New environmentally friendly fluids for battery cooling

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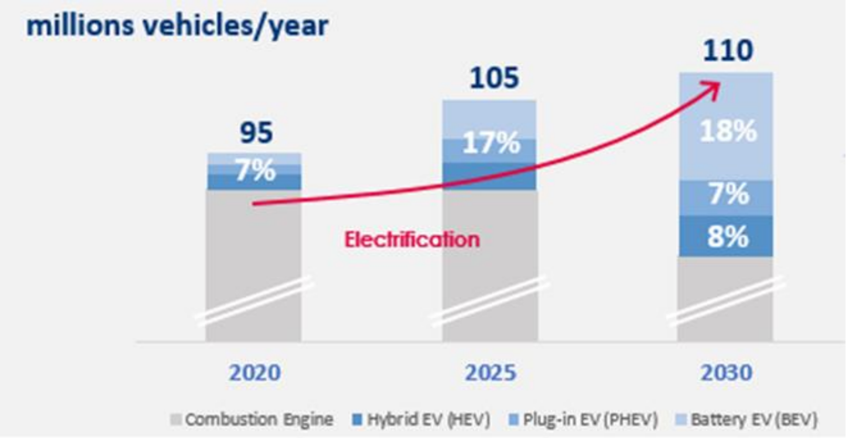
ARKEMA
INNOVATIVE CHEMISTRY

EV market moving to mainstream adoption

LONG TERM OUTLOOK REMAINS BRIGHT

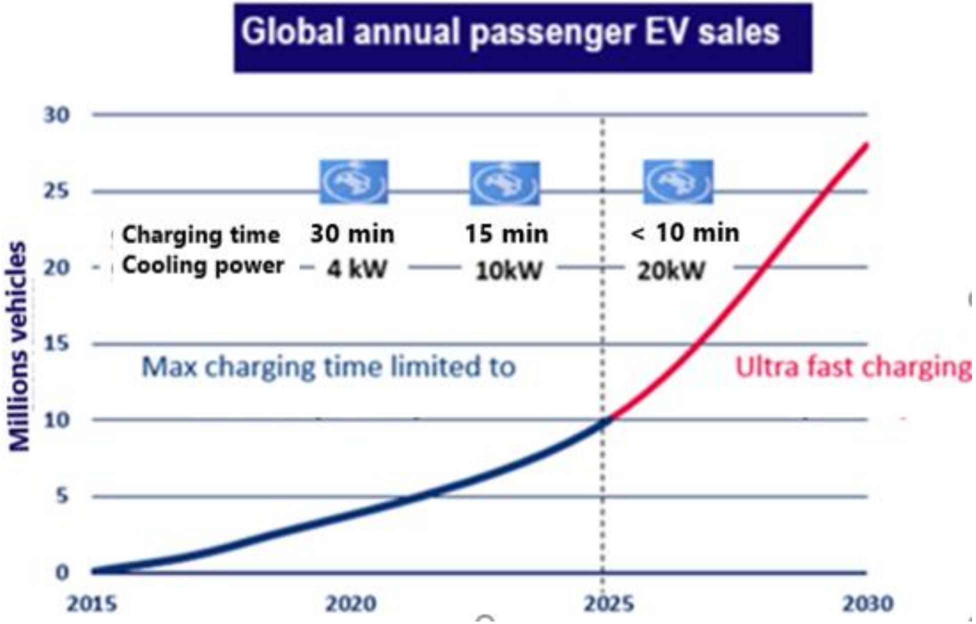


Source: BCG January 2020

- **Impact of covid-19**
  - Strong States Subsidies in Europe
  - Timelines maintained in Europe and China
- **Long term outlook**
  - Decrease of costs
    - Decrease of battery prices: towards 100$/kWh
    - Government supportive policy
  - Technology improvement needed for customers for large market acceptance

EV market moving to mainstream adoption

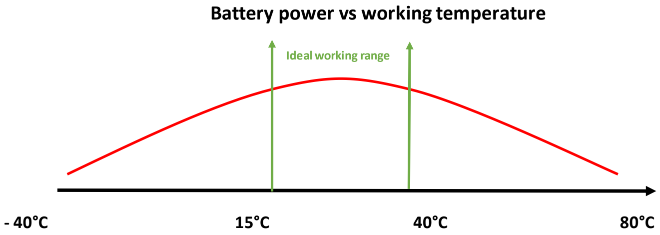
- Fast and ultrafast charging are key challenges for mainstream adoption



(*) *C-rate*, is a measure of the rate at which a battery is charged or discharged. 1C means charge/discharge in 1h. 4C means 15mn

Crucial role played by thermal management
Battery temperature stakes on performances, lifetime and safety

- **Performance and lifetime duration**
- Narrow controlled temperature operating range
- Limited and controlled thermal gradient in the pack and in the cell

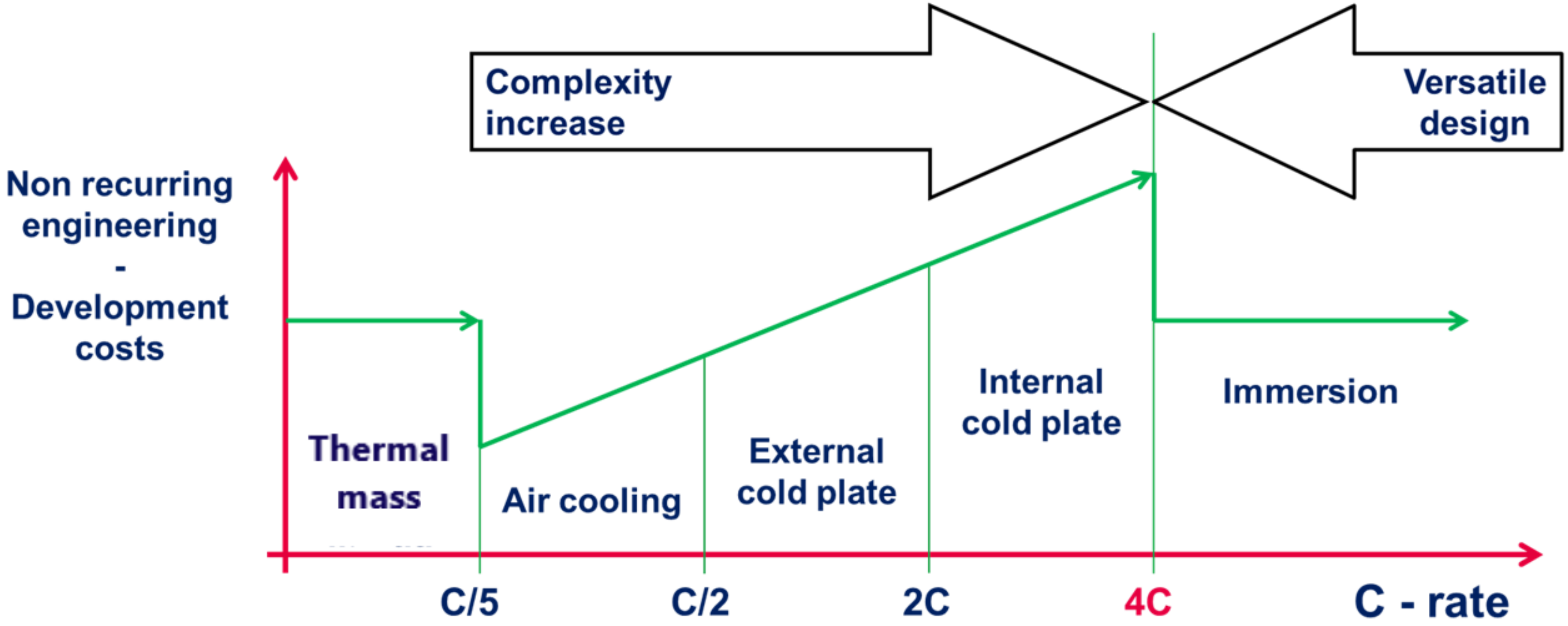


- **Safety**
- No thermal runaway propagation
- No Flammability

- **System**
- Integration with existing AC loops and system interactions
- Battery weight control to maintain optimum Energy density and efficiency

Cooling technologies vs charging time - The 4C* limit

Source: EXOES



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What is immersion cooling?

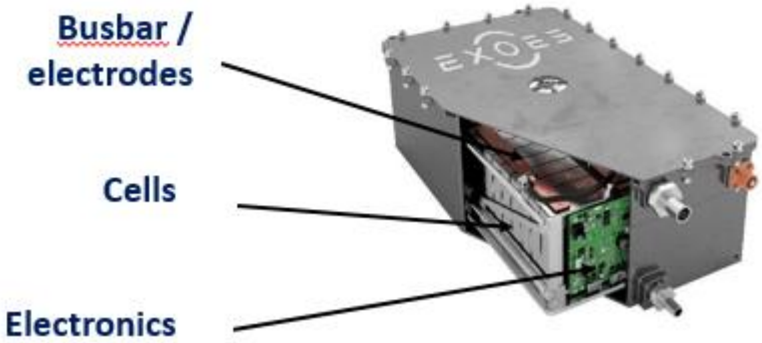
a dielectric fluid in contact with the cells

Increased thermal conductance

Better temperature uniformity

Cooling of all peripherals at the same time

No thermal runaway propagation

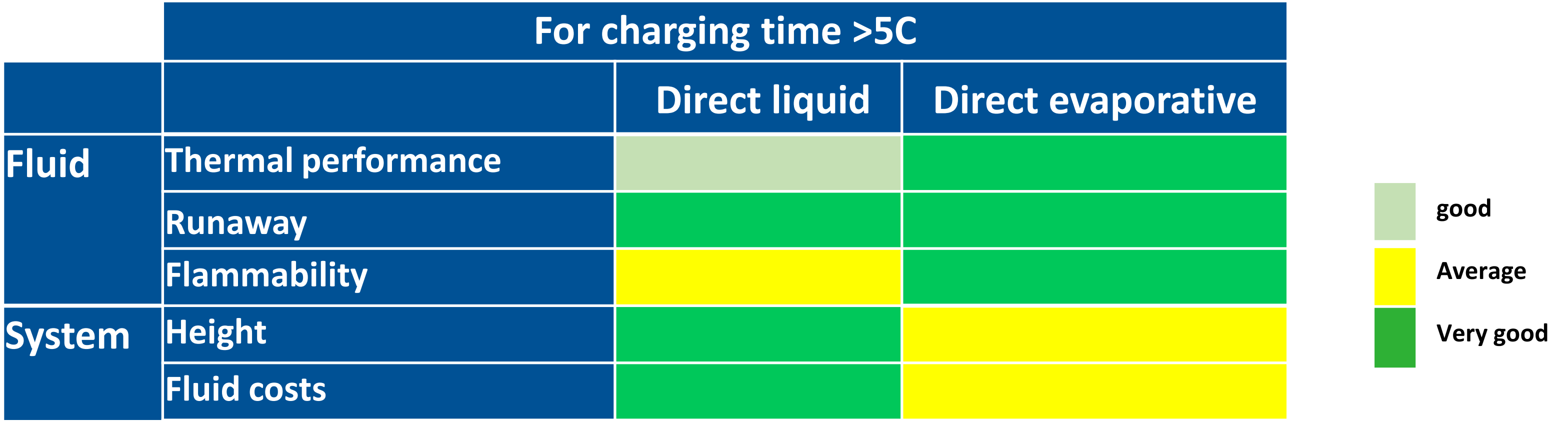


Competitive immersive cooling technics

Direct liquid (one phase)

Battery

Direct evaporative (2 phases)



		For charging time >5C	
		Direct liquid	Direct evaporative
Fluid	Thermal performance	▨	🟩
	Runaway	🟩	🟩
	Flammability	🟨	🟩
System	Height	🟩	🟨
	Fluid costs	🟩	🟨

▨	good
🟨	Average
🟩	Very good

A new approach toward immersive cooling

- **Engineered fluids based on blends containing dielectric oil**

Good dielectric properties

Good thermal properties

Blend

Environment friendly

Non toxic

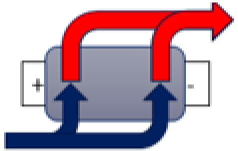
Non flammable

Properties can be tailored by adjusting the composition

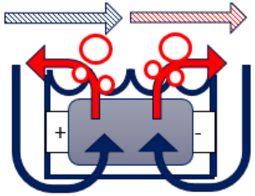
Fluids for immersive cooling: state of the art

DIELECTRIC + NON FLAMMABLE + HE FRIENDLY + CHEMICALY STABLE

HE = Health and environment



- **Liquid immersion cooling fluids: commercially available fluids**
  - Dielectric oils, perfluorochemicals, HFE, etc…
  - Flammability, or GWP may be an issue depending on the fluid

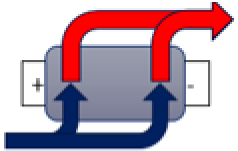


- **Evaporative immersion cooling fluids: No ideal candidate**

$15 < T_{boiling} < 40°C$

Engineered fluid benefits for immersive cooling technologies

- Liquid immersion benefits vs dielectric oils
  - Example: Composition 1, high boiling point

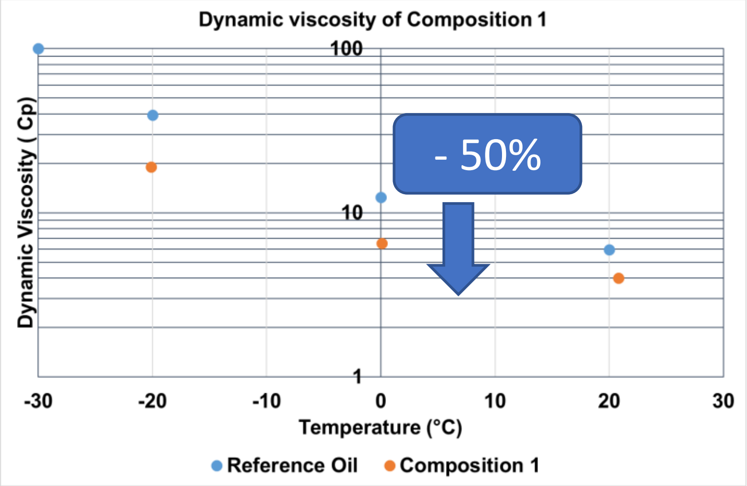


Non flammable

Low viscosity

- Lower energy consumption
- Lower investment costs

	For charging time >5C		
		Reference Oil	Composition 1
Fluid	Thermal performance	🟩	🟩
	Flammability	🟨	🟩
System	Fluid costs	🟩	🟩
	Investment costs	🟨	🟩

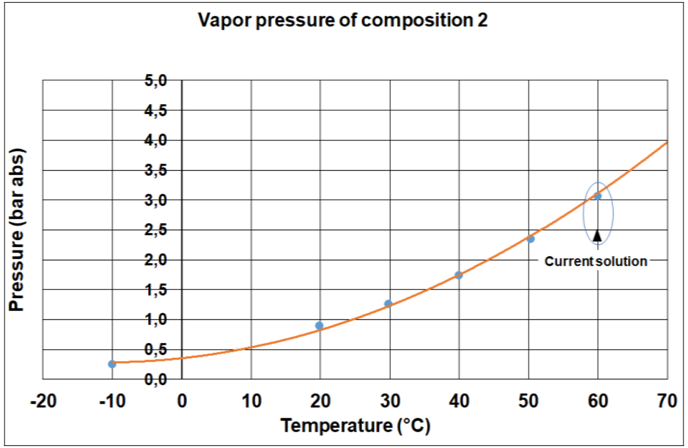


Engineered fluid benefits for immersive cooling technologies

- Evaporative immersion benefits vs pure evaporative solution
  - Composition 2, Low boiling point

Higher heat transfer coefficient vs liquid immersion

Lower fluid costs vs pure evaporative solution



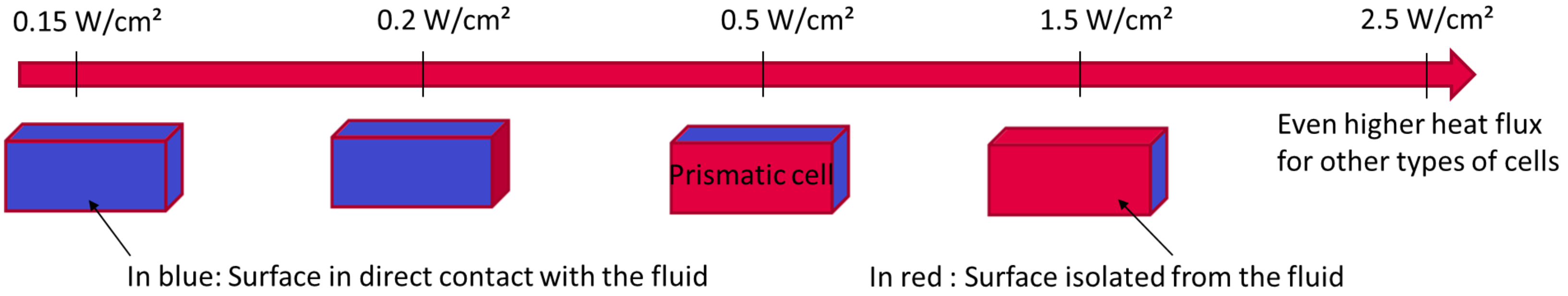
	For charging time >5C rate		
		Composition 2	Pure evaporative solution
Fluid	Thermal performance	🟩	🟩
System	Fluid costs	▨	🟨

Vapor pressure will be affected by composition nature

Heat flux for battery cooling for fast charging rates

Example of thermal requirements

- At 5C charge rate, a 50Ah prismatic Li-ion cell having ~1mOhm of internal resistance generates ~60W of hea
- The resulting heat flux for this cell in stationary conditions depends on the available cooling surface :



0.15 W/cm²

0.2 W/cm²

0.5 W/cm²

1.5 W/cm²

2.5 W/cm²

Prismatic cell

Even higher heat flux for other types of cells

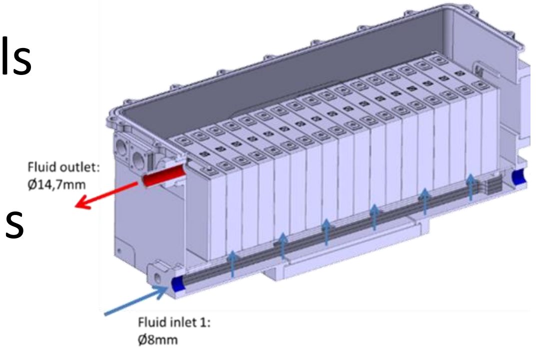
In blue: Surface in direct contact with the fluid

In red : Surface isolated from the fluid

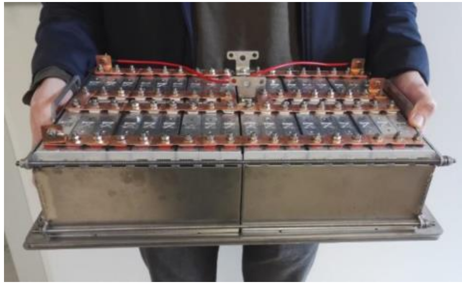
Battery cooling need typically ranges between 0.15 to 2.5 W/cm²

Performance assessment for 5C - Single phase direct cooling test

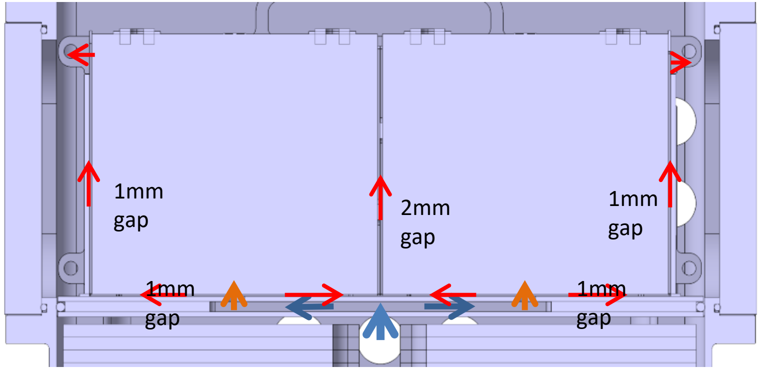
- Dummy battery module made of prismatic LTO* cells
- Direct cooling with a liquid fluid
- Measure with various fluids and flow rate conditions
- Heat transfer coefficient,
- Temperature uniformity
- Wall superheat



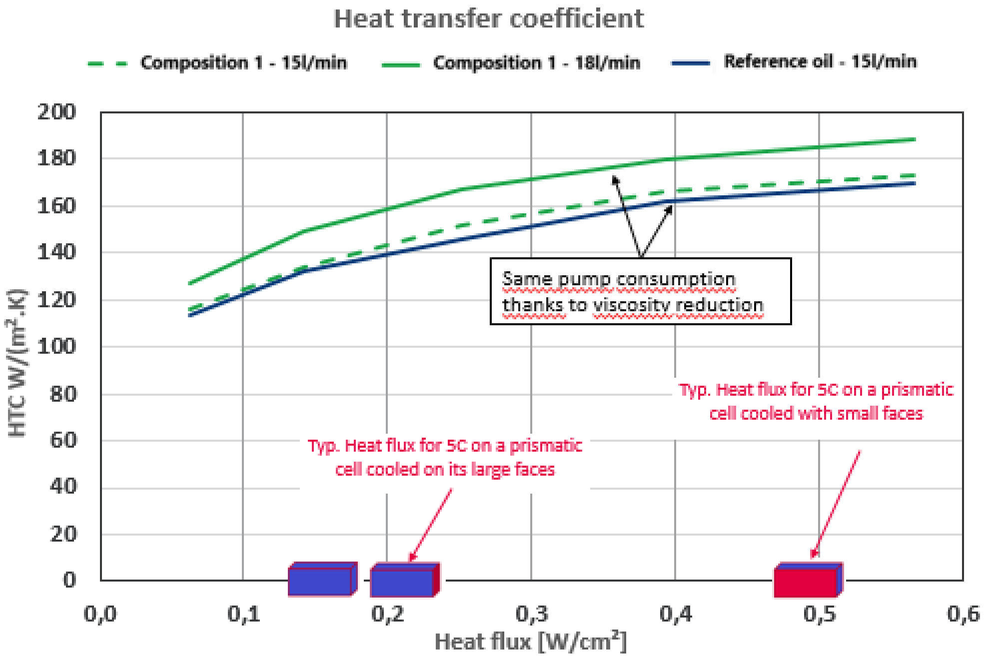
Source: EXOES



(*) LTO Toshiba 10Ah



HTC vs C-rate & flow rate: conclusion for liquid immersion



$$\overline{HTC} = \frac{\text{Total thermal power}}{(\overline{\text{Tcells}} - \text{Tfluid at box inlet}) \text{ x } S}$$

20% Increase on max flowrate @ same pump speed

ie for the same energy consumption flowrate was increased by 20%

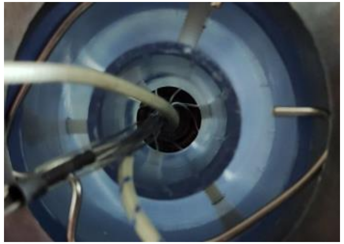
@0.5W/cm² : Mean HTC is 185W/m²/K

Performance assessment
Evaporative direct cooling pool boiling test rig

- Heat resistor (D15xH80mm) immersed in a cylinder full of saturated liquid
- Condenser on top of the box
- Copper
- Roughness Ra=0,8μm

- Measurements of
- Heat transfer coefficient
- Temperature uniformity
- Wall superheat

- Measured impact of
- Channel gap
- Liquid return



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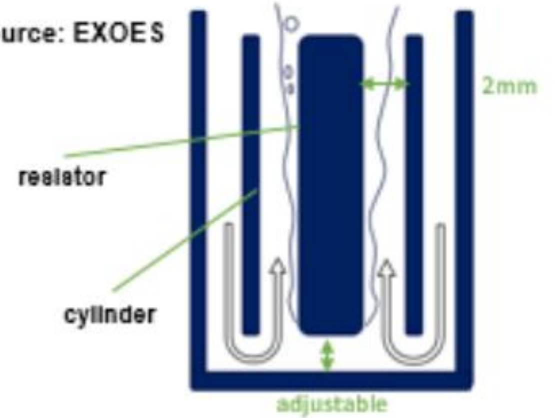
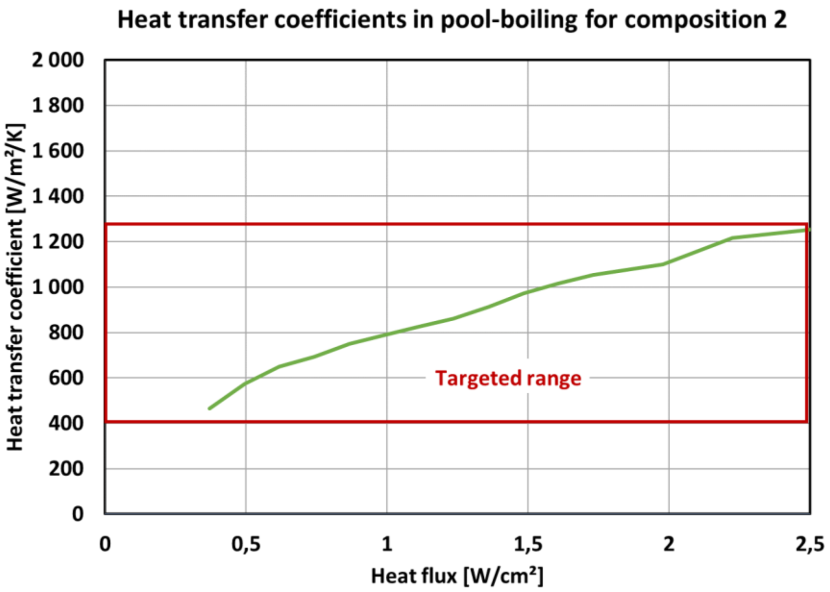


HTC vs heat flux : conclusion for evaporative immersion



. Cooling water in condenser @ 10° C

. Power steps on resistor 0 to 6W/cm^2

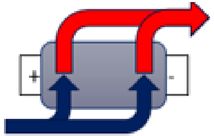
500 W/m2/K @ 0.5W/cm^2

Meet the targeted range

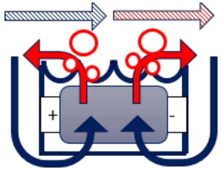
Conclusion

- A new concept of engineered fluids has been developed to support the adoption of immersive cooling technology

- In direct immersion cooling, the addition of a fluid lead to improved performance and safety
  - Non-flammability
  - Increased performance driving lower equipment/component costs



- For evaporative cooling, a good compromise between pressure and thermal performance has been found
  - Lower density than pure evaporative solution
  - Significantly higher HTC than liquid immersive cooling



- *Continued work to assess thermal runaway propagation and potential application to other cooling needs (Electronic, power train, e-motors)*

Acknowledgements

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Thank you

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