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First Assessment of Liquid Glass for CSP Applications

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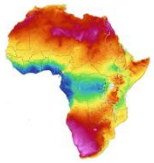

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Introduction to high-temperature heat transfer fluids and storage media

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State of the art HTF and storage medium

- Heat transfer fluid: *Solar Salt* (for central receiver)
  - T_{low} = 222 °C
  - T_{high} = 593 °C
  - receiver flux ≤ 1 MW_t/m^2
  - receiver efficiency ≤ 90 %

- Storage medium: *Solar Salt*
  - Large volumetric heat capacity
  - Low cost

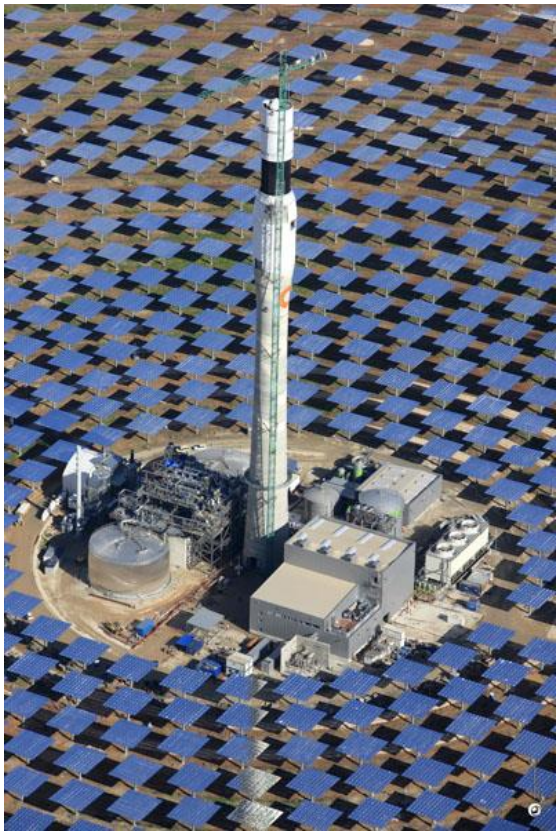


Figure: *Solar Salt* receiver and storage tanks of the *Gemasolar* plant

Alternative HTF

- Sodium (Na)
  - T_{low} = 98 °C
  - T_{high} = 883 °C
  - receiver flux ≥ 2.5 MW_t/m^2
  - receiver efficiency ≥ 90 %
  - problematic reactivity
  - Not suitable for storage due to high cost and low volumetric heat capacity

High-temperature storage medium

- Liquid glasses
  - High volumetric heat capacity
  - Low cost
  - Inert, stable, abundant
  - Solid/viscous up to very high temperatures (~2000 °C)

- *Haloglass RX*
  - T_{low} = 450 °C
  - T_{high} = 1200 °C
  - Still viscous at T_{low} => pumping challenging

Thermophysical properties of liquid glass

Available information on *Haloglass RX*

Technical Specifications

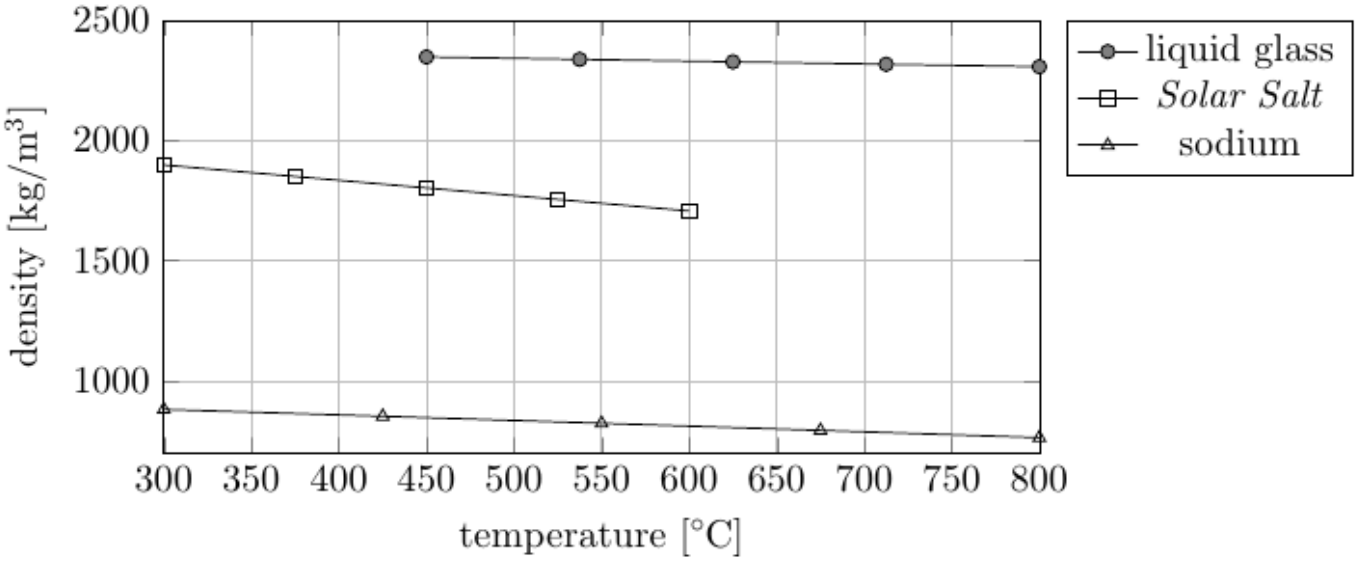
Melting Point	450 °C
Maximum Operating Temperature	1200 °C
Density*	2,400 kg/m^3
Heat Capacity at 450 °C	1.362 J/g·°C
Viscosity at 450 °C	10,064.0 cP
Viscosity at 600 °C	599.9 cP
Viscosity at 800 °C	84.3 cP
Viscosity at 1000 °C	23.6 cP
Viscosity at 1200 °C	11.1 cP
Thermal Conductivity**	0.8 W/m·°C

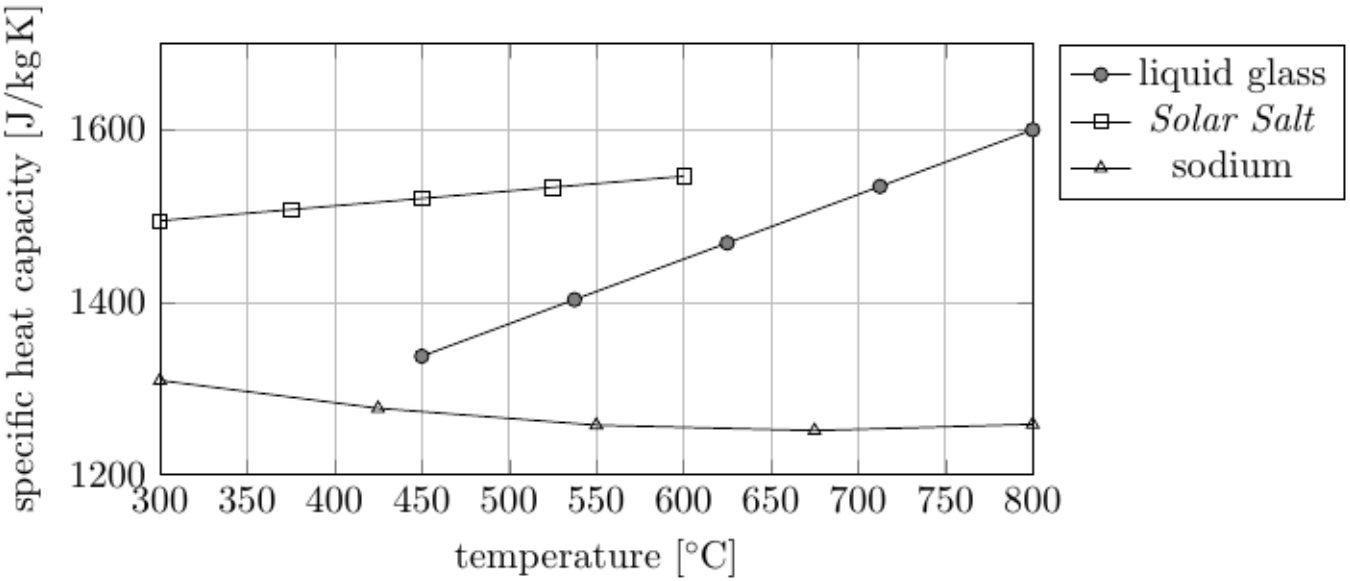
* Calculated from individual components

** Estimated

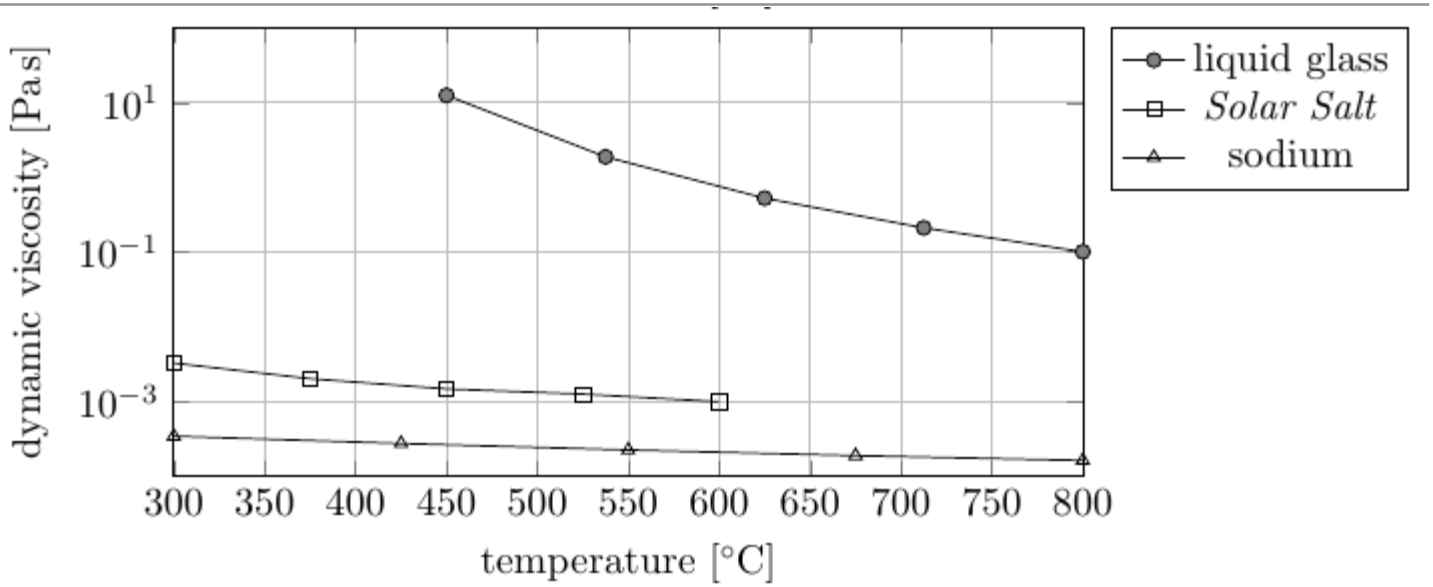
- Data points are extrapolated for the whole temperature range with dependencies found for other glasses (except viscosity)

Density and specific heat capacity



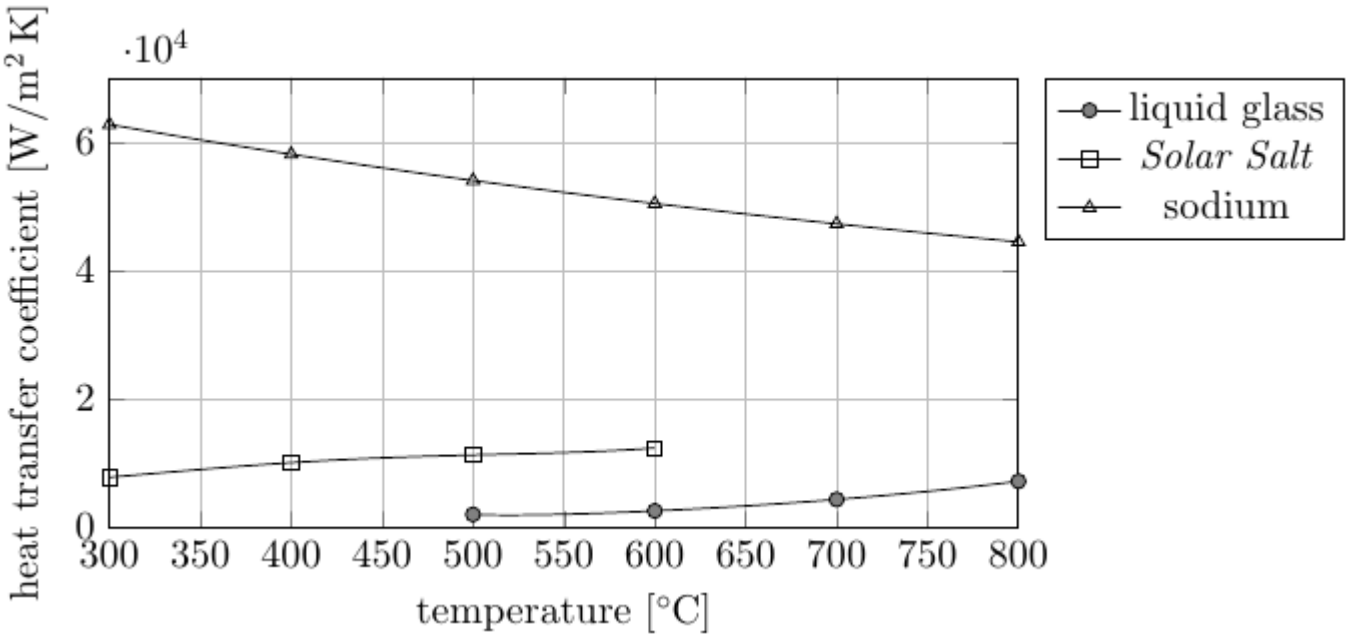


Viscosity



- Haloglass RX is pumpable at temperatures > 450 °C
- Even at elevated temperatures its viscosity is still orders of magnitude higher than the other HTFs'

Heat transfer coefficient



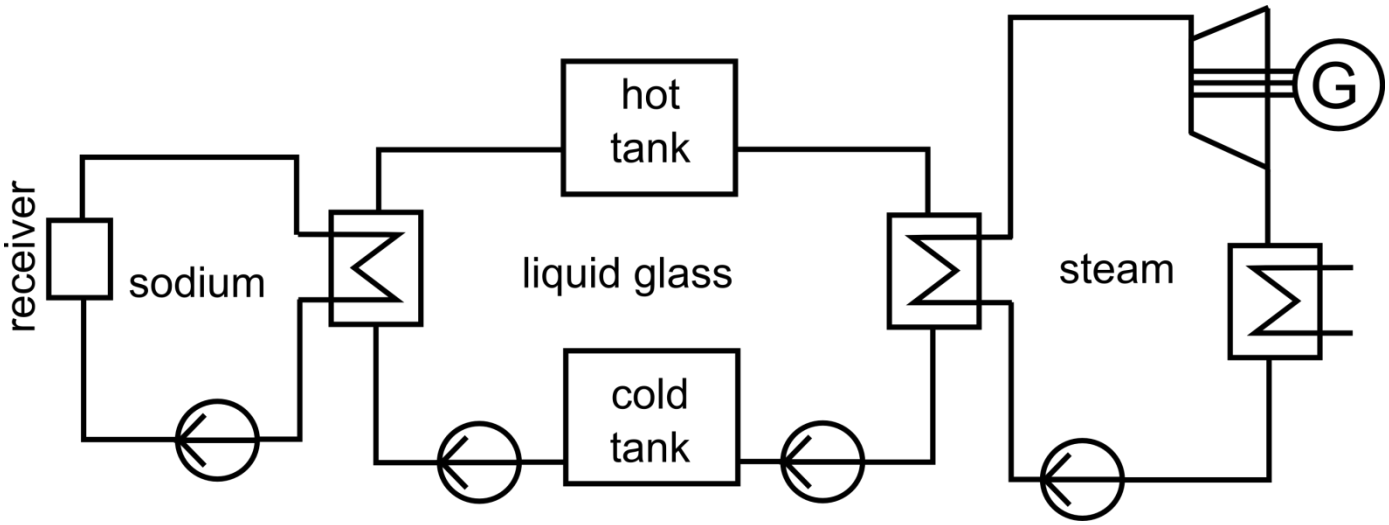
- Data generated with identical fluid velocities (u = 3 m/s) through a tube of D_i = 1 cm

Conclusion on thermophysical properties

- Properties of liquid glass seem well suited for high temperature thermal storage applications
- Pumping power and freeze protection have be considered
- Heat transfer properties are not as good as for *Solar Salt* or sodium

Potential cycle with liquid glass storage

- Supercritical steam cycle with $T_{high} \geq 630$ °C and $\eta_t \geq 47$ %
- Sodium receiver with $\eta \geq 90$ %
- Liquid glass storage system that separates sodium- and steam cycles (safety)



Outlook

- Investigate the potential of a CSP system utilizing *Haloglass RX* as the storage medium or – in a direct system – also as the HTF
- Simulate a plant to determine economic viability
- Assess technical feasibility of components (especially pumps and heat exchangers)

Acknowledgements:

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References:

- http://www.smartplanet.com/blog/intelligent-energy/solar-plant-generates-power-day-and-night/
- Halotechnics, 2013. *Haloglass™ RX*, Available at: http://www.halotechnics.com/products/haloglassrx.html.