INL/CON-22-67858-Revision-0

Optimization of a Dynamic Single Bubbler in Immiscible Fluids for Nuclear Safeguards Applications

November 2022

Changing the World's Energy Future

Ammon N Williams, Tae-Sic Yoo

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/CON-22-67858-Revision-0

Optimization of a Dynamic Single Bubbler in Immiscible Fluids for Nuclear Safeguards Applications

Ammon N Williams, Tae-Sic Yoo

November 2022

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Optimization of a Dynamic Single Bubbler in Immiscible Fluids for Nuclear Safeguards Applications

Ammon Williams, Tae-Sic Yoo, & Anthony Bessler

ANS Winter Meeting – 2022

INL/CON-22-67858

Motivation and Approach

- Special Nuclear Materials (SNM) must be tracked for safeguards (domestic and international)
- In nuclear fuel recycling, SNM is present in bulk liquids
- Standard approach of the IAEA is double bubblers to measure density and level
  - Operation reliance to detailed calibration information
  - Recalibration/maintenance (e.g., corrosion and material buildup)
  - Fluid surface tension assumption
  - Applicable to single-phase homogenous fluids
- We propose a dynamic single bubbler (DSB) approach to measure density and level
  - No calibration and minimal maintenance
  - No fluid property assumption
  - Operation in immiscible fluids
  - Superior statistical estimate quality

DSB Approach

Overall Governing Bubble Pressure Equation

Hydrostatic pressure

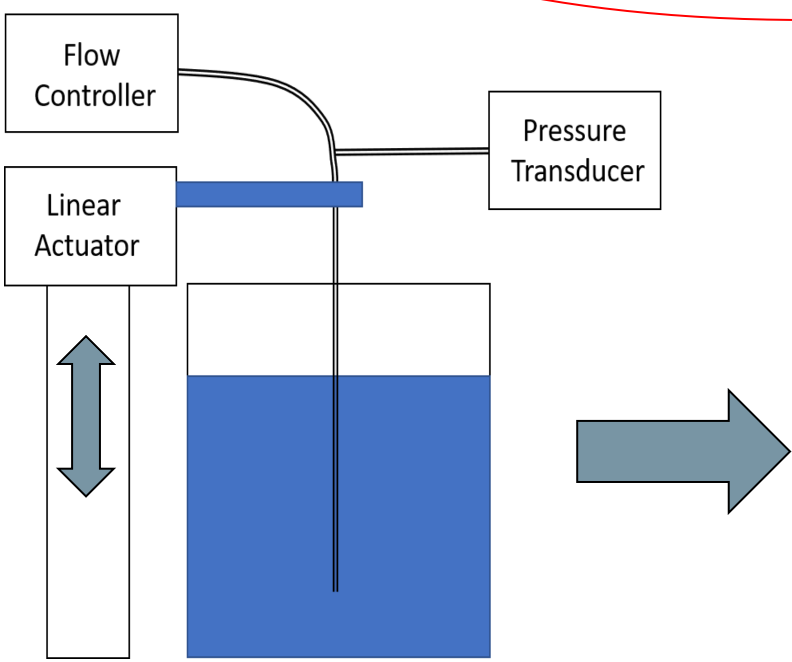
Depth

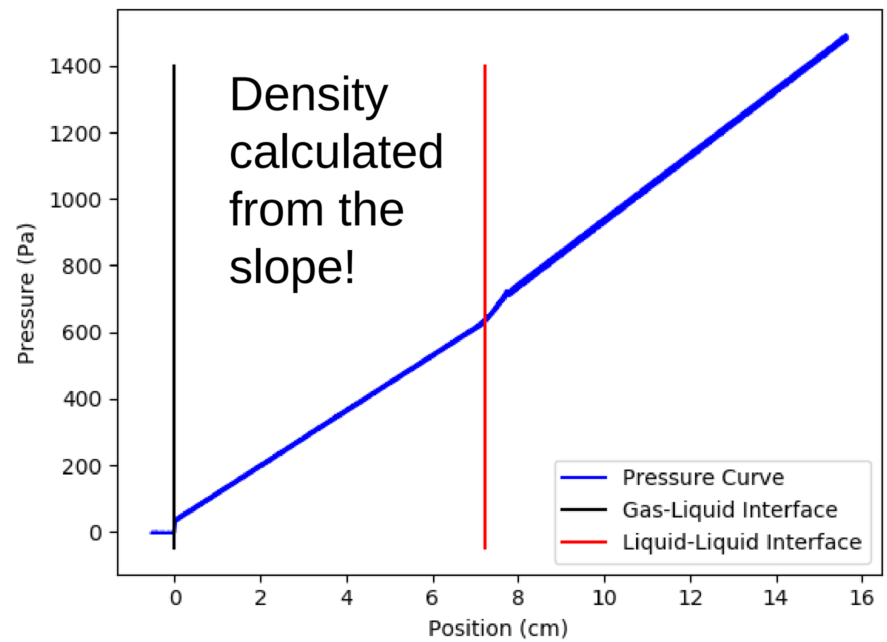
Density

$$P = \rho g d + P_B$$

Excess bubble pressure:
- Tube shape & size
- Liquid surface tension
- Density

P_B cancels when using a single bubbler!





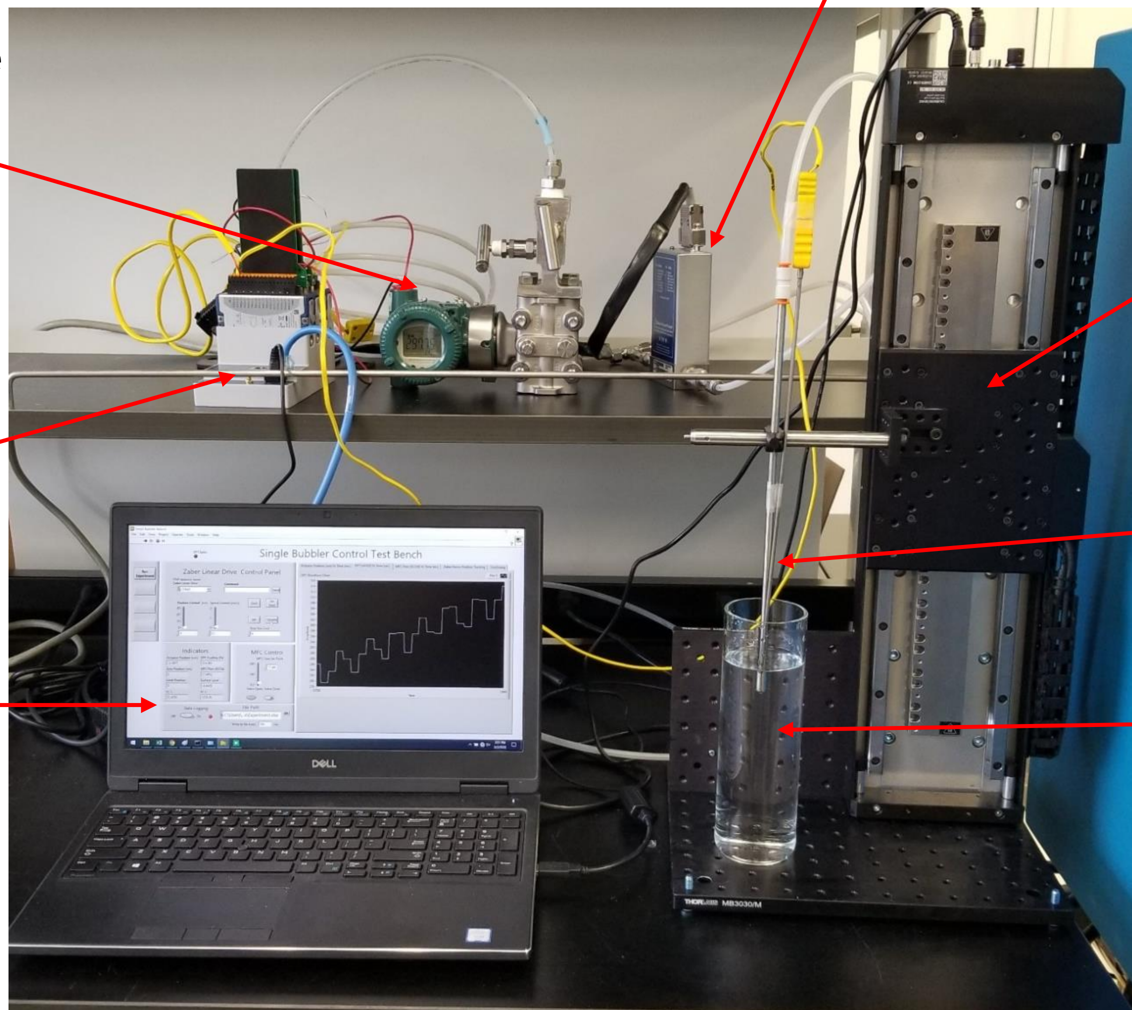
Experimental Setup

Mass flow controller (MKS GMA50A)

Differential pressure transducer (Yokogawa EJA110E)

National Instruments cDAQ

LabVIEW



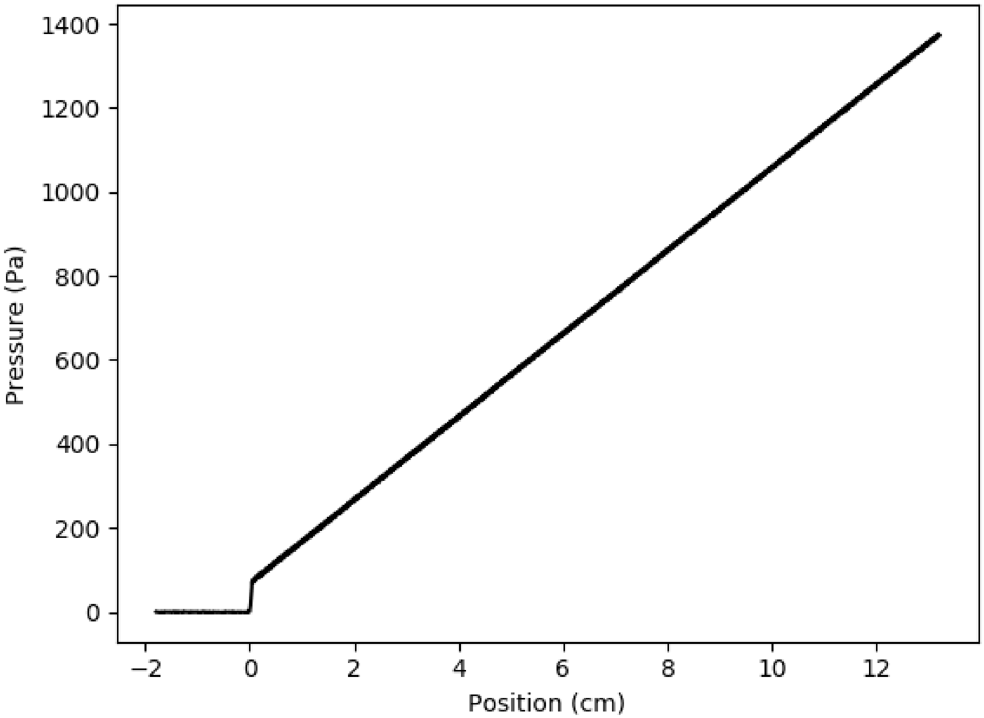
Linear Stage (Zaber X-LDQ0300C)

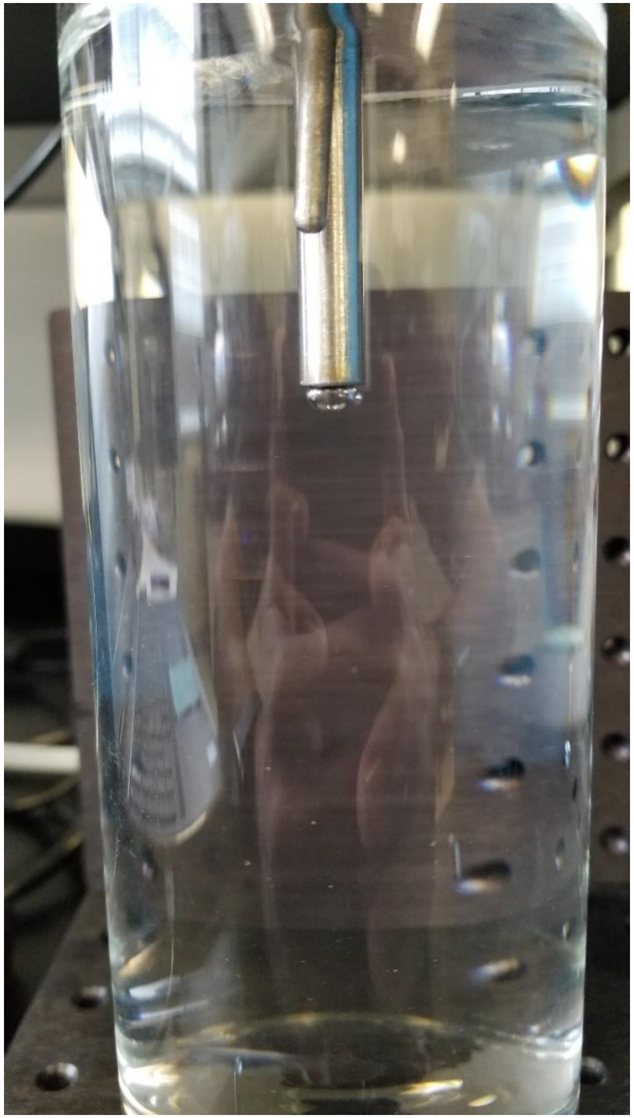
Dip Tube

Sample

Optimization Study (Single Phase)

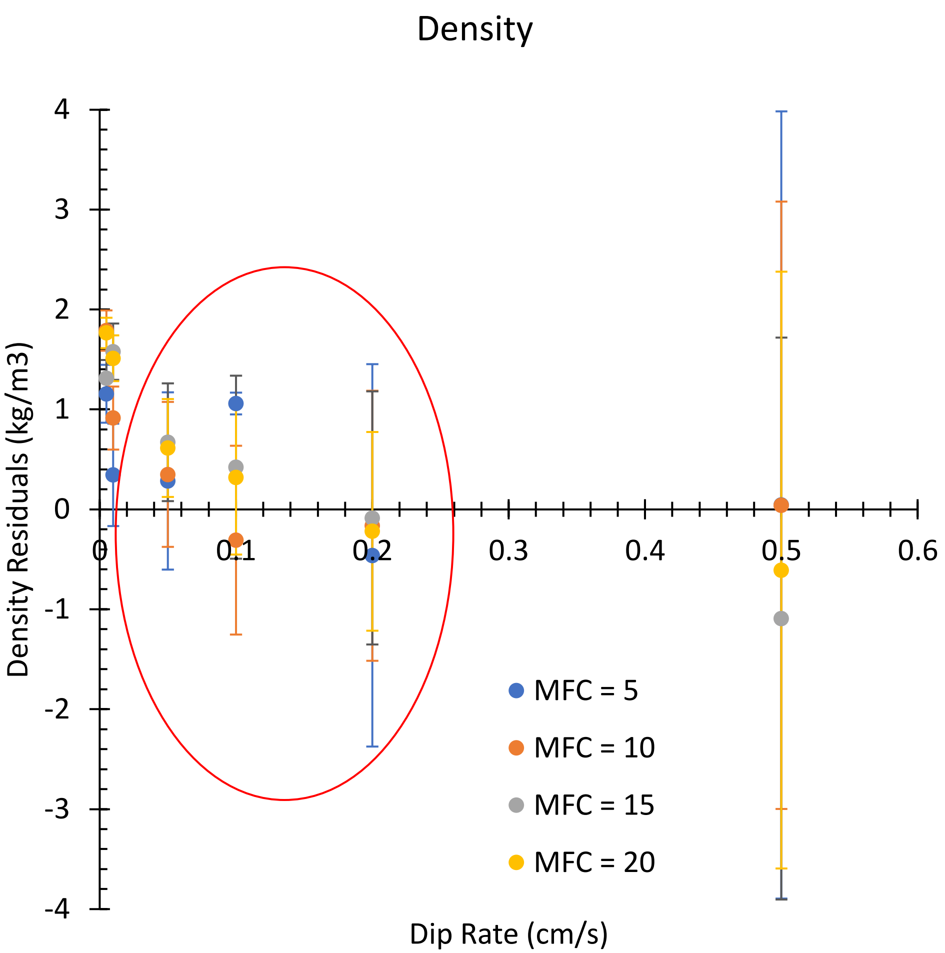
- Tests performed in water while varying:
  - Dip rate (0.005 - 0.5 cm/s)
  - Gas flow rate (5 - 20 cm^3/min)
- 2-3 sets per condition, each with 1-6 dips
- Optimize with respect to residuals





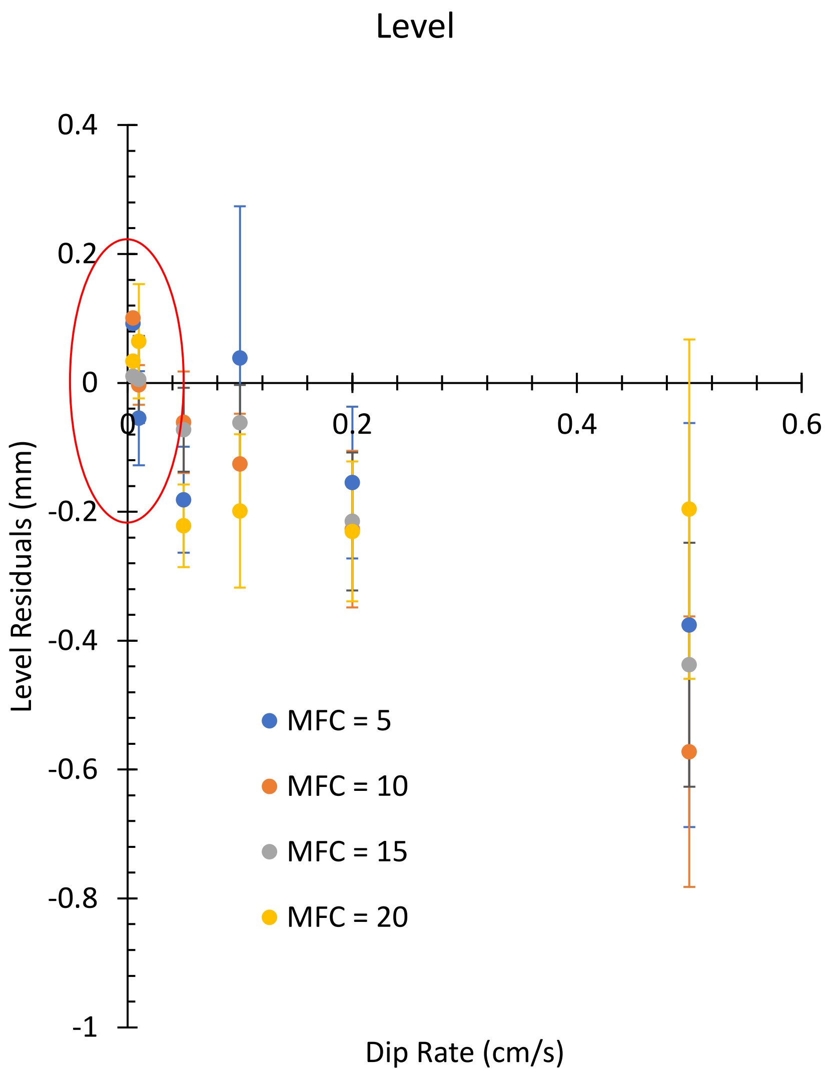
Optimization Study: Density

- All conditions yielded results closer than 0.25% from accepted values
- Low variance with flow rate (limited effect)
- Increasing rate = higher uncertainty
- Decreasing rate ~ lower accuracy
- Best accuracy & uncertainty between 0.05 and 0.2 cm/s



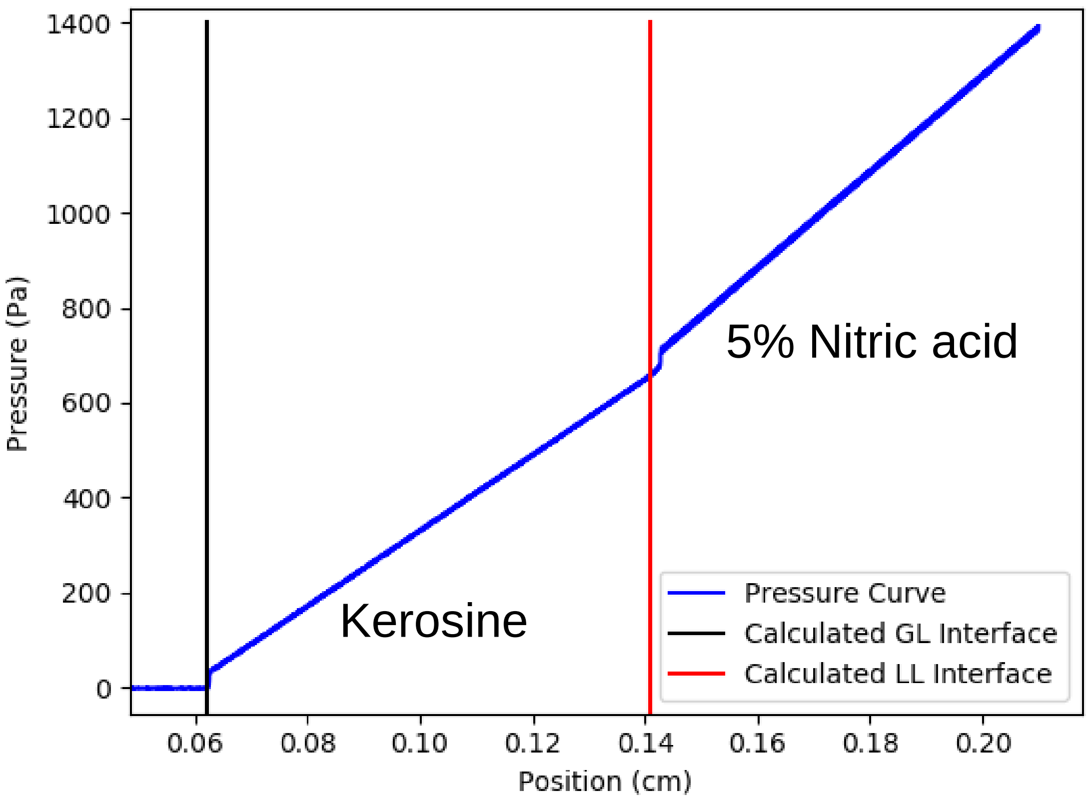
Optimization Study: Level

- All conditions yielded results closer than 1% from accepted values
- Faster rates had higher uncertainty and lower accuracy
- Some latency due gas line length that becomes dominate at faster rates
- Best dip rate 0.005 or 0.01 cm/s



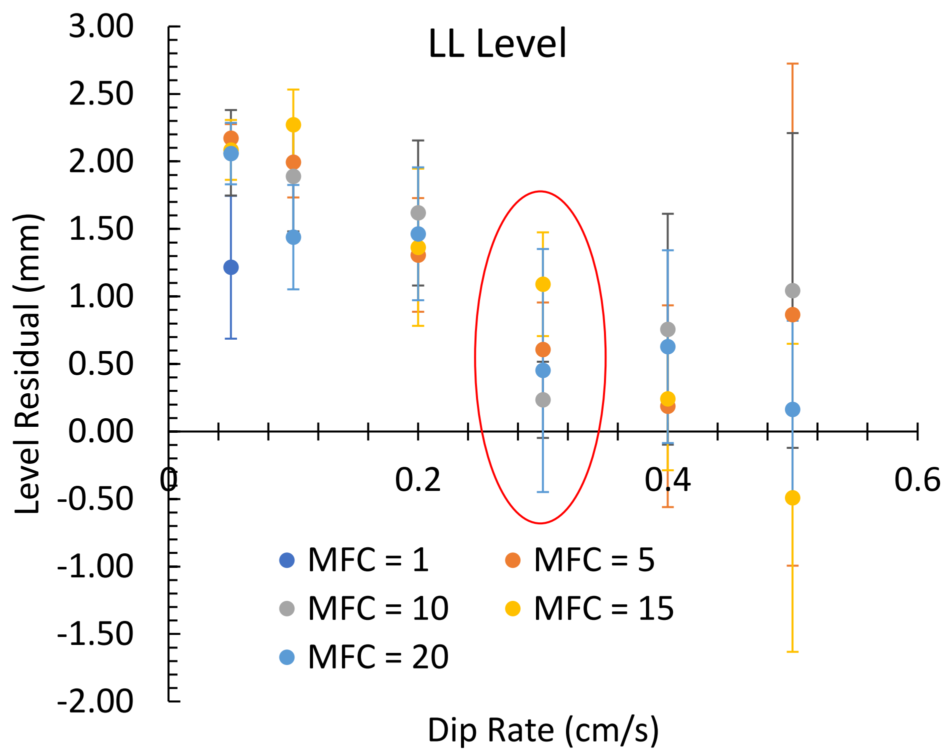
Immiscible Fluids Optimization

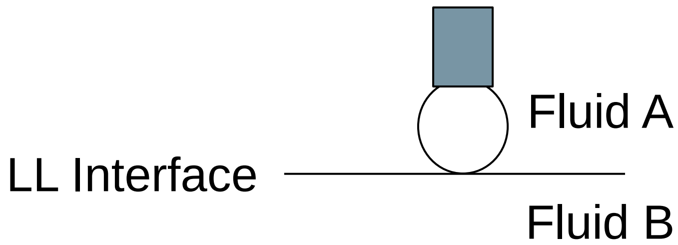
- Systems studied;
  - Water & mineral oil
  - 5% nitric acid & kerosine
- Density and GL level consistent with single phase results



Liquid-Liquid Interface Optimization

- All results were within 0.2% and 2% of the independently measured level
- Faster dip-rates = better accuracy but higher uncertainty
- Optimal is 0.3 cm/s
- Why is faster better?
  - Pressure starts changing as bubble interacts with the interface
  - Latency in the system
- Update our change point detection model?





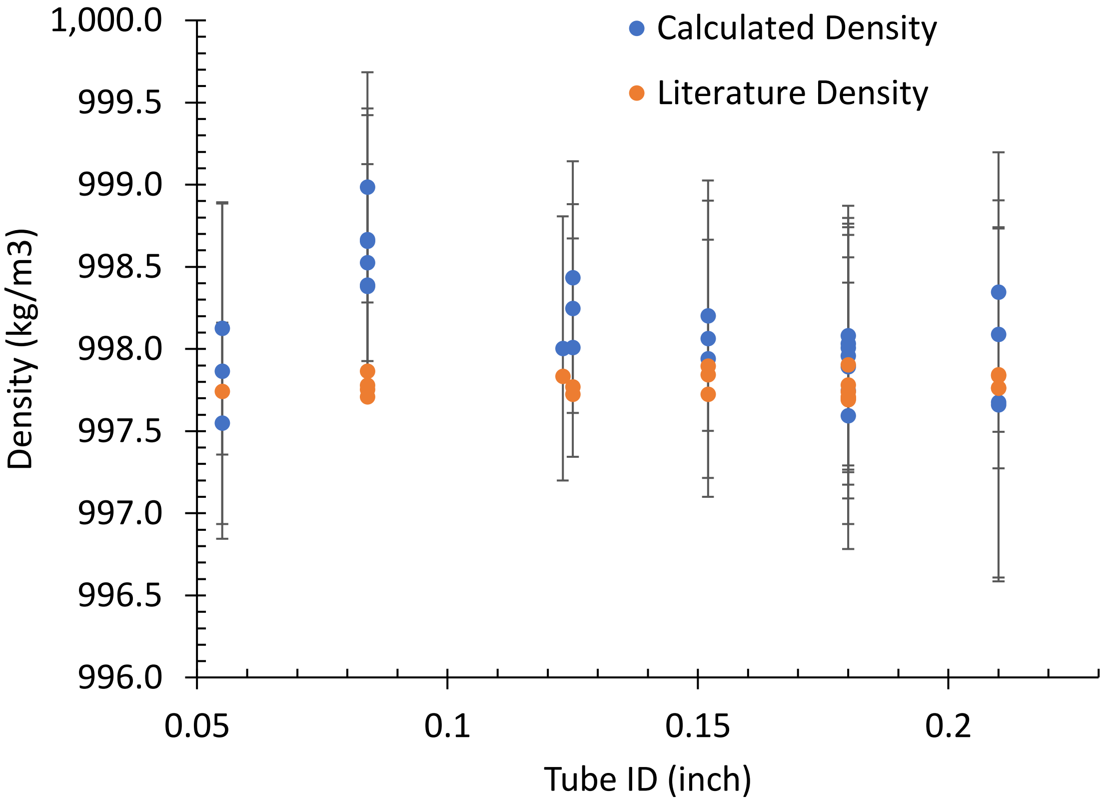
Tube Geometry & Calibration Free Approach

- Six different diameters to test diameter effect (diameter change due to corrosion or material buildup)
- “Smashed” and “Notched” tubes were mixed in to explore effect of rough handling
- Tubes were simply cutoff and deburred (no machining)
- Flow rate of 10 cm^3/min and dip rate of 0.05 cm/s

0.055”　0.084”　0.125” Notched & Normal　0.152”　0.180” Smashed & Normal　0.210” Smashed & Normal

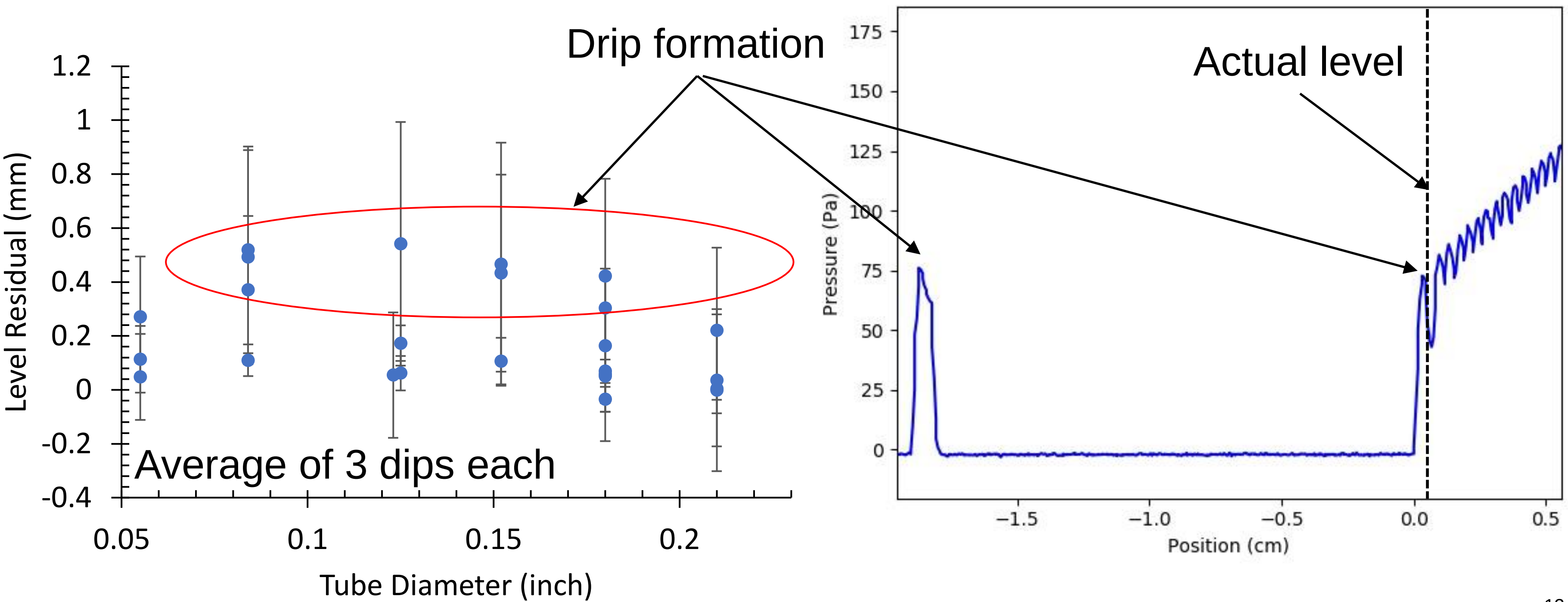
Tube Geometry: Density Results

- Calculated density was within 0.03% on average with a max deviation of 0.12% (at 0.083” ID)
- Densities from the literature were typically within the uncertainties of the single bubbler values (one exception was tubes at 0.083” ID)
- Indicated this approach is calibration free within the parameters studied!



Tube Geometry: Level Results

- Occasionally a drip formed on the tube near the G-L interface
- Drip contacts the fluid first, creating a step pressure signal giving a biased reading
- Multiple dips provide better statistics
- Less probability of drip formation on thinner tubes and tubes with a bevel



Fluid Measurements (Single Phase):

Fluid	Fluid T (°C)	Density (kg/m^3)	Density unc. (kg/m^3)	Lit. Density (kg/m^3)	Level % Difference	Density % Difference
Acetone	20.90	787.86	0.56	789.20	-0.37	0.17
Methanol	21.32	788.74	0.58	790.20	-0.14	0.19
Kerosine	22.14	802.82	0.67	800.00	0.00	-0.35
Water	21.15	998.03	0.71	997.90	0.08	-0.01
5 wt% Nitric acid	23.27	1022.75	0.87	1025.60	-0.16	0.28
10 wt% NaCl	21.56	1069.42	1.05	1070.17	0.15	0.07
22.5 wt% NaCl	20.87	1164.28	1.01	1163.60	0.04	-0.06
21 wt% CaCl	21.34	1186.87	0.76	1181.05	-0.13	-0.49
Glycerol	21.46	1260.40	1.74	1260.10	-0.07	-0.02
35 wt% CaCl	21.49	1332.15	0.96	1337.51	0.83	0.40

Less than 1%!

Conclusions

- Approach is capable of density and level determinations to < 1% in single phase and immiscible fluids
- Calibration not necessary
- Density is relatively insensitive to variations in tube geometry
- Dip-tube tip geometry effects drip formation and thus repeatability for GL interface level measurements
- Optimizations:
  - Insensitive to flow rates
  - Optimal dip rate for density: 0.05 – 0.2 cm/s
  - Optimal dip rate for GL interface: 0.005 – 0.01 cm/s
  - Optimal dip rate for LL interface: 0.3 cm/s
- Easy to automate to operate at the optimal rate for density, GL interface and LL interface
- Accurate results over large range of fluids

Acknowledgements

Funding provided by:

- Laboratory Directed Research & Development (LDRD)
- Nuclear Technology Research & Development (NTRD), Materials Protection, Accounting and Control Technologies (MPACT) Campaign

Questions?