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Liquid carry-over in an injection moulded all-polymer chip system for immiscible phase magnetic bead-based solid-phase extraction

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ABSTRACT

We present an all-polymer, single-use microfluidic chip system produced by injection moulding and bonded by ultrasonic welding. Both techniques are compatible with low-cost industrial mass-production. The chip is produced for magnetic bead-based solid-phase extraction facilitated by immiscible phase filtration and features passive liquid filling and magnetic bead manipulation using an external magnet. In this work, we determine the system compatibility with various surfactants. Moreover, we quantify the volume of liquid co-transported with magnetic bead clusters from Milli-Q water or a lysis-binding buffer for nucleic acid extraction (0.1 (v/v)% Triton X-100 in 5 M guanidine hydrochloride). A linear relationship was found between the liquid carry-over and mass of magnetic beads used. Interestingly, similar average carry-overs of 1.74(8) nL/μg and 1.72(14) nL/μg were found for Milli-Q water and lysis-binding buffer, respectively.

1. Introduction

Paramagnetic particles or magnetic beads (MBs) are increasingly being applied within different fields of science as sensors, labels, carriers/separators *etc.*, [1]. In particular, the use of MBs as the solid-phase matrix for solid-phase extraction (SPE) has become popular and spawned a number of commercial kits and functionalised particle solutions [2,3].

Within the last ten years a variant of MB-based SPE has emerged, where an immiscible phase is used as a filtering step to circumvent the washing steps otherwise needed to perform a successful extraction. This is done by transporting the target–MB cluster through an immiscible phase, such as oil [4–6], wax [4,7,8], or air [8], often using an external permanent magnet. Such systems have been demonstrated for a number of applications including enzyme linked immunosorbent assays [6,9,10], nucleic acid extraction [4,7,8,11–14], protein extraction [8], and cell extraction [15,16].

The efficacy of these immiscible phase filtration systems relies heavily on the ability to limit the amount of co-transported liquid with the MB cluster. They are mostly "open" systems, often connected by capillary microvalves that rely on surface tension forces to function. Interface tension is, however, a complex entity that together with the rest of the system is influenced by a number of parameters. These include, but are not limited to MBs (size, amount, magnetisation, transport speed and morphology); liquid viscosity; dimensions of the capillary microvalve; surface modifications (chemical or physical); magnet geometry; strength of the magnet; magnet to MB cluster distance; any agents altering the intrinsic surface energy of the respective liquids, such as surfactants. The amount of co-transported liquid is thus an important benchmark and has been reported for a number of different published systems. However, all of these systems vary in respect to the parameters stated above, so a direct comparison should be done with caution. The carry-over, that is, the amount of co-transported liquid per mass of MBs, does, however, provide a simple number for the efficacy of the system.

Shikida et al. determined an average carry-over of 0.08 nL/μg using 150–600 μg of 32.7 μm MBs in a 10% KCl solution [5]. Chen et al. reported 3.62 nL carry-over of water using 5×10^5 MBs having a diameter of 3.12 μm amounting to approximately 0.37 nL/μg [6]. Sur et al. used 40–180 μg of 450 nm MBs to estimate the carry-over of Tris buffer in their system amounting to 2.02 nL/μg. They also tested guanidinium isothiocyanate (GuSCN) and ethanol carry-over using 85 μg MBs [7]. Berry et al. did not report details of their carry-over; however, they claim to be able to successfully extract 5.95 μg MBs in a 1% Triton X-100 (TX-100) PBS solution [4]. den Dulk et al. reported an average

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Table 1
Summary of liquid carry-over reported for immiscible phase magnetic bead-based SPE systems in the literature. Volume denotes the starting liquid volume.

Study	*Volume* (μL)	*Avg. carry-over* (nL/μg)	*Bead type*	*Bead diameter* (μm)	*Bead mass* (μg)	*Surfactant*	*Immiscible phase*
Shikida et al. [5]	50	0.08*	Non-commercial	32.7	150–600	None	Silicone oil
Chen et al. [6]	0.14	0.39*	Bangs laboratories	3.18	9*	None	Silicone oil
Sur et al. [7]	50	2.02	Ambion MagMax	0.45	40–180	None	Liquid wax
Berry et al. [4]	8.5	N/A	Oligo-dT Dynabeads	2.8	6*	1% TX-100	Olive oil
den Dulk et al. [8]	14	0.86	M-270 COOH Dynabeads	2.8	150	None	Air
This work	200	1.74	MyOne SILANE	1.0	10–120	None	FC40 oil
This work	200	1.72	MyOne SILANE	1.0	10–60	0.1% TX-100	FC40 oil

* Indicates that the values were not stated directly and had to be estimated.

water carry-over of 0.86 nL/μg using 150 μg of 2.8 μm MBs [8]. An overview of the reported characteristics is given in Table 1.

A common feature of microfluidic chip systems is that they are rapid prototyped, meaning that they are produced by hand in small volumes, since the fabrication methods are most often not applicable in an industrial setting [17]. In this study, we present a planar chip system that has been fabricated using industrially relevant machinery. The main chip part containing the channels and Luer inlets and outlets is injection moulded in COC and sealed with a COC foil lid using ultrasonic welding – both techniques can readily be applied in mass production. This approach provides a substantial number of single-use chips for research and circumvents the need for re-thinking the design and materials for a production scale-up. The chip is fitted with geometric capillary microvalves for MB-based SPE using immiscible phase filtration and is capable of handling sample volumes up to 200 μL.

We first determine the basic parameters needed to investigate the influence of surfactants on the liquid handling compatibility of the system. Next, we systematically investigate the volume of co-transported liquid for the system as function of the amount of magnetic beads suspended in milli-Q water and in a lysis-binding buffer containing detergent, which is typically used for SPE extraction of nucleic acids using the Boom method [18].

2. Experimental section

2.1. Chip fabrication

The polymer chip consists of two parts: an injection moulded main part of Cyclic Olefin Copolymer (COC) (TOPAS grade 5013L-10) and a 0.152 mm thick extruded COC foil (TOPAS grade 5013S-04), both from TOPAS Advanced Polymers GmbH, Frankfurt-Höchst, Germany. Injection moulding was conducted on an Engel Victory 80/45 Tech injection moulder (ENGEL, Schwertberg, Austria) fitted with a custom computer numerical control milled aluminium mould insert, featuring the negative counter-part of the microfluidic layout on one side of the injection moulding tool, and a Luer-Slip layout counter-part with through-holes on the other, see [19] for details. To complete the chip, the injection moulded part was bonded to the COC foil using a Telsonic USP4700 ultrasonic welder (Telsonic, Erlangen, Germany).

2.2. Chip design

The assembled chip is disc shaped (⌀=50 mm) and built for immiscible phase filtration SPE using MBs. It features a Luer-Slip layout with an inlet channel connected to an oil-containing parallel "filter" channel via a geometric capillary microvalve. The filtration channel is further connected to an outlet chamber *via* another capillary microvalve. Energy director welding seams (height=10–18 μm) are located all around the channel lay-out and enable bonding by ultrasonic welding. Fig. 1(a,b) shows the design and a photograph of the chip system. The red arrow denotes the motion path of the permanent magnet stack and thus the path of the MB cluster during extraction. The blue arrows indicate the welding seams and the white arrows show the positions of the geometric capillary microvalves. A zoom-in of the first capillary microvalve with the relevant dimensions can be seen in Fig. 1(c). The width and height of the capillary microvalve are $w=500$ μm and $h=150$ μm, respectively. The channel heights outside the capillary microvalve region are 500 and 300 μm in the inlet/outlet and filter channels, respectively.

2.3. Magnetic bead transportation setup

MB transportation was conducted in a custom built setup consisting of a chip mount set above a Thorlabs LTS150 lateral motorised stage (Thorlabs, Newton, NJ, USA). The stage was fitted with a permanent magnet stack consisting of four axially aligned cylindrical magnets (top to bottom): two N48, NdFeB, ⌀3 mm, 1 mm high magnets (#S-03-01-N, Supermagnete, Germany) and two N45, NdFeB, ⌀6 mm, 3 mm high magnets (#S-06-03-N, Supermagnete, Germany). The magnet stack was positioned so it could be moved around just below the chip.

2.4. Reagents

Solutions used were Milli-Q water, TE buffer and lysis-binding buffer (citrate buffered guanidine hydrochloric acid (GuHCl) (AppliChem, Germany)). For the contact angle and liquid carry-over experiments a 5M GuHCl, pH 4.1 lysis-binding buffer was used and for the surfactant compatibility experiments a 6 M GuHCl, pH 4.5 lysis buffer was used. Surfactants used were Triton X-100 (Sigma-Aldrich, MO, USA), Sarkosyl (Sigma-Aldrich, MO, USA) and Tween-20 (Sigma-Aldrich, MO, USA). Rhodamine B (#R6626, Sigma-Aldrich) was used as fluorophore. 3M fluorinert electronic liquid FC40 oil (Walbom A/S, Kastrup, Denmark) was used as the immiscible phase. Dynabeads MyOne SILANE (Life technologies, CA, USA) were used as MBs. They were 1 μm in diameter (CV < 5%), coated with silanol groups and delivered in a 40 mg/mL stock.

2.5. Contact angle and interfacial tension measurements

Contact angles and interfacial tensions are basic parameters for wetting and passive filling and give insight into the liquid spreading. They are also needed for burst pressure calculations.

The average advancing contact angles ($\theta_{aq,air}$) and interfacial tensions ($\gamma_{aq,oil}$ and $\gamma_{aq,air}$) were measured using a Krüss DSA10 Contact Angle Measuring System (Krüss GmbH, Hamburg).

For the advancing contact angles, a droplet of water, lysis-binding buffer alone, or lysis-binding buffer with either Triton X-100, Sarkosyl, or Tween-20 (the amounts of surfactant indicated in Table 2) was deposited on an injection moulded flat COC (TOPAS 5013L-10) disc using a syringe. The advancing contact angle was

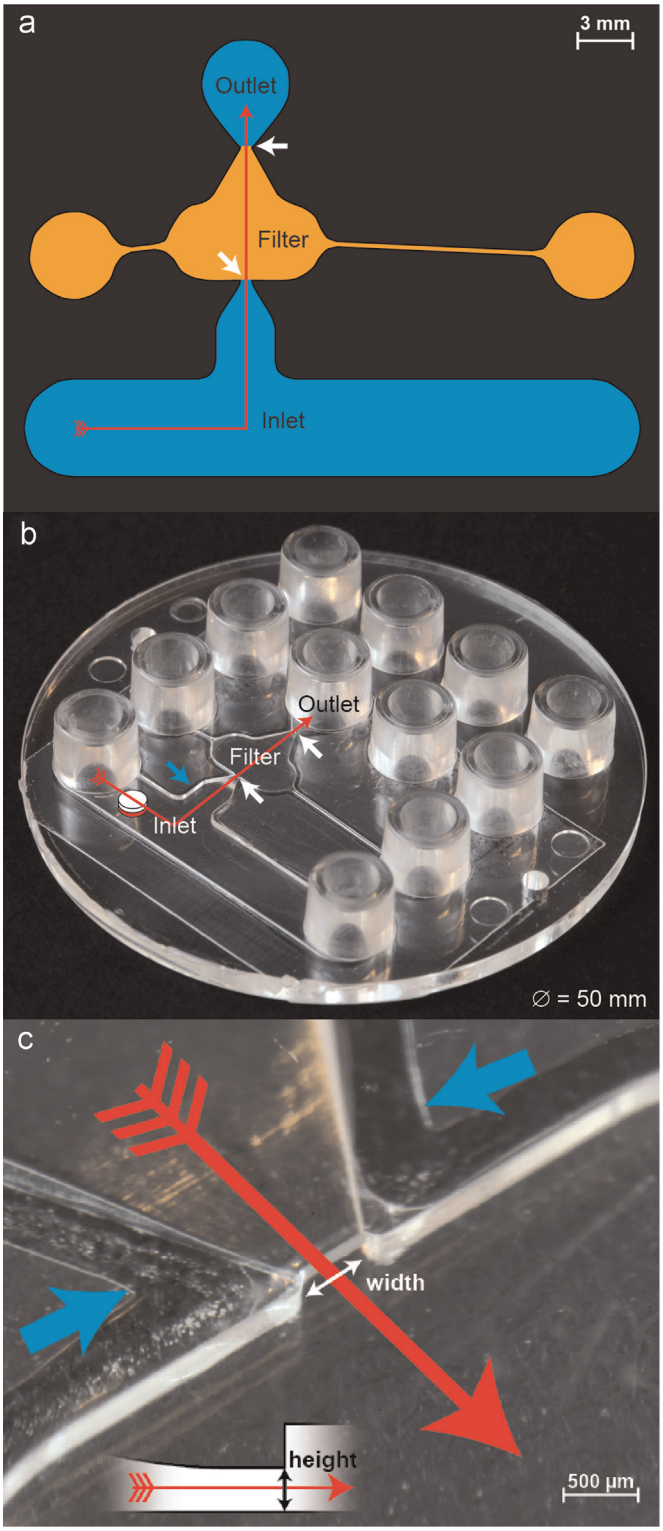

Fig. 1. The chip system. (a) Sketch of the chip design. Blue areas denote aqueous phases, orange area denotes immiscible phase. The red arrow indicates the magnet path from inlet to outlet. White arrows indicate the positions of the capillary microvalves. (b) An overview photograph of the whole chip. The ultrasonic welding seams are located at the blue arrows (c) A zoom-in photograph of the first capillary microvalve. Width $w=500\ \mu m$ and height $h=150\ \mu m$, as sketched in side-view (inset). Note, that the lower image is rotated 90° around the plane of the chip to provide a better view of the capillary microvalve. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

then recorded while the meniscus propagated forward during a continuous increase of the droplet. The chip was then rinsed with Milli-Q water, ethanol, and dried before the process was repeated.

The interfacial tensions were measured using the pendant drop method [20]. For the measurements of $\gamma_{aq,oil}$, FC40 oil was dripped into the various surfactant-containing lysis-binding buffers, since FC40 oil has the highest density (1855 kg/m^3).

2.6. Burst pressure calculations

The burst pressure is used to predict whether or not the solution meniscus will propagate through a capillary microvalve, and is hence an important reference parameter for designing geometric capillary microvalves.

Capillary microvalve burst pressures for the filling of aqueous solutions were estimated using the Young–Laplace equation modified for a rectangular capillary microvalve derived by Cho et al. [21]:

$$p_{burst} = -\gamma\left(\frac{2\cos\theta}{w} + \frac{\cos(\min\{\theta+\alpha, 180°\})}{h} + \frac{\cos\theta}{h}\right), \quad (1)$$

where $\alpha=90°$, $h=500\ \mu m$, $w=150\ \mu m$, $\theta=\theta_{aq,air,}$ and $\gamma=\gamma_{aq,air}$ for the solution under investigation. The hydrostatic pressure exerted by the liquid column in the Luer-Slip inlet was calculated to $p_{hyd}=\rho gh=998\ kg/m^3\times 9.82\ m/s^2\times 6\ mm=59\ Pa$. The Young–Laplace pressure inside the luer was calculated using $p_{luer}=-2\gamma_{aq,air}(\cos\theta_{aq,air}/r_{luer})$, where $r_{luer}=2\ mm$.

2.7. Surfactant compatibility with chip

Compatibility was defined as the ability to form a stable liquid system during filling, and to transport the MB cluster without forming a liquid bridge through the oil phase connecting the two chambers. If this was achieved, the system was considered compatible with MB-based SPE.

For the compatibility experiments, the following liquids were added sequentially to the respective Luer reservoirs (*cf.* Fig. 1): (1) 100 µL of lysis-binding buffer (inlet), (2) 100 µL TE buffer (outlet), and (3) 50 µL FC40 oil (filter). Subsequently, 40 µg of MyOne SILANE MBs was added to the inlet and transferred to the outlet by moving the external permanent magnet at 1 mm/s using the motorised stage.

2.8. Liquid carry-over determination

The liquid carry-over was estimated by relating the concentration of rhodamine B in the starting solution, to the concentration of rhodamine B post-extraction in the outlet chamber.

The chip was mounted in the setup with the magnet situated under the inlet Luer. 200 µL of 2 mM rhodamine B containing solution was pipetted into the inlet channel and 100 µL solution without dye was pipetted into the outlet chamber. 100 µL FC40 oil was added to the middle filter channel to complete the loading. Various volumes of the MB suspension corresponding to MB masses between 10 and 140 µg were then added to the inlet from a 1:10 diluted stock. MBs were then transferred from the inlet to the outlet by moving the magnet at 1 mm/s. After removing the magnet from the outlet chamber, the MBs were resuspended and 90 µL of the outlet solution was transferred to a microtiter plate. The MBs were then removed using a PickPen (Bio-Nobile, Pargas, Finland).

The liquid carry-over volume was estimated from analysis of the dye content of the microtiter plate well. The microtiter plate was placed in a LaVision BioAnalyzer 4F/4S Scanner (LaVision Biotech Germany) and exposed to 1 ms of light through a Cy3 filter. The concentration of rhodamine B in the outlet was

Table 2
Compatibility of various surfactants with the chip system including the measured interfacial tensions ($\gamma_{aq,oil}$ and $\gamma_{aq,air}$), advancing contact angles ($\theta_{aq,air}$), burst pressures (p_{burst}) calculated using Eq. (1), and $\Delta p = p_{burst} - p_{hyd} - p_{luer}$, where p_{hyd} and p_{luer} are the hydrostatic and capillary pressures of the luer inlet, respectively. A chip was considered compatible if filling of the chip was successful and a 40 μg MB cluster could be transported across the immiscible phase without bridge formation. In the case of 0.25% Triton X-100 and 0.125% Sarkosyl, the filling was unsuccessful. All solutions apart from Milli-Q water were prepared from surfactant free lysis-binding buffer.

Solution ((v/v)%)	$\gamma_{aq,oil}$ **(mN/m)**	$\gamma_{aq,air}$ **(mN/m)**	$\theta_{aq,air}$ **(deg)**	p_{burst} **(Pa)**	Δp (Pa)	***Compatibility***
Milli-Q water	44.1 ± 0.4	72.0 ± 0.0	96.1 ± 2.6	562	495	YES
0.1% Triton X-100	9.5 ± 0.1	52.8 ± 1.0	63.5 ± 2.6	101	65	YES
0.25% Triton X-100	6.2 ± 0.2	42.8 ± 0.6	50.7 ± 6.5	−4	−36	NO
0.0625% Sarkosyl	7.8 ± 0.2	44.7 ± 1.0	64.0 ± 4.8	89	50	YES
0.125% Sarkosyl	5.3 ± 0.4	39.0 ± 0.6	41.3 ± 5.2	-53	-82	NO
1% Tween-20	8.3 ± 0.2	49.2 ± 0.7	65.6 ± 4.9	111	73	YES

estimated using a standard curve generated from reference concentrations (0–5 μM) of rhodamine B over 11 steps. The obtained outlet concentration c_{outlet} was converted to a volume using $(c_{outlet}/c_{inlet})V_{outlet}$, where c_{inlet} is the inlet dye concentration (corrected for the addition of the magnetic bead suspension) and V_{outlet} is the outlet volume.

Two series of data were recorded; one with Milli-Q water, and one with lysis-binding buffer containing 0.1 (v/v)% Triton X-100. All experiments were performed in triplicate.

3. Results and discussion

The chip presented in this study is designed for MB-based SPE, a process where the starting material is often a complex biological matrix that has to be disrupted in order to gain access to the target of interest, *e.g.* using a combined lysis-binding buffer for nucleic acid extraction. To facilitate this, surfactants are often added to extraction buffers, and it is hence of interest to map the compatibility of the extraction system with common surfactant types and concentrations. Because surfactants alter biological systems they may also interfere with downstream processes relying on proteins. For this reason, knowing the contamination level of surfactant post SPE is important.

3.1. Fabrication process

To fabricate chips we first created a mould insert. This was done through rapid prototyping by CNC micromachining of an aluminium sheet and took 3–5 h. The mould insert was then placed in the injection moulder for chip production. The cycle time of the injection moulder is ~45 s per chip and the ultrasonic welding process takes ~30 s including mounting and release, which allows for an average production time of less than 1.5 min/chip. Ultrasonic welding is fast compared to other common bonding types, such as thermal bonding and has the added feature that it avoids elevated temperatures. The rapid and robust production allows for all experiments to be conducted on new chips, ensuring that the system is indeed single-use compatible.

3.2. Surfactant compatibility

We investigated the compatibility of the different solutions with our system *via* (1) calculation of the burst pressure, and (2) by experimental investigations of the filling and magnetic bead transportation.

Table 2 shows the measurements of the interfacial tensions between the aqueous solutions and the FC40 oil ($\gamma_{aq,oil}$), the interfacial tensions between the aqueous solutions and air ($\gamma_{aq,air}$), and the advancing contact angles of the solutions on COC ($\theta_{aq,air}$).

The Young–Laplace pressures required for the aqueous solutions to burst through the capillary microvalves (p_{burst}) were calculated using Eq. (1). Other important parameters are the hydrostatic pressure exerted by the inlet (p_{hyd}) and the Young–Laplace pressure of the inlet (p_{luer}), see Section 2.6. The success of the filling could then be quantified by the difference $\Delta p = p_{burst} - p_{hyd} - p_{luer}$. A negative difference indicates incompatibility of the system, *i.e.*, that the capillary microvalve will burst. From Table 2 it is evident that the burst pressures of the non-compatible solutions are negative and are hence expected to burst. For the rest of the solutions, Δp is positive indicating that the capillary microvalve should be compatible with these solutions. Ideally, the microvalve should burst if the total pressure becomes negative. However, we note that measurement uncertainties together with the unavoidable surface roughness introduced by the CNC milled master insert may cause deviations from Eq. (1). In addition, Eq. (1) is only valid for systems in equilibrium and it is known that adding surfactants to solutions also affects the wetting kinetics and result in a time-dependant contact angle [22,23].

The experimental evaluation was done through a qualitative study of the compatibility of the range of common surfactants with the chip system. A surfactant was deemed compatible if filling and transport of 40 μg of MBs could be completed without problems. As can be seen in Table 2, concentrations of Triton X-100 and Sarkosyl (two common detergents used in lysis) above 0.1% and 0.0625%, respectively, were not compatible with the present system. Tween-20 was compatible up to concentrations of 1%, which is sufficient for most applications. For this reason, higher concentrations of Tween-20 were not investigated. These observed results correlate well with the calculated Δp-values in Table 2.

Compatibility of concentrations of Triton X-100 and Sarkosyl up to 1% is preferred, because this amount of surfactant is sometimes needed to perform a successful lysis (depending on the starting material). Berry et al. [4] claim that their system is compatible with such a level of surfactant, but show no quantitative results. The system presented here has a relatively low intrinsic contact angle of about 90° to water, which is not ideal for working with surfactants. It is expected that the surfactant compatibility could be improved by either switching to a more hydrophobic polymer, such as polypropylene, or by coating the chip with a highly hydrophobic compound, such as perfluoro-decyl-trichloro-silane (FDTS). Both of these approaches are compatible with ultrasonic welding [24].

3.3. Liquid carry-over

When the MB cluster is pulled through the immiscible phase, a small amount of the inlet volume will always be carried along, since it is trapped between the magnetic beads and to a certain extent covers the beads as a thin film. As stated in the introduction, the amount of co-transported liquid is an important benchmark for a MB-based SPE system and it was thus quantified. The amount of target (*e.g.* DNA) that can be extracted depends on

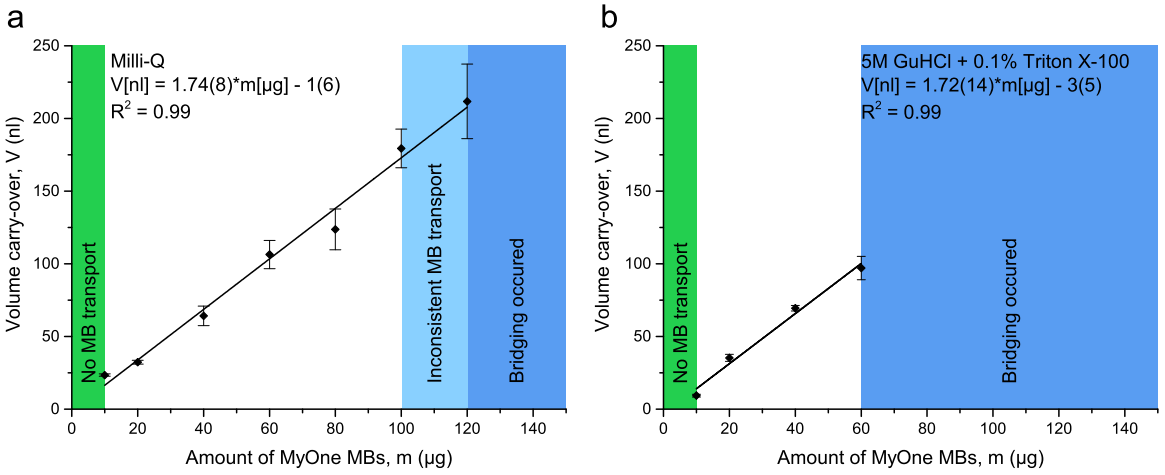

Fig. 2. The liquid carry-over of (a) Milli-Q water and (b) 0.1% Triton X-100 in 5 M guanidine hydrochloride. The extraction was repeated for different amounts of MyOne Silane MBs, and the liquid volume carry-over was estimated using fluorescence. The green area sets the lower limit of the system and the dark blue area sets the upper. The light blue area indicates MB amounts where not all MBs could be transferred in one extraction, and the MB extraction therefore had to be done stepwise. $n=3$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the available MB surface area which is determined by the amount of MBs used. Moreover, the ability to perform the MB transportation through the interface separating the two phases also depends on the amount of beads. For this reason, we chose to quantify the liquid carry-over *vs.* the amount of MBs used. We chose to investigate the carry-over of rhodamine B dye dissolved in Milli-Q water and in lysis-binding buffer with 0.1% Triton X-100 as this surfactant is commonly used. To our knowledge, this is the first time liquid carry-over of a surfactant containing solution has been quantified in the literature for this type of system.

Fig. 2a shows the liquid carry-over of Milli-Q water as a function of MB mass and Table 1 shows the data needed to compare these results with already published work. As also reported by Sur et al. [7], a linear correlation was found with a liquid carry-over of 1.74(8) nL/µg. MB extraction was not possible for less than 10 µg of MBs, because the magnetic force that could be applied to the MB cluster was insufficient to overcome the interfacial tension between the sample solution and the FC40 oil. Above 100 µg, the MB extraction also became problematic, as the MB clusters tended to get stuck in the geometric capillary microvalve and hence broke up. Still, MB extraction could be completed by sequential extraction of several MB clusters. For more than 120 µg of MBs, liquid bridges formed through the FC40 oil. Thus, this set the upper amount of MBs compatible with the present system for Milli-Q water.

Fig. 2b shows the results obtained for 0.1% Triton X-100 in lysis-binding buffer. Interestingly, the found liquid carry-over of 1.72 (14) nL/µg was within the uncertainty identical to that obtained for Milli-Q water. However, the upper compatibility limit decreased to 60 µg. 1.72–1.74 nL/µg fits with the general tendency of a smaller carry-over for larger bead diameters, *cf.* Table 1. There are, however, notable differences between the systems in regard to materials, fabrication and magnetic bead properties, as noted in the introduction, so comparing the systems directly should be done with caution.

Table 2 also presents the measured values of $\gamma_{aq,oil}$. The value of $\gamma_{aq,oil}$ is important, since it together with $\gamma_{oil.surface}$ defines the force the MB cluster must overcome to enter the immiscible phase. Moreover, it sets the energy scale for the interface between the oil and the aqueous phase. The presence of surfactants modify all involved surfaces and interfacial tensions [22,23] and to get a full picture of when bridge formation will occur, the total energy associated with the surfaces, $\Delta E = \Delta A(\gamma_{aq,surface} - \gamma_{oil,surface} + \gamma_{aq,oil})$ should be considered. ΔA is the change in the footprint area of the solutions. Berry et al. [4] also comments on this equilibrium while discussing liquid bridge forming and points to unexpected results, because some reagents affect multiple parameters, *e.g.*, $\gamma_{oil,surface}$ may change after contact with the surfactant molecules. However, the value of $\gamma_{aq,oil}$ still hints at whether liquid bridge formation will occur, since a small $\gamma_{aq,oil}$ will increase the likelihood of a positive ΔE, implying a lower risk of bridge formation. This is consistent with our observation that higher amounts of MBs can be successfully transported through Milli-Q water ($\gamma_{aq,oil}$ =44.1 mN/m) than the 0.1% Triton X-100 containing solution ($\gamma_{aq,oil}$=9.5 mN/m).

One might expect that a decrease of $\gamma_{aq,oil}$ would also result in a larger carry-over, since the interface between the liquids will exert less force on the sample solution covering the MB cluster and a decrease in $\gamma_{aq,surface}$ would allow for the sample solution to easier wet the COC surface. This is not observed and can possibly be explained by the complex nature of the total energy associated with the surfaces, as stated above. In addition, the capillary microvalve used in this system is geometrical and hence imposes a physical restriction on the movement of the MB cluster, compared to, *e.g.*, the capillary microvalve employed by den Dulk et al., which consists of two parallel glass plates selectively modified with a hydrophobic coating [8]. In the system employed by den Dulk et al. [8], the MB cluster can expand into the hydrophobic regions, since there is no physical barrier forcing the MB cluster together at the capillary microvalve. If geometrical capillary microvalves impose a normalisation effect on the carry-over of different solution types it would be beneficial to systems, where such a variation in carry-over is undesirable.

The system presented here is compatible with volumes up to 200 µL, which is larger than any of the systems presented in Table 1. However, Berry et al. have later presented a system compatible with liquid volumes up to 500 µL [13]. This is important, since a sample volume of several hundred microlitres is often needed when extracting targets from patient samples, since the concentrations of targets are too low to be quantified from small volumes.

4. Conclusion

We have presented an injection moulded all polymer chip system, capable of forming a stable immiscible phase system. It is a

passive microfluidic system and the fabrication process, which at present takes 1.5 min per chip, is compatible with mass production technologies to provide low-cost and single-use polymer chips. The chip is designed for MB-based SPE, is compatible with various surfactants in low concentrations, and elicits a liquid carry-over of 1.74(8) nL/μg and 1.72(14) nL/μg for Milli-Q water and lysis-binding buffer with 0.1% Triton X-100, respectively. The chip can process a 10–100 μg MB load for Milli-Q water and 10–60 μg for a lysis buffer with surfactant.

Future work will focus on chip applications, including nucleic acid extraction from large volume biological samples.

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