INL/CON-18-44300-Revision-0

Visually Determining the Thermal Expansion of a Triple Bubbler System in Pyroprocessing Molten Salt

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University of Idaho College of Engineering

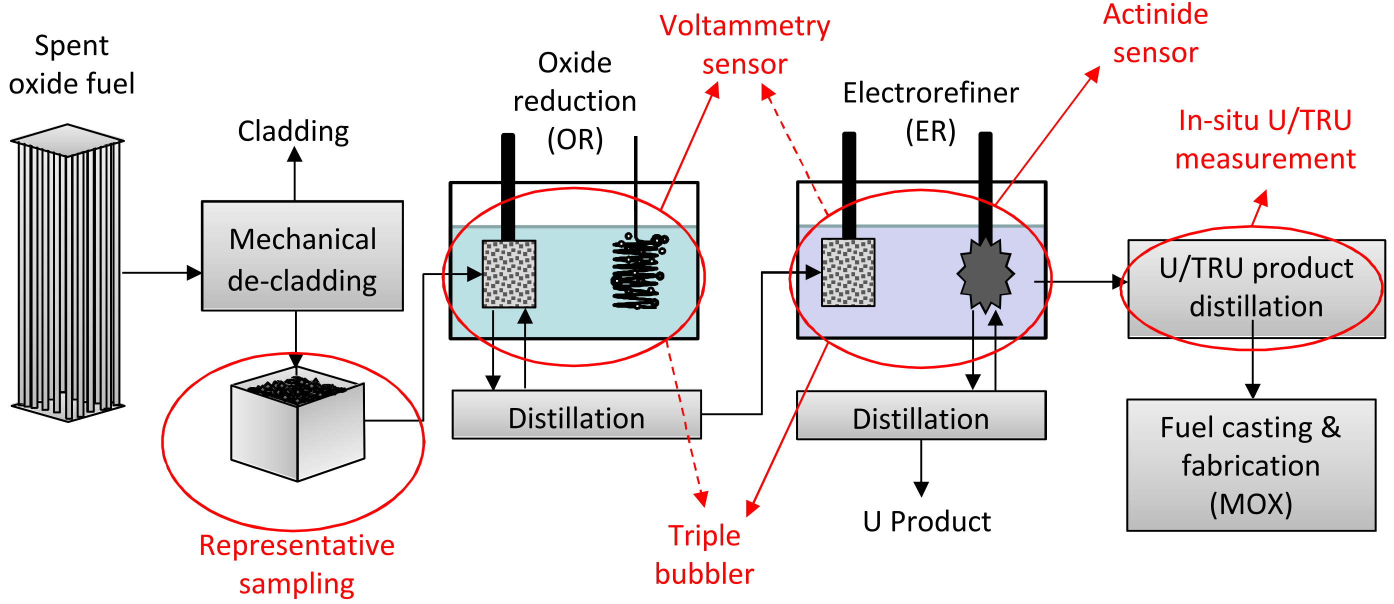
OUTLINE

- Background
- Motivation
- Approach
- Experimental Setup and Math
- Results and Analysis
- Conclusions
- Future work

PYROPROCESSING

Key locations for process monitoring and material accountancy.

Other efforts (INL and other Labs).



BACKGROUND

- Nuclear material accountancy (NMA) is pivotal in pyroprocessing.
- Process monitoring (PM) of electrorefiner (ER) constituents.
- Double bubbler assemblies are currently used in aqueous processes.

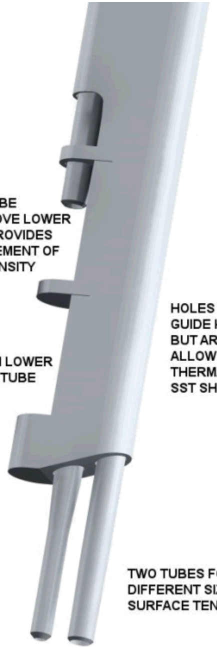
MOTIVATION

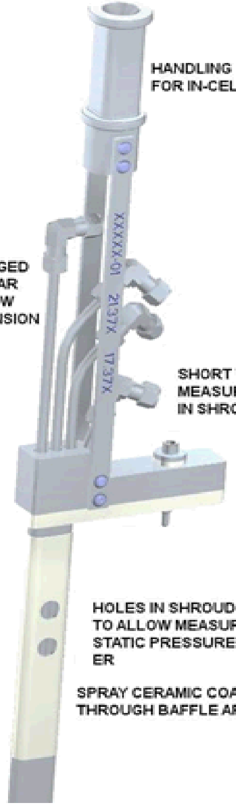
- Two main challenges to overcome in order to implement the bubbler successfully in the ER
  - Thermal expansion
  - Calibration of probe

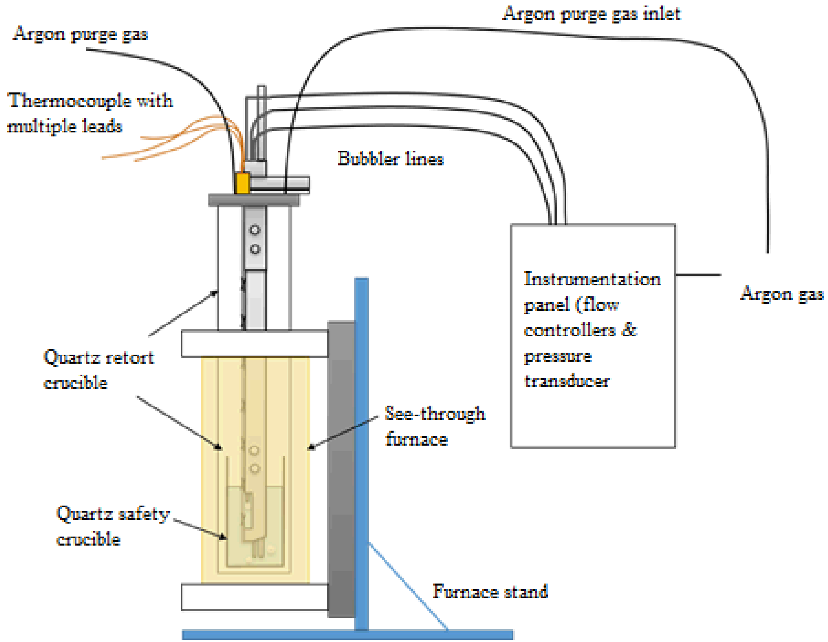
APPROACH

- Visual measurements
- Calibration with multiple salts

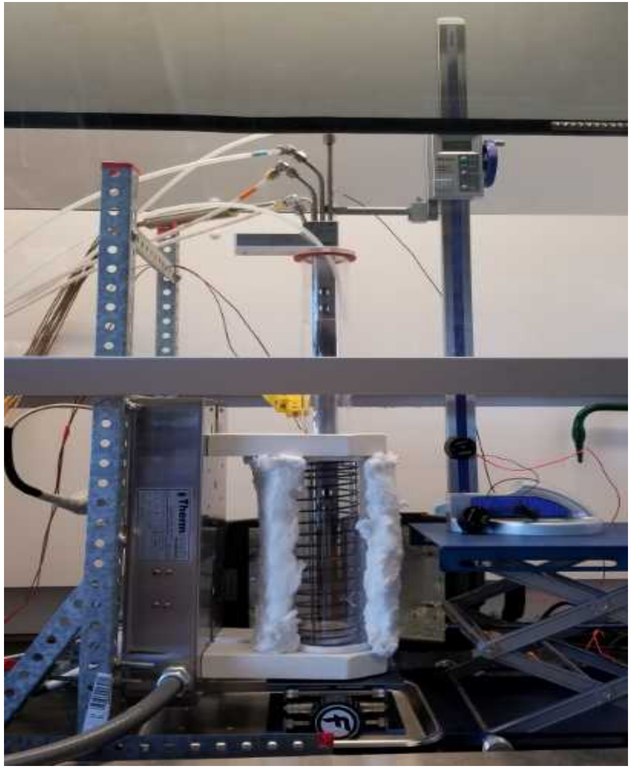
EXPERIMENTAL SETUP





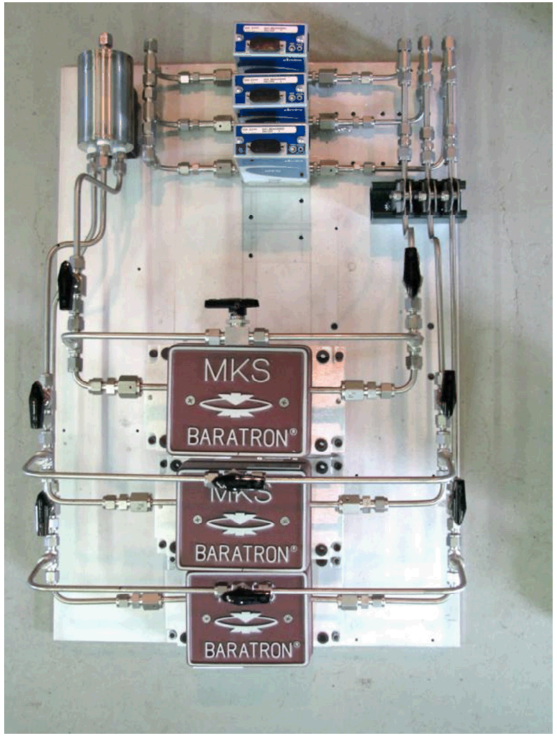


Transparent Tube Furnace Schematic



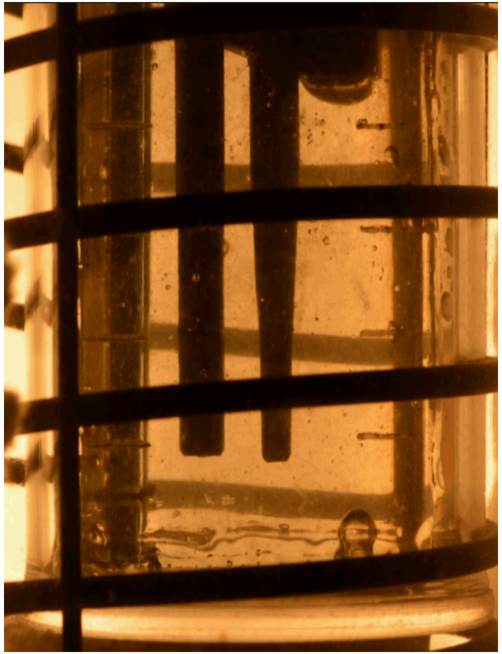
Transparent Tube Furnace

Oxygon Two-Zone Furnace

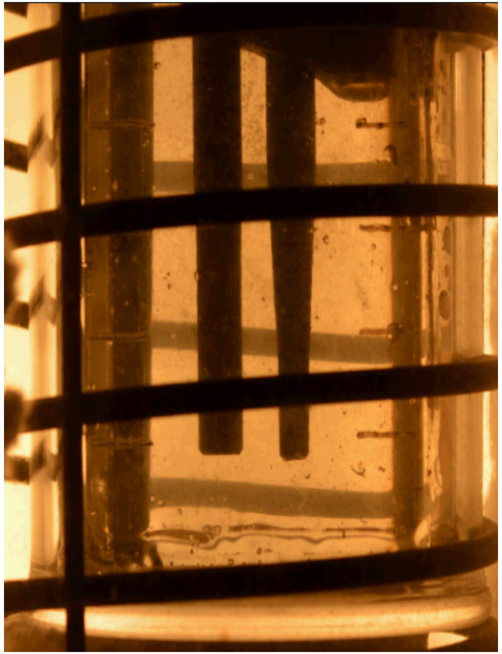


Pressure and Mass Control Board

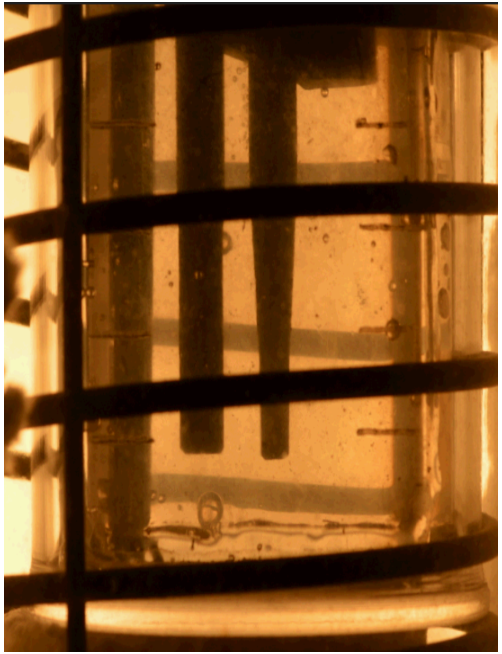
Bubbler in Molten LiCL-KCl Eutectic



450°C



475°C



525°C

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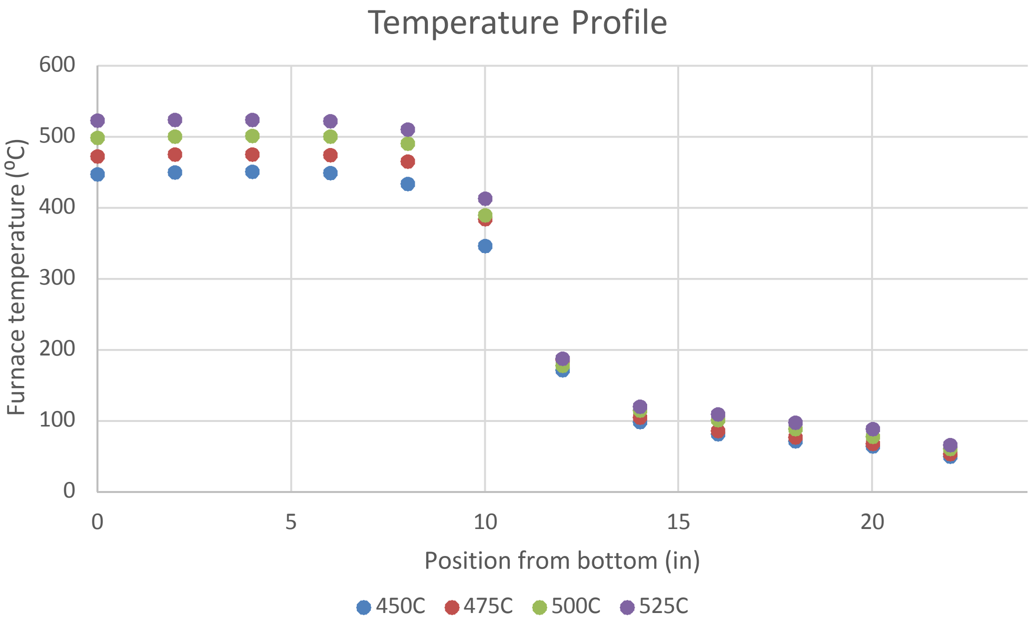
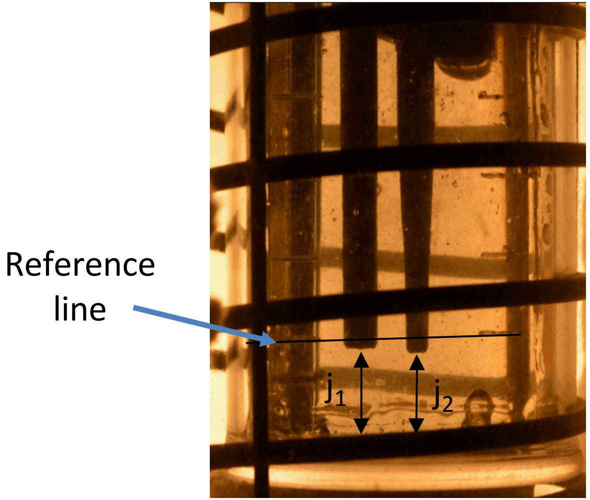
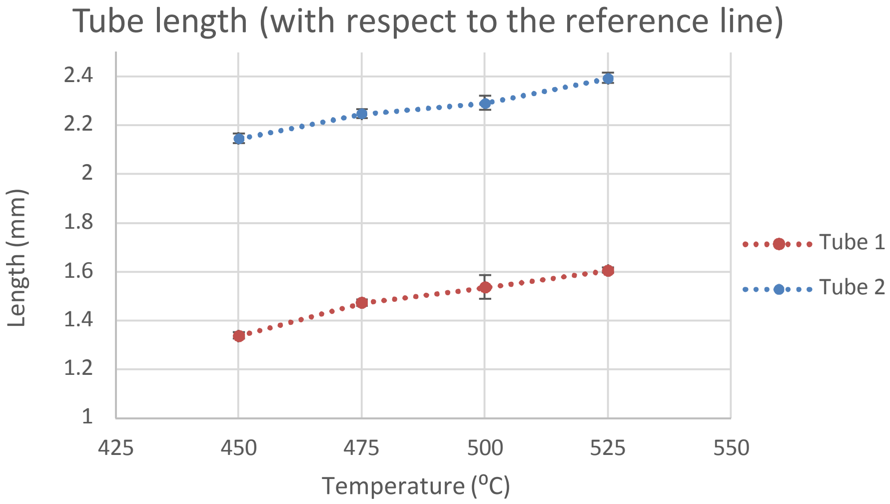
RESULTS: Transparent Tube Furnace



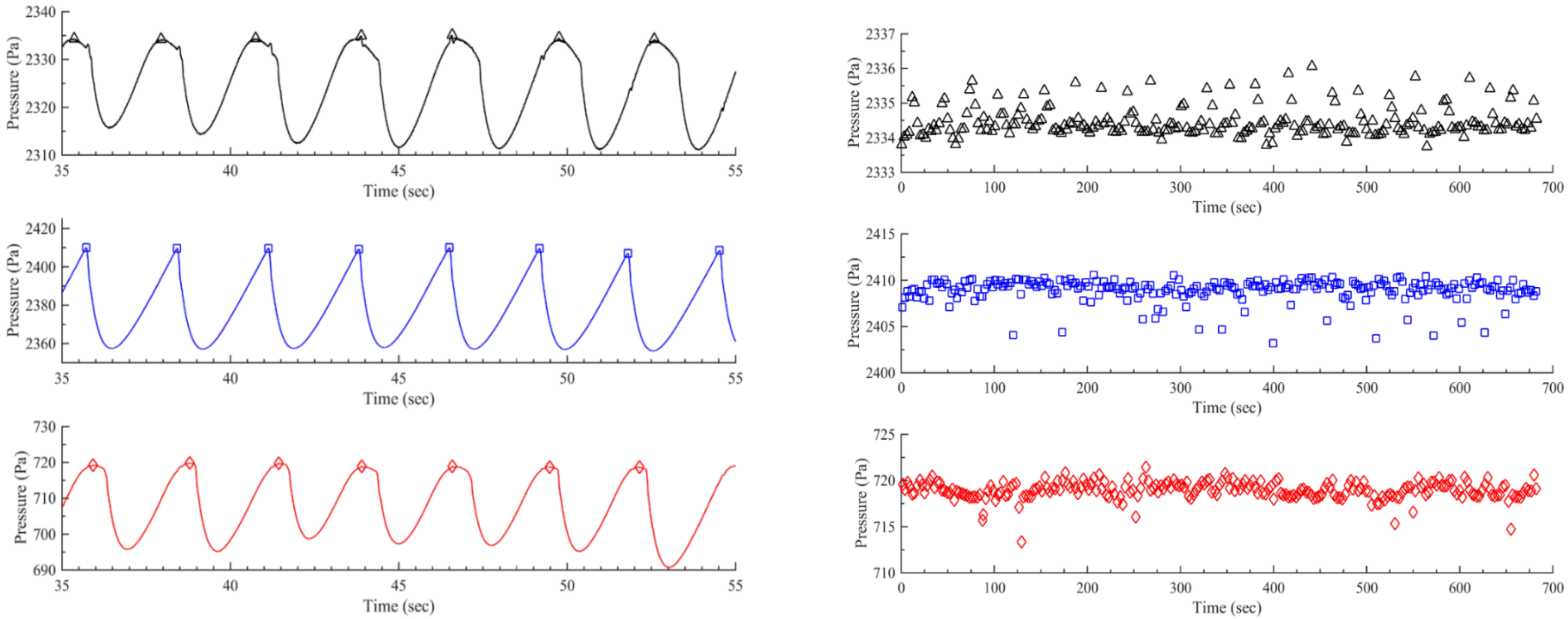




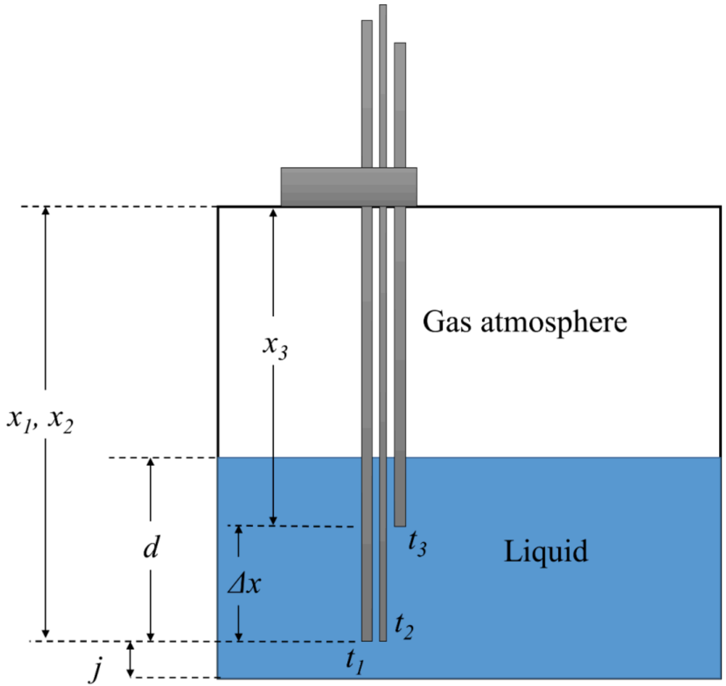
Thermal expansion in bubbler tubes

	Visually Observed		Expected (calculated)			
°C	j_1 (mm)	j_2 (mm)	j_1 (mm)	j_2 (mm)	% diff (j_1)	% diff (j_2)
450	10.10 ± 0.13	9.34 ± 0.13	9.81 ± 0.09	9.20 ± 0.09	-2.95	-1.52
475	9.98 ± 0.13	9.26 ± 0.13	9.75 ± 0.10	9.14 ± 0.10	-2.30	-1.36
500	9.93 ± 0.13	9.21 ± 0.13	9.66 ± 0.10	9.05 ± 0.10	-2.72	-1.80
525	9.85 ± 0.13	9.11 ± 0.13	9.58 ± 0.11	8.97 ± 0.11	-2.78	-1.58

Bubbler Pressure Data



MATHEMATICAL MODEL



$$\rho = C_P \frac{P_1 - P_3}{g \Delta x}$$

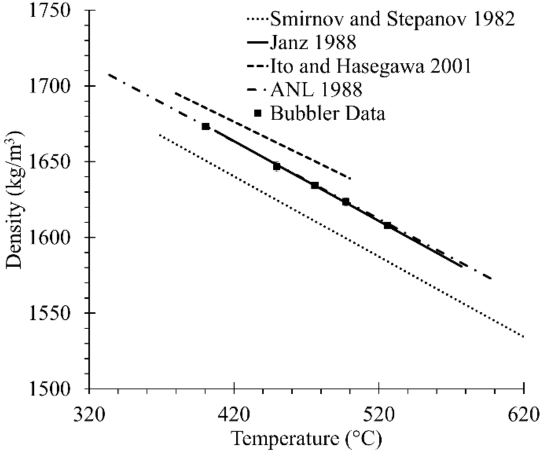
$$\gamma = \alpha \frac{P_2 - P_1 + 0.69 r_1 g \rho}{1000}$$

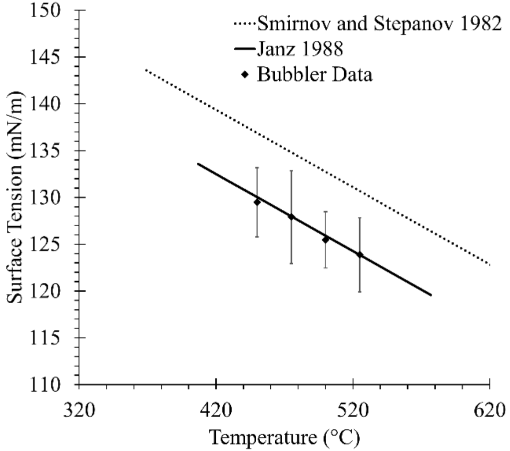
$$d = \frac{P_1 - P_B}{g\ \rho}$$

$$P_B = \frac{2}{3} \rho g r_1 + \frac{2\gamma}{r_1}$$

$$D = d + j_1$$

Calibration in LiCl-KCl Eutectic





T (°C)	C_P	α
456.4	1.0015 ± 0.0018	1.260 ± 0.026
475.7	1.0012 ± 0.0022	1.260 ± 0.035
505.2	1.0019 ± 0.0020	1.260 ± 0.022
524.7	1.0015 ± 0.0022	1.264 ± 0.029
Average	1.0015 ± 0.0020	1.261 ± 0.028
Std	0.0002	0.005

Note: In aqueous testing C_P = 1.0017 and α = 1.16

Bubbler determined depth matches within 0.4%!

T (°C)	Density (kg/m³)	Surface Tension (mN/m)	Measured Depth (mm)	Calculated Depth (mm)	% Difference
456.4	1644.3 ± 4.2	129.5 ± 3.7	148.56 ± 0.04	148.2 ± 0.4	0.22
475.7	1634.2 ± 5.2	127.9 ± 5.0	149.26 ± 0.05	148.9 ± 0.5	0.27
505.2	1618.6 ± 4.5	125.5 ± 3.0	150.33 ± 0.05	149.8 ± 0.5	0.36
524.7	1608.3 ± 4.9	123.9 ± 4.0	151.42 ± 0.04	150.8 ± 0.5	0.39

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Validation

Transparent Furnace Data

- LiCl-KCl eutectic.
- No contact sensor data.

T (°C)	ρ† (kg/m^3)	ρ (kg/m^3, Bubbler)	% diff.	γ† (mN/m)	γ (mN/m, Bubbler)	% diff.	Depth (mm, Bubbler)
400.4	1673.78	1674.9 ± 3.9	-0.07	134.10	130.1± 3.9	3.01	150.1± 0.3
449.5	1647.96	1647.6 ± 4.9	0.02	130.06	128.1± 3.9	1.52	152.6± 0.5
475.8	1634.07	1634.5 ± 4.4	-0.03	127.89	123.9± 4.1	3.15	154.1± 0.4
497.3	1622.77	1623.3 ± 4.6	-0.04	126.12	121.1± 4.5	4.07	155.5± 0.4
526.0	1607.62	1607.0 ± 4.3	0.04	123.75	119.7± 4.0	3.35	156.8± 0.4

Two-Zone Furnace Data

- CsCl-LiCl eutectic.
- Property values interpolated/extrapolated.
- Contact sensor potentially biased by the salt meniscus (~0.3 to ~0.8 mm).

T (°C)	ρ‡	ρ†	ρ (Bubbler)	γ†	γ (Bubbler)	D (Measured)	D (Bubbler)	Residual	% diff.
422.5	2450.92	2420.11	2428.1 ± 6.0	112.40	131.0 ± 3.6	149.06 ± 0.10	148.5 ± 0.4	0.52	0.35
456.6	2426.30	2391.83	2399.7 ± 6.1	109.78	124.4 ± 4.5	151.59 ± 0.10	150.7 ± 0.4	0.88	0.58
476.8	2411.68	2375.04	2382.9 ± 6.3	108.23	123.7 ± 3.3	152.45 ± 0.12	151.2 ± 0.4	1.24	0.82
498.7	2395.87	2356.88	2364.7 ± 6.5	106.55	122.0 ± 3.2	152.94 ± 0.10	151.8 ± 0.4	1.12	0.73
523.6	2377.94	2336.29	2343.8 ± 6.7	104.63	122.1 ± 3.8	154.09 ± 0.11	153.0 ± 0.5	1.12	0.73

FUTURE WORK

- Fundamental Studies
  - Explore different salts, compositions and wider temperature range
  - Explore ER calibration approaches
- Future Directions
  - Adapt/modify bubbler for reduction in material holdup & corrosion

ACKNOWLEDGEMENTS

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