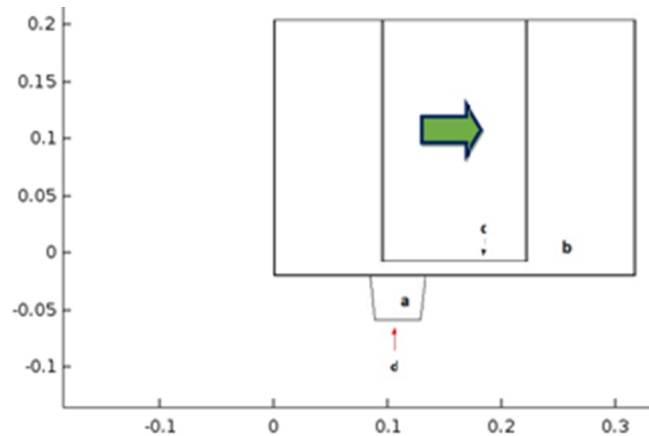


Figure 1. 2D Geometry of the ultrasonic bath with one transducer at frequency 40 kHz (a-Ultrasonic transducer, b-bath (water at 25°C), c-cotton fabric, d-pressure input boundary)

Table 1. Two different sets of simulations with the position of the fabric at different vertical and horizontal directions of the ultrasonic bath

Trial No:	A:	B:	Trial No:	A:	B:
1	1	4	7	1	14
2	1	6	8	4	14
3	1	8	9	7	14
4	1	10	10	10	14
5	1	12	11	13	14
6	1	14	12	16	14

A: The distance between the fabric and the bottom wall of the ultrasonic bath, cm

B: The distance between the fabric and the midpoint of the x-axis of the ultrasonic bath, cm

Pressure field in the bath was computed with Helmholtz equation (1) by Finite Element Method [6].

$$\nabla^2 P + k^2 P = 0 \quad (1)$$

P is the acoustic pressure and k is the wave number which is defined by the ratio of angular velocity to the speed of sound in the medium (ω/c). The bath medium was assumed as homogenous water.

The boundary condition for the water – air interface at the open surface on the top of bath was set as soft boundary and all the metallic surfaces of the bath were defined as hard boundaries. The pressure input to the system was set as a pressure input boundary on the interface between piezoelectric disk and transducer horn. Pressure magnitude on the input boundary was calculated by the following equation (2);

$$I = \frac{p}{2\rho_0 c} \quad (2)$$

where p is the pressure magnitude, I is the power per area, ρ_0 and c are density and speed of sound in the domain respectively.

3. Results

The total acoustic pressure distribution in the bath is shown in Figure 2 corresponding to the different fabric positions at horizontal direction.

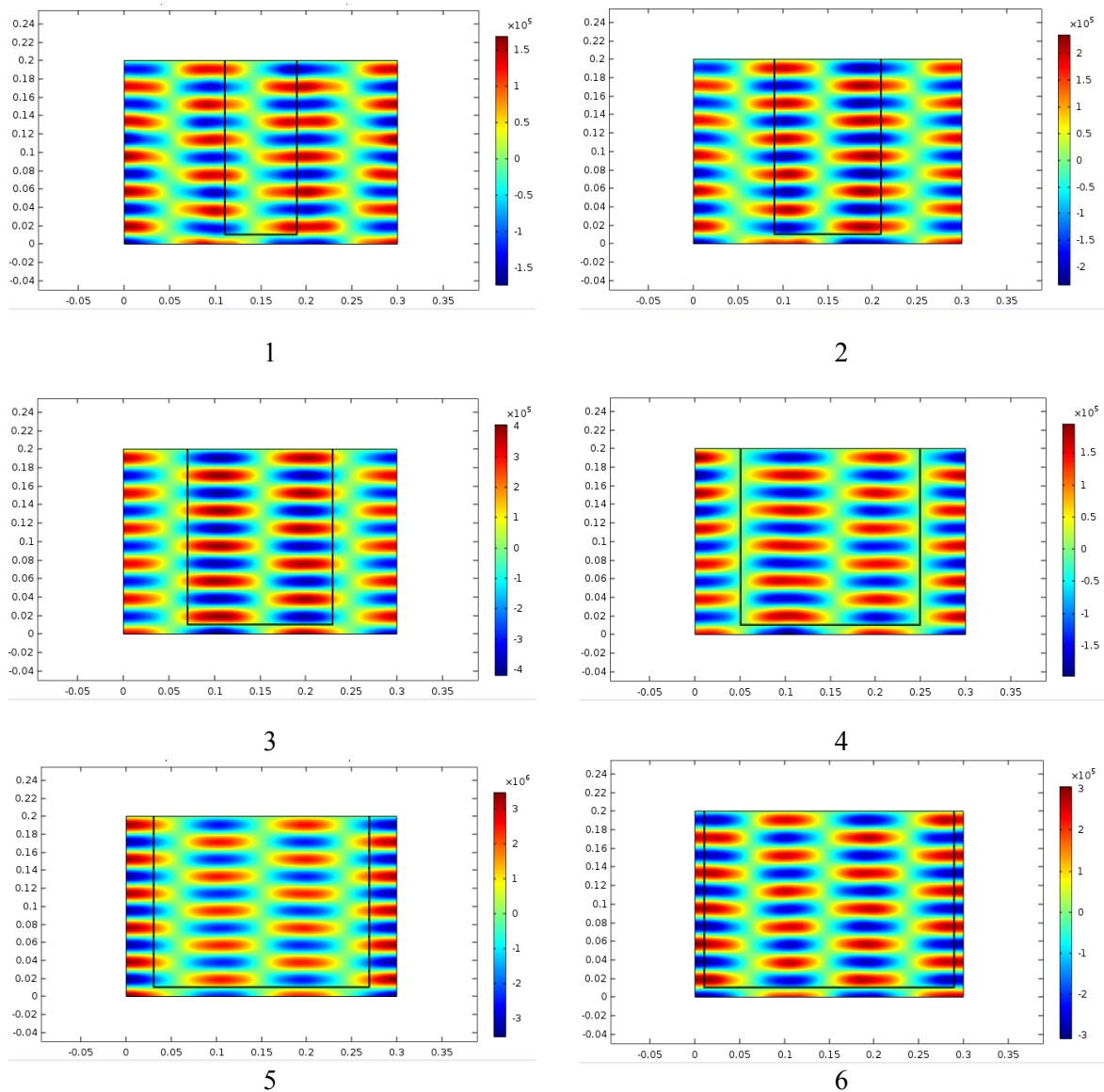


Figure 2. The Total Acoustic Pressure Distribution – The effect of the distance between the fabric and the midpoint of the x-axis of the ultrasonic bath

Although the shape of total acoustic pressure distribution was similar to the various positions of the fabric, as the distance between the fabric and the side boundaries of the bath decreased, the maximum pressure that was induced in the bath increased from 200 kPa to 3 MPa. High pressure fields were achieved near the fabric.

Local pressure magnitude in the bath was compared with a threshold pressure which was assumed as the half of the maximum pressure. Percentage of pressure points exceeding the threshold is calculated with the respect to the whole bath (Figure 3). Results showed that the percentage is oscillating around 17.5% and hits a minimum at 0.11 cm.

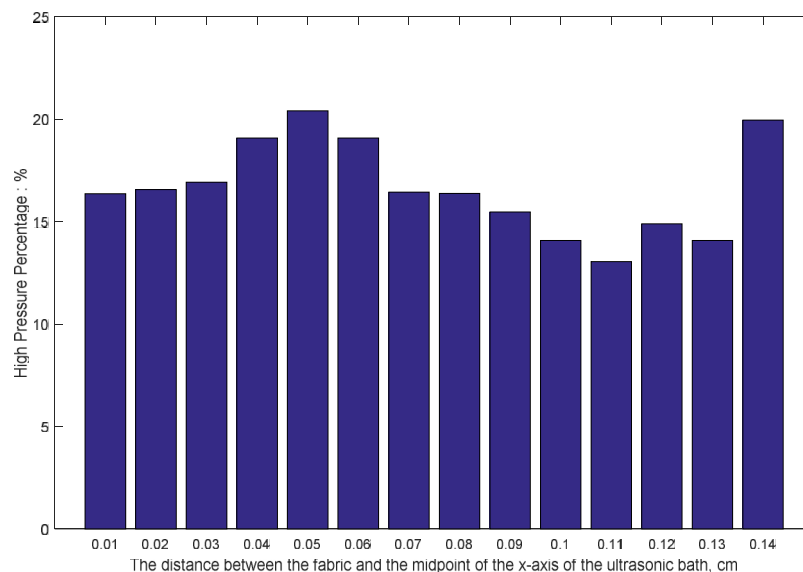


Figure 3. Percentage of higher pressure points compared with the threshold pressure as a function of fabric movement along x-axis of the ultrasonic bath

As a result of our study, the maximum (nearly 21%) and homogeneous acoustic pressure distribution was achieved, when the fabric was placed at 14 cm far away from the midpoint of x-axis of the ultrasonic bath.

In the context of the second part of simulations, the fabric was placed at 14 cm far away from the midpoint of x-axis of the ultrasonic bath. And the effect of the fabric movement along y-axis on to the acoustic pressure distribution and magnitude was investigated (Figure 4).

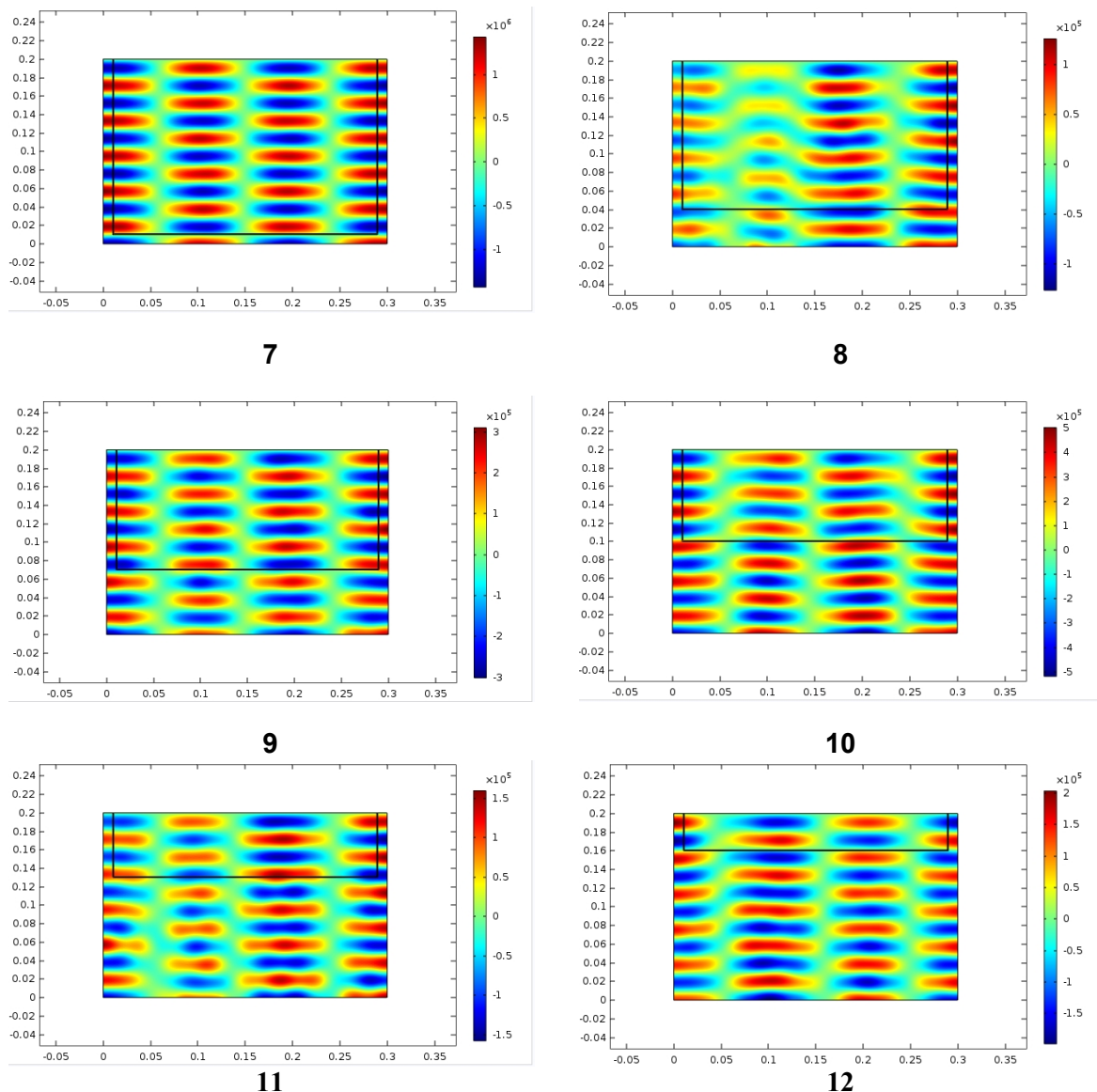


Figure 4. Total Acoustic Pressure Distribution – The effect of the distance between the fabric and the bottom wall of the ultrasonic bath

As seen from Figure 4 that the shape of total acoustic pressure distribution significantly changed with the position along y-axis of the fabric. Generally, it can be said that as the distance between the fabric and the bottom wall of the bath decreased, the maximum pressure that was induced in the bath increased from 200 kPa to 1 MPa.

The same pressure percentage procedure was applied to the second set of simulations. Even though there was an upward trend in pressure percentage as a fabric moves away from the bottom wall, there were distinct locations that pressure percentage reached its maximums (Figure 5). When the fabric was placed at 1 cm away from the bottom wall of the ultrasonic bath, the maximum percentage (nearly 20%) and the uniform acoustic pressure distribution was achieved.

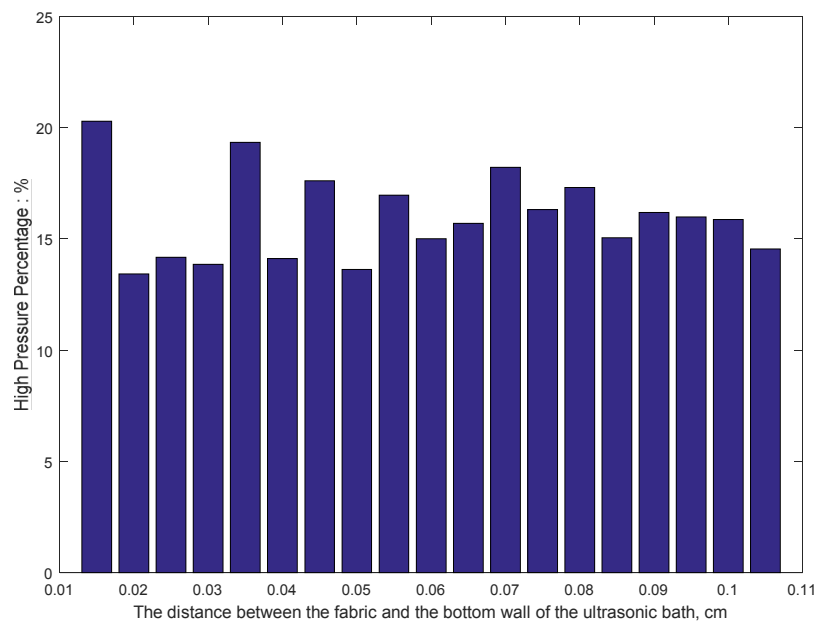


Figure 5. Percentage of higher pressure points compared with the threshold pressure as a function of fabric movement along y-axis of the ultrasonic bath

As a result of the study, it was found that the position of the fabric is important because it affects the magnitude, the wave shape of pressure, and uniformity of acoustic pressure distribution.

4. Conclusion

Even though the thickness of fabric is thin compared to the size of geometry, the position of the fabric has a disturbing effect on the distribution of acoustic field. Especially, when the fabric is too close to the ultrasonic sources, fabric surface tends to limit the transmission of pressure into the bath. Thus, the position and geometry of the fabric should be included in the design process of ultrasonic baths used in textile wet processes.

Acknowledgments

Financial support for this study was provided by TUBITAK-The Scientific and Technological Research Council of Turkey, Project Number: 315M534.

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