Examining Influence of The Ultrasonic Power and Frequency on Microbubbles Dynamics Using Real-Time Visualization of Synchrotron X-Ray Imaging: Application to Membrane Fouling Control

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Abstract : Membrane fouling poses severe challenges in membrane-based wastewater treatment applications. Ultrasound (US) has been considered an effective fouling remediation technique in filtration processes. Bubble cavitation in the liquid medium results from the alternating rarefaction and compression cycles during the US irradiation at sufficiently high acoustic pressure. Cavitation microbubbles generated under US irradiation can cause eddy current and turbulent flow within the medium by either oscillating or discharging energy to the system through microbubble explosion. Turbulent flow regime and shear forces created close to the membrane surface cause disturbing the cake layer and dislodging the foulants, which in turn improve the cleaning efficiency and filtration performance. Therefore, the number, size, velocity, and oscillation pattern of the microbubbles created in the liquid medium play a crucial role in foulant detachment and permeate flux recovery. The goal of the current study is to gain in depth understanding of the influence of the US power intensity and frequency on the microbubble dynamics and its characteristics generated under US irradiation. In comparison with other imaging techniques, the synchrotron in-line Phase Contrast Imaging technique at the Canadian Light Source (CLS) allows in-situ observation and real-time visualization of microbubble dynamics. At CLS biomedical imaging and therapy (BMIT) polychromatic beamline, the effective parameters were optimized to enhance the contrast gas/liquid interface for the accuracy of the qualitative and quantitative analysis of bubble cavitation within the system. With the high flux of photons and the high-speed camera, a typical high projection speed was achieved; and each projection of microbubbles in water was captured in 0.5 ms. ImageJ software was used for post-processing the raw images for the detailed quantitative analyses of microbubbles. The imaging has been performed under the US power intensity levels of 50 W, 60 W, and 100 W, in addition to the US frequency levels of 20 kHz, 28 kHz, and 40 kHz. For the duration of 2 seconds of imaging, the effect of the US power and frequency on the average number, size, and fraction of the area occupied by bubbles were analyzed. Microbubbles' dynamics in terms of their velocity in water was also investigated. For the US power increase of 50 W to 100 W, the average bubble number and the average bubble diameter were increased from 746 to 880 and from 36.7 µm to 48.4 µm, respectively. In terms of the influence of US frequency, a fewer number of bubbles were created at 20 kHz (average of 176 bubbles rather than 808 bubbles at 40 kHz), while the average bubble size was significantly larger than that of 40 kHz (almost seven times). The majority of bubbles were captured close to the membrane surface in the filtration unit. According to the study observations, membrane cleaning efficiency is expected to be improved at higher US power and lower US frequency due to the higher energy release to the system by increasing the number of bubbles or growing their size during oscillation (optimum condition is expected to be at 20 kHz and 100 W).

Keywords : bubble dynamics, cavitational bubbles, membrane fouling, ultrasonic cleaning
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