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GAS-LIQUID MICRO-SEPARATORS FOR TRAPPING OF VOLATILE ORGANIC COMPOUNDS

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KEY WORDS

Microfluidics, two-phase flow, mass transfer, uptake yield, real time detection, ultra-portability, miniaturization, high sensitivity, formaldehyde, air-borne pollution, analyzer

ABSTRACT

Volatile Organic Compounds (VOCs) are substances which were proved to be harmful for the human health. People are spending about 90% of their time indoors where these chemicals are present in high concentrations [1]. Among VOCs, formaldehyde is a major pollutant due to multiple indoor pollution sources (furniture, paintings, etc.) and high degree of toxicity being classified internationally as carcinogenic. Starting from the necessity of real time measurement of formaldehyde concentration, a device has already been developed by both ICPEES and In'AirSolutions in Strasbourg [2] which was proved to be sensitive and portable.

The analyzer works following three main stages. In the first stage, an annular two-phase flow is established in order to trap gaseous formaldehyde into an aqueous solution containing a chemical reagent. In the second stage, the kinetics of the reaction between formaldehyde and reagent are accelerated inside an oven at a specific temperature. Resulted chemical reaction product is a fluorescent compound and its concentration is measured inside a fluorescent cell, in the third stage of the process. Separation techniques using two-phase flows in micro- and mini-channels turned to be much more interesting since the increasing scientific interest in the fields of microfluidics and microfabrication techniques registered a consistent advancement. Among all applications of microfluidic separation, utilization of this technique for identification of air pollutant concentrations is very important due to its high miniaturization potential. For being capable of promoting merchandisable micro-separation systems, it is necessary to develop microsystems working in stabilized and reproducible conditions.

This work is part of a common effort for improving and miniaturizing the capabilities of this existing formaldehyde analyzer to integrate it into a real time miniaturized, ultra-portable, autonomous and reliable formaldehyde measurement system. More precisely, two areas for improvement have been identified. On one hand, a new approach for improving the uptake yield of the gaseous formaldehyde has to be proposed in order to diminish the response time and the liquid reagent consumption. On the other hand, the current fluorescent

detection cell comes with a large dead volume and it is necessary to develop another design configuration as part of the improvement of the detection process. Some commercial fluorescent cells with different volumes have been previously tested and different problems affecting either the response time or the quality of the measured formaldehyde concentration have been identified.

In order to identify new solutions for improving the uptake yield, a detailed knowledge of the flow conditions is required. Despite all the progress registered until now, not all the phenomena regarding two phase micro-flows are completely understood, many aspects being under investigation and closely interconnected to the progress registered in adjacent fields, such as flow visualization and numerical techniques [3]. Flow patterns are strongly affected, indeed, by a multitude of parameters at microscale, e.g. surface roughness, material properties, geometry of the inlet, channel diameter, channel cross section, superficial velocities, fluids properties [4]. Among all two-phase flow patterns, slug and annular patterns are utilized in the majority of the proposed separation processes in the literature due to large interfacial area and high uptake yield. In order to establish which is the suitable compromise between all the characteristics proposed by the two patterns, they have to be experimentally analyzed. The interplay of all effects involved have to be controlled and fully understood in order to propose a highly efficient and reproducible micro-separation method.

Regarding the detection stage, we are interested in developing and testing a new fluorescent integrable detection configuration in order to avoid large liquid dead volumes. It should respect some criteria such as low-cost, low detection limit, long term stability and working properly in a broad range of environmental conditions. There are some attempts in the literature to develop integrated fluorescence micro-detectors for in time measurement [6-7], fluorescence being largely used in lifetime measurements due to its selectivity, sensitivity and multiplexing capabilities. A prototype is under development in this moment in our team and the challenge consists in overcoming the constraints related to the microfabrication limitations, inlet configuration (which many times is a source of bubble entry), light pathways, LED/photodiode miniaturization and materials used for the cell. Polymeric materials and especially polydimethylsiloxane comes with promising characteristics regarding the possibility of developing embedded fluorescent systems for continuous monitoring. PDMS is optically transparent over the entire visible range and over a part of the UV range, permits rapid prototyping and scalable manufacturing with lower costs comparing the other materials used in microfluidics such as glass or silicone, which are expensive.

A preliminary experimental set-up is under development in order to visualize and characterize the specific parameters of the two-phase flow. Accordingly with the state of the art in the field of two-phase micro-flows, we are interested in quantifying parameters which are relevant and influential for the uptake process such as gas and liquid flow rates, gas-liquid-solid interface behavior, temperature, material properties (wettability), pressure drop. Temperature influence is very important due to our interest in coupling the first two stages of the analyzer. Heat transfer effect will be studied and its influence over the uptake yield will be emphasized and carefully analyzed. These steps will provide us with important information being helpful in the process of evaluation of mixing, mass and heat transfer and reaction yield. Iteration and evaluation of the reaction zone by quantitative criterion and correlations is a key method in designing methodology of micro-integrated structures.

Experimental campaigns will be conducted for different experimental conditions (e.g. different materials, diameters and cross sections for the micro-channels, different flow patterns and flow rates, heating coupled with the uptake stage) in order to study the uptake yield. As a first step, the experiments will be conducted using fused silica micro-channels with different diameters ranging from 50μm to 530μm in order to quantify the results through empirical and optical methods. Starting from the experimental set-up and results proposed by (Guglielmino et al., 2017) regarding the efficiency of the uptake yield which is increased with the interior diameter, we are planning to characterize the flow dynamics in these circumstances in order to be able to propose an improved trapping system. The possibility of integrating experimental colorimetric methods, as for example the one proposed by Yang et. al. [5], will be analyzed for a better visualization of mixing hydrodynamics and interface interaction. Further, according to the conclusions of the experimental campaigns, numerical analysis using Direct Simulation Monte Carlo (DSMC) will be conducted to characterize diffusion kinetics at molecular level. In parallel, according with the results of the bibliographical review about fluorescent micro-integrated systems, a new prototype will be proposed, analyzed and iteratively improved in order to acquire the desired capabilities.

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