Jessica Clish
Supervisor: Dr Nicholas Fang

Turning CO_2 Into Power: Investigating How Ni-Co Morphology Affects Electrode Performance in pH-Sensitive Thermally Regenerative Cells With Circulating Hydrogen For Long Discharging Time and High-Power Output

Introduction

Electrode morphology (roughness, thickness, porosity) strongly affects electrochemical behaviour. In **pH-sensitive thermally regenerative cells (pH-TRCs)**, hydrogen circulates between two catalytic electrodes, and the cell generates power from a **pH gradient**. The **surface structure** of Ni–Co coatings on the electrodes influences reaction kinetics and overall cell performance. While Ni–Co composition is well studied, the effect of **deposition conditions** on morphology and performance is less understood.

This project investigates how changing Co deposition parameters (current density + time) alters morphology and how these changes affect open-circuit voltage, current density, and power output.

Methodology

Electrode Preparation (using 2x3 carbon cloth):

- **Ni baseline coating:** multi-step deposition under controlled parameters.
- **Co variable coating: (baseline 2mA, 2min)**
  - Current densities: **0.5 mA**, **2 mA**, **4 mA**
  - Deposition times: **2min, 4min, 6min**

Electrochemical Testing:

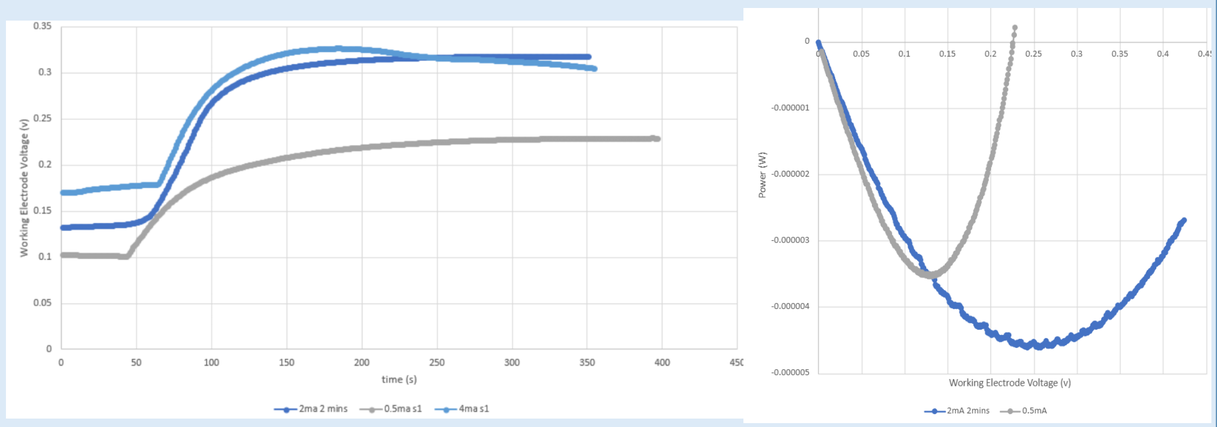
- **Open-Circuit Potential (OCP):** measure voltage stability
- **Linear Sweep Voltammetry (LSV):** obtain current–voltage behaviour.
- **Power calculation:**
  - P=I×V from LSV data
  - Compare peak power across deposition conditions.

Surface Characterisation:

- **XPS:** identify changes in Co oxidation states caused by deposition conditions.

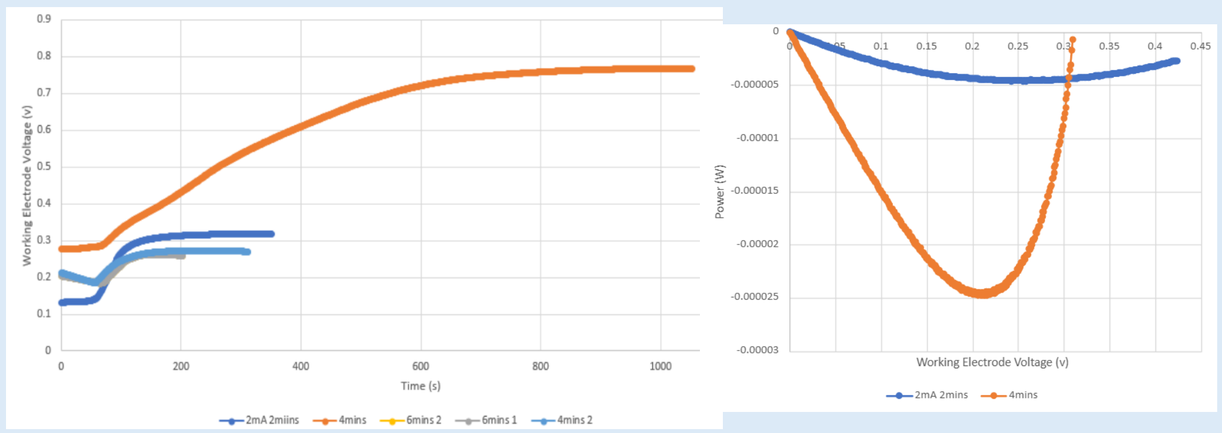
Results

Changing current density parameters



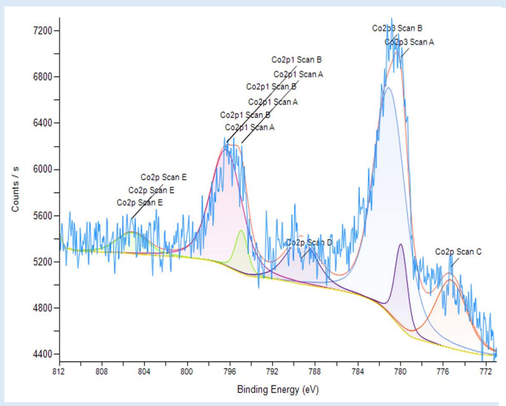
Across the current-density samples, the **2mA** electrode produced the **highest** and **most stable voltage** and generated the **greatest power** (–5 µW). The 0.5mA electrode showed a lower but stable voltage (229 mV) and correspondingly lower power (–3.5 µW). The 4mA electrode produced a high initial voltage but rapidly destabilised, preventing any power measurement.

Changing time parameters



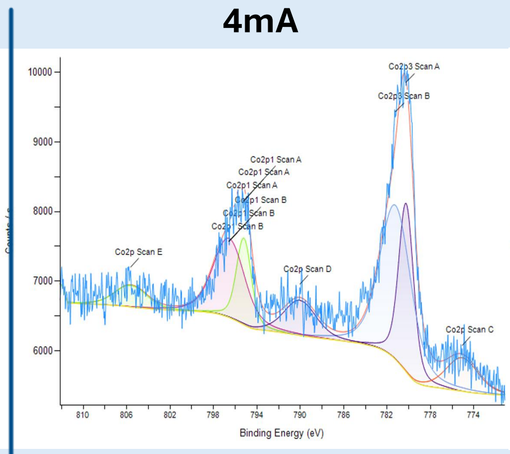
Across the time-variation samples, the **4min** electrode produced the **highest and most stable voltage** (768 mV) and the **greatest power** (–25 µW). The 2min control produced a moderate, stable voltage (317 mV) and lower power (–5 µW). The 6min electrode produced a low initial voltage (260 mV) followed by an immediate decline, preventing any power measurement.

0.5mA



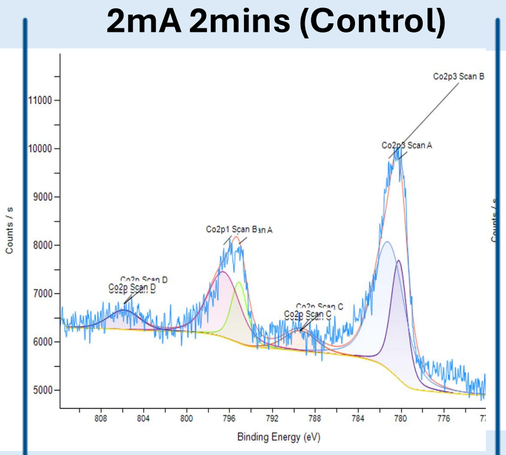
Low Co 2p intensities and few fitted components indicate a simple cobalt surface, consistent with the lower but stable voltage and reduced power output.

4mA



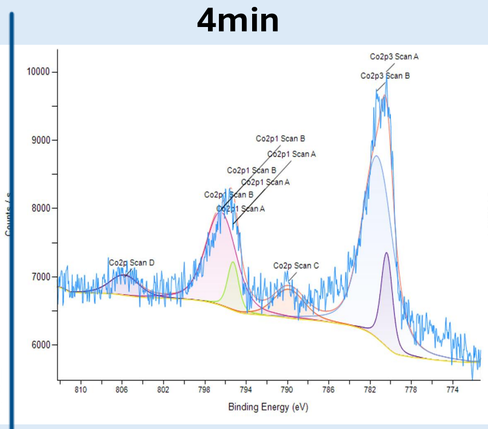
High Co 2p intensities and many fitted components indicate a highly mixed cobalt surface, aligning with the unstable voltage behaviour and absence of measurable power.

2mA 2mins (Control)



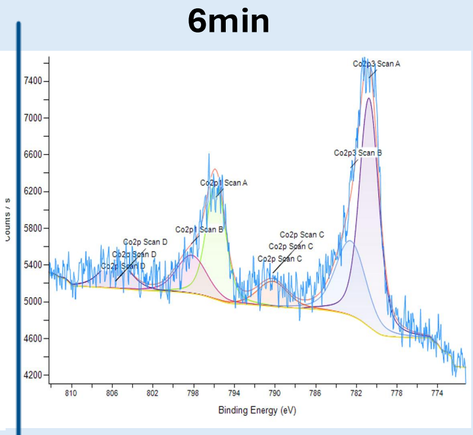
Strong Co 2p peaks with multiple fitted components, indicating a well-developed cobalt surface consistent with its stable voltage and mid-range power output.

4min



Moderate Co 2p intensities and several fitted components indicate a developed cobalt surface, matching the highest voltage stability and greatest power output.

6min



Low Co 2p intensities and few fitted components indicate an underdeveloped cobalt surface, consistent with unstable voltage behaviour.

Discussion / Conclusion

- **2mA, 4min** produced the **highest and most stable voltage**, giving the **best overall power output**.
- **2mA, 2min (baseline)** showed moderate performance — useful as a reference but clearly improved by longer deposition.
- **2mA, 6min** became **unstable**, and LSV did not flatten, likely an **over-grown coating** causing inconsistent behaviour.
- **0.5mA** gave **lower voltage and power**, consistent with a **thinner, less active Co layer**.
- **4mA** reached similar peak voltage to baseline but was **unstable**, suggesting **rougher or defective morphology**.

Overall: Moderate deposition time (4min) at baseline current (2mA) gives the **best balance of stability and power**. Very low, very high, or very long deposition conditions reduce performance or stability.

Limitations: Some OCP scans did not flatten (6 min, 4mA), so these conditions should be **repeated** for confirmation. XPS trends support the performance differences, but further morphology imaging (e.g., SEM) would strengthen the interpretation.

References