

DIRECT CARBON FUEL CELL WETTABILITY STUDY

Evaluating molten carbonate electrolyte spreading on carbon substrates at 900°C using high-temperature furnace testing, contact-angle analysis, and Python video processing.

High-Temp Furnace Testing	Contact Angle Analysis	Python Video Processing	Carbonate Electrolytes	DCFC Interfaces	Electrochemistry
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900°C Molten electrolyte testing	2–3 h Video test cycles	10 min Frame extraction intervals	~18 Total experimental runs
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CONTEXT

The DCFC program and my role in it

The Advanced Hydrogen Production and Direct Carbon Fuel Cell Technologies group at CanmetENERGY Ottawa is working on a clean-energy pathway built around methane thermal cracking. The process splits natural gas into solid carbon and hydrogen. The solid carbon goes into a Direct Carbon Fuel Cell (DCFC) that converts it into electricity while producing a pure, sequestrable CO₂ stream. The liberated hydrogen feeds into fuel cells or industrial processes in parallel. Together the two outputs turn a fossil input into useful energy while eliminating uncontrolled emissions.

A key bottleneck in DCFC development is the carbon-electrolyte interface. For the cell to work efficiently, the molten carbonate electrolyte needs to spread well across the carbon anode surface and maintain stable contact over time. Poor wetting reduces the effective reaction area and degrades electrochemical performance. The group needed experimental wettability data on candidate electrolytes to support material selection.

During my co-op at CanmetENERGY I reached out independently to the lead researcher on this program to contribute analysis work alongside my primary placement. This project ran concurrently with the bio-oil binder work but under a separate team. My focus was wettability testing: preparing samples, running furnace trials, processing video data, and measuring contact angles across candidate electrolytes and atmospheric conditions.

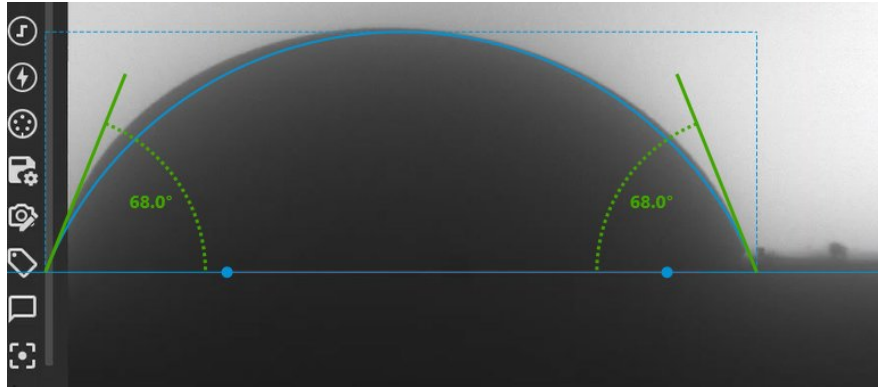


Fig. 1 — Contact angle measurement from sessile-drop analysis software showing a molten carbonate electrolyte droplet on a carbon substrate. Bilateral angle measurement reads 68.0° — indicating partial wetting behavior at the carbon-electrolyte interface.

EXPERIMENTAL SETUP

The high-temperature tensiometer system

The experiments used a specialized tensiometer/furnace system developed at Natural Resources Canada capable of reaching 1500°C , making it well suited for reproducing molten carbonate conditions. In each test, a carbon plate was placed at the base of the furnace chamber as the electrode substrate. A compressed pellet of powdered electrolyte — prepared using a hydraulic press — was placed on top and the system was heated gradually to 900°C , at which point the electrolyte melted and formed a droplet on the carbon surface.

To approximate real DCFC operating conditions, the tensiometer was also equipped to introduce controlled gas flows. Trials were run in parallel under ambient air and CO_2 -rich atmospheres. The CO_2 environment simulates conditions at a DCFC anode where carbon oxidation produces large quantities of CO_2 , which can react with the carbon substrate surface and alter wetting behavior.

A high-resolution black-and-white scientific camera was aimed at the reaction interface throughout. Each experiment was filmed continuously for 2 to 3 hours across the full heating cycle. Frames were extracted at 10-minute intervals from the point of melt and analyzed using contact angle software to measure how the droplet profile evolved over time.



Fig. 2 — Left: interior view of the tensiometer furnace chamber showing the molten electrolyte droplet sitting on the carbon substrate plate at high temperature. Right: the full high-temperature tensiometer/furnace system (IDS camera + HTFC 1700 controller) used for all wettability trials.

DATA PROCESSING

Python video workflows

Each run produced 2 to 3 hours of continuous video. Before any contact-angle measurement could happen, the footage needed preprocessing. The raw files included long heat-up phases where nothing was visible, the droplet region was small relative to the full frame, and some clips ran at speeds that made frame-by-frame review impractical.

I wrote three Python scripts to handle this systematically across all runs:

video_speed.py	Sped up droplet cycle footage for fast review and QC across long experimental runs.
screen_crop.py	Cropped and focused on the droplet region to isolate the contact line for accurate angle extraction.
video_crop.py	Trimmed videos to the relevant reaction window starting from the melt point, discarding the heat-up phase.

The processed frames were loaded into the contact angle software at CanmetENERGY for bilateral angle measurement. This workflow made batch processing consistent across candidates and reduced the time from raw footage to usable data significantly.

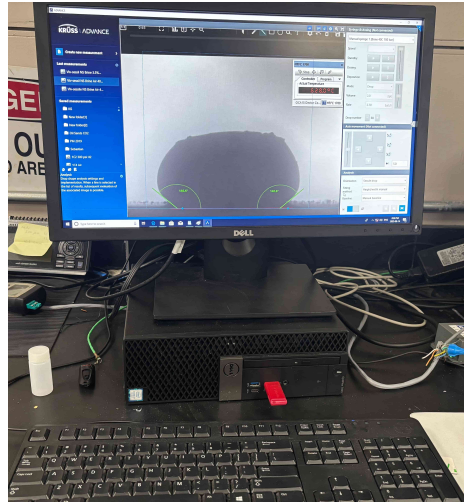


Fig. 3 — KRUSS ADVANCE contact angle measurement workstation at CanmetENERGY Ottawa. Screen shows a live molten droplet at 828°C with bilateral angle measurement reading 140.6°, captured at the beginning of a melt cycle. The HTFC 1700 furnace controller is visible on the right panel.

EXPERIMENTS AND FINDINGS

Wettability of two electrolyte candidates

Two carbonate-based molten electrolyte candidates were evaluated. Exact formulations are confidential under NDA — they are referred to here as Electrolyte 1 and Electrolyte 2. Both were tested in ambient air and CO₂-rich atmospheres across multiple runs.

Electrolyte 1 — strong wetting behavior

Electrolyte 1 consistently showed favorable spreading behavior. Starting at approximately 140° at the point of melt, the contact angle dropped steadily over the 120-minute observation window, stabilizing around 45°. This sharp decline indicates good surface interaction with the carbon substrate and suggests effective ionic conduction pathways would form in a working cell. The spreading was stable — no rebound or oscillation — which points to a consistent film formation mechanism at the interface.

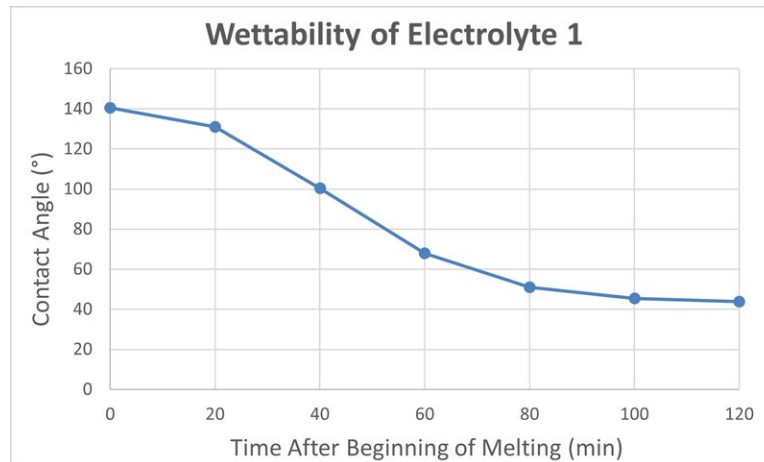


Fig. 4 — Wettability of Electrolyte 1: contact angle vs. time after melt onset. Angle drops from 140° to 45° over 120 minutes under ambient conditions, indicating strong and stable spreading behavior across the carbon substrate.

Electrolyte 2 — poor wetting behavior

Electrolyte 2 showed limited affinity for the carbon surface. Contact angles remained high throughout the observation window, starting around 110° and dropping only marginally to approximately 90° over 120 minutes. Droplets retained a near-spherical profile with minimal spreading, indicating poor surface interaction. In a working DCFC this would translate to limited effective reaction area and reduced electrochemical output.

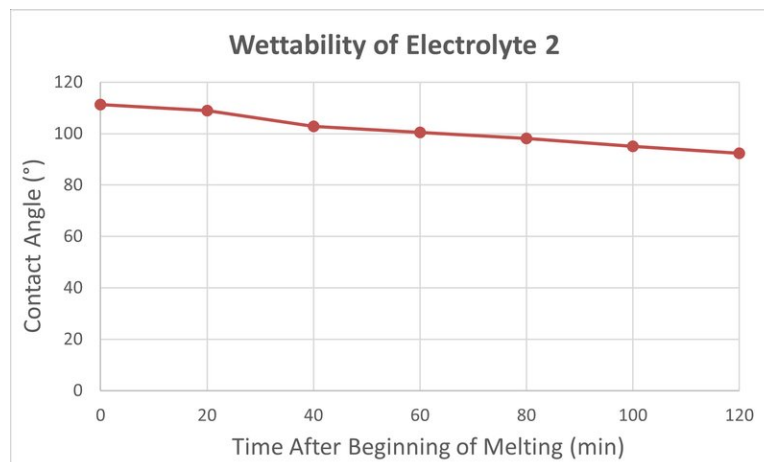


Fig. 5 — Wettability of Electrolyte 2: contact angle vs. time after melt onset. Angles hold between 90–110° throughout the 120-minute window, confirming poor spreading and limited electrode-electrolyte contact.

Effect of CO₂ atmosphere on Electrolyte 1

Electrolyte 1 was retested under a CO₂-rich atmosphere to approximate actual DCFC anode conditions. The results showed a modest increase in contact angle compared to the ambient air baseline — indicating slightly reduced wettability. This was attributed to surface carbonation effects on the biocarbon substrate, where CO₂ exposure alters the surface energy of the carbon plate. While the effect was not severe enough to disqualify Electrolyte 1, it underscored the importance of validating candidate materials under realistic operating gas environments rather than relying on ambient air measurements alone.

EXPERIMENTAL CHALLENGES

What went wrong and how it was fixed

Biocarbon substrate surface variability

The biocarbon surfaces occasionally displayed variations in roughness from one sample to the next, which influenced droplet spreading behavior independently of the electrolyte properties. To reduce this confound, sample preparation was standardized — substrates were flattened and made as uniform as possible before each run. This improved repeatability and ensured that performance differences between electrolytes reflected material behavior rather than substrate condition.

Blurred droplet edges reducing measurement accuracy

Some raw droplet images had blurred edges that made contact line detection unreliable in the angle measurement software. This was solved in preprocessing — the Python cropping script was adjusted to improve edge detection through zoom adjustments and focused region selection, producing sharper images and more consistent angle readings across runs.

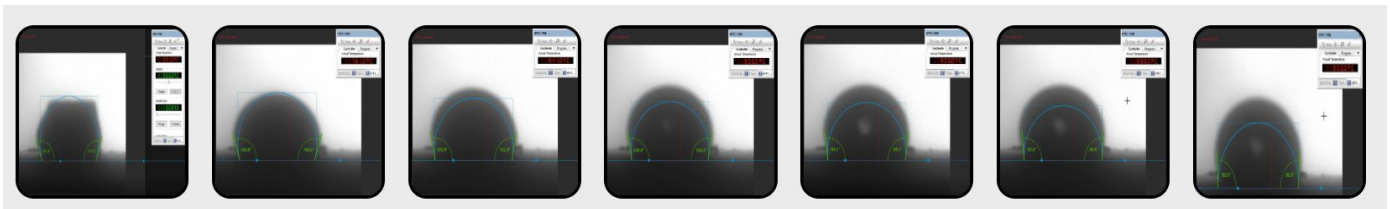


Fig. 6 — Time-lapse sequence of Electrolyte 1 droplet frames extracted at 10-minute intervals from melt onset, showing progressive spreading across the carbon substrate. Contact angle visibly decreases from left to right as the electrolyte wets the surface over the 120-minute window.

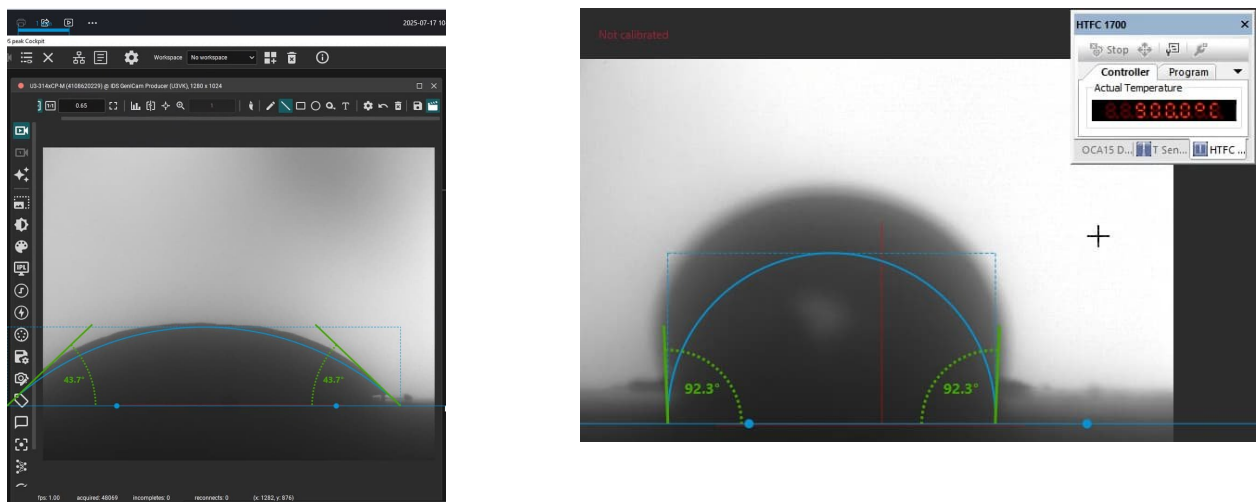


Fig. 7 — Left: IDS peak Cockpit live view showing Electrolyte 1 at 43.7° bilateral contact angle after 120 minutes — strong wetting, flat droplet profile, good electrode contact. Right: KRUSS ADVANCE view showing a candidate at 92.3° bilateral at 900°C — poor wetting, near-spherical droplet, limited surface interaction.

RETROSPECTIVE

What I'd do differently

01 Automate angle extraction from video frames

Manually loading processed frames into the contact angle software and measuring angles one at a time was the biggest time sink in the workflow. Writing a computer vision script to detect the droplet edge and extract bilateral contact angles automatically would have made the dataset much larger and the results more statistically robust.

02 Standardize substrate preparation with a surface roughness measurement

Flattening substrates by eye reduced variability but did not eliminate it. Adding a profilometry step before each test would have given a quantitative surface roughness value to accompany each data point, making it possible to separate substrate effects from electrolyte behavior in the final analysis.

03 Run more replicates per condition earlier

The experimental schedule meant that most conditions were tested with a limited number of replicates. Running a small number of repeat trials per electrolyte and atmosphere earlier in the program would have helped identify outliers sooner and given the final dataset more statistical weight when comparing the two candidates.

REFERENCE

Technical specifications

Organization	CanmetENERGY Ottawa — Natural Resources Canada
Research group	Advanced Hydrogen Production and Direct Carbon Fuel Cell Technologies
Engagement type	Self-initiated volunteer contribution alongside co-op placement
Duration	May 2025 to August 2025 (concurrent with bio-oil binder project)
Test temperature	900°C (molten carbonate conditions); system rated to 1500°C
Instrument	High-temperature tensiometer/furnace system, NRCan CanmetENERGY Ottawa
Electrolytes tested	2 carbonate-based candidates (exact formulations under NDA)
Atmospheres	Ambient air; CO ₂ -rich (simulating DCFC anode conditions)
Video duration	2–3 hours continuous per run
Frame interval	10-minute extraction from melt point onward
Total runs	~18 experimental runs across both candidates and atmospheres

Python scripts	video_speed.py, screen_crop.py, video_crop.py
Key finding	Electrolyte 1: strong wetting (140° to 45° over 120 min). Electrolyte 2: poor wetting (110° to 90°, minimal decay)
CO2 effect	Modest contact angle increase for Electrolyte 1 under CO2 — attributed to surface carbonation
Confidentiality	Public technical summary only — exact electrolyte formulations, internal datasets, and validation details excluded
