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# **Isopropyl Alcohol Volatile Sensor Development for In-Flight Air Quality**



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## 1.0 SUMMARY

Breathing air quality within commercial airline cabins has come under increased scrutiny due to the identification of volatile organic compounds from the engine bleed air used to provide oxygen to cabins. Ideally, a sensor would be placed within the bleed air pipe itself, enabling detection before it permeated through and contaminated the entire cabin. Current gas phase sensors suffer from issues with selectivity, do not have the appropriate form factor, or are too complex for commercial deployment. Here, we chose isopropyl alcohol (IPA), a main component of de-icer spray for airframes and engines and a cleaning solvent for breathing lines and life support gear used in the aerospace community, as a target analyte. IPA exposure has been hypothesized to be a key component of aerotoxic syndrome before, during, and after flight. It has been reported that IPA functions as a central nervous system inebriant and may result in respiratory irritation, drowsiness, dizziness, and headache in an individual if exposed to it over a duration of time. IPA's proposed mechanism of action is that of an anesthetic and central nervous system depressant. Given the presence of IPA and the risk of cognitive effects in pilots/passengers, there is a need to ensure exposure does not exceed acceptable risk levels; ideally, that would be done by measuring the concentration of in-flight and breathing-line IPA. Currently, there is no commercial off-the-shelf sensor available that can monitor the quality of pilot breathing air or distinguish to which contaminants the individual may be exposed. This work developed and validated an IPA selective gas sensor that can distinguish the target molecule from other volatile organic compounds such as acetone or isoprene in real time.

## 2.0 INTRODUCTION

In this work, we proposed to develop and validate a gas-selective sensing element for isopropyl alcohol (IPA) that can differentiate the target molecule from acetone and isoprene. No commercial off-the-shelf sensor currently exists that can effectively discriminate IPA (at ppb or low-ppm levels) from other molecules, and the selectivity from acetone and isoprene in particular will tie the proposed sensor in with newly funded 711<sup>th</sup> Human Performance Wing projects involving evaluating exhaled breath for biomarkers indicative of human performance (hypoxia, stress, fatigue). The study goals were as follows:

1. Design an IPA gas-selective capture element.
2. Implement the selective IPA capture element into a sensing platform.
3. Validate the function of the IPA gas-selective sensing element by simulated exposures at conditions (altitude and 0% humidity) relevant to high-performance U.S. Air Force aircraft.

The IPA sensor development process consists of three main components: a polyvinylpyrrolidone (PVP) polymer that serves as the analyte capture matrix, oxidizing agents that react with IPA, as well as carbon nanotubes (CNTs) that change resistivity as a function of ion concentration.

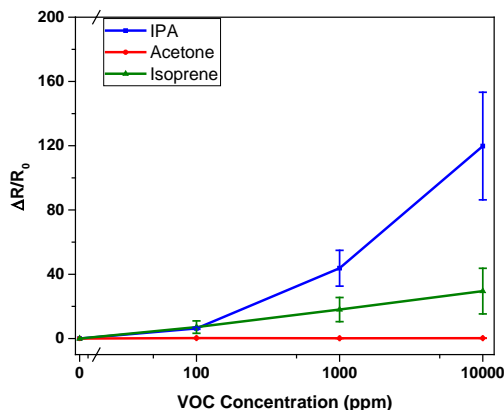
### 3.0 METHODS/RESULTS

Methods of fabrication for a CNT-based sensor were explored via spin coating and/or dipping process. Commercial interdigitated electrodes with 10- $\mu\text{m}$  gap, 20- $\mu\text{m}$  width on 28x5-mm glass supported with 150-nm gold layer were used in preliminary experiments as the base electronic structure. In addition, CNTs with 90% purity grade were suspended in the PVP polymer medium prior to dielectrophoresis (DEP) deposition. DEP uses alternating current to propagate CNTs along the electric field and deposits them onto the desired locations. Process parameters such as voltage applied, time of exposure, CNT size, and solution concentration were studied to determine suitable parameters for assembling CNT. Optimal conditions were 60-second deposition time at a frequency of 10 MHz with a peak-to-peak voltage of 6V. This produced  $1.5 \pm 0.88 \text{ k}\Omega$  CNT resistance indicating repeatable nanotube assembly for further experiments. Commercial grade polymers such as PVP, polyvinyl alcohol, poly(1-vinylpyrrolidone-co-styrene), poly(1-vinylpyrrolidone-co-vinyl-acetate), and poly(1-vinylpyrrolidone-co-2-dimethylaminoethyl-methacrylate) were utilized to compare and contrast device performance and ideal coating thicknesses. The thickness of the film is crucial for device performance, as a thick layer will create a large diffusion barrier, which reduces sensitivity. Dip-coating has been shown to be a better method for casting the polymer film onto the CNT device. For 0.25 wt % and 0.55 wt % poly(1-vinylpyrrolidone-co-vinyl-acetate), dip-coating resulted in film thicknesses of 35 nm and 53 nm, respectively. Dip-coating with 0.08 wt % poly(1-vinylpyrrolidone-co-2-dimethylaminoethyl-methacrylate) resulted in a film thickness of 15 nm and using 0.152 wt % resulted in a film thickness of 20 nm. Due to the viscosity of poly(1-vinylpyrrolidone-co-styrene), the majority of the film thicknesses were 75 nm or higher regardless of wt % concentration used. Of the polymers previously mentioned, PVP (40k molecular weight) provided the thinnest uniform coating (15 nm at 0.2 wt % concentration). Based on this, using PVP in dip-coating has been shown to produce better films and sensor response.

To further enhance device sensitivity, a water-based chromic acid dopant solution was added after the polymer coating process. The solution contains potassium dichromate in distilled water with 1M sulfuric acid. When IPA molecules are absorbed into the dichromate, the concentration of protons decreases, which then increases the CNT resistance indicated by a change in the IPA sensor response. We have shown that the sensor displayed greater signal response change when dichromate agents were added to the polymer film compared to no dichromate agent. The devices were also tested before and after coating to verify that the treatment process didn't break the electrical connection. The device successfully displayed consistent device conductivity and maintained electrical stability throughout the coating process.

Experiments on initial devices were conducted in a custom-built static vapor chamber that controls chemical compound concentration. The sensors were tested simultaneously with a commercial off-the-shelf piD-TECH® *plus*<sup>TM</sup> photoionization detector (PID) (MOCON Inc., Brooklyn Park, MN). Acetone, IPA, and isoprene chemicals were fed and circulated into the chamber at various concentrations ranging from 100 ppm to 10,000 ppm. Voltage changes were measured and monitored in real time with a constant current of 1  $\mu\text{A}$  applied to the device terminals and a user-specified voltage compliance of 0.5V. The interaction between the IPA analyte and the film coating is depicted by the sensor signal change upon exposure. It was found that poly(1-vinylpyrrolidone-co-2-dimethylaminoethyl-methacrylate), poly(1-vinylpyrrolidone-co-vinyl-acetate), and poly(1-vinylpyrrolidone-co-styrene) did not give noticeable response to

the IPA vapors regardless of the concentration. Even with poly(1-vinylpyrrolidone-co-2-dimethylaminoethyl-methacrylate) being the thinnest film (approximately 15 nm), there was no signal response detected upon exposure to IPA. Both poly(1-vinylpyrrolidone-co-vinyl-acetate) and poly(1-vinylpyrrolidone-co-styrene) displayed identical no response behavior. PVP was the better candidate vs. its copolymers in responding to IPA (Figure 1).



**Figure 1. Sensor response at different chemical concentrations with PVP polymer film.**

IPA showed larger response change compared to other volatile organic compounds (VOCs) (acetone and isoprene) and also outperformed the PID in regard to selectivity. The commercial PID displayed no specificity to IPA and instead showed higher signal changes for other compounds.

## 4.0 CONCLUSIONS

In summary, we successfully constructed a sensor that drastically improved sensor performance while distinguishing IPA from other VOCs at higher concentrations. Key metrics such as film thickness, CNT deposition, and presence of dopants directly impact sensor performance. Our results so far have shown improved signal response and that the device is selective enough to detect IPA while outperforming the commercial PID at high concentrations. This basic foundation will help us further develop methods of optimizing the chemistry and device geometry to decrease the limit of detection to a low ppm and high ppb range.

In addition, more work will be done to incorporate the IPA sensor into the real-time air quality sensor system for real-time monitoring and multiplexed data collection. Recent in-house device modifications consist of 8-9 CNT devices onto a single chip as well as in-house chromic acid development. Current work involves the microchamber, which will be used to further test sensors at a low ppm/ppb range while controlling flow rate, humidity, and temperature of the VOC. Also, diffusion tube technology with continuous flow will be used instead of manual target injections inside the chamber. Data results obtained from the microchamber will be compared to the higher concentration VOC chamber.

## **LIST OF ABBREVIATIONS AND ACRONYMS**

<b>CNT</b>	carbon nanotube
<b>DEP</b>	dielectrophoresis
<b>IPA</b>	isopropyl alcohol
<b>PVP</b>	polyvinylpyrrolidone
<b>VOC</b>	volatile organic compound