Characterizing the chemically powered motion of Ag/UiO-66/SiO_2 micromotors

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Introduction

Chemical warfare agents continue to pose a major threat to humanity. Because of their high lethality, efficient methods are needed to decontaminate these agents. Current methods show many flaws including toxic products, long reaction times, advanced equipment, strong reagents, and damaging environmental impact (Singh & Wang, 2015). In this project, the motion of silver micromotors with UiO-66 was characterized and optimized as a potential alternative to current methods.

Micromotors are nanoscopic particles with the ability to self-move. This movement causes mixing which can drastically decrease reaction times and can increase decontamination. In a study performed by Wang et al. (2017), micromotors were used to clean 97% of Rhodamine B, an organic pollutant, from contaminated water. This research shows the promise of micromotors for decontamination purposes.

Metal-organic frameworks (MOFs) are a developing field of materials science. These materials exhibit high porosity and high surface area to volume. Therefore, these materials also serve as excellent catalysts. UiO-66 is a MOF capable of degrading nerve agents. In research done by Ryu et al. (2018), UiO-66 was found to be efficient at decontaminating nerve agents in many different conditions.

This study combined the decontamination abilities of micromotors and MOFs to develop a MOF-based micromotor that could provide a future method to decontaminate nerve agents. Additionally, this study characterized the movement of these new micromotors.

Materials and Methods

The micromotors in this study are composed of a 40–60 µm silicon dioxide base with UiO-66 MOF grown on the surface. They were synthesized by researchers at Penn State and shipped to the lab at APG. From there, the motors were placed in methanol solution. One milliliter of the solution was used to cover a glass slide. After the methanol had evaporated completely, the micromotors remained adhered to the slide. A 10 nm nanolayer of silver was then deposited on the slide using a Denton sputtering system. The micromotors were then removed from the slide using DI water and chemical brushes. Afterwards, the speed of the micromotors in a hydrogen peroxide solution was measured.

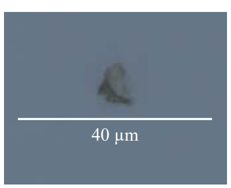
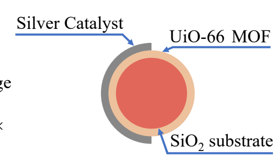


Figure 1 (Right): Diagram of Ag/UiO-66 micromotor nanoparticle.

Figure 2 (Left): Image of stationary micromotor at 1500× magnification.



Materials and Methods (continued)

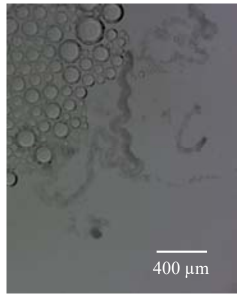
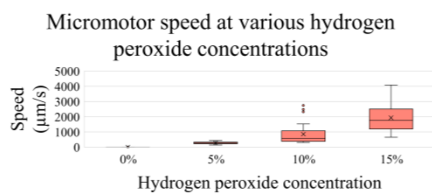


Figure 3 (Above): Frame 45 of a video of micromotors in 10% peroxide and 2% sodium cholate. Video taken at 100× magnification.

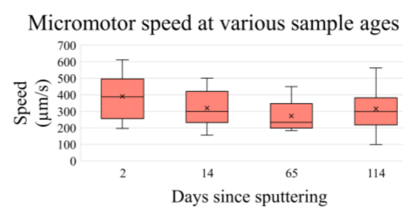
When not being used, the micromotors were stored in a fridge at 5 °C. To measure the speed of the micromotors, a Digital Keyence microscope was used. Twenty microliters of micromotor solutions, 20 µL of hydrogen peroxide solution, and a surfactant were mixed in a 1.5 mL Eppendorf tube. Twenty microliters of this mixture was placed on a clean glass slide. One-minute videos at 100× with 2048 × 1536 resolution at 15 frames per second were collected. An image from one of these videos can be seen in Figure 3. Three-second segments from these videos were converted to a TIFF image stack by Virtual Dub®. These image stacks were then manually tracked in MtrackJ, a plug-in to FIJI®, to calculate speed.

Results



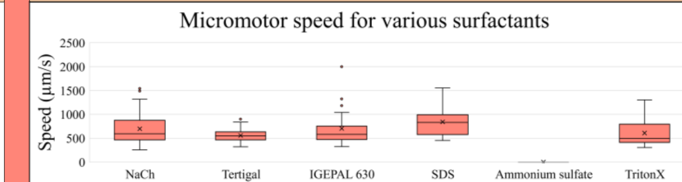
Graph 1 (Left): Boxplot displaying the speed of 24B micromotors in solutions of various hydrogen peroxide concentrations and 1% sodium cholate.

Graph 2 (Right): Boxplot of the speed of micromotors various days after being synthesized. The motors were created on November 14th and recorded in a 5% hydrogen peroxide solution and 1% sodium cholate.



A correlation test was done on the data in Graph 1. It was found that hydrogen peroxide concentration and micromotors speed were positively correlated, $r(108) = 0.758$ and a $p < .001$. Using an alpha level of 0.05, the concentration of hydrogen peroxide did significantly impact micromotor speed. Another correlation was run on the data in Graph 2. The study found a weak negative correlation, $r(52) = -0.201$ and $p = .153$. Using an alpha level of 0.05, no significant correlation was found between sample age and speed.

Results (continued)



Graph 3 (Above): Boxplot displaying the speeds of micromotor when placed in a 10% hydrogen peroxide solution and 1% of different surfactants. 124 micromotors were recorded for this graph.

A one-way ANOVA on the data in Graph 1 excluding Ammonium sulfate found a statistically significant difference between NaCh (M = 697, SD = 367), Tertigal (M = 556, SD = 144), IGEPAL 630 (M = 705, SD = 372), SDS (M = 842, SD = 294), and TritonX (M = 608, SD =276), $p = .014$, $F(1, 4) = 7.71$. With an alpha level of 0.05, the test concluded that the type of surfactant had a significant impact on micromotor speed. In a post-hoc test with an alpha level of 0.05, it was determined that the only SDS and Tertigal differed with $p = .004$. Thus, micromotors with SDS are significantly faster than micromotors with Tertigal.

Discussion

The purpose of this study was to characterize the motion of Ag/UiO-66 micromotors and optimize their capabilities. This study found that hydrogen peroxide concentration had a significant impact on micromotor speed, but no significant impact on speed was attributed to sample age. Therefore, the motors created in this study exhibited stability and could be used after storage. Additionally, of the six surfactants tested, micromotors with Ammonium sulfate did not show any movement. Ammonium sulfate was also the only cationic surfactant tested. Future research should test if other cationic surfactants display similar behavior. Other future research is needed to characterize the speed of the micromotors in various salinity and acidities. Due to safety concerns, the decontamination abilities of the micromotors was never tested.

References

Ryu, S. G., Kim, M.-K., Park, M., Jang, S. O., Kim, S. H., & Jung, H. (2018). Availability of Zr-Based MOFs for the degradation of nerve agents in all humidity conditions. *Microporous and Mesoporous Materials, 274*(2), 9–16. https://doi.org/10.1016/j.micromeso.2018.07.027

Singh, V. V. & Wang, J. (2015). Nano/micromotors for security/defense applications. A review. *Nanoscale, 7*(46), 19377–19389. https://doi.org/10.1039/C5NR06254C

Wang, R., Weilin, G., Li, X., Liu, Z., Liu, H., & Ding, S. (2017). Highly efficient MOF-based self-propelled micromotors for water purification. *RSC Advances, 7*(67), 42462–42467. https://doi.org/10.1039/C7RA08127H