Novel radial jet reattachment for analyte extraction from porous surfaces

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Abstract

There is a technical gap that poses a potential threat to the warfighter and civilians of being able to sample sub-surface analyte. Most techniques sample only the surface or capture very slightly below the surface. Moving away from swabbing and optical techniques provides an opportunity to extract sub-surface analyte from rough, porous surfaces. Herein, a novel radial jet reattachment (RJR) nozzle is employed to preferentially project heated air flow annularly downwards towards a surface and, upon reattaching with the surface, is curled and entrains analyte into the heated airflow that is pulled up through the center of the nozzle for sampling.

Scientists from the Chemical Biological Center accessed the capabilities of the RJR nozzle with analyte that ranged in vapor pressure from < $8x10^{-4}$ torr to > 2 torr on both smooth, non-porous (stainless steel) and roughened, porous surfaces (concrete). Extraction capability was characterized by liquid extractions of the remaining analyte on the surface and the amount of vaporous analyte via gold-standard analytical techniques. Dwell times over the surface with analyte 0.5 s – 10 s with surface concentrations of 5 g/m^2 – 10 g/m^2. Analytes were extracted from the roughened porous substrate in all conditions. Analyte extraction was *more efficient* from roughened porous substrates than smooth, non-porous substrates by up to 30 times. Extraction efficiency from the roughened porous substrates increased as the vapor pressure of the analyte increases.

Background

The proof-of-concept RJR system consists of a conditioning elements and a proprietary nozzle providing an annular-shaped heated air flow to a surface (Figures 1 and 2). The surfaces that were tested were placed on a translational stage to bring under the heated air flow (Figure 2C) and gold-standard techniques were used to characterize the amount of analyte in the air flow of the return air. Four analytes were tested on concrete surfaces and two were additionally tested on stainless steel surfaces. The heat flow of the system was explored on a custom-made aluminum 6061 substrate (Figure 3). All testing was completed at an optimal height.

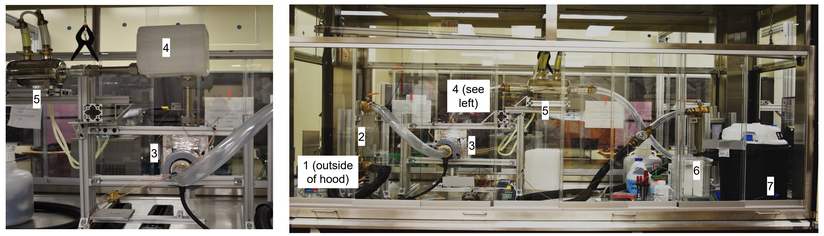

Figure 1: A photograph of the set up in CBC's CASTLE Laboratory (right), and a close up of the sampling area that laboratory personnel sampled from (left). The air is pulled in from outside the hood and pushed into an adjustable air valve (1,2), into a heater element (3), and pushes the shaped and heated air to the surface. The heated air with or without entrained analyte is pulled through the RJR nozzle (3), through the sampling area (4), and chilled (5) prior to filtering.

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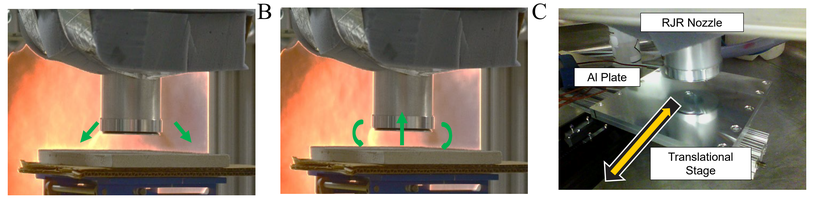

Figure 2: Schlieren imaging performed at NIST with only the radial jet turned on (A) and with the radial jet and suction air streams turned on (B) on a 6" x 6" concrete substrate. The green arrows highlight the visualized air flow (seen as a white stream of air coming out of the left side of the nozzle). A pictorial representation (C) of the motion of the substrate with respect to the RJR nozzle whereby the stage first approaches the nozzle (yellow arrow) and retracts after residing under the nozzle for the preset time (black arrow).

Results and Discussion

Figure 3 shows a pictorial representation of how the air flows over the substrate with a transient area (i.e. the RJR is just passing over that area, red-dashed area) and a stationary area (solid, semi-transparent area) where the RJR dwells for the prescribed amount of time (between 0.5 and 10 s). The energy imparted on the surface (in the form of heat) vaporizes the analyte on the surface and soaked into the porous substrates. The temperature difference imparted on the surface that can be measured is indicative of the energy transferred to the substrate that can potentially vaporaize the analyte.

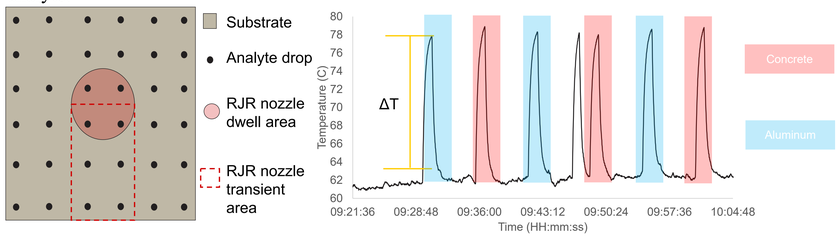

Figure 3: Pictorial representation of RJR sampling (left) and temperature profile on Al (blue) and concrete (red) substrates (right).

Liquid extractions of what remained on the surface showed that nearly all of the analyte could be recovered from the stainless-steel surface, but only a small portion of it could be recovered from the concrete. This is indicative of the analyte having an infinity towards the substrate and has been documented elsewhere (ECBC-TR-855). The vapor extractions show that there was more vapor pulled out of the concrete to what was proportionally extracted in the liquid (Figure 4). That is, the extraction from concrete is more efficient than extraction from a smooth, nonporous surface (Table 1).

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Additionally, the efficiency of the RJR nozzle scales with the vapor pressure (Table 1) such that the greater the vapor pressure, the greater the extraction efficiency. Furthermore, the efficiency is greater for porous surfaces as the air flow tends to push the analyte across a smooth surface (Table 1).

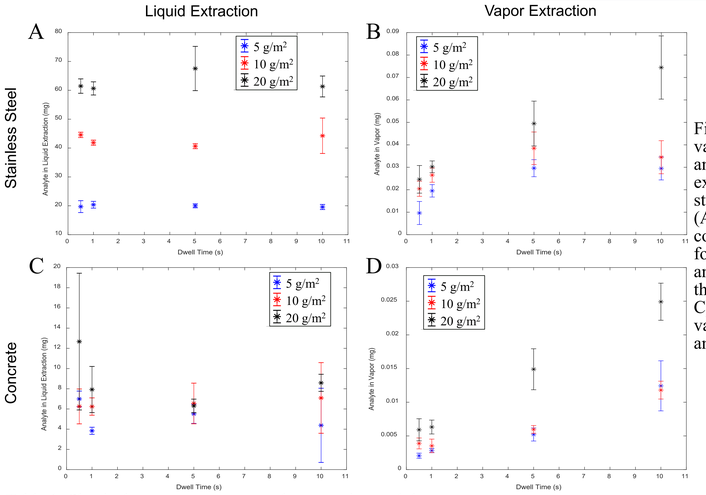

Figure 4: low vapor pressure analyte extractions on stainless steel (A, B) and concrete (C, D) for both the analyte left on the surface (A, C) and the vaporized analyte (B, D).

Table 1: Physical parameters compared to experimental data.

Analyte / Surface	Approximate vapor pressure (torr)	Approximate exposure guidelines (mg/m^3)*	Captured concentration (mg/m^3)	RJR Efficiency (%)
A / SS	< $9x10^{-4}$	$5x10^{-4}$ – 0.029	$4x10^{-3}$ – $9x10^{-2}$	0.04 ± 0.04
A / Conc	< $9x10^{-4}$	$5x10^{-4}$ – 0.029	$2x10^{-3}$ – $2.8x10^{-2}$	1.2 ± 0.9
B / Conc	0.1	0.4 – 3.9	0.69 – 9.09	3 ± 2
C / SS	0.4	200 – 500	1.18 – 9.86	1.3 ± 1
C / Conc	0.4	200 – 500	2.4 – 47.3	6 ± 8
D / SS	< 2	$6.9x10^{-3}$ – 0.38	3.44 – 52.98	19 ± 11

Conclusion

The RJR nozzle was evaluated for it's efficiency and capability of extracting various analytes (4) with differing vapor pressures (>$9x10^{-4}$ torr - < 2 torr) from out of concrete surfaces and resulted in a rank ordered extraction efficiency that is consistent with their vapor pressure. The lowest vapor pressure material was able to be extracted with a 0.5s dwell time and a surface concentration of 5 g/m^2, which were the shortest dwell times and lowest surface concentrations that were tested in this study. For further information regarding this work, please see our technical report: DEVCOM CBC-TR-1931.