

MICROWAVE TECHNIQUE FOR MONITORING PHASE SEPARATION OF A MULTIPHASE-FLOW REGIME UTILISED FOR CONTINUOUS MOLECULAR ENRICHMENT

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ABSTRACT

A 3.0 GHz hairpin microwave resonator has been developed and applied to monitor the liquid compositional output of a multiphase-flow liquid phase separator. An integrated, planar segmented flow generating and separating device is utilised for phase transfer molecular extraction. Extraction efficiency is determined in real time by flow-through UV absorption, whilst microwave resonance analysis simultaneously monitors phase separation efficiency. A promising integrated approach for enhanced efficiency chemical separations and real time performance monitoring.

KEYWORDS: Microwaves, Multiphase Flow, Phase Separation, Liquid Extraction

INTRODUCTION

Solvent extraction is a widely utilised technique to separate or isolate compounds on the basis of their relative solubility in two immiscible liquids. Widely employed in sample preparation (e.g. pharmaceutical and clinical analysis), and as part of the work-up process to isolate products of chemical reactions, the drive for both time and yield efficiency together with process selectivity is huge.

THEORY

Controlled elution of immiscible fluids into a common duct generates segmented flow regimes of alternating immiscible fluid packets, each exhibiting high internal mixing with a continually refreshing interface, together with a large surface area to volume ratio. This enables the rapid attainment of chemical equilibrium between adjacent fluid phases [1]. Consequently, massively accelerated solvent-solvent extractions can be performed, with the extent of analyte removal from the sample enhanced through inclusion of a solid affinity phase suspended in the extracting fluid [2]. Here we demonstrate subsequent on-chip liquid-phase separation of the segmented flow stream through capillary forces [3], enabling continual collection of the desired analyte-purified phase. Microwave resonators [4] [Fig 1] characterise the dielectric properties of the separated liquid streams, continually monitoring phase separator performance. UV interrogation of the aqueous phase assesses extraction efficiency.

EXPERIMENTAL

Segmented flow regimes of aqueous propranolol solutions (50 μ M) and chloroform (\pm molecularly imprinted polymer solid phase adsorbent [MIP] 1mg/ml) were generated on-chip by a T-junction geometry flowing into a 35cm long 500x500 μ m micromilled channel. An array of 140 Gaussian profile ($w = 34\mu$ m, $h = 130\mu$ m),

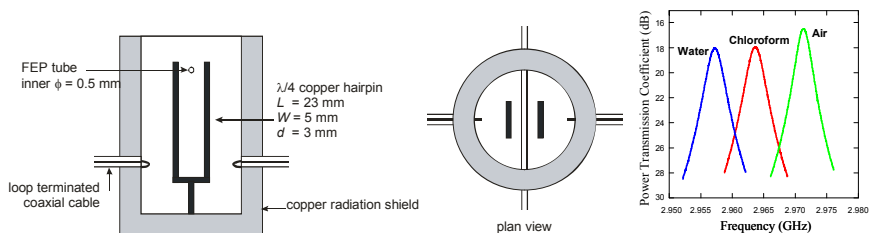


Figure 1: Schematic of the copper hairpin resonator. The phase separated liquid sample flows through the tubing positioned at the region of maximum electric field at the open end of the resonator. The measured resonance responses of the device with the capillary filled with water, chloroform and air are illustrated.

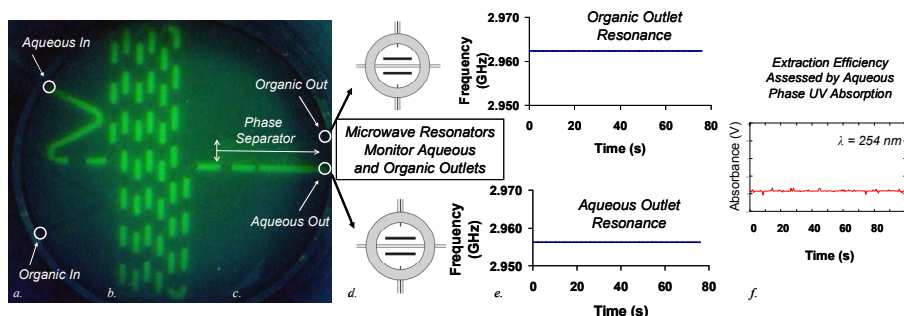


Figure 2: a) Segmented flow generated between the aqueous sample and the extracting chloroform phase (\pm Molecularly Imprinted Polymer). b) Efficient mixing facilitates rapid mass transfer of analyte from the sample to the extracting phase. c) Phase separation based on capillary forces separates the segmented flow stream into its component fluid phases. d) Microwave resonators interrogate the electrical properties of the two separated streams in real time. e) Experimental data - resonant frequency vs time for the fluid flow from each outlet of the separator, confirming 100% phase separation efficiency. f) flow cell UV absorbance of the aqueous phase is used to calculate the concentration of analyte remaining in the aqueous phase.

laser machined, side channels, branch from the main fluidic duct to elute into a second exit channel. The pressure differential between the two fluidic outlets was carefully regulated maintaining sufficient pressure to support the flow of the wetting organic phase through the separation ducts, whilst not breaching the aqueous breakthrough pressure. The organic and aqueous outlets exited the chip through FEP tubing (I.D. 500 μ m), which was interrogated by a hairpin resonator (Fig. 1). The capillary passed through the open-end of the hairpin where the microwave electric field is largest, and the transmitted microwave power over a range of frequencies measured. The aqueous outlet was interfaced with an HPLC UV detector to continually assess the analyte concentration remaining in the aqueous phase. Extraction of propranolol from the aqueous sample was assessed over a range of flow rates and validated by microplate fluorescence spectroscopy of collected fractions.

RESULTS AND DISCUSSION

Microwave interrogation in the frequency domain of fluid flowing from the phase separator outlets confirmed complete phase separation (Fig 2) and instances where ineffective pressure regulation caused the separator to fail (Fig 3). UV absorption confirmed an extraction of 20 μ M propranolol from the aqueous sample, independent of the flow rates employed (Fig 4), indicative of attainment of equilibrium. The addition of MIP to the extracting phase was seen to enhance the extent of extraction (Fig 4).

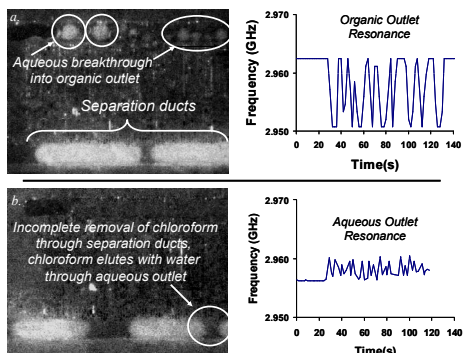


Figure 3: Microwave resonance response to inefficient phase separation. a) Too great applied pressure differential. b) Too low applied pressure differential.

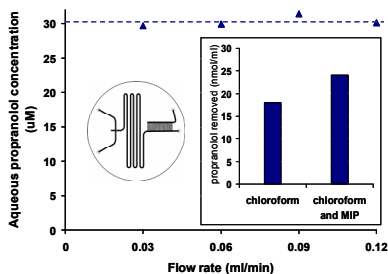


Figure 4: Propranolol remaining in the aqueous phase following on-chip extraction of a 50 μ M sample with chloroform. Inset: Schematic of extraction chip and enhanced efficiency of extraction by incorporation of MIP affinity phase.

CONCLUSIONS

Segmented flow and liquid phase separation on the basis of capillary forces, enables the continuous on-chip extraction of analyte species from an aqueous sample. Microwave resonators provide an ideal method for the assessment of liquid phase separation performance. The frequency dependant transmission of microwave power can be assessed rapidly (<10ms), enabling continual, non-contact analysis. Unlike optical approaches the technique can be applied to opaque matrices, as reported here with the use of suspended MIP particles which enhance extraction efficiency. The possibility of resonator feedback pressure regulation of the phase separator is easily envisaged, which together with MIP optimisation is a focus of ongoing work.

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