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# Infrared-assisted drying of NMP-based Li-ion cathodes: balancing speed, quality, and energy in roll-to-roll production


**Max-Wolfram von Horstig [1,2], Payam Hashemi [1,2], Jürgen Weber [3], Larisa von Riewel [3], Peter Michalowski [1,2], Arno Kwade [1,2]**

1. Institute for Particle Technology (iPAT), Technische Universität Braunschweig, Volkmaroder Str. 5, 38104 Braunschweig, Germany
2. Battery LabFactory Braunschweig, Langer Kamp 19, 38106 Braunschweig, Germany
3. Excelitas Noblelight GmbH, Heraeusstraße 12-14, 63450 Hanau, Germany

E-Mail: payam.hashemi1@tu-braunschweig.de


## Objective

- Electrode drying is a major energy and cost driver in Li-ion battery production, accounting for nearly 48% of total energy consumption [1-4].
- This research aims to reduce drying time and improve energy efficiency of continuous roll-to-roll (R2R) drying of NMP-based NMC cathodes using infrared (IR) radiation without compromising electrode quality.

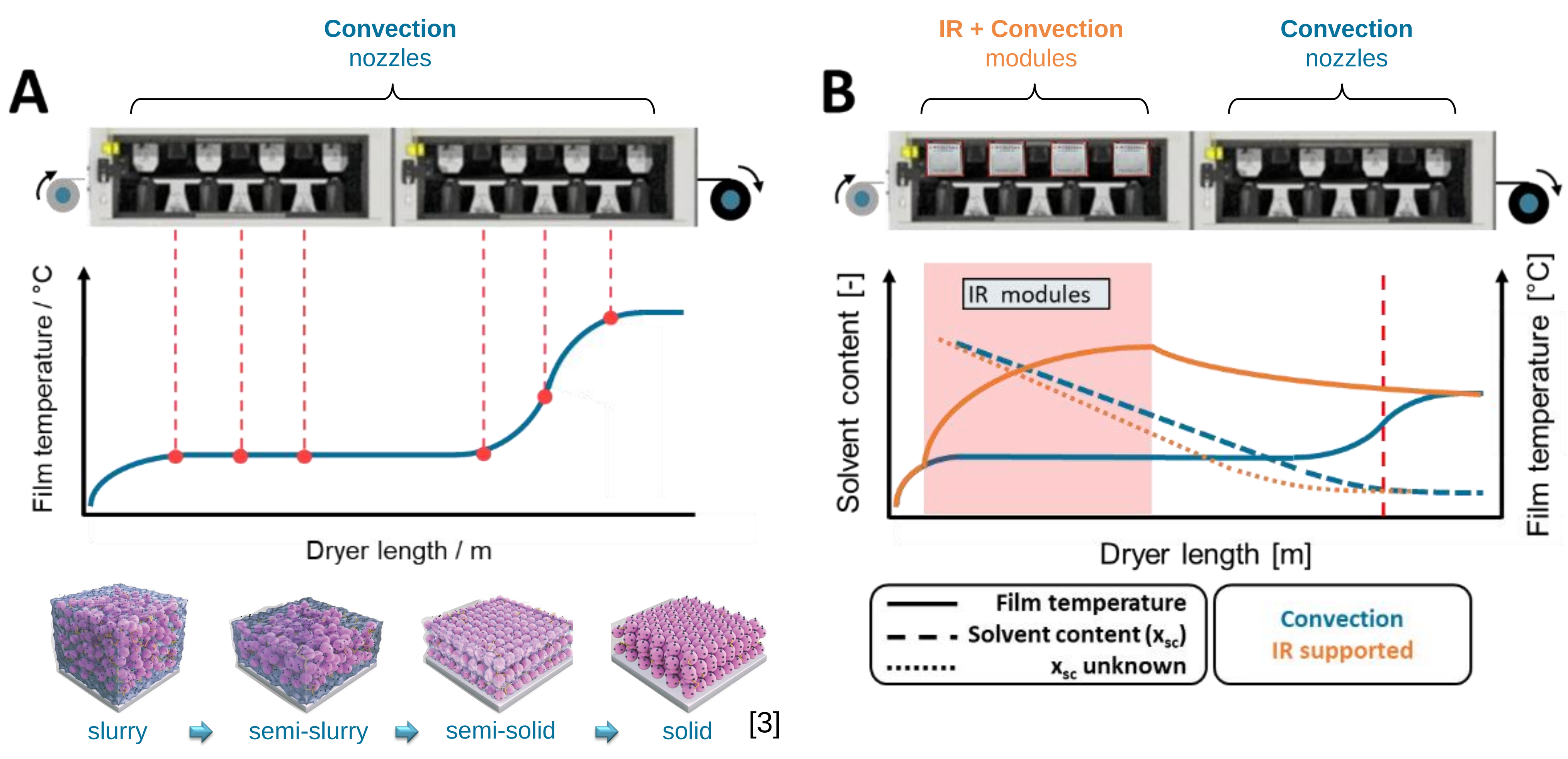


**Fig. 1. A**) Schematic depiction of R2R convective drying of the electrode and the surface temperature profile; **B**) Schematic depiction of drying time reduction with additional IR heating compared to pure convective drying, as well as solvent content and film temperature of the electrode during the drying process.

## Methodology

### 1. Discontinuous Trials (Emitter Investigation)

- Stationary tests were conducted to identify the impact of emitter technology on drying kinetics.
- Slurries of NMC (70 wt.% solids) were coated on Al-foil and positioned 11 cm below 3 identical emitters. 4 types of emitter were investigated (12 emitters in total). Results in *Fig. 2* and *Fig. 3*.

| Emitter Code | Filament | Reflector | Nominal Power |
|---|---|---|---|
| **TSW**-QRC | **Tungsten** Short Wave | **Quartz** | 290 W |
| **TSW**-**Gold** | **Tungsten** Short Wave | **Gold** | 550 W |
| **CIR**-**Gold** | **Carbon** Mid Wave | **Gold** | 850 W |
| **CIR**-QRC | **Carbon** Mid Wave | **Quartz** | 860 W |

### 2. Continuous Trials (Pilot Implementation)

- Findings were scaled to a R2R pilot coater (2m oven) using four CIR-QRC emitters (1350 W each) in the first segment (*Fig. 1-B*). We evaluated the *Specific Radiative Heat Input* ($Q_{A,rad}$) by varying web speeds (1–3 m/min) and emitter power settings (*Fig. 4* and *Fig. 5*).
- Online IR pyrometers and NMP sensors monitored film temperature and solvent explosion limits (%-LEL).

## Results

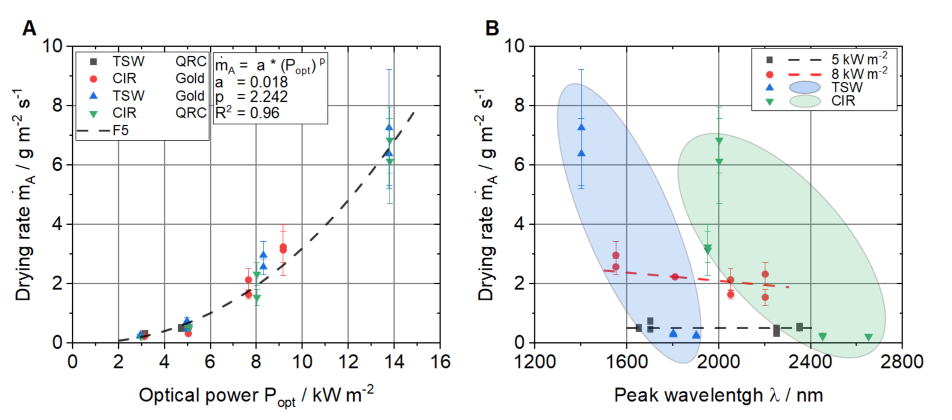

**Fig. 2.** Drying rate against **A**) Optical power; and **B**) Peak wavelength; in the discontinuous trials

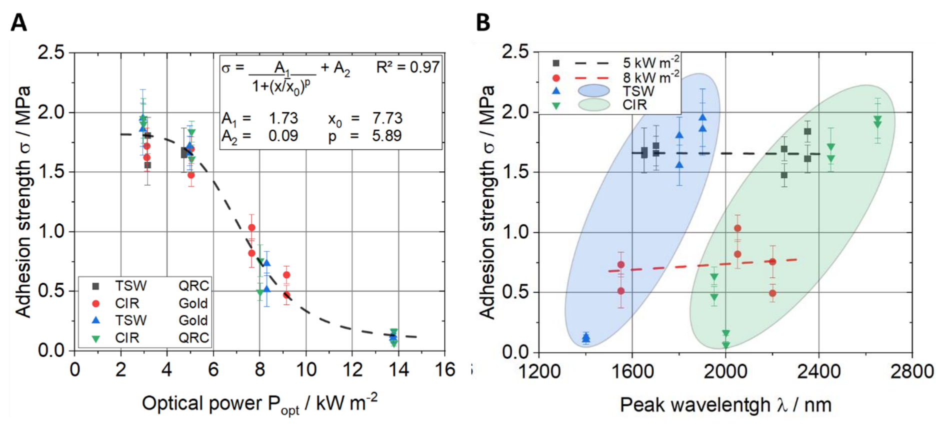

**Fig. 3.** Adhesion strength against **A**) Optical power; and **B**) Peak wavelength; in the discontinuous trials

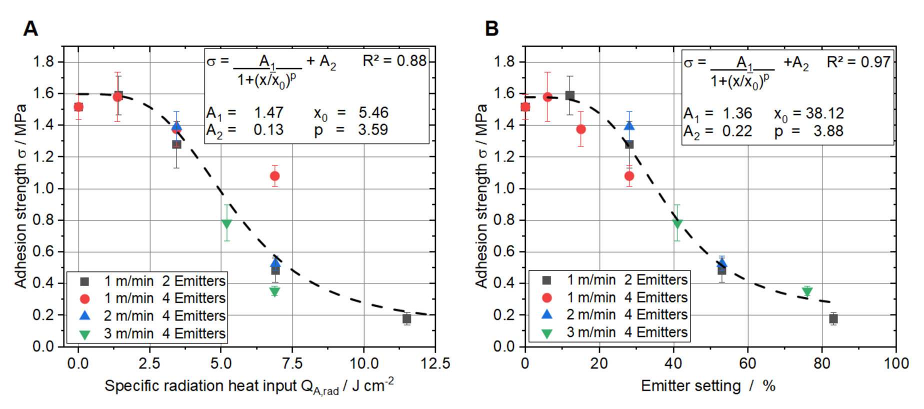

**Fig. 4.** Adhesion strength against **A**) specific radiation heat input; and **B**) emitter settings; in the continuous trial

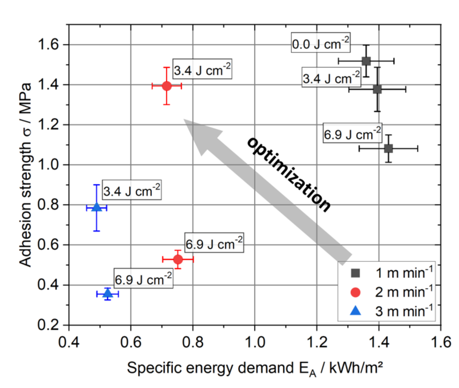

**Fig. 5.** Optimization plot comparing electrode quality and specific energy demand

- **Emitter Dominance:** Discontinuous trials revealed that total optical power is the primary driver of drying kinetics; emitter wavelength (TSW vs. CIR) had no significant impact when power levels were matched.
- **Kinetic Gains:** Increasing power from 5 to 14 kW/m² reduced drying time by 90% (180s to 15s). A quality "sweet spot" was found at 7 kW/m², yielding a 280% throughput increase while maintaining adhesion >1 N/mm².
- **R2R Scalability:** In continuous trials, web speed was successfully tripled (1 to 3 m/min). At 2 m/min and 7.5 J/cm², energy demand was cut by >50% (1.4 to 0.7 kWh/m²) with minimal adhesion loss.
- **Adhesion Correlation:** A sigmoidal relationship ($R^2$ = 0.97) exists between adhesion and emitter power. Higher web speeds require higher power to maintain $Q_{A,rad}$, creating thermal peaks that can impair adhesion.

## Discussion

Our results align with KIT fundamental models [5], confirming that accelerated drying induces capillary-driven binder migration. This leads to binder depletion at the current collector interface, reducing mechanical integrity. However, IR-assisted convection is more energy-efficient than induction or laser alternatives because the IR emitters effectively provide a portion of the convective heating requirement without requiring complex cooling-water infrastructure.

## Conclusion

- 7 kW/m² is the optimal benchmark for maximizing R2R throughput.
- High-intensity IR emitters effectively reduce dryer footprint and cut specific energy consumption by half.
- Online markers (color values and surface roughness) can successfully track segregation and pore closure during production.


## References

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