A new moving boundary model for simulation of the ultrasonic horn reactors

Ultrasonic-assisted technology (UAT) has found astonishing uses in different areas due to its high potential for improving the yield of industrial processes. For example it is used in chemistry and chemical engineering due to its effects on breaking the chemical bonds, releasing free radicals, catalyzing the reactions, creating micro emulsions, streaming and mixing. In biology, UAT is used as a method of inducing fermentation of the microorganisms as well as extraction of the enzymes, proteins, DNAs and RNAs. In material processing, power ultrasonic technology is employed to synthesize nanomaterials for water treatment purposes.

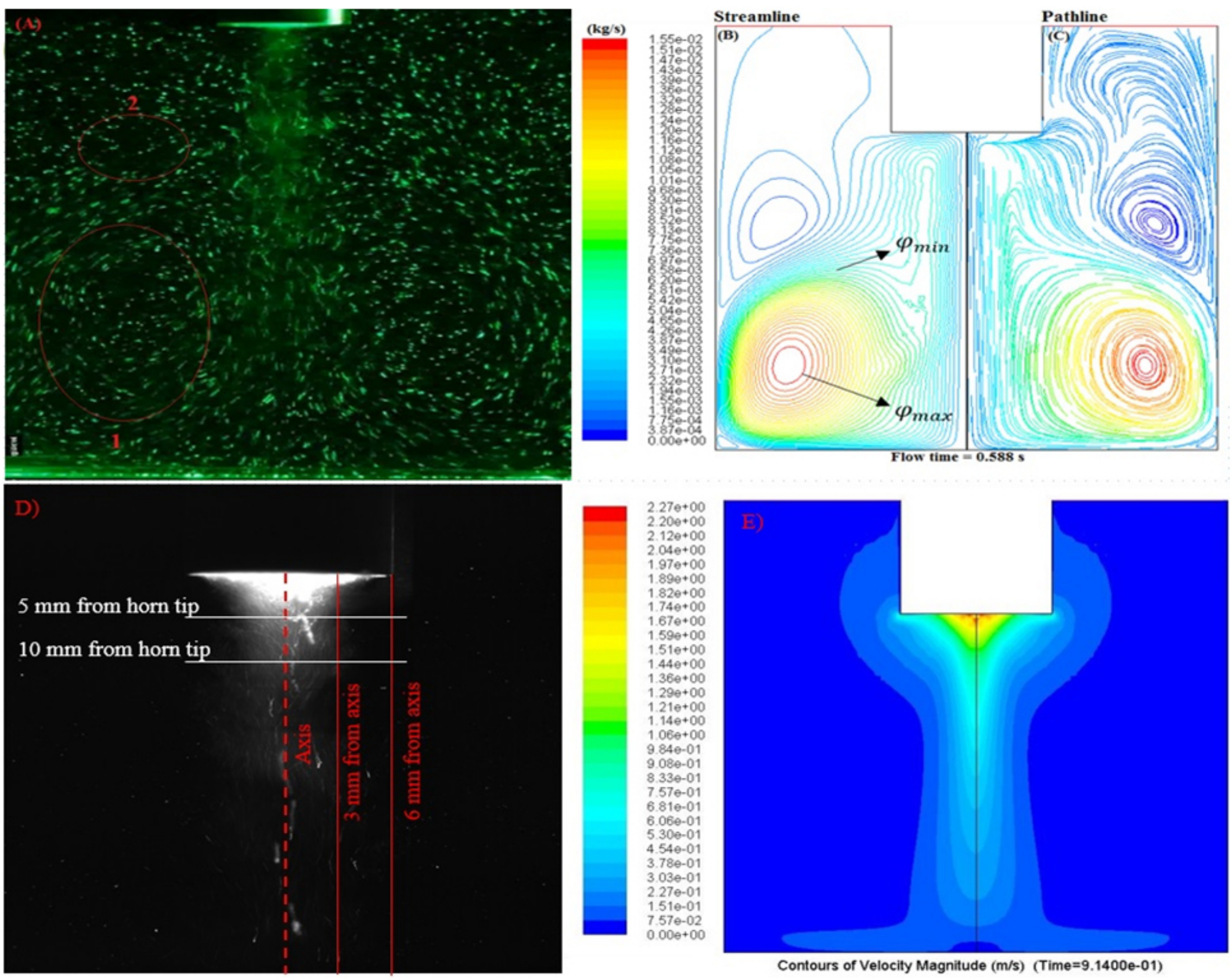

Fig. 1. (A) Visualization of the velocity pattern, the white points visible in the green domain under the horn tip are the PVC particles, (B) and (C) Contours of streamline function (kg/s) and Pathlines colored by stream function (kg/s), D) The photographic image of the jet induced below the horn tip and E) Contour plots of velocity magnitude.

Characterizations of the phenomena involved in the sonoreactors are important for optimal design of the chemical processes. The experimental methods for obtaining more insight about what happens in a sonoreactor might be a troublesome and costly procedure due to very fast phenomena involved in the reactor. On the other hand, numerical simulation would be used as a low-cost tool to investigate the flow patterns in the sonoreactor resultin in a high-accuracy flow field. Thus, it can be beneficial to provide some insight into the complex fluid behavior as well as scale-up of the sonoreactors. Physical characteristic of the horn tip oscillation, which causes acoustic wave generation into the system and also a reliable cavitation model are essential to describe the flow field, which could help to simulate the ultrasonic horn reactor (UHR) more accurately.

The ultrasonic waves may be generated using a piezoelectric transducer. The basis of this phenomenon is a mechanical vibration of a piezoelectric crystal. This leads to a peak-to-peak displacement at the probe tip. According to longitudinal vibration of the horn tip, one may consider the mode of the probe vibration at the horn tip based on the concentrated displacement at the center. This means vibration at the horn tip center is stronger than the periphery.

Therefore, the main objective of our study was to find an accurate equation for capturing the horn tip movement in the UHRs. Hence, a more realistic model to describe the moving boundary condition was derived based on the stronger vibration at the center of the horn tip than its periphery. Moreover, a computational fluid dynamic (CFD) simulation has been conducted to predict the acoustic streaming as well as acoustic cavitation induced by a UHR.

In fact, successful prediction of the flow field can be achieved when an accurate moving boundary condition, including the instantaneous deflection at the horn tip is applied. The velocity and pressure fields inside the fluid medium, the vapor volume distributions and the stream functions were investigated. The particle image velocimetry (PIV) technique was carried out for both analysis and validation of the numerical results. Evaluating the acoustic jet-like streaming induced by moving boundary wall indicated that the average velocity magnitude of the injected tracer bellow the horn tip at the axis pivot was greater than the velocity at the line 3 mm from the axis pivot for all power inputs. The CFD results also exhibited that the axial velocities have a conical trend at different depths below the horn tip in which, for instant, the axial velocity changes from 0.86 m/s to 0.095 m/s for 5 mm from the horn tip in radial direction. Furthermore, the CFD results showed that the pressure was directly related to the vapor volume generated below the horn tip. The larger the volume of the generated cavity, the quicker the wave damping. The CFD predictions were both qualitatively and quantitatively compared with the experimental data, which showed a close agreement. The outcome of the present work is crucial to develop and scale up the processes where ultrasonic horn is utilized.

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