Accumulation of microparticles along radial axis of cylindrical tube using low and high frequency acoustic wave

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Introduction

Focusing or filtering of microparticles could be utilized in various applications ranging from medical diagnostic, additive manufacturing to waste detection/treatment in water. For filtering of micro-sized waste, physical filter or porous obstacles are generally used which require time-consuming and burdensome maintenance and replacement. Fine physical filters obstruct water flow and may reduce flow rate. Therefore, extra pressure is needed to maintain water flow rate at the terminal. Additionally, physical filters also mainly rely only on the size of microparticle/micro waste. The efficiency of waste detection may also be increased by focusing adulterated substance to the detector. In this work, we would like to propose another approach to focus microparticles in the tube using acoustic wave. Acoustic waves work well with microparticle which has a large difference of its compressibility and density comparing to that of water/medium.

Most of the works related to manipulation of microparticles using acoustic wave require a container with rectangular or square shape (Zhang et al. 2014; Suthanthiraraj et al. 2012; Courtney et al. 2010; Raeymaekers et al. 2011). Such a container may not be suitable for general industrial application using cylindrical tube/pipe. In this work, a cylindrical tube was used and also demonstrate a different pattern of pressure nodes by changing an excitation frequency. This would improve tunability of microparticles in the cylindrical tubes. Additionally, numerical simulation was modelled to predict the suitable excitation frequency.

Material and Methods

For numerical simulation, the glass tube with an inner and outer diameter of 6.6 and 7.0 mm were studies. To excite vibration, a plate of piezoceramic (11x11x2 mm^3) was attached to one side of the glass tube. The vibration direction of the piezoceramic plate was perpendicular to the tube surface. The model was simulated in COMSOL 5.2 and consists of piezoelectricity, solid structure and acoustics, particle trajectory phenomena. By applying sinusoidal wave signal to the piezoceramic, it induces piezoceramic and glass tube to vibrate and form the pressure nodes in the water. Thus, microparticles inside the glass tube accumulate on the pressure nodes. 169, 394 and 932 kHz was used for excitation frequency in the simulation.

In this experiment, the above-mentioned piezoceramic plate (No.355, APC International, PA USA) was glued (Insta-Flex+, Bob Smith Industries, CA, USA) to the glass tube (Glass Pasteur Pipet, Corning, NY USA). In this experiment, the sinusoidal signal with frequencies of 173, 390 and 976 kHz were used. The signal was generated from a function generator (AFG3000, Tektronix, Beaverton, OR, USA) and then amplified (ENI 240L, NY USA). To maximize device efficiency, impedance matching unit was made to adjust piezoceramic's impedance to ≈ 50 Ω. A temperature of piezoceramic and glass tube were constantly monitored by laser thermometer (AR320, Arco Science & Technology Ltd, Guangdong PRC). 20-µm microparticles (02708-AB, SPI supplies, PA USA) were suspended (1% w/w) in DI water.

Results and Conclusions

In this study, we found that results from our numerical simulation results agree well with experiment results to predict excitation frequency and location of pressure nodes in the glass tube. Activation of acoustics could induce glass tube to vibrate in different vibration mode by adjusting excitation frequency. The vibration direction should be perpendicular to the glass tube. In this work, we demonstrate three excitation frequencies which accumulate microparticle along a radial axis. Lowest frequency which accumulates microparticles to the centre is 173 kHz (See Fig 1b), while predicted frequency from the numerical simulation is 169 kHz (See Fig 1a). This slight shift may due to the inaccuracy of material property value or inconsistent thickness of the glass tube. Inside the glass tube, most of the microparticles were gradually move toward the centre of the tube. Next harmonic frequency is at 390 kHz which splits microparticles to two large group near to the centre and two small groups away from wall (Horizontal streamlines in Fig 2b.), while the corresponding pattern in the simulation appears at a frequency of 394 kHz. Lastly, at 976 kHz, microparticles establish four main streamlines along the radial axis and its corresponding pattern in the simulation appear at a frequency of 932 kHz. At high frequency, sound wavelength in water is short. So that the distance between pressure nodes is reduced and the number of observable pressure nodes in the glass tube also increases. However, in the simulation, some microparticles move back and forth in across the cross-sectional plane of the glass tube. This might be due of lack of secondary Bjerknes force (attractive inter-particle force) which gather microparticles into a lump (Garcia-Sabaté et al. 2014). In the experiment, this lump may gradually grow and get trapped in the pressure node at the centre of the glass tube.

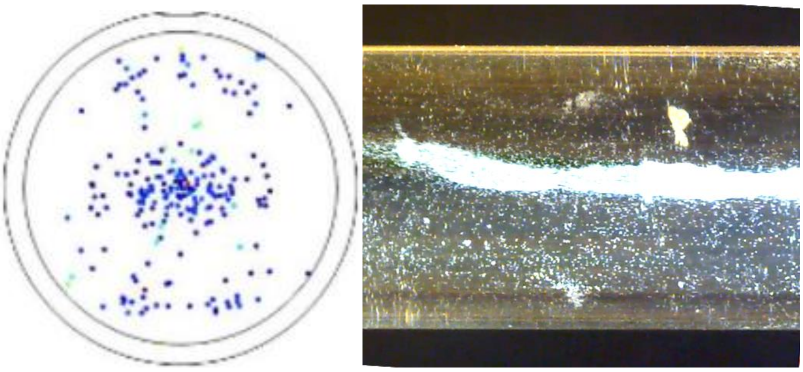

Figure 1 Accumulation of microparticles in cylindrical glass tube (a) simulated results at 169 kHz, (b) experiment results at 173 kHz

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