Controlled Hydrogen Propulsion Submarine

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Background

Traditional diesel-electric or nuclear-reactor powered submarines require surfacing for oxygen or are costly, respectively[1]. This project explores a method of achieving air-independent propulsion (AIP) be means of an aluminum-water reaction to create and expel hydrogen gas. The reaction is catalyzed by an alloy of indium and gallium which permeates the Al oxide layer.

$$2\mathrm{Al}(s) + 6\mathrm{H_2O}(l) \rightarrow 2\mathrm{Al(OH)_3}(s) + 3\mathrm{H_2}(g)$$

$$\Delta H = -284\ \mathrm{kJ/mol\ H_2}\ (\mathrm{at}\ 100^\circ\mathrm{C})$$

Objectives

- Optimize reaction by pretreating aluminum to make H2 more consistently (parameters: surface area, Al oxide layer uniformity, mass)
- Design reaction vessel with control over the reaction rate and temperature

Methods: Reaction Optimization

- Tested Al surface areas since reaction rate depends on SA: tested mesh, rod, pellet shapes
- Tested pretreatments since different Al manufacturers make Al with different oxide thicknesses: sanding, chemical etching

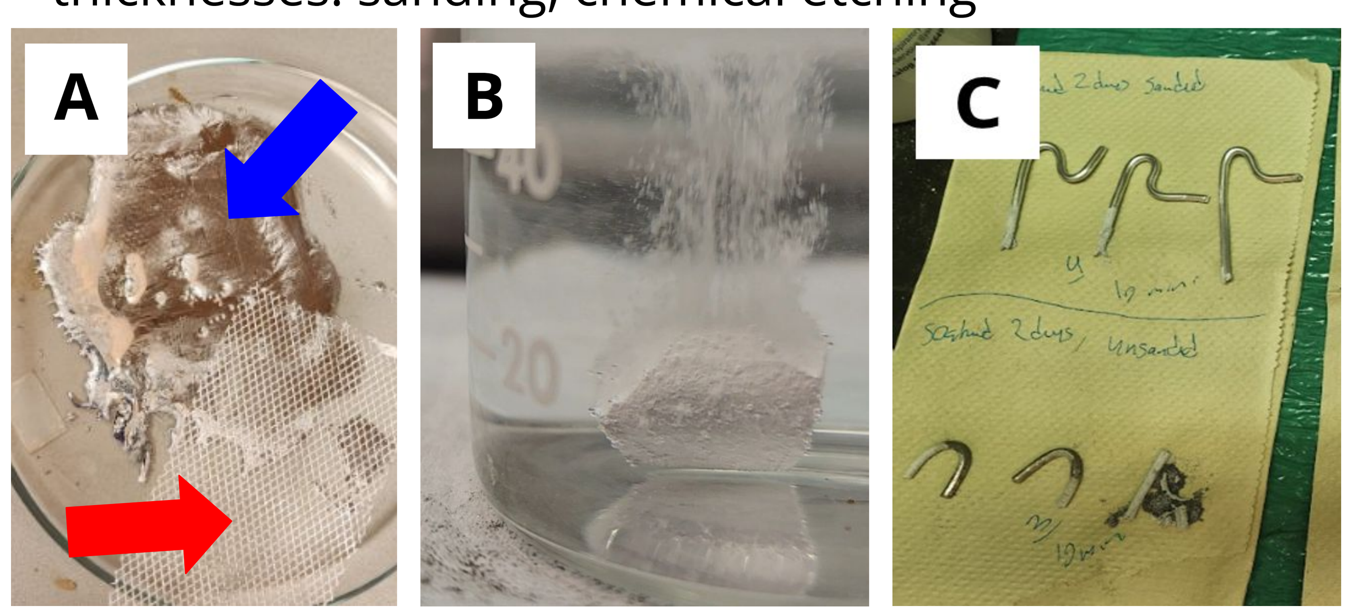

Figure 1. A) coating Al mesh (red arrow) in eutectic alloy (blue arrow) B) Checmal pretreat of Al pellet with sodium hydroxide C) qualitative comparison of sanding (top) vs no sanding (bottom) for 2 day eutectic soak

Exp	Al Form	Pretreatment	Eutectic Soak Time	Measurement
1	Mesh	Sanded	5min	Qualitative
2	Wire	Sanded vs none	5min vs 2 days	Qualitative
3	Wire	None / light / heavy sanding	1 vs 2 days vs 7 days	Gas evolution
4	Wire + pellets	Crimp / 240 grit sanding / 2.5% NaOH (60 s, pellets)	Fixed (2 days)	Gas evolution
5	Pellet	5% acetic acid + NaCl etch	Fixed (2 days)	Gas evolution
6	Pellet	5% NaOH (60 s) / 2.5% NaOH (120 s)	Fixed (2 days)	Gas evolution

Table 1. Test matrix for reaction optimizing

Results: Reaction Optimization

- Chemical pretreatment using sodium hydroxide solution yielded highest H2 production
- Sanding resulting in some samples not reacting

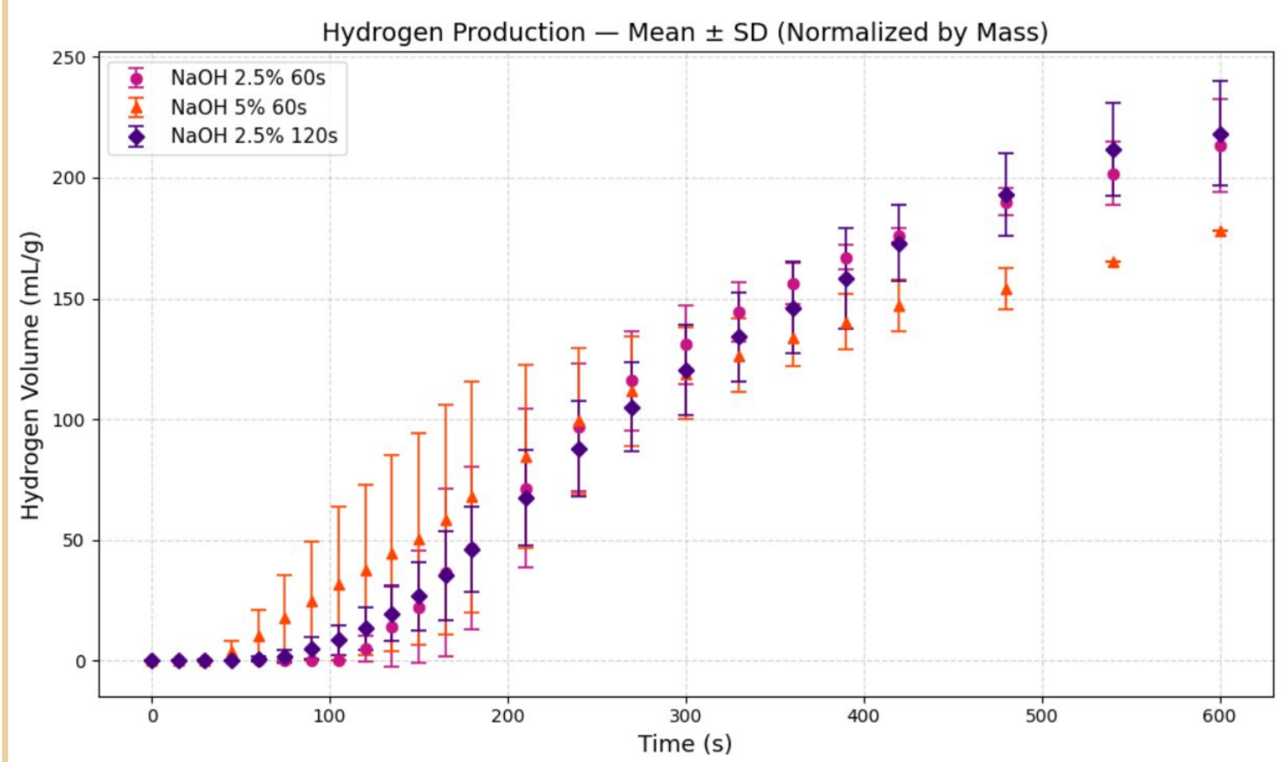

Figure 2. Hydrogen production rates after pretreatment of Al pellets with differing concentrations of sodium hydroxide solution for different times

Methods: Vessel Optimization

- Reaction chamber integrated with DC motor pumps to allow control of reaction
- Thermocouple-Arduino feedback system to control water pumping based on temperature

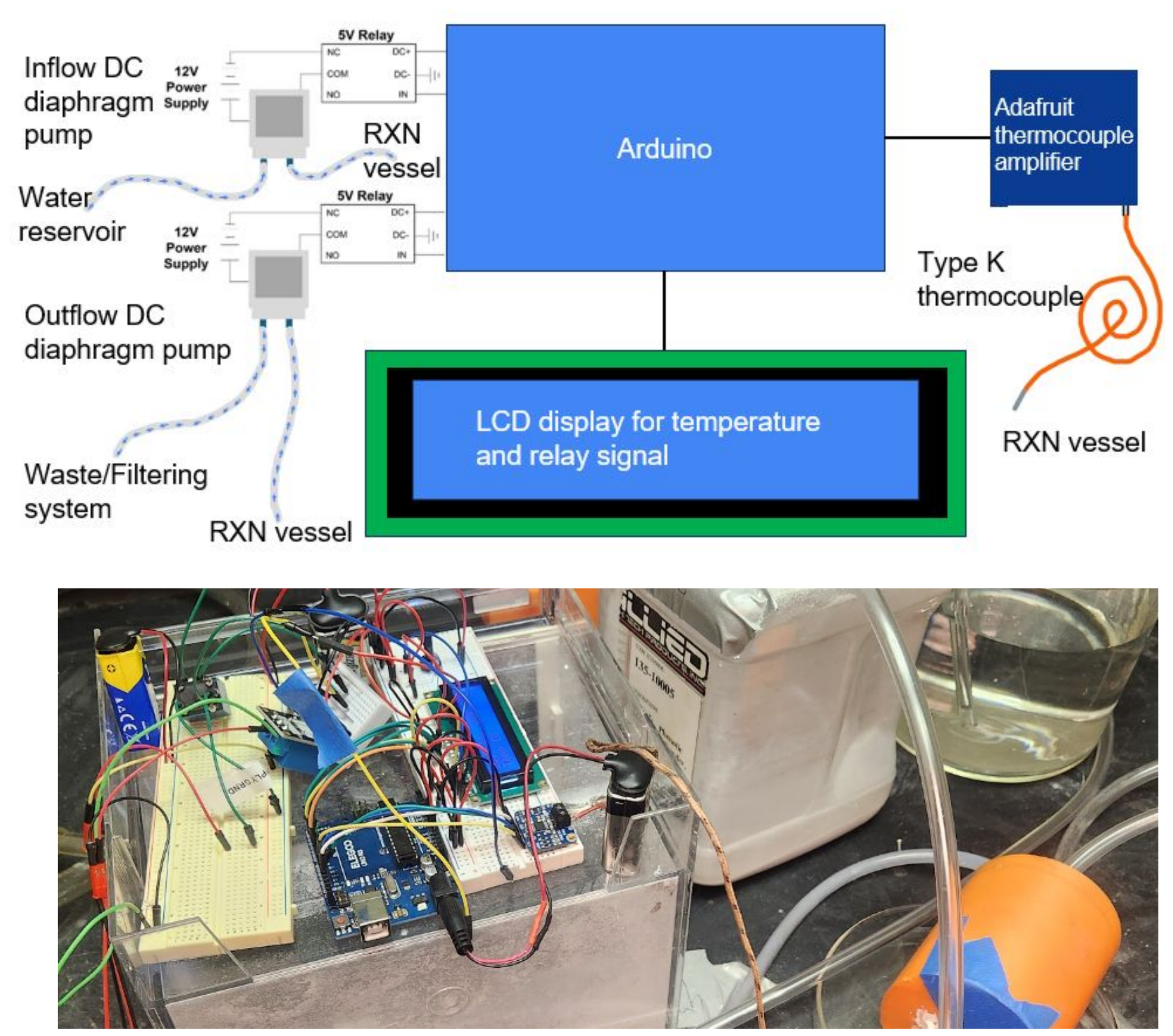

Figure 3. Pump-arduino-integrated reaction vessel schematic and prototype

- Reaction exotherm and failing O-ring influenced switch to steel pipe reaction vessel

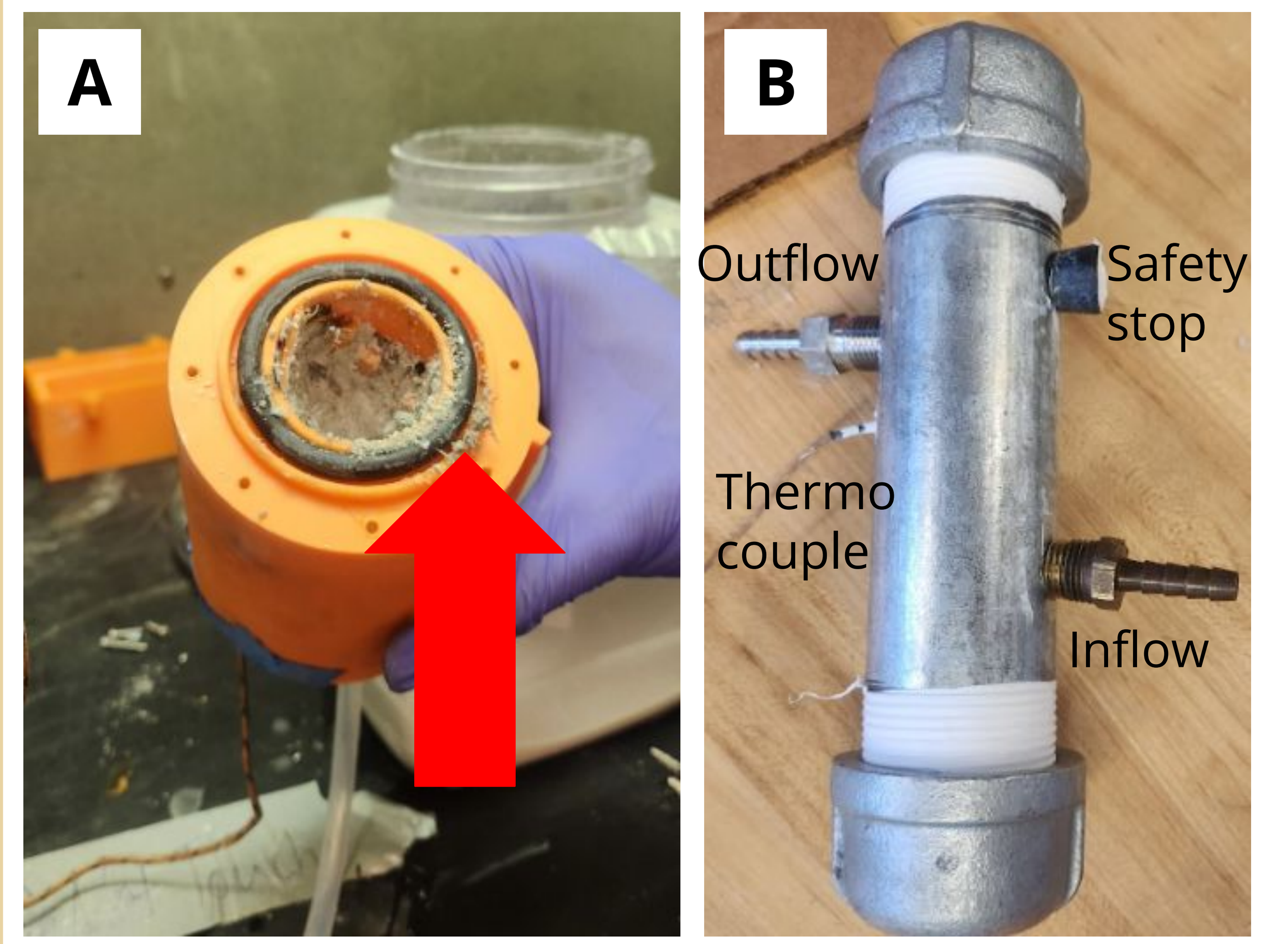

Figure 4. A) Failed PLA reaction vessel prototype due to O-ring sealing failure (red arrow) B) Steel pipe reaction vessel

Results: Vessel Optimization

- Able to demonstrate controlled flow via pumping mechanism
- Time delay between switching off pump and reaction slowdown
- Temperature fluctuations between 35° C and 60° C

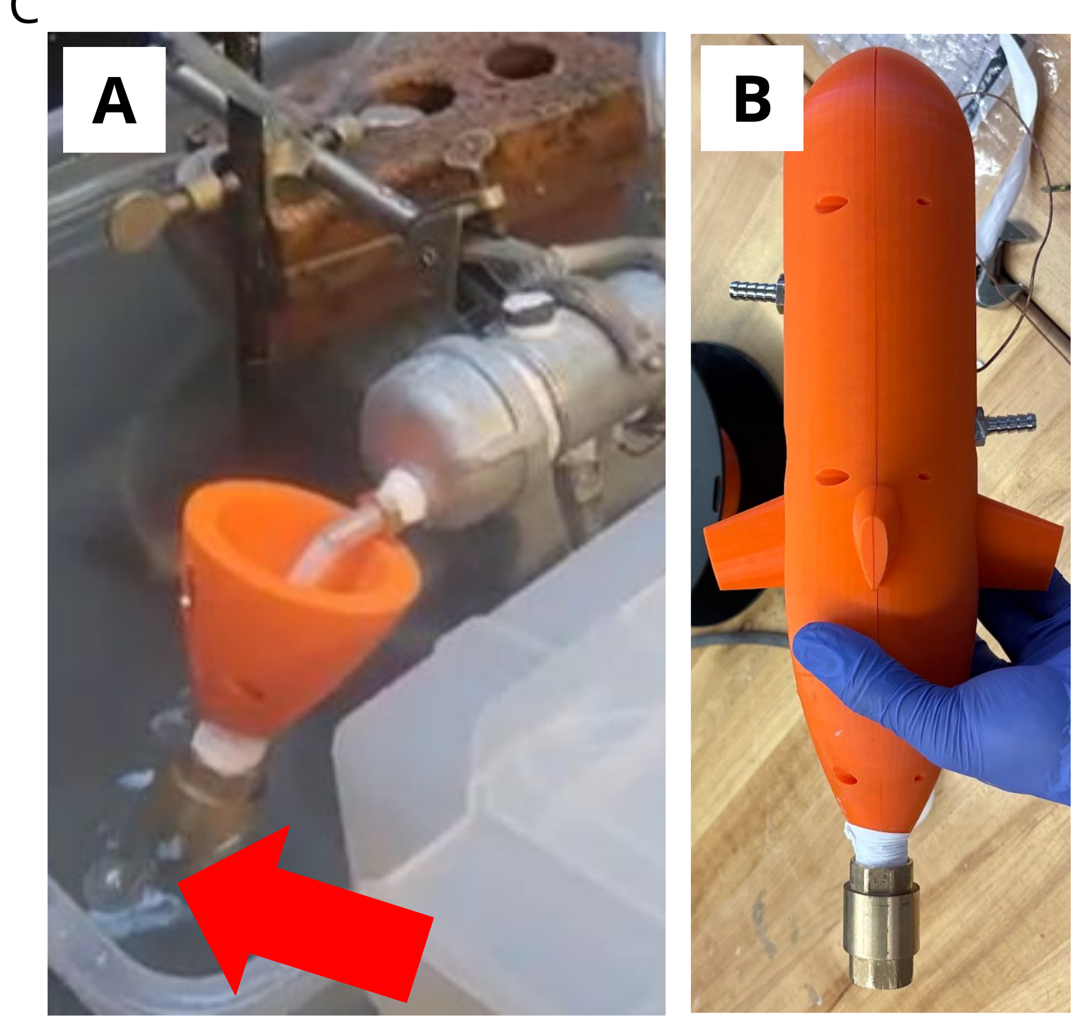

Figure 5. A) Steel pipe reaction vessel producing hydrogen out of a check-valve (red arrow) B) Integration of vessel into external sub structure

Conclusions and Future Work

- We found that chemical etching provides a more consistent reaction than mechanical pretreatment due to uneven buildup of oxide layer via mechanical processes
- We found that volume and time interval over which water added plays role in how drastic exotherm spike is
- It may be worth investigating ways to control the reaction after the reaction rate spikes as opposed to controlling it at low temperatures
- It may also be worth investigating using Al as the limiting reagent as opposed to water
- This system would need then be integrated into a sub structure, possibly needing a power supply
- Filter system for indium-gallium recovery and aluminum hydroxide needs to be researched - particle size distribution of aluminum hydroxide waste was investigated with the idea of designing a filter system for the reaction waste

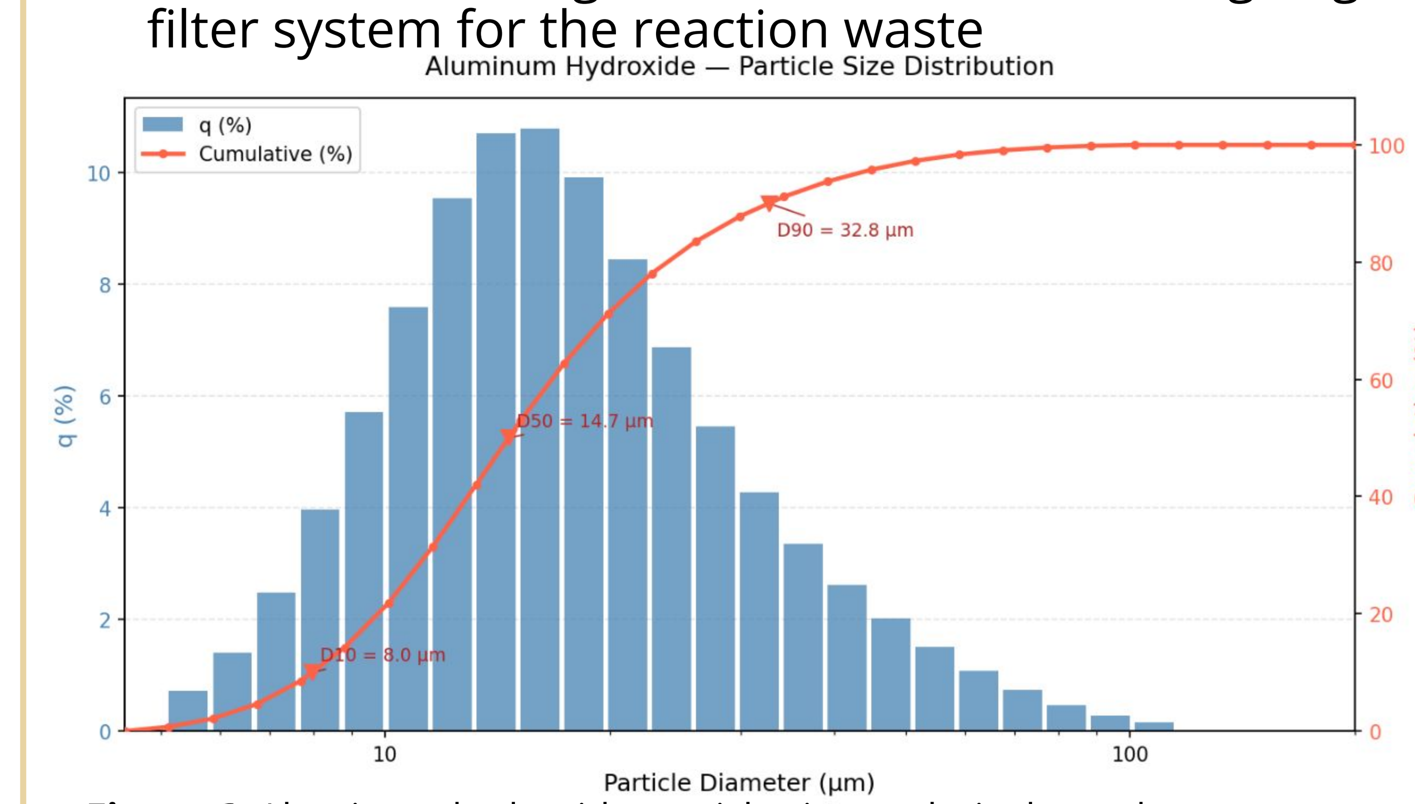

Figure 6. Aluminum hydroxide particle size analysis data taken on waste from reaction test

Acknowledgments

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References

[1] G. G. Santi and F. Popia, "The Promise of Better Submarine Air-Independent Propulsion," *Proceedings*, vol. 147, no. 3, Mar. 2021. [Online]. Available: https://www.usni.org/magazines/proceedings/2021/march/promise-better-submarine-air-independent-propulsion.

[2] J. Petrovic and G. Thomas, *Reaction of Aluminum with Water to Produce Hydrogen: A Study of Issues Related to the Use of Aluminum for On-Board Vehicular Hydrogen Storage*, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC, USA, 2010. doi: 10.2172/1219359.

[3] A. V. Parmuzina and O. V. Kravchenko, "Activation of aluminium metal to evolve hydrogen from water," *International Journal of Hydrogen Energy*, vol. 33, no. 12, pp. 3073–3076, Jun. 2008. [Online]. Available: https://doi.org/10.1016/j.ijhydene.2008.02.025.