A Lateral Mode Flow-through PMMA Ultrasonic Separator

N.R.Harris*[1], A. Keating[2], and M. Hill[3]
[1]School of Electronics and Computer Science, University of Southampton, SO17 1BJ, UK,
[2]School of Electrical, Electronic and Computer Engineering, The University of Western Australia, Crawley, WA, Australia
[3]School of Engineering Sciences, University of Southampton, SO17 1BJ, UK,

*Corresponding author: Email nrh@ecs.soton.ac.uk

Abstract: A flow-through ultrasonic separator constructed entirely from PMMA has been demonstrated for the first time. Continuous extraction of lipids from milk has been achieved. Construction is simple, requiring channels to be embossed at low temperatures (120°C) with a room temperature solvent bond used to close the channel.

1 Introduction: Ultrasonic standing waves have been used previously to allow particle concentrators and separators to be realised. Such devices can either be lateral or planar in their operating mode, with planar devices being more suitable for concentrating particles onto a surface [3], and lateral devices being more suitable for continuous separation [1]. In both cases construction has been from acoustically hard materials such as glass and silicon, resulting in complex construction requiring specialist equipment. Recently planar devices, constructed from more convenient materials such as plastic (PMMA) have been shown to be viable[4].

In this paper we extend the use of plastic and demonstrate for the first time a flow-through lateral separator constructed entirely from PMMA, offering the potential for easily constructed and disposable flow-through separators for lab-on-chip style systems.

2 Theory: Theory developed in [2] for compressible material in a fluid shows that the time-averaged acoustic radiation force on a spherical particle of radius a, at position x within a one dimensional standing wave of acoustic energy density ε is given by:

$$F(x) = 4\pi k \varepsilon a^3 \, \Phi(\beta,\rho) \sin(kx) \qquad (1)$$

$$\Phi(\beta,\rho) = \frac{\rho_p + \frac{2}{3}(\rho_p - \rho_f)}{2\rho_p + \rho_f} - \frac{\beta_p}{3\beta_f} \qquad (2)$$

where β and ρ are the compressibility and the mass density of the fluid and the particle, indicated by subscripts f and p respectively. The wave number, k is equal to $2\pi/\lambda$ where λ is the wavelength, and the compressibility is related to the speed of sound, c, by $\beta = 1/\rho c^2$.

The practical result of this is that particles will move to either the node or antinode of the standing wave, dependent of the value of Φ.

Although 1-D modelling allows the prediction of planar solutions where the dimension of interest is an integer number of half-wavelengths, in practice 2-D effects are noticed, resulting in irregularities within the acoustic field [5]. By trying to enhance the lateral acoustic modes, it is possible to create separators that allow lateral modes to be dominant, resulting in separation effects orthogonal to the direction of the applied field. As lipids move to pressure antinodes, a device with a width of half a wavelength would result in the lipids being driven to the sidewalls. However, a device with a width of one wavelength allows concentration within the centre of the channel, as well as at the walls. Previous researchers have overcome this by using hydrodynamic focussing to pre-concentrate the subject fluid into a central area. For this study we were interested in confirming the suitability of PMMA and were therefore expecting results at the side wall. However, as can be seen in figure 3, it is possible to not have concentration at the side, but just in the centre. In this device, this is believed to be due to imperfections in the channel further upstream, but in the acoustically active area causing a pre-concentrating effect, and this will be investigated in more depth in future studies.

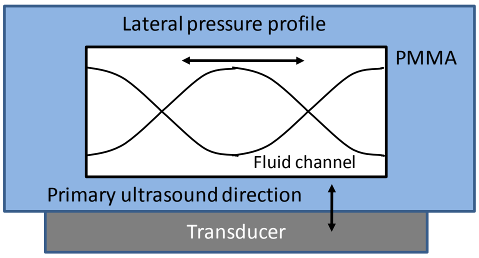

Figure 1 Generation of lateral pressure profile within device, orthogonal to primary acoustic direction.

3 Design and Construction: A device with a nominal channel width of one wavelength was designed, as shown in figure 2.

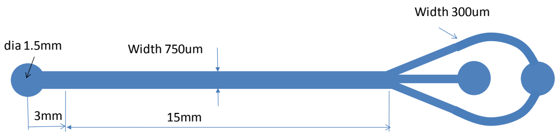

Figure 2 Planar separator design showing channel arrangement

The device was fed by a single inlet and had two outlets as shown. The target width was 750um, corresponding to a drive frequency of 2MHz. The design was converted to a metal mould for the embossing process by etching steel plates with a wet etch process, although other methods such as direct milling could also be used. The resulting moulds had an actual width of 850um and a height of 70um. The mould was used to emboss a channel into a 1.5mm thick PMMA blank, by placing in a hot press and pressing at 125 °C at a force of 1500kg for 30 minutes. A sheet of thin PMMA (125um) is then solvent bonded on top of the channel. Solvent bonding is achieved by pipetting a mix of 33% acetone and 66% ethanol onto one surface, bringing the other surface into contact and applying pressure via a mass for 20 minutes at room temperature.

4: Experiment: Milk was driven via a syringe into the device, and the acoustic field applied with the transducer drive being 25V pk at 2.01MHz. Within a few seconds, separation occurs with the lipids being driven to the antinode in the centre of the channel (fig 3).

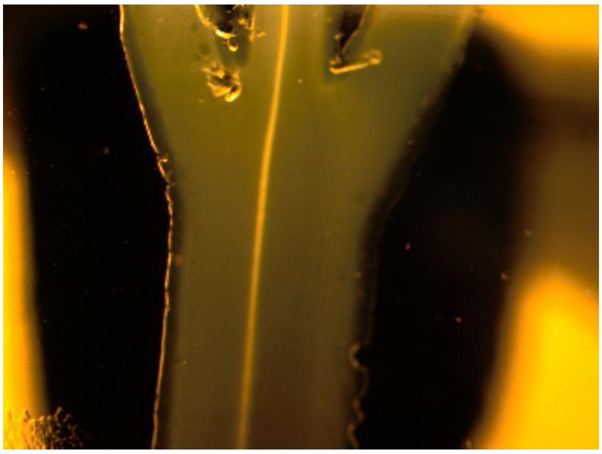

Figure 3 Outlet of channel showing concentration of lipids primarily concentrated into the centre laterally and moving through the centre outlet. Flow is from bottom to top.

5 Conclusion: This work reports a lateral ultrasonic separator fabricated from PMMA, and it is demonstrated that such a device can separate lipids from milk on a continuous basis.

Acknowledgements

This work has been supported by the World University Network

References

[1] Grenvall C, Augustsson P, Riis Folkenberg J, Laurell T, Harmonic Microchip Acoustophoresis: A Route to Online Raw Milk Sample Precondition in Protein and Lipid Content Quality Control *Anal. Chem.* 2009, 81, 6195–6200

[2] Yosioka, K. and Y. Kawasima (1955). "Acoustic radiation pressure on a compressible sphere." *Acustica* 5: 167-73.

[3] Martin, S. P., R. J. Townsend, et al. (2005). "Spore and micro-particle capture on an immunosensor surface in an ultrasound standing wave system." *Bio-sensors and Bioelectronics* 21(5): 758-767.

[4] Glynne-Jones, P.,Boltryk, R., Hill,M., Harris, N. and Baclet, P. (2009) Robust acoustic particle manipulation: a novel thin-reflector design for moving particles to a surface. *Journal of the Acoustical Society of America*, 126 (3). EL75-EL79

[5] Townsend, R., White, N., Harris, N., and Hill, M. (2006) Investigation of two-dimensional acoustic resonant modes in a particle separator. *Ultrasonics, 44 (Supple*). e467-e471