Advanced Drying Process for Lower Manufacturing Cost of Electrodes

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Project ID: ES246

LAMBDA TECHNOLOGIES

Overview

Timeline

- Project Start: October 1, 2014
- Project End: April 1, 2016
- Percentage Completed To Date: 50%

Budget

- ***Total project funding***
  - ***$1,011,453 (DOE)***
  - ***$288,547 (Lambda)***
- ***$107,907.66*** *received in FY14*
- ***$164,600.75*** *received so far in FY15*

Project Goals / Barriers

- Higher electrode loading for high energy density batteries
- Rapid drying of higher loading electrodes using ADP
- Build and test ADP prototype for anticipated 30% - 50% cost reduction of Li-ion battery as compared long convection ovens

Partners

- ***Navitas Systems, LLC***

NAVITAS SYSTEMS

Relevance and Project Objectives

- Drying of electrode slurries is a high cost operation for lithium ion batteries.
  - Convection oven can hence be up to 40 meter long.
  - ADP/VFM oven will be shorter in length
- Advanced Drying Process (ADP) for 30%-50% lower cost manufacturing of electrodes utilizes unique Variable Frequency Microwave (VFM), which can process metal electrodes and is being successfully used for production processes in semiconductor electronics.
- Microwaves penetrate the electrode slurry and interact with polar water or solvent molecules and rapidly drives them out of thick coatings.
- The project objective is to significantly reduce the drying time by a factor of 5 at least for the aqueous electrode slurries.
- The Advanced Drying Process is expected to reduce the cost of manufacturing of lithium ion batteries used in Electric Vehicles.

Milestones

Date	Milestone & Go/No Go	Status
Start + 2 months	**Milestone 1:** Evaluate Static to Dynamic Processing Parameters	Complete
3 months	**Milestone 2:** Microwave Choke Prototype Testing	Complete
6 months	**Milestone 3:** Final Design Review	Complete
10 months	**Go/No-Go 1:** Lambda Factory System Acceptance	In Process
11 months	**Milestone 4:** Tool Integration at Navitas	
16 months	**Milestone 5**: Prototype cell fabrication	
18 months	**Milestone 6**: Cycle life demonstration and final report	

Approach / Strategy

- Electrodes slurries, especially thicker coatings are slow to dry because of the surface heating by convection or infrared radiation (frequency much higher than microwaves).
- Use Variable Frequency Microwaves (VFM) to penetrate the thickness of the thick slurry electrode coatings.
- Water and other solvent molecules are polar. Microwaves selectively target these polar molecules and are sets the molecules into rotation.
- The enhanced mobility rapidly drives the water or solvent vapors out of the thick electrode coatings.
- The hot air flowing over the electrode carries these vapors away through the exhaust ports on the equipment.
- The result is a rapid drying cycle which saves drying time and cost.

Variable Frequency Microwaves (VFM)

- With Variable Frequency Microwaves (VFM), a bandwidth (5.85-6.65GHz) of frequencies is rapidly swept in a fraction of second (0.1s).
- The standing wave pattern for any single frequency rapidly changes allowing 4096 frequencies in the bandwidth to sweep in 0.1s, thereby providing electronic stirring of the modal pattern.
- As a result heating is much more uniform than fixed frequency microwaves processes.
- The rapid sweep allows the resident time of only 25 micro-seconds for standing wave pattern for each frequency. Thus there is no charge build up, hence no need to discharge (or arc as with fixed frequency) and no damage.
- This unique feature allows processing on metal foil as well as semiconductor electronics.

Generic Drying Rate Comparison

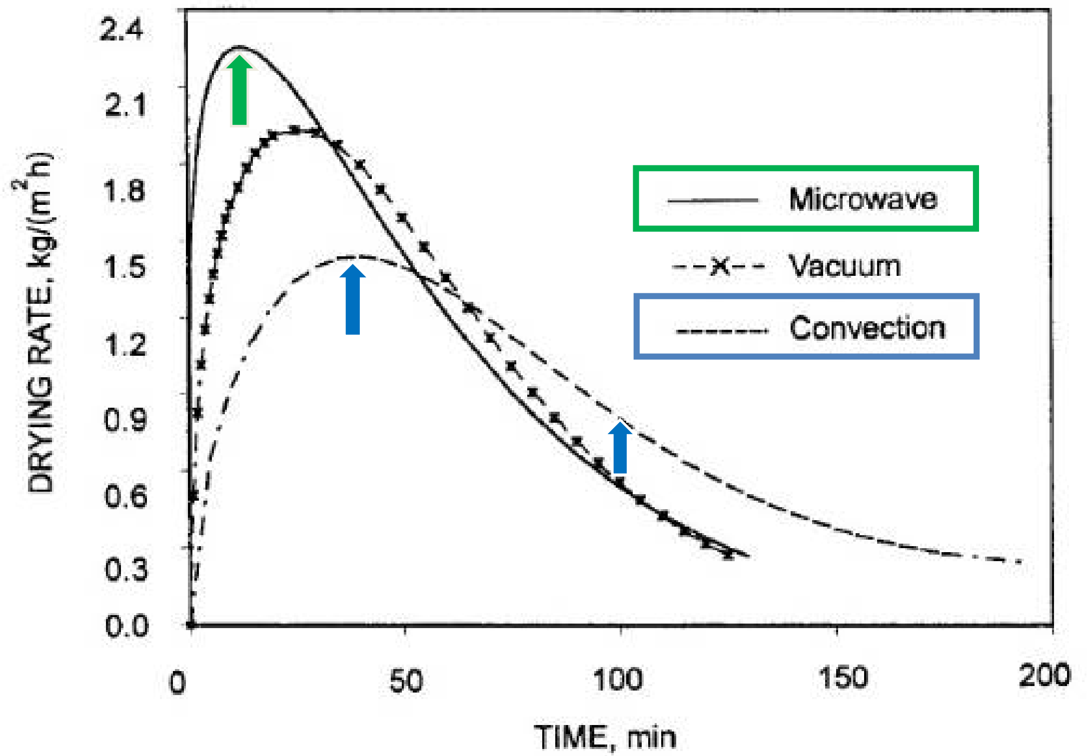
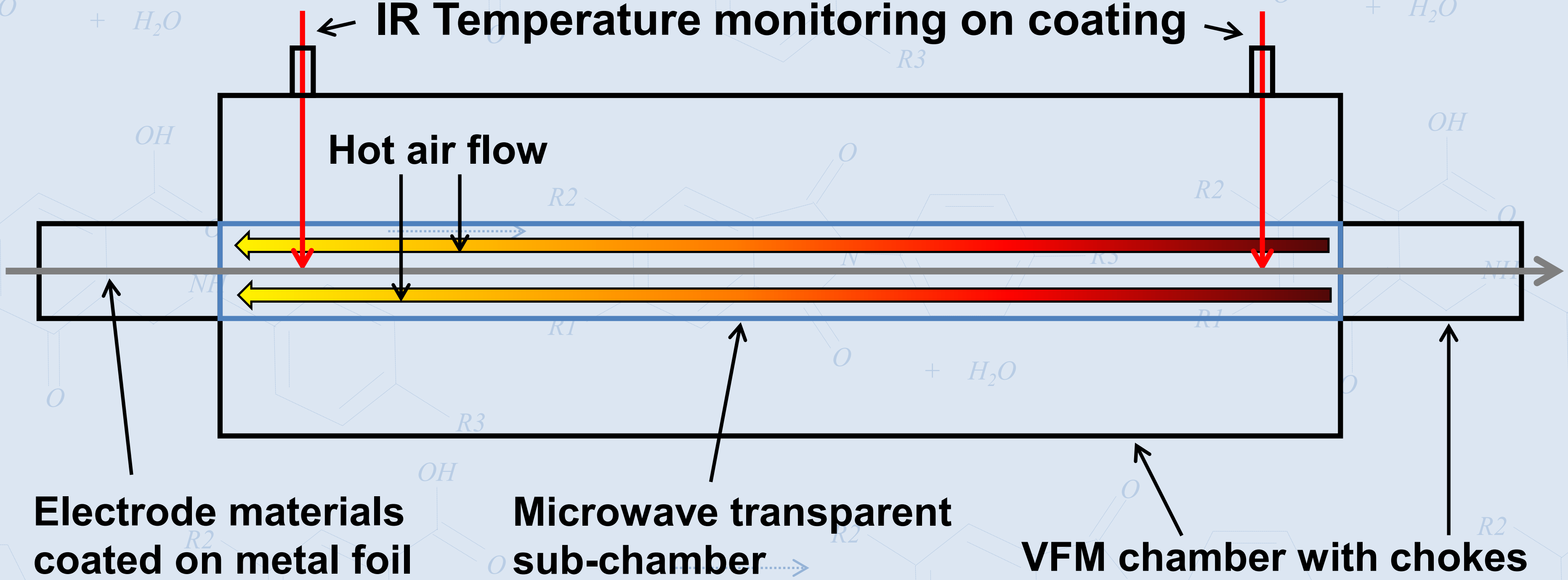


Figure 25.1 Convective, vacuum, and microwave drying of chlorpropamide: $T = 60°C$, $P = 0.1$ atm, $u = 5.4$ m/s, $P' = 385$ W/kg. (From Kardum et al., 2001.)

- ***Advanced Drying Process (ADP) employs both the higher microwave drying rate earlier in the process followed by the higher convection drying rate as illustrated in following slide.***

Advanced Drying Process (ADP)
VFM & Hot Air

Preliminary test apparatus for Milestone 1 Drying



Coated foil moves from the left to the right, while hot air moves from the right to the left. This arrangement provides higher temperature convection contribution where the foil exits and carries the solvent vapors towards the wet side at the entrance.

Milestone 1: ADP Drying Apparatus

- Used existing MicroCure 2100-700 system for controlled VFM power delivery.
- Used existing MicroCure 1300-900 cavity to dry electrodes.
- IR temperature device to monitor film temperature and fiber optic probe for hot air temperature.
- Variable speed and variable temperature heat gun used to deliver and control hot air into sub-chamber.
- Fabrication of hot air delivery and exhaust channels from a combination of metal and Teflon components.
- Designed and fabricated sub-chamber with PolyCarbonate (good to verify hot air delivery and low temp anode drying).
- Fabrication of PI film sub-chamber (good for high temp and NMP).

Sub-chamber Material Selection

- A silicon die was used to observe the highest temperature achieved with 500W of VFM power for 1 minute in the following arrangements. The material with highest temperature achieved is best for this project.
  - In PC sub-chamber 90°C
  - In ***Quartz enclosure*** ***180°C***
  - In PI film wrap sub-chamber 170°C
  - In PE + PI sub-chamber 148°C
- Material of choice is ***Quartz***. Other potential options include Radome ceramics and composites as well as Ultem (solid polyimide) but these are expensive and long lead materials that could be considered for production systems but were not practical for this prototype equipment.

Technical Accomplishments

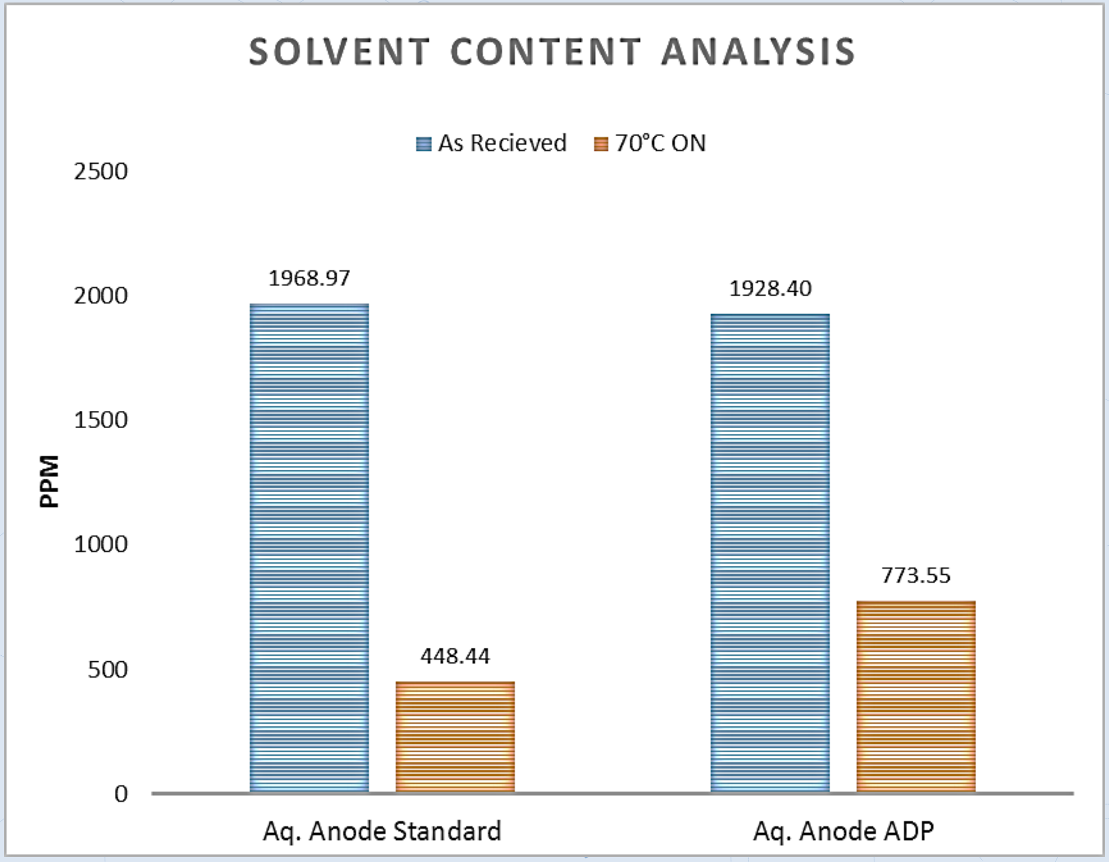
- Fabricating of a few components allowed assembly of a laboratory setup to perform the Advance Drying Process (ADP) which employed hot air as well as VFM power delivery for drying the electrode materials on metal webs.
- Slurries were rapidly dried in the laboratory set up. Aqueous anode drying was 5 times faster and NMP based cathode was 2 times faster.
- The dimensions or the VFM chamber and microwave sub-chamber as well as the sub-chamber material were identified.
- Several samples of aqueous anode and NMP cathode were dried.
- Navitas' test results showed that electrical and mechanical properties, as well as battery cell performance, pass all requirements.
- Based on the above experience the final VFM and sub-chamber were designed and fabricated.
- The wider chokes (175mm) have been designed and fabricated and testing is underway.

Samples prepared at Lambda and sent to Navitas for characterization

Electrodes	Drying method	Solvent	Drying time (min)	Loading (mg/cm^2)
Anode	Standard	Water	7.0	10.4
	ADP	Water	1.5	10.6
Cathode	Standard	NMP	7.0	18.2
	ADP	NMP	3.5	18.9

- ✓ ***Electrodes were hand casted using a doctor-blade technique onto Cu and Al foils and then dried using either hot air (standard) or Lambda advanced drying process (ADP)***
- ✓ ***Electrode testing at Navitas constituted: solvent content, adhesion, binder distribution experiments***
- ✓ ***Electrochemical validation included: half coin cell testing: formation, rate capability and cycling***

Material Characterization by Navitas: Solvent content



✓ ***Initial solvent content (as received) was ~2000 ppm, which is lower than Lambda-Navitas target (<5000 ppm)***

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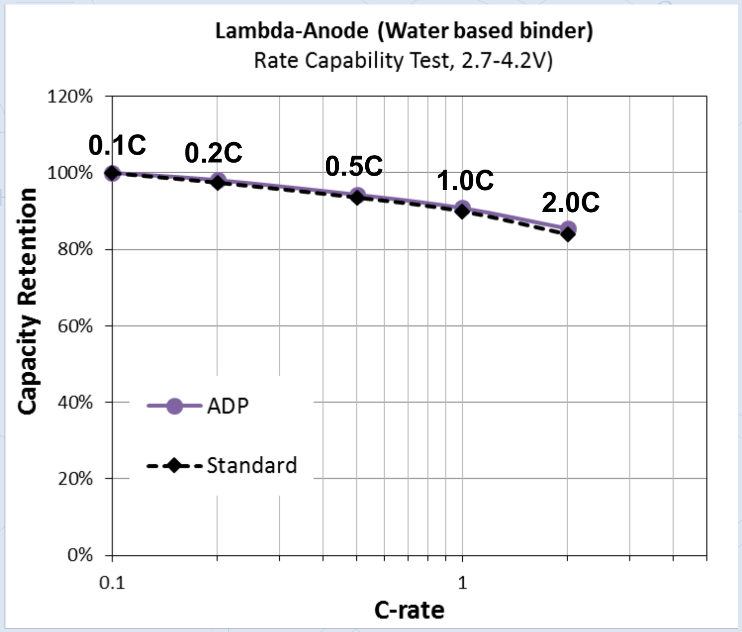
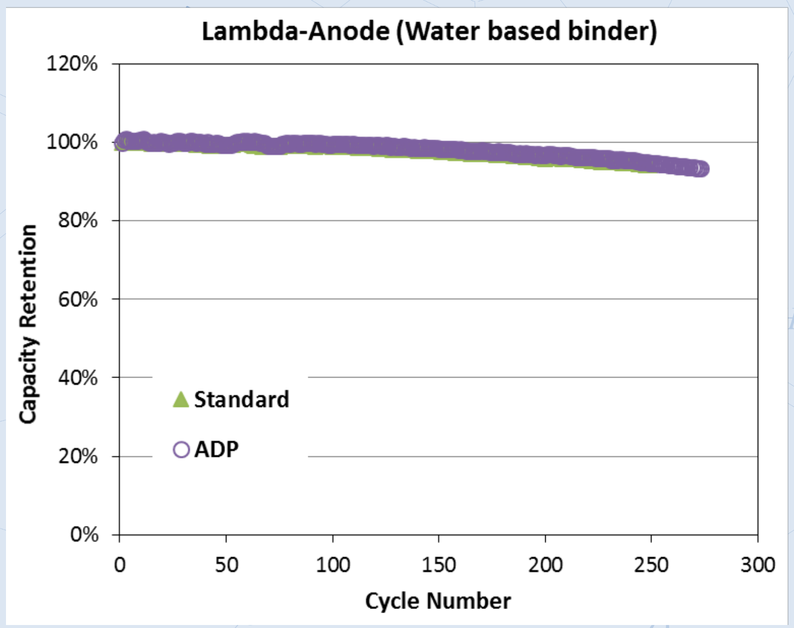
Adhesion & Binder Distribution

Electrode	Drying Method	Solvent	Drying time (min)	Adhesion	Binder Distribution
Anode-water	Standard	Water	7.0	Pass	1.08
	ADP	Water	1.5	Pass	1.06
Cathode-NMP	Standard	NMP	7.0	Pass	1.03
	ADP	NMP	3.5	Pass	1.04

- ✓ *All the electrodes have passed both (wet and dry) adhesion test*
- ✓ *Binder distribution ratio (electrode surface to near foil substrate) observed values were <1.3 target*
- ✓ ***Electrodes fabricated by Lambda whether dried by hot air (standard) or by the advanced drying process (ADP) have passed Navitas standard electrode qualifications***

Li ion Cell Testing: ADP Anode (Aqueous Binder, 3 mAh/cm²)

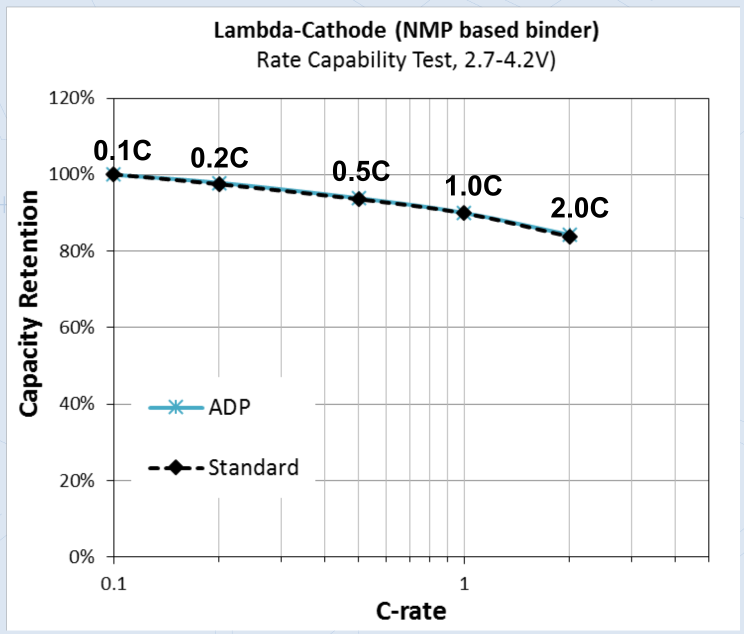


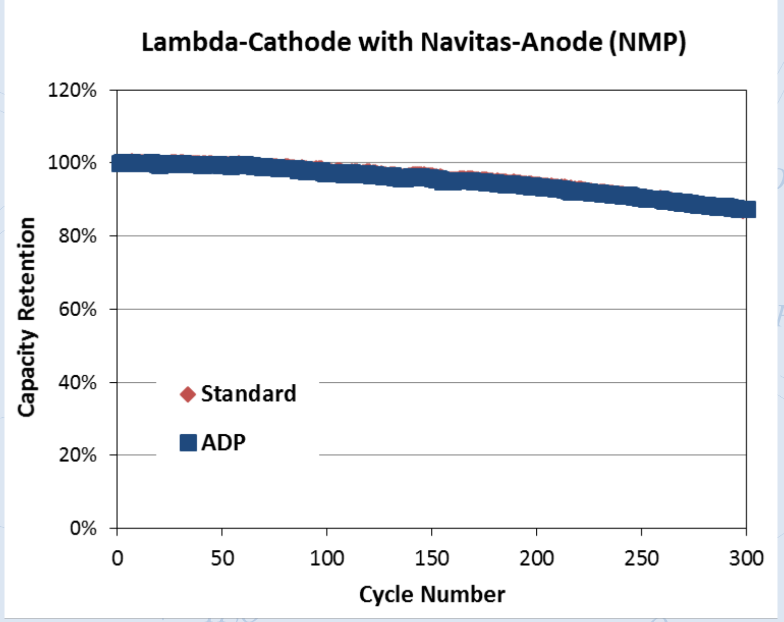


Electrode	Drying Method	Drying time (min)	Cap. Retention (%)	Cycle #
Natural Graphite Anode (Water based binder)	Standard	7.0	92	275
	ADP	1.5	92	275

✓ ***ADP dries the aqueous anode 5 times faster than the baseline without sacrificing its performance***

Li ion Cell Testing: ADP Cathode (PVDF/NMP Binder, 3 mAh/cm^2)

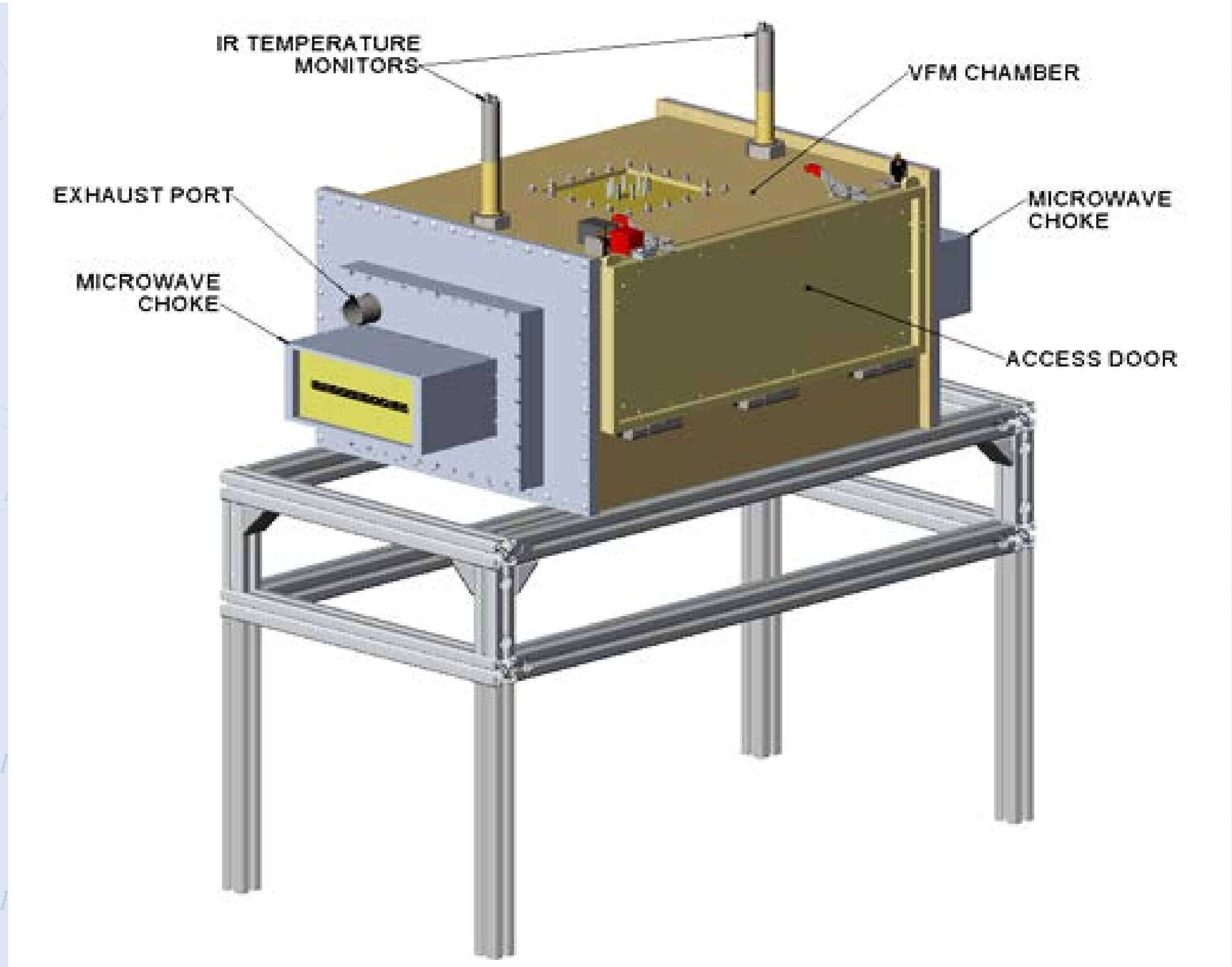




Electrode	Drying Method	Drying time (min)	Cap. Retention (%)	Cycle #
NCM 523 Cathode (PVDF/NMP Binder)	Standard	7.0	85	300
	ADP	3.5	85	300

✓ ***ADP dries the PVDF/NMP cathode 2 times faster than the baseline without sacrificing its performance***

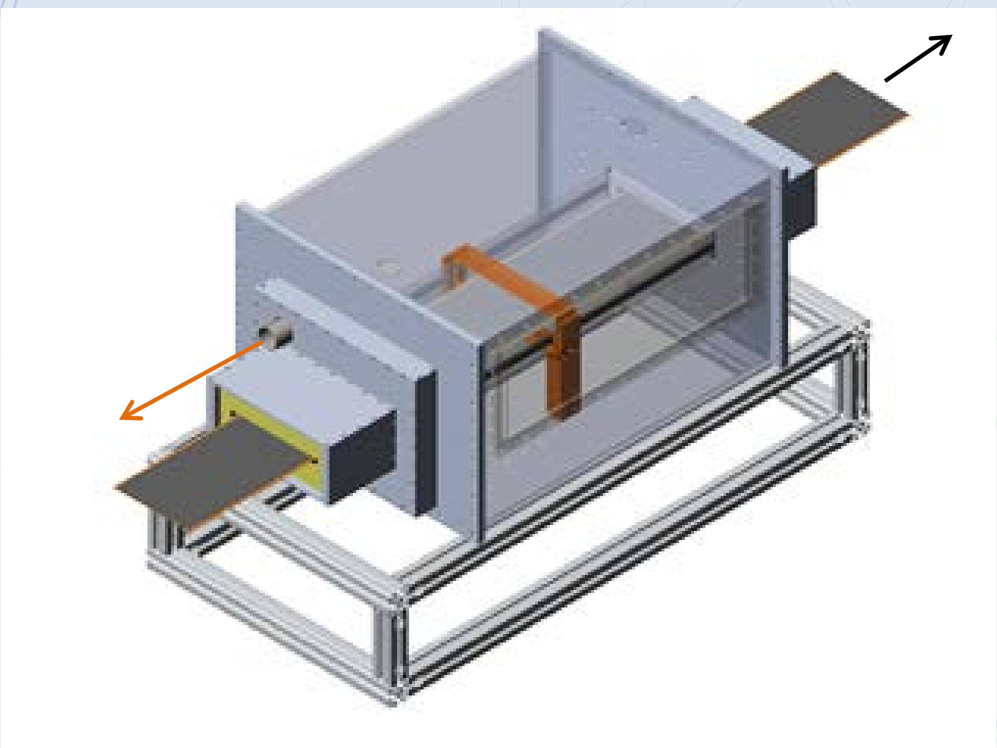
VFM/ADP Pilot Line Processing Chamber



Processing chamber for slower coating speed with double loading slurries

VFM/ADP Pilot Line Modules

MicroCure 1600-2000
(Standard VFM Power Module)



VFM Process Cavity
(Custom Module)

Proposed Future Work

- Complete assembly and test of ADP system at Lambda.
- Have Navitas personnel on site for Factory System Acceptance.
- Confirm rapid drying of casted electrode slurries.
- Ship tool and integrate at Navitas pilot line in fall of 2015.
- Prototype cell fabrication after ADP system is functional at Navitas.
- Cycle life demonstration.
- Write and submit final report in spring of 2016.

Summary

Relevance
- Drying of electrode slurries is a high cost operation for lithium ion batteries.
- ADP/VFM can rapidly dry electrodes slurries on metal foils.
- ADP is expected to reduce the cost of manufacturing of lithium ion batteries used in Electric Vehicles.

Approach
- Microwaves target solvent molecules
- Use VFM to couple with polar solvent molecules.
- Use penetrating VFM to reach deep in thick coatings and drive solvent out.
- Use hot air to exhaust solvent vapors.

Technical Accomplishments
- Fabricated a laboratory ADP setup for drying anode and cathode materials on metal webs.
- Dried samples sent for analytic and electrochemical characterization.
- Identified dimensions and materials for VFM chamber and sub-chamber.
- ADP process was 5 times faster for aqueous anode yet providing equivalent properties.

Future Work
- Assemble and test prototype ADP system.
- Ship, install and test at Navitas.
- Cell fabrication and Cycle life demonstration at Navitas.
- Prepare and submit final report.