Activated Aluminum-Water Reactions at High Pressures

Aly Kombargi
alyk@mit.edu

Advisor: Prof. Douglas P. Hart
MIT Mechanical Engineering
Hatsopoulos Microfluids Laboratory
Beaver Works

MIT Portugal
2022 Annual Conference

Objective & Reaction

Develop an **aluminum-based fuel** to power an autonomous underwater vehicle (AUV) through a hydrolysis reaction producing hydrogen:

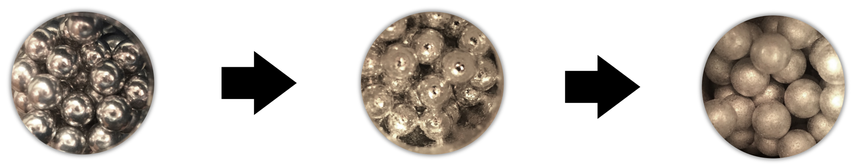
$$Al_{(s)} + 2H_2O_{(l)} \longrightarrow \frac{3}{2}H_{2\,(g)} + AlO(OH)_{(s)} + Q$$

Advantages

Aluminum:	Hydrogen:
▪ **Energy Dense**: 2x diesel & gasoline by volume, 40x Li-ion by volume	▪ **Long autonomy** (30 days for AUV)
▪ **Available**: 3rd most abundant element, most abundant metal	▪ **No toxic or polluting gases** (carbon dioxide, carbon monoxide)
▪ **Cheap**: $1.70/kg ($1/kg for scrap)	▪ Produced without carbon emissions
	▪ Stored as aluminum

Process

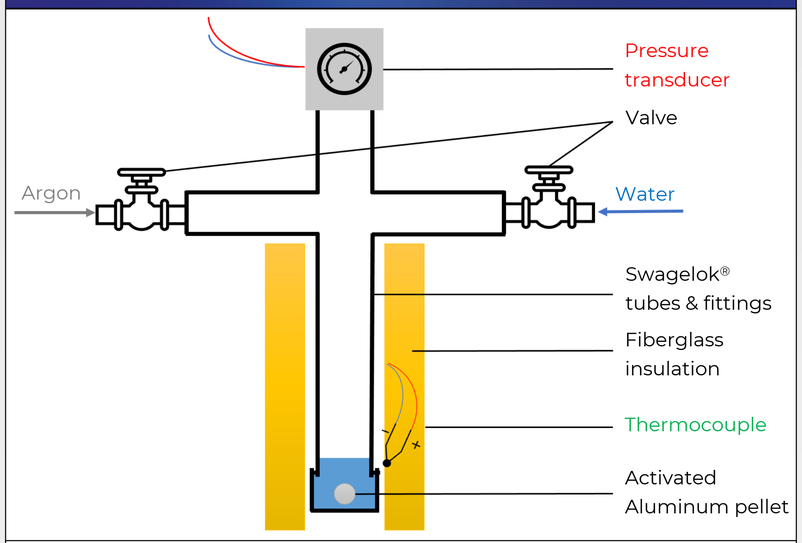
Activate aluminum through a liquid metal (eutectic) surface treatment:



Pelletize Aluminum → eGaIn Surface Treatment at 200 °C → Sit for 48 Hours at 20 °C

- eGaIn = 80% Gallium + 20% Indium
- Embrittlement at the grain boundaries
- **Disruption of the oxide layer**
- Catalyst for the Al-water reaction

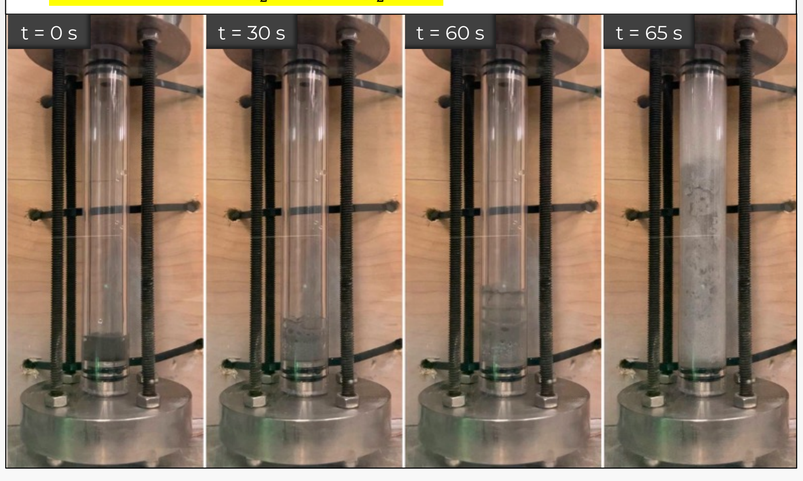
Experimental approach



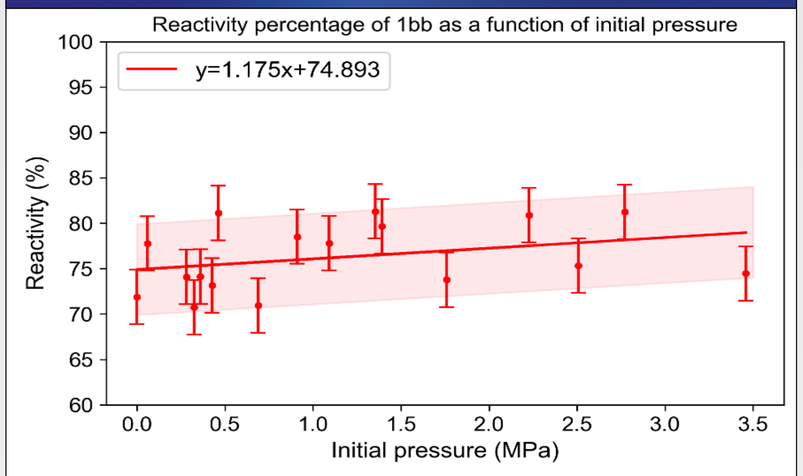
The AUV is modeled as an isochoric reaction chamber. The reactivity is computed at various initial ambient pressures, from atmospheric to ~10MPa (representing 1km depth).

Computing the reactivity percentage:

- $n_{H_2}(th) = \frac{3}{2} * \frac{m_{Al}}{M_{Al}}$ (theoretical)
- $n_{H_2}(exp) = \rho_{n_{H_2}}(P_{H_2}, T_f) * V_f$ (experimental)
- $P_{H_2} = P_f - P_{H_2O} - (P_i + P_{atm})$ (Dalton's Law)
- $V_f = V_{reactor} - V_{H_2O}$
- % reactivity = $n_{H_2}(exp) / n_{H_2}(th)$



Results

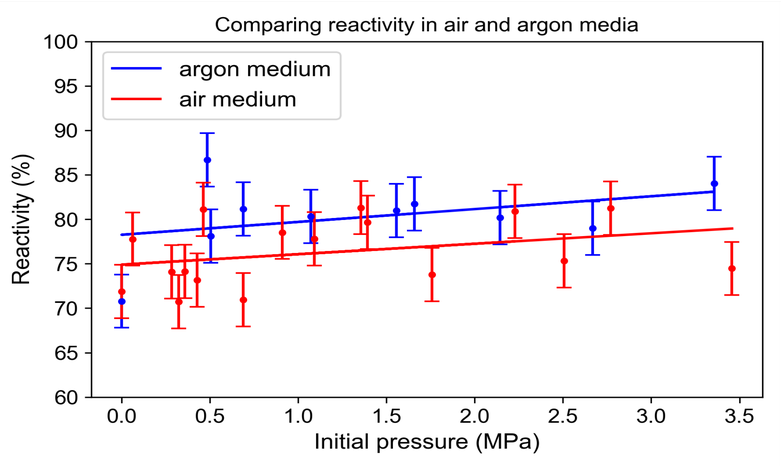


Observation: reactivity increases with initial ambient pressure.

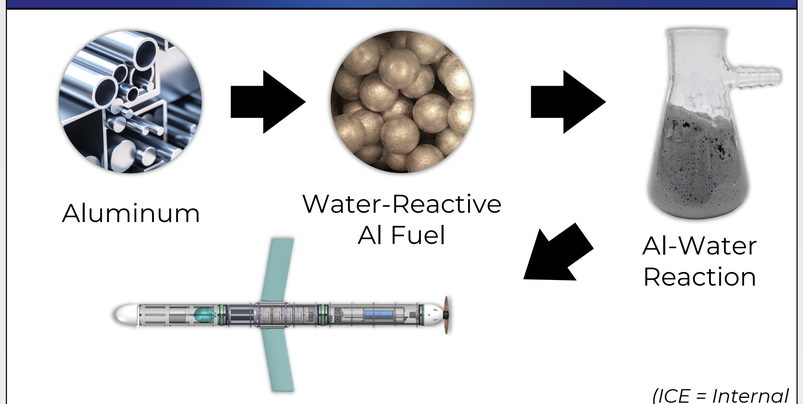
Hypothesis: bubble formation (steam, Hydrogen) allows the air to penetrate the system, and the Oxygen re-passivates the oxide layer of the bulk Aluminum.

Higher ambient pressure reduces bubble size. Test in argon medium shows a ~5% increase in reactivity, partially proving our hypothesis.

Reaching up to 95% reactivity at 6.4 MPa (about 642m underwater).



Roadmap

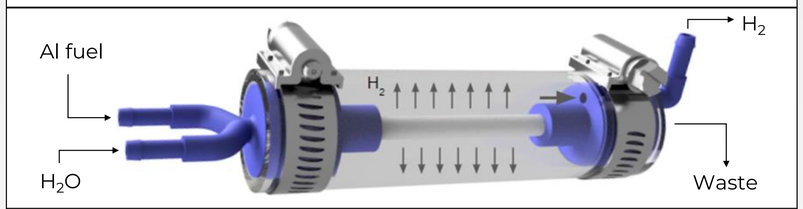


Towards a practical system

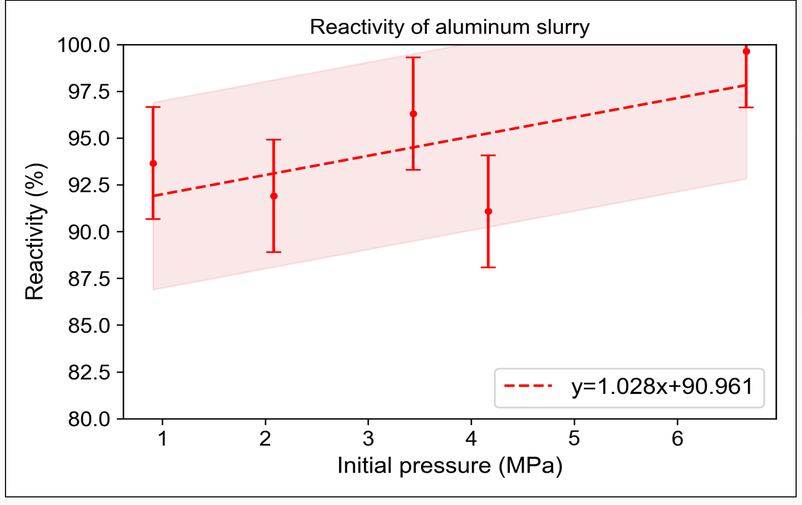
Hard to anticipate the position and orientation of the AUV → need for a pumpable fuel.

Process:

- Grind eGaIn coated aluminum pellets in colloid mill
- Mix with Silicone Oil
- Add Aerosil® Fumed Silica to make a homogeneous Aluminum slurry



Aluminum powder has a higher surface area-to-volume ratio than pellets → significantly higher reactivity (~93% at atmospheric pressure).

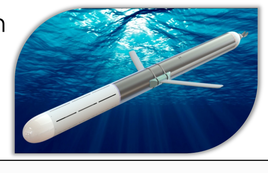


Future work

- Improve the pumping system – solve clogging issues
- Recover Ga in Al slurry
- Design an adapted hydrogen & steam engine
- Use sea water for the AUV

Applications

- Commercial
- Research
- Military



- Oil spill detection
- Pipeline inspection
- Plastic pollution characterization
- Air crash investigations

Co-funded by:

under the Flagship Project: K2D - Knowledge and Data from the Deep to Space | Area: Oceans to Near Space