

A 3D MICROFLUIDIC CAGE COLLECTOR FOR AIRBORNE PARTICLES

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ABSTRACT

We designed, manufactured, and integrated the first 3D microfluidic collector for capturing airborne particles directly into liquid; using an integrated electrostatic precipitator (ESP) sampler, designed for breath diagnostic purposes. The novel collector increases the sampler's air-to-liquid capture efficiency by 35 times, when compared with previous 2D collectors.

KEYWORDS: 3D collector, microfluidic, aerosol, electrostatic precipitator, 3D printing, airborne particles

INTRODUCTION

To this day, viral epidemics remain a serious threat to public health around the world. Transmission of such infectious viral agents occur either via direct contact with infected subjects/surfaces, or through airborne pathways, the latter of which can lead to rapidly spreading infectious diseases. Airborne transmission of viral particles occurs in the form of aerosol droplets, known to originate from human airways, from talking, breathing, coughing, or sneezing. Hence, sampling these aerosol droplets from breath would allow for a non-invasive method of diagnostics (Fig 1), for identification of virus-induced respiratory infections, and as a result, help to curb deadly epidemics. Furthermore, integrating such breath collection to downstream, highly-sensitive analytical techniques for viral detection, such as ELISA or PCR, would make for a potentially powerful diagnostic instrument. Therefore, collection of airborne particles directly to miniaturized liquid volumes would provide high-concentrate solutions, requiring no additional dilution steps (as in collection to solid surfaces), for downstream liquid-based analysis [1].

Previously, Sandström et al. [2] and Pardon et al. [3] demonstrated electrostatic precipitation of aerosol droplets from air to a 2D liquid-air surface, but further investigations revealed that the majority of sample was collected on surfaces, rather than into the liquid, due to 1) a non-optimized design of the fluidic and electrostatic field distributions around the collector; and 2) unwanted adsorption of sample to the solid surface. We present here, a novel 3D collector design for the collection of airborne particles directly into small liquid volumes, which is compared with the previous 2D collector design by electrostatic precipitation of aerosolized dye particles, and analyzed using absorption spectroscopy.

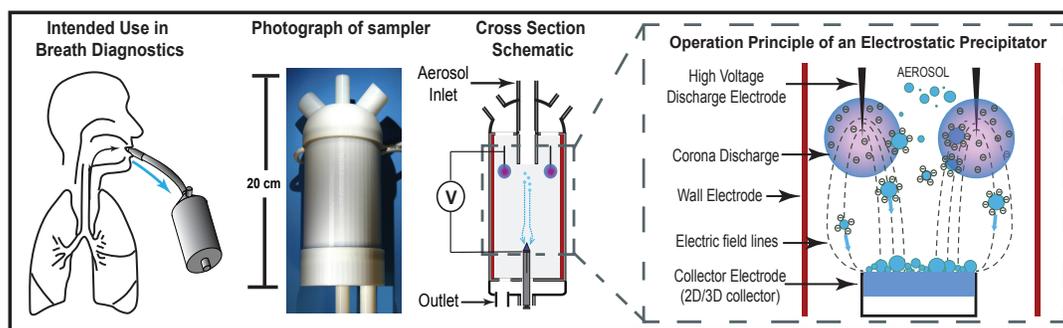


Figure 1: ESP Sampler for breath diagnostics, schematic of device target function and its functionality (inset).

THEORY

An ESP consists of, at the basic level, discharge and collection electrodes with a voltage difference that results in a strong electric field (Fig 1 inset). This high field combined with a high curvature-

discharge electrode induces a gas ionization in the region around the active electrodes. Incoming aerosol droplets collide with the ionized air molecules, become electrically charged, and are transported by the electrostatic force towards the collector electrode. Conventional electrode configurations include point-to-plane (needles as discharge electrodes and flat surfaces as collection electrodes), or wire-to-plane, however more complicated collector electrode designs, such as the 3D design proposed here (Fig 2), have seldom been investigated. Our 3D liquid cage design features:

- high geometrical curvature, thus high electrical field strength, thus high precipitation, at points of large air-liquid interface
- sufficiently large cone height to increase air-to-liquid precipitation
- large fraction of air-liquid to air-solid surface to minimize sample-to-solid adsorption.

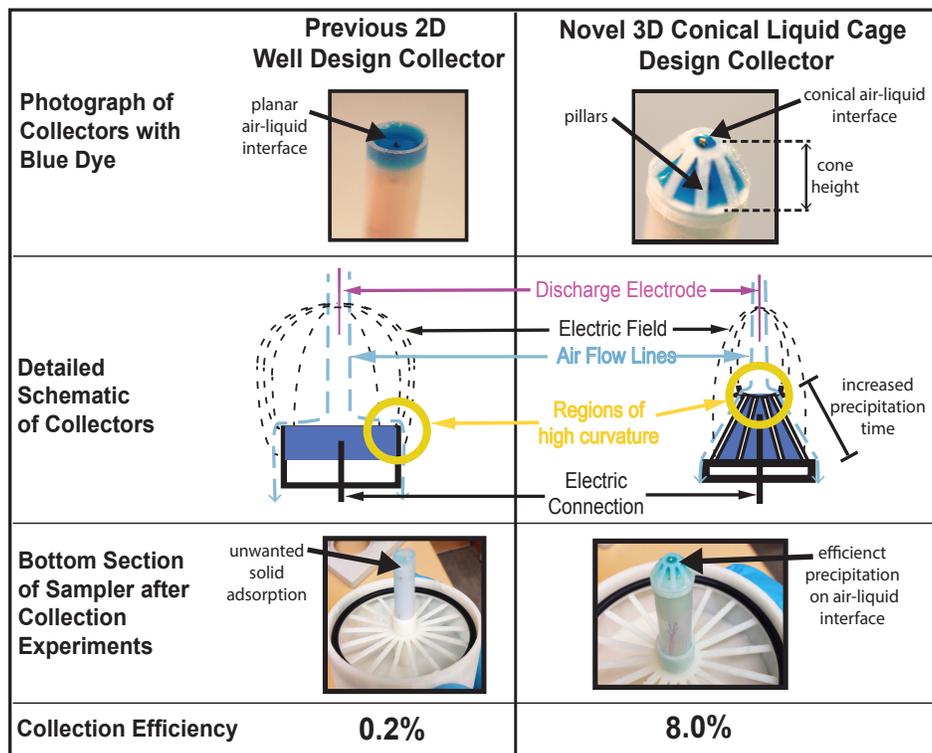


Fig 2: Comparison of 2D collectors from previous work, and the novel 3D liquid cage collector for aerosolized blue dye.

EXPERIMENTAL

We 3D printed the collector in ABS plastic with overall diameter $D=11.3$ mm, 5.1 mm cone height, 0.85 mm diameter solid pillars and 3 mm pillar interspacing (Fig 2). The interspacing between the solid pillars in the liquid cage is large enough to provide sufficient air-liquid capture surface, but small enough for the liquid surface energy to provide gravitational invariance of the device (Bond number $Bo = \frac{\Delta\rho \cdot h \cdot w \cdot g}{\gamma} \lesssim 2.2$).

For comparison, we also manufactured previously designed [2] 2D well collectors with the same overall diameter, 11.3 mm. Both collectors can hold a 200 μL liquid volume; they are electrically connected using a gold-plated nickel pin. The total air-liquid to air-solid fraction is 1.8 for the 3D design, while only 1.1 for the 2D design.

Both 2D well collectors and the novel 3D collectors were filled with 0.5 M KCl buffer and integrated as collecting electrodes in a 3-electrode, point-to-plane ESP sampler. An AIOLOS nebulizer was connected to the sampler using tubing. 44 μM of blue dye was aerosolized with mean droplet diameter 3.8 μm during 25 s, while the ESP sampler was operated at a potential difference of 8 kV. The mass

transport of blue dye from the nebulizer to the collector was investigated by visual control and measured by spectroscopy to determine captured moles of dye in the collector liquid after operation, as in [3].

RESULTS AND DISCUSSION

The improved collection efficiency of the 3D over the 2D collector is clearly visible as an intense colour change (Fig 2). Despite visible large sample losses in the tubing between nebulizer and ESP, solely related to the non-optimised experimental setup, we collected 8,0% of the nebulized dye in the 3D liquid cage collector, but only 0.23% in the 2D collector. Hence the novel 3D liquid cage performs 35 times more efficiently than previous 2D collectors (Fig 3). Passive collection (without electrostatic field) captured 0.01 μM (0.02%) and is hence negligible.

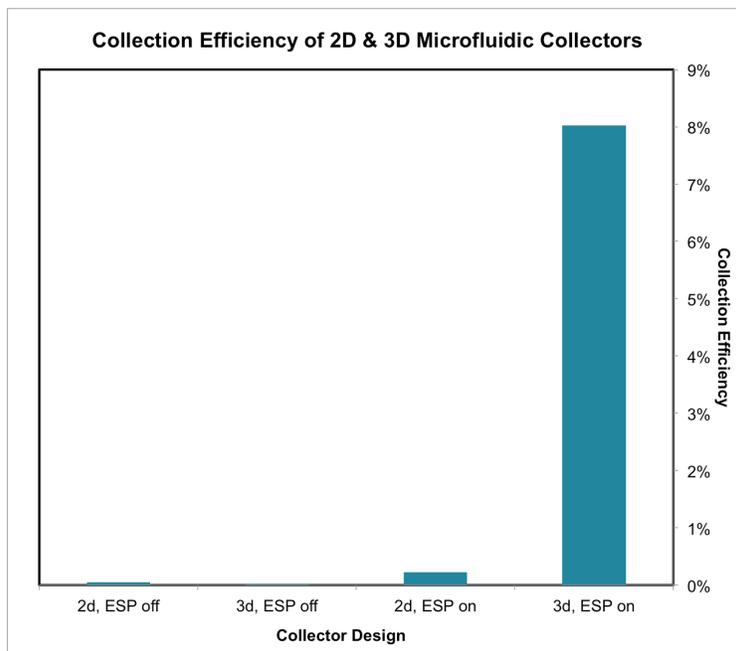


Fig 3: Collection Efficiency of ESP.

CONCLUSION

In conclusion, we have designed and tested a novel 3D micro-volume collector for capture of airborne particles directly into liquid. The 3D design is compared with the previously tested 2D design and shows an improved collection of aerosolized dye particles by 35 times. The collector is integrated with an electrostatic precipitator developed for breath diagnostics.

REFERENCES

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