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Simulation of Ultrasonic Separating Particles Technology for Microfluidic Channel

Zhujie Bao, Yefei Li*, Yin He, Zhenxuan Jiang, Meixia Li, Hao Ge and Yangchun Ye

Jiangsu University, Zhenjiang, China

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***Corresponding author:** YefeiLi, Jiangsu University, Zhenjiang, China, Email: 2450986514@qq.com

Abstract

In order to verify that standing acoustic surface waves (SSAW) are used for the separation of lubricating oil particles in a microfluidic channel (φ50um), the theory and principles of particle separation using SSAW microfluidic channels are described. Software Comsol was used to simulate the movement and separation effects of the particles under different stages of the acoustic radiation force. The simulation can more accurately calculate the particle displacement in the SSAW microfluidic channel. The results of the study show that the rational design of microfluidic size and the reasonable choice of surface acoustic wave (SAW) transducer frequency can be applied to the separation of different microfluidic size impurity particles.

Keywords: Microfluidic channel; Particle separation; Standing surface acoustic wave (SSAW); Simulation

Introduction

Microfluidic chip is a kind of application of MEMS [1]. In recent years, with the rapid development and application of ultrasonic technology and microfluidic chip technology [2-4], ultrasound separation technology has begun to be applied in medical test analysis, drug synthesis and composition screening, and biomedical field, as well as environmental detection and monitoring, criminal science, military science and space science and other fields [5-10]. Ultrasound separation technology will be further expanded to include all aspects of component detection and analysis. When analyzing blood, red blood cells and white blood cells must be classified. This process is usually achieved by means of centrifugation [11], but this method does not apply to microsystems. Because the centrifugation method requires a very high speed. At this point the microfluidic chip separation method has become an effective way. Ultrasound separation methods can also be applied to blood cleansing in cardiac surgery [12]. Concentration of fat particles in the blood is very dangerous when performing cardiac surgery. These particles can cause capillary embolism in the patient's brain. Ultrasound separation technology removes fat particles from the blood stream and allows continuous operation. This becomes the preferred method of blood cleansing procedures.

In the aerospace and mechanical fields, foreign particles in the engine oil can cause engine wear and reduce the life of the engine and even cause major accidents [13]. This requires the removal or detection of foreign particles in the oil as much as possible. Conventional methods of purifying oil in the engine oil include sedimentation, distillation, pickling, caustic washing, filtration etc., although they can remove impurities from the oil to some extent [14-18]. Particles, but for large-scale precision machines (such as vehicle engines, fighter jets); require oil particles as low as a few microns in size, which is difficult to achieve with traditional separation methods. Ultrasonic separation and aggregation techniques may result in more selective, accurate, and reliable analytical results. Therefore, it is of great significance for pre-processing techniques such as separation or aggregation of samples.

The microfluidic chip is a device that uses acoustic radiation force to separate particles and can be applied to the purification of impurity particles in engine oil. In this paper, the ultrasonic standing wave field and the principle of generating acoustic radiation force are studied. Through simulation by software Matlab and Comsol, the microfluid size is rationally designed and the SAW transducer parameters are reasonably selected to provide ultrasonic separation technology for impurity particles in lubricating oil. A feasible research method.

The Basic Theory of Standing Wave and Acoustic Radiation Force

Standing wave generation

In a boundary less medium, continuous vibration sources of disturbance generate continuous harmonics that continue to propagate outward. However, if the medium is bounded, the wave will be returned to the wave source and interfere with the waves generated by the wave source, resulting in a complicated process under certain conditions. The result is a standing wave or structural vibration. Therefore, when considering the same SAW propagating in the opposite direction on both sides of the microfluidic channel,

$$u_{1(x,t)} = \frac{1}{2} e^{i(\gamma x - \omega t)} \text{ .... } 1$$

$$u_{2(x,t)} = \frac{1}{2} e^{-i(\gamma x + \omega t)} \text{ .... } 2$$

The total movement is the superposition of these two waves, ie

$$u(x,t) = u_{1(x,t)} + u_{2(x,t)} = \frac{1}{2} e^{i(\gamma x - \omega t)} + \frac{1}{2} e^{-i(\gamma x - \omega t)} = \frac{1}{2}(e^{i\gamma x} + e^{-i\gamma x}) e^{-i\omega t} \text{ ......} 3$$

Consider the Euler formula, $\cos\alpha = \frac{1}{2}\left(e^{i\alpha} + e^{-i\alpha}\right)$, so equation (3) will be changed to

$$u(x,t) = (\cos\gamma x) e^{-i\omega t} \text{ ....} 4$$

Formula (4) represents a standing wave with a spatial shape of $(\cos\gamma x)$ and harmonic variation amplitude of $e^{-i\omega t}$. Standing waves have specific nodes and anti-nodes and have a fixed position in space. Over time, the amplitude of wave bending increases or decreases, but the nodes remain fixed.

Acoustic radiation force generation

These lead the microparticles to migrate toward the pressure node or antinode depending on size, density, and compressibility of the particles. The expression of acoustic radiation force generation F_{SSAW} is shown as following [19]

$$F_{SSAW} = -\left(\frac{\pi u^2 V \beta_m}{2\lambda}\right)\varphi(\beta,\rho)\sin(2kx) \text{ .... (5)}$$

$$\varphi(\beta,\rho) = \left(\frac{5\rho_P - 2\rho_m}{2\rho_P + \rho_m} - \frac{\beta_P}{\beta_m}\right) \text{ .... (6)}$$

Here, u, V, λ, ρ_p and ρm are the acoustic pressure amplitude, particle volume, wavelength, particle density and oil density, respectively. βp and βm are compressibility's of the particle and the medium, respectively. x is the distance from the pressure node to the initial particle position. k is the wave number. $\varphi(\beta,\rho)$ is the acoustic contrast factor. The shape and position of the acoustic wave are depending on the design of SSAW microfluidic channel. In this research, u is 50V, the density of liquid ρp is 945kg/m^3, particle density is 7850 kg/m^3, viscosity coefficient is 13m2/s and wave length λ is 1000μm,

Acoustic Wave Separation Technology Used for Particle Separation Simulation Analysis in Microfluidic Channels

The relationship between frequency and radius

When the position of the particle is constant and the SAW amplitude is constant, the relationship between the minimum SAW frequency of the separated particle and the particle radius satisfies the relationship

$$32\pi^4 \rho_p A^2 K_S f_{0\min}^2 = 6\pi\mu v + 4\pi\beta 6\mu v + 4.12\beta\mu v R_\varepsilon \text{ ....(7)}$$

Substitute the corresponding parameters to get the relationship between the minimum frequency and the particle radius as shown in Figure 1. As shown in Figure 1, the smaller the particle radius, the larger the minimum IDT frequency required to separate particles, that is, the smaller the impurity particle radius in the medium, the more difficult it is to separate. When the IDT center frequency used is 5MHz, the smallest particle radius that can be separated is 2.4μm, which satisfies the requirement for less than 10μm particles that are difficult to separate in the microfluidic channel.

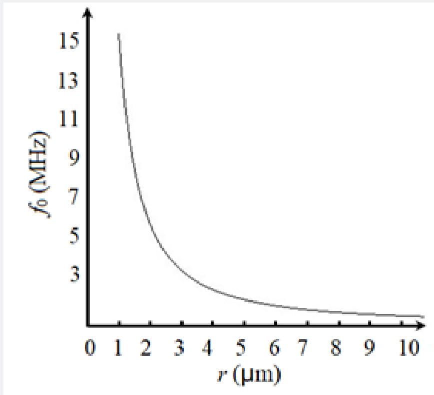

Figure 1: Relationship between standing wave frequency and particle radius.

Software Comsol was used for numerical simulation modeling and analysis. When the microfluidic channel was used with a width of 500μm, a depth of 300μm and a laminar flow velocity of 10mm/s, the particle motion velocity was 1mm/s, the excitation signal was a sine wave and the standing wave was calculated when the excitation frequency was 5MHz. produce. By adjusting the frequency, changing the wavelength, and controlling the standing wave through changes in nodes and antinodes, a change in the acoustic radiation force can be obtained. Figure 2 shows the sound pressure distribution of the microfluidic channel under the SSAW. The change of the sound pressure distribution before and after the standing wave can be used to analyze the force of the particles. It can be seen from the figure that the position of the sound pressure balance is located at the crest and trough the middle position.

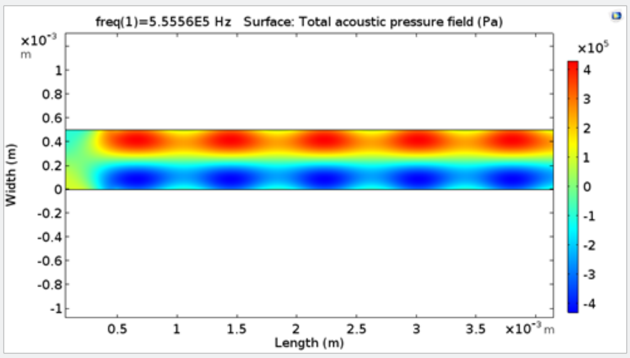

Figure 2: Sound pressure distribution of micro fluidic channel under SSAW.

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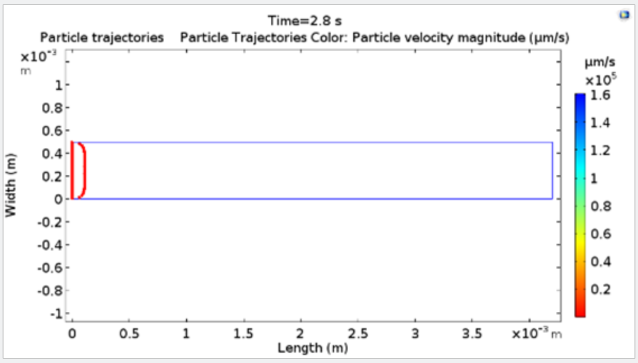

Figure 3a: Particle distribution at 0.1s.

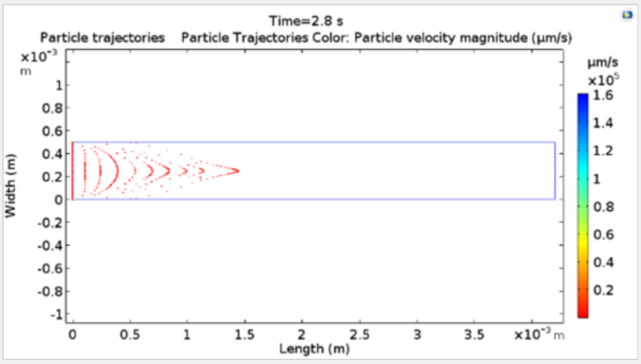

Figure 3b: Particle distribution at 1s.

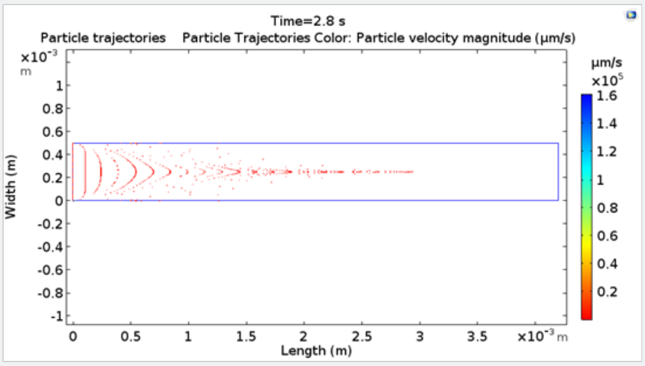

Figure 3c: Particle distribution at 2s.

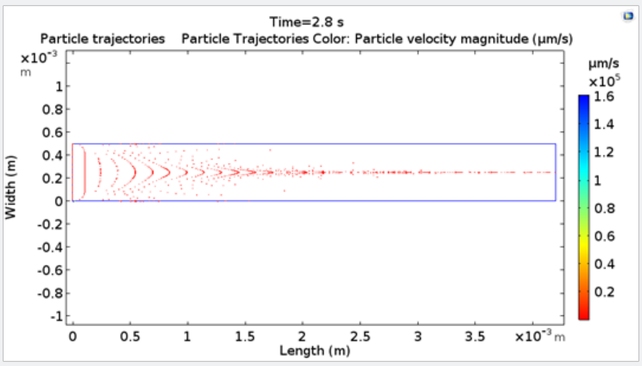

Figure 3d: Particle distribution at 3s. The distribution of particles at different moments under the action of SSAW.

Figure 3a-d shows the distribution of particles when the time is 0.1s, 1s, 2s and 3s respectively. It can be seen from the figure that when the frequency is reduced to a certain degree, particles are gradually concentrated toward the center due to the effect of the standing wave. A band of particles concentrates, thus verifying the effect of frequency changes on particle concentration effects. When the microchannel width is half the wavelength, a complete particle concentration band can be formed. The acoustic radiation force can push the metal particles to move toward the pressure node, and the particles are separated by adjusting the position of the pressure node.

Conclusion

This paper describes the theory and principle of using SSAW microfluidic channel for particle separation. Through the simulation, the phenomenon of concentration of suspended particles in lubricating oil under the action of SSAW is realized, which provides research conditions for further analysis of the separation of suspended particles. Due to the large interference of the tiny particles in the viscous fluid, the force of the particles under different flow conditions will undergo a greater change. Therefore, how to accurately and comprehensively analyze the forces and movements of the particles in the microchannels will have the effect on the separation of particles. Larger impacts are important for achieving the aggregation of particles.

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