# PARTICLE FLOW SWITCH UTILIZING ULTRASONIC PARTICLE SWITCHING IN MICROFLUIDIC CHANNELS

**Filip Petersson, Andreas Nilsson, Henrik Jönsson and Thomas Laurell**

*Department of Electrical Measurements, Lund Institute of Technology, P.O. Box 118, S-222 10 Lund, Sweden*

**Abstract**

This paper describes a method to switch suspended particles from one medium to another. The method combines an ultrasonic standing wave field with the laminar flow properties of a silicon micro channel. Suspended particles in a contaminated medium enter the channel through side inlets and a clean medium enters through a centre inlet, forming three laminated streams. Acoustic radiation forces subsequently drive the particles in the suspension into the middle of the channel thereby switching them from the contaminated medium to the clean. The channel is split into three exit channels separating the particles, now in the clean medium, from the contaminated fluid in the side outlets via the centre outlet. Experiments have shown that more than 90% of the contamination can be removed using this method.

**Keywords: particle separation, radiation force, ultrasound, suspended particles**

## 1. Introduction

If suspended particles are exposed to an ultrasonic standing wave field they are affected by acoustic radiation forces. These forces move the particles towards either the pressure nodes or the pressure anti-nodes depending on the density and compressibility of the particles and the medium [1]. By combining this effect with laminar flow in a micro channel the particles can be separated from their original medium [2-3]. The channel must have vertical side walls and a width chosen to correspond to one half of the ultrasound wavelength. This results in an acoustic standing wave between the vertical side walls, perpendicular to the direction of flow (Figure 1).

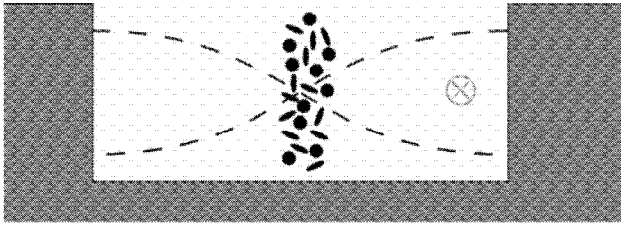

**Figure 1.** Cross section of a channel with particles focused in the acoustic standing wave node by the acoustic radiation forces. The direction of the flow is into the paper.

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A pressure node is generated along the middle of the channel and one pressure anti-node along each channel wall. If the density of the particles is higher than that of the medium they will be forced into the node as they flow along the channel. The end of the channel is split into three outlets (Figure 2 and 3). When using a micro fluidic structure with only one inlet the particles will exit the channel through the centre outlet together with some of the medium while most of the medium exits through the side outlets. However, in some applications of particle separation, for example blood washing, the medium (blood plasma) can be contaminated and must be totally separated from the particles. This can be achieved by modifying the separation channel inlet. When recovering blood during post surgery treatment the blood plasma is commonly heavily contaminated by inflammatory and complement activation factors that need to be removed before reinfusing the erythrocytes to the patient. Today this is done by collecting a large volume of shed blood (about 500 ml); centrifugation of the volume; removal of the supernatant and subsequent reinfusion of the collected erythrocytes. This paper proposes a new approach to blood washing utilizing a modified version of the earlier reported principle for fat emboli reduction in intraoperatively recovered blood [2-3].

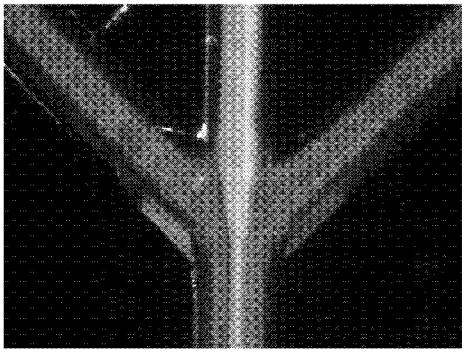

**Figure 2:** The end of the channel is split into three outlets. If the ultrasound is turned on the almost all particles will exit through the centre outlet.

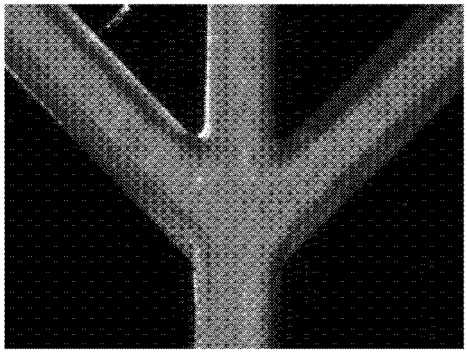

**Figure 3:** If the ultrasound is turned off the mix of particles and medium will be uniform in all outlets.

If the inlet thus is split in three (the original channel had only one inlet), like the outlet, and the suspended particles enter through the side inlets and a clean medium enters through the centre inlet the particles can be switched from the contaminated medium to the clean by the acoustic forces (Figure 4).

## 2. Theory

Pressure fluctuations (sound waves) in a liquid medium result in radiation forces on suspended particles. As long as the diameter of the particles is smaller than half the wavelength of a periodic fluctuation these forces will act mainly in one direction and the particles will move against either a pressure node or a pressure anti-node. The acoustic impedances of the particles and the medium must differ otherwise no net force will be exerted on the particles. The direction and size of the force is defined by the acoustic force theory presented by Yoshioka and Kawashima [1] (Equation 1 and 2).

$$F_r = -\left(\frac{\pi p_0^2 V_c \beta_w}{2\lambda}\right) \cdot \phi(\beta,\rho) \cdot \sin(2kx) \tag{1}$$

$$\phi = \frac{5\rho_c - 2\rho_w}{2\rho_c + \rho_w} - \frac{\beta_c}{\beta_w} \tag{2}$$

$V_c$ is the volume of the particle, $p_0$ is the pressure amplitude and $\phi$ is defined by Equation 2. The density of the medium and particles are denoted $\rho_w$ and $\rho_c$ respectively and the corresponding compressibilities $\beta_w$ and $\beta_c$. It can be noted that the sign of the force depends on the $\phi$-factor which is dependent of the densities and compressibilities of the particles and the medium.

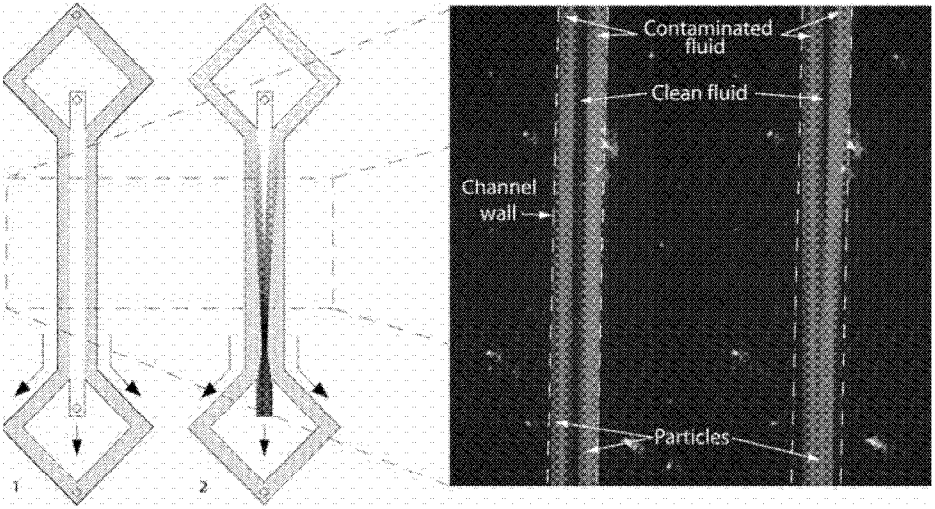


**Figure 4:** When the ultrasound is turned off (1) the particles will stay with the contaminated medium in the flow lines along the walls of the channel. When the ultrasound is turned on (2) they will instead be shifted over to the clean medium in the flow lines in the middle of the channel.

## 3. Experimental

The separation channel (350 μm wide and 250 μm deep) was etched into a <100>-silicon wafer using anisotropic wet etching. The channel was sealed with a glass lid by anodic bonding and silicone tubes were glued to the inlets and outlets on the backside. The ultrasonic excitation (2 MHz) was made from the backside by attaching a piezo ceramic crystal with ultrasonic gel. The flow was controlled using two syringe pumps (0.1 ml/min through all inlets). Care was taken to balance the flows in the side outlets and the centre outlet. A contaminated fluid with suspended particles was simulated by a mixture of latex spheres (5 μm in diameter), blue pigment (Evans blue) and distilled water and a clean medium with distilled water only. The same experiment was then repeated using blood contaminated with "Evans blue" and non-contaminated blood plasma. A spectrophotometer was used to measure the degree of contamination.

## 4. Results and discussion

Because of the intense colouring from "Evans blue" contamination of the clean medium in the centre channel could be detected visually. Observations showed that the contaminated fluid that entered through the side inlets exited through the side outlets with very little contamination of the clean medium in the centre of the channel while the particles were shifted from the contaminated fluid to the clean. More than 95% percent of the particles were shifted from the contaminated medium to the clean and exited through the centre outlet. Absorbance measurements confirmed these observations. Less than 5% of the contaminant exited the system through the centre outlet when latex particles were shifted from contaminated distilled water to clean distilled water. The corresponding measurements on contaminated blood showed that less than 15% of the contamination followed the red blood cells out through the centre outlet.

## 5. Conclusion

The experiments have shown that this method is a powerful complement to the original particle separation method described by Nilsson et al. [2-3]. Suspended particles can be almost totally separated from their medium. One application of this method is the washing of erythrocytes recovered during post surgery treatment. Further efforts focus on improving separation efficiency.

## References

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