Effect of Water Dilution and Method of Slurry Dispense on Silicon Dioxide Removal Rate for STI CMP using a Ceria Slurry

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Outline

- Motivation and ceria-based slurry removal theory
- The Araca slurry injection system (SIS)
- Mixing methods and dilution effects on RR
- Applying the Araca SIS
- Selected Cases Studies

    - ❖ Pre-mix dilution
    - ❖ Point-of-use dilution (pad-center single-point application)
    - ❖ SIS rotation studies
    - ❖ Point-of-use dilution (with the SIS at -8°)

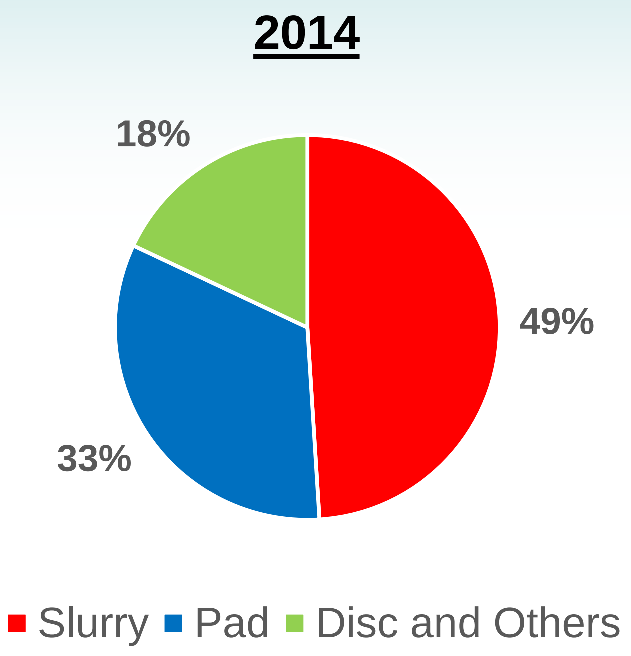
- Summary

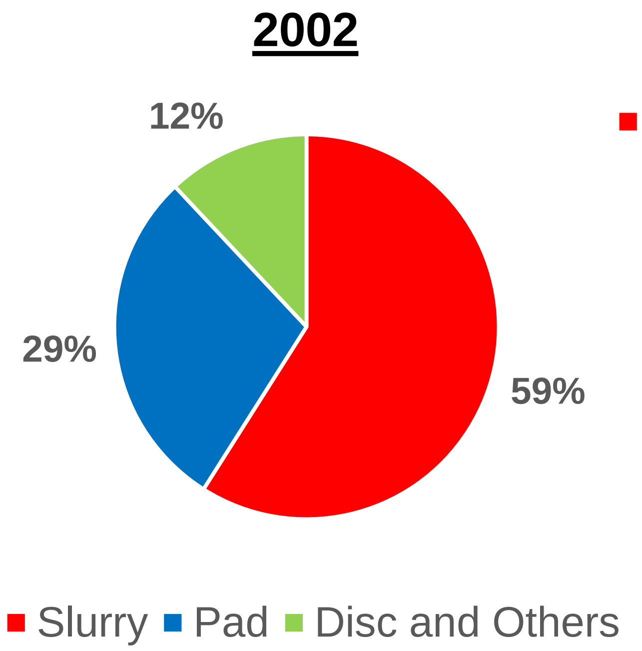
Experimental Conditions

- **Wafer: 300-mm blanket Silicon Dioxide**
- **Wafer pressure: 4.0 PSI**
- **Platen/Carrier RPM: 77/75**
- **Slurry flow rate: 100 cc/min**
- **Slurry: HVM Ceria-Based “Reverse”**
- **Pad: DOW IC-1000 K-Groove**
- **Conditioner: 3M A165**
- **Conditioning downforce: 9.91 lb_f**
- **Conditioning: In-situ at 95 RPM & 10 per minute sweep frequency**
- **Polishing time = 20 seconds**

Why Reduce Slurry Use?

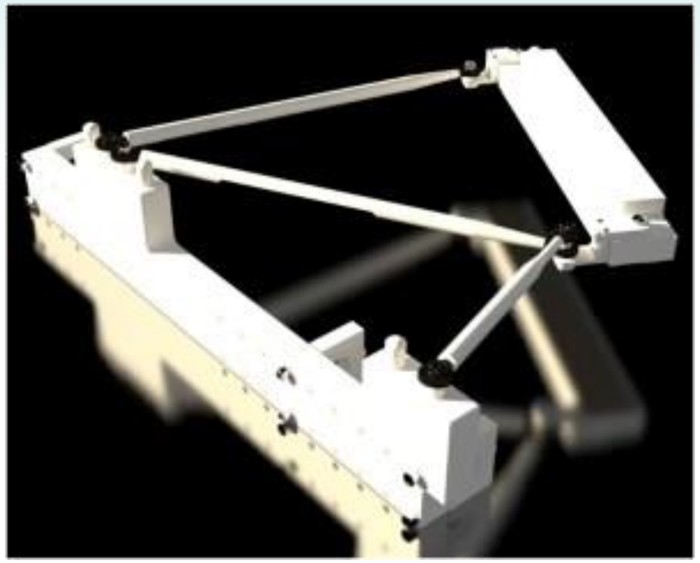
- **Slurry accounts for nearly half of the consumables COO in the CMP module.**
- **In addition, slurry abrasives and additives present significant EHS issues.**
- **Slurry utilization efficiency is less than 5% in commercial processes.**
- **Reducing use or applying "smarter" methods can significantly impact COO and EHS.**

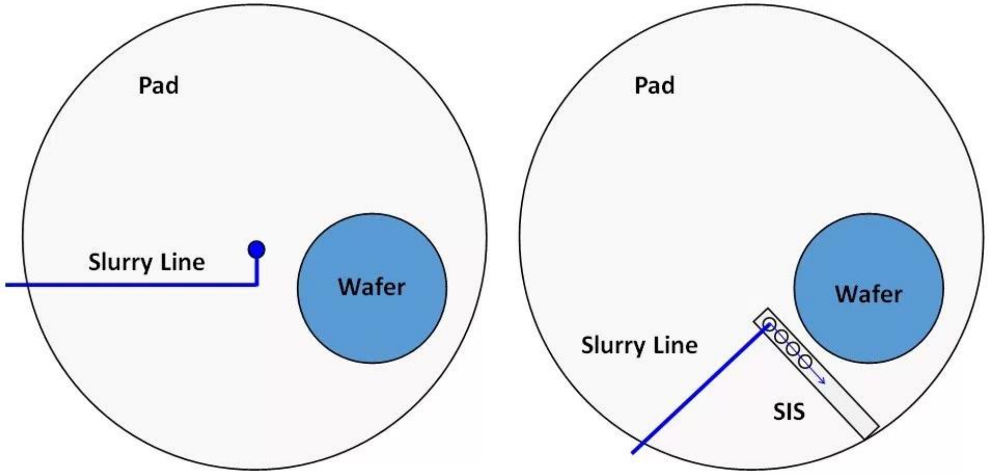




The Slurry Injection System (SIS)

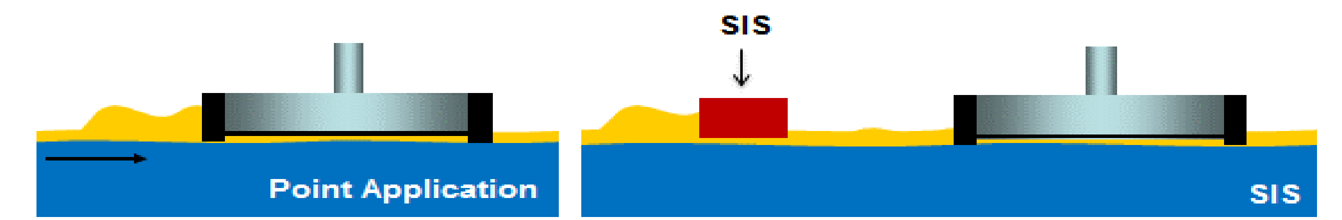
- Reduces slurry consumption (usually by 40%).
- Slurry is applied between the injector bottom and the pad (uniform slurry film with minimal MHDL effects due to excess slurry)
- Injector bottom is made of PEEK and it contacts the pad.
- Normally, the injector blocks residual water from entering pad-wafer interface, reducing fresh slurry dilution.
- However, we will use the SIS in this study to increase dilution by modifying the rotational orientation.



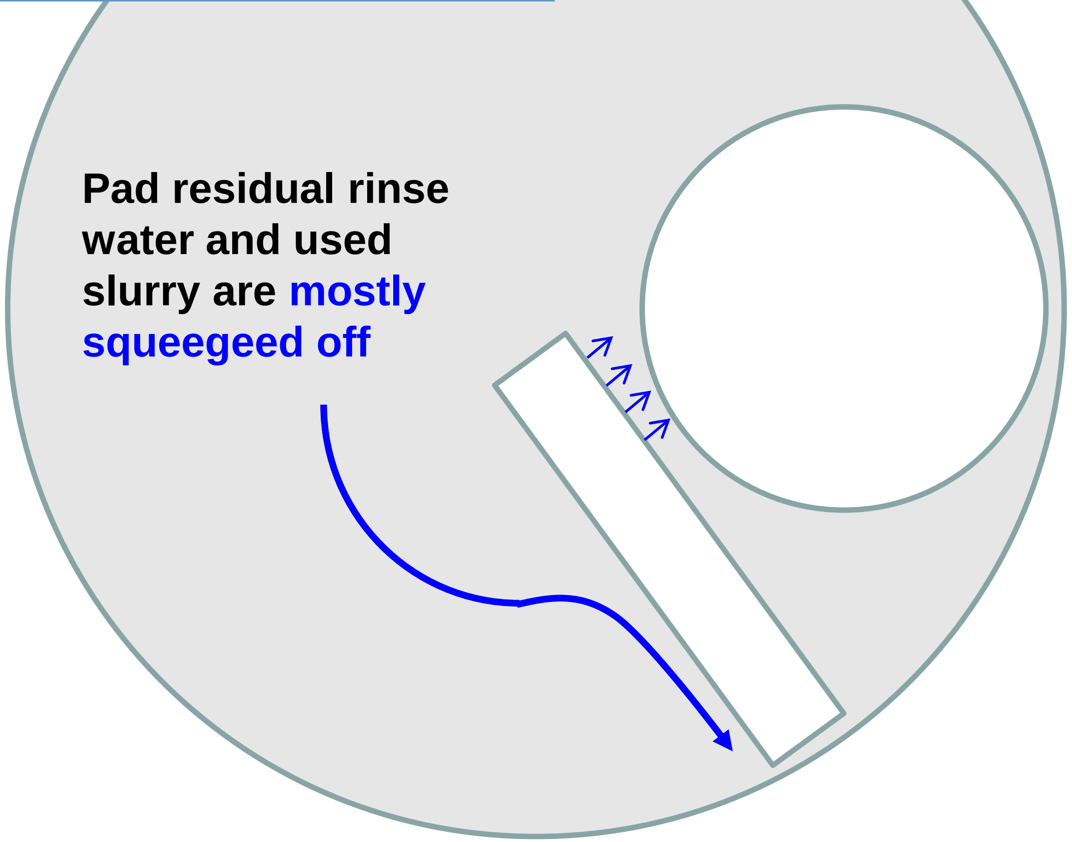


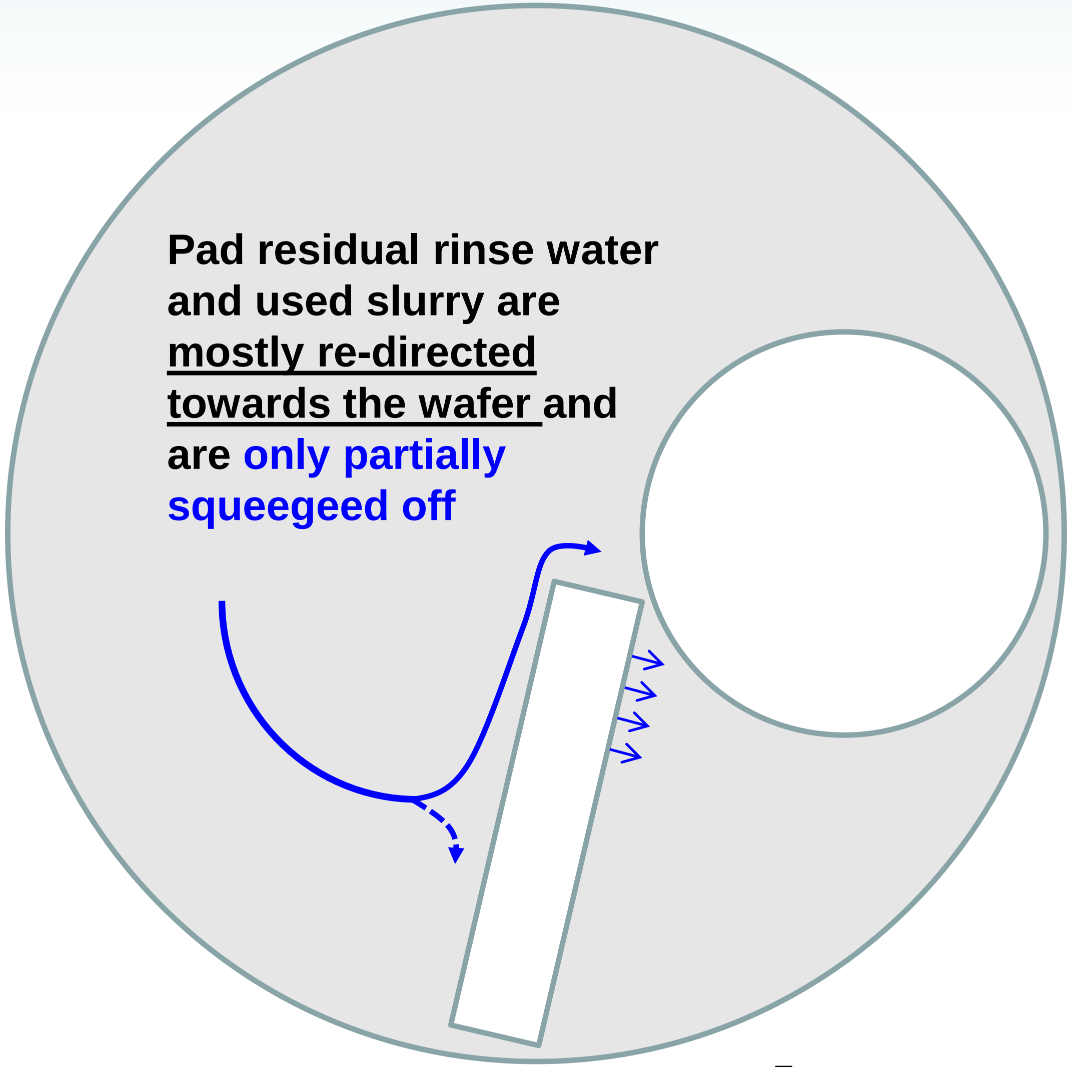
(a) (b)

SIS Video



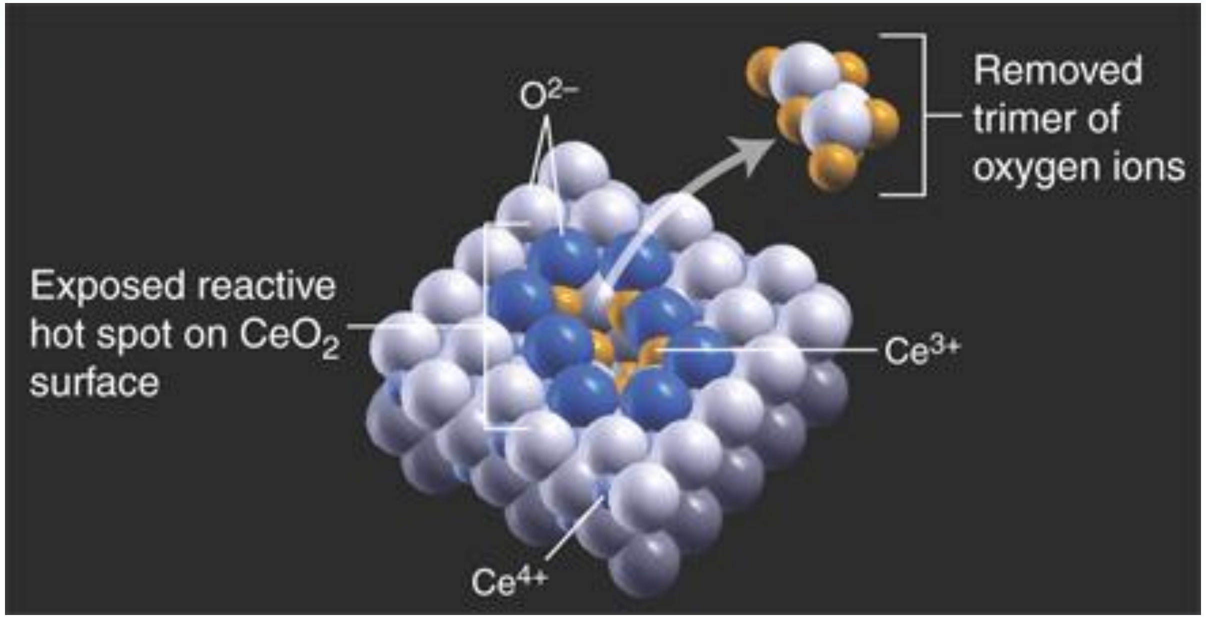
SIS Orientation Effects





A Brief Theory on Ceria-Silica Removal

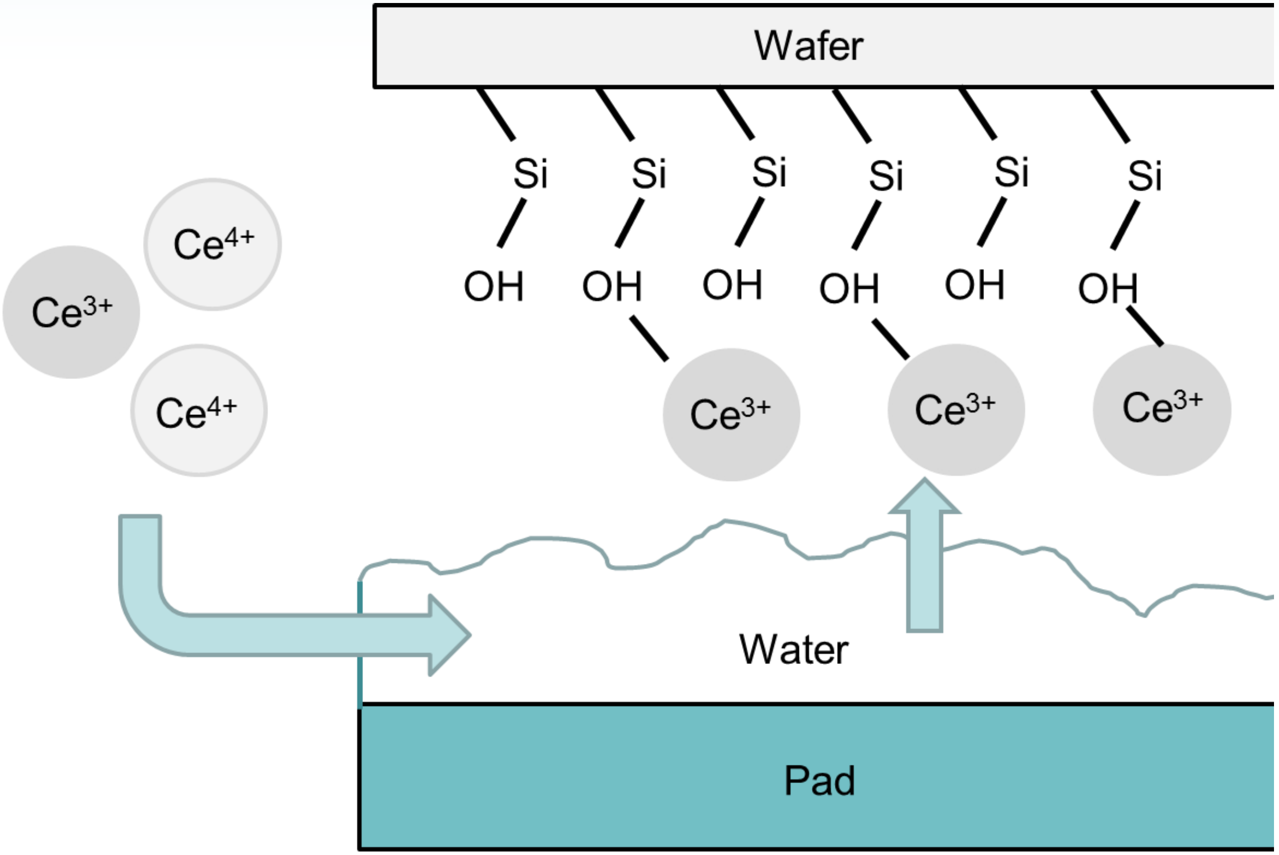
- Ce^{3+} is responsible for silica removal
- Stoichiometry states that CeO_2 particles should consist of Ce^{4+} ions.
- Surface defect model: CeO_2 particles have oxygen vacancies.
- Vacancies lead to localized electrons that reduce Ce^{4+} to Ce^{3+}
- Particle surface consists of both Ce^{4+} and Ce^{3+} (extent of each species modified by additives, stabilizers, …).



Source: C. Campbell and C. Peden, Science, 309, 713 (2005).

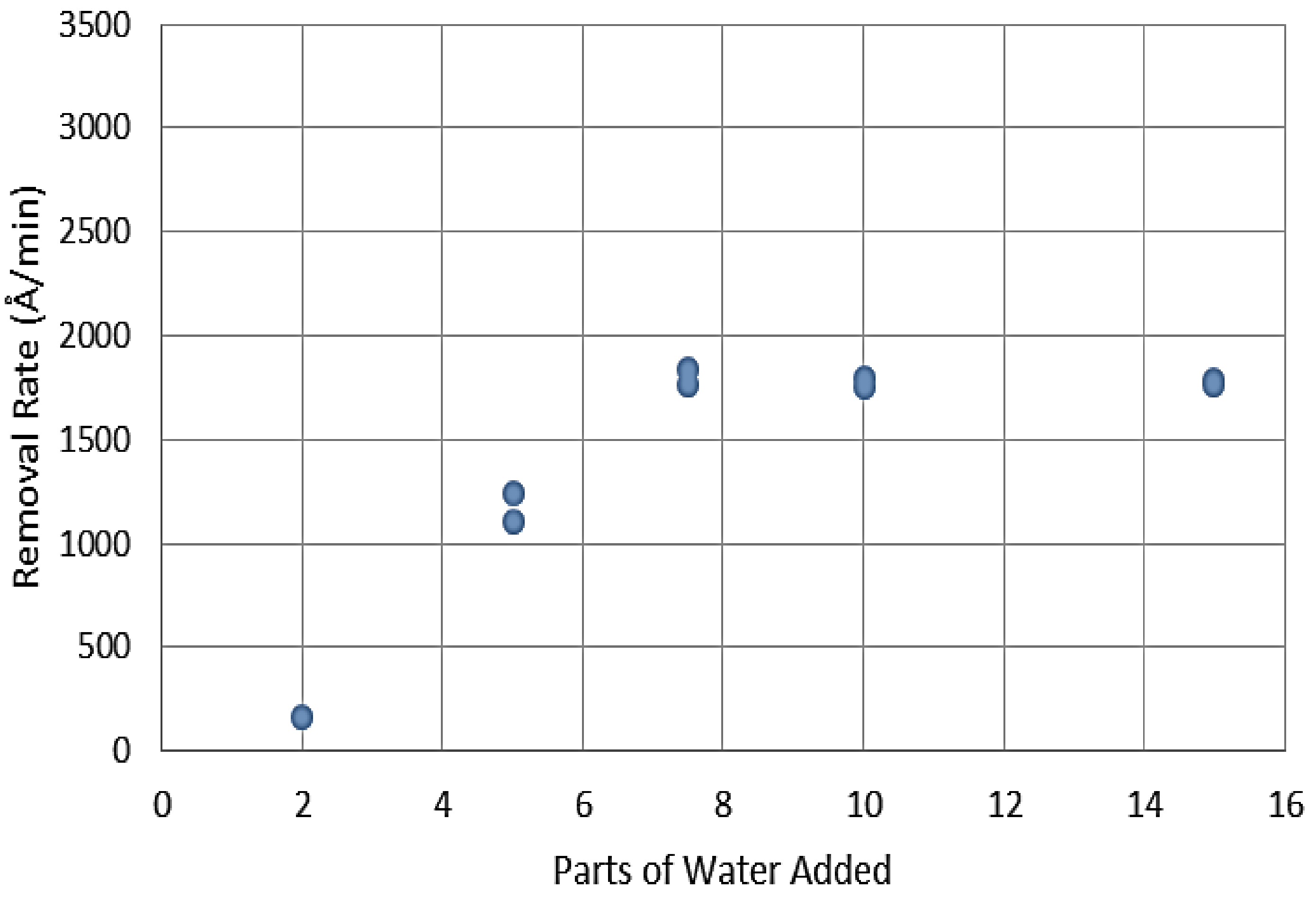
A Brief Theory on Ceria-Silica Removal

- Particular ceria slurries exhibit “reverse” behavior (i.e. we see an increase in RR with increasing dilution).
- Literature claims that Ce^{3+} is responsible for removal, and that addition of water reduces the ionic state of the ceria particle surface.
- Many differing models exist, but all are rooted in same principle (see RHS figure).
- In our case, slurry dilution increases RR.

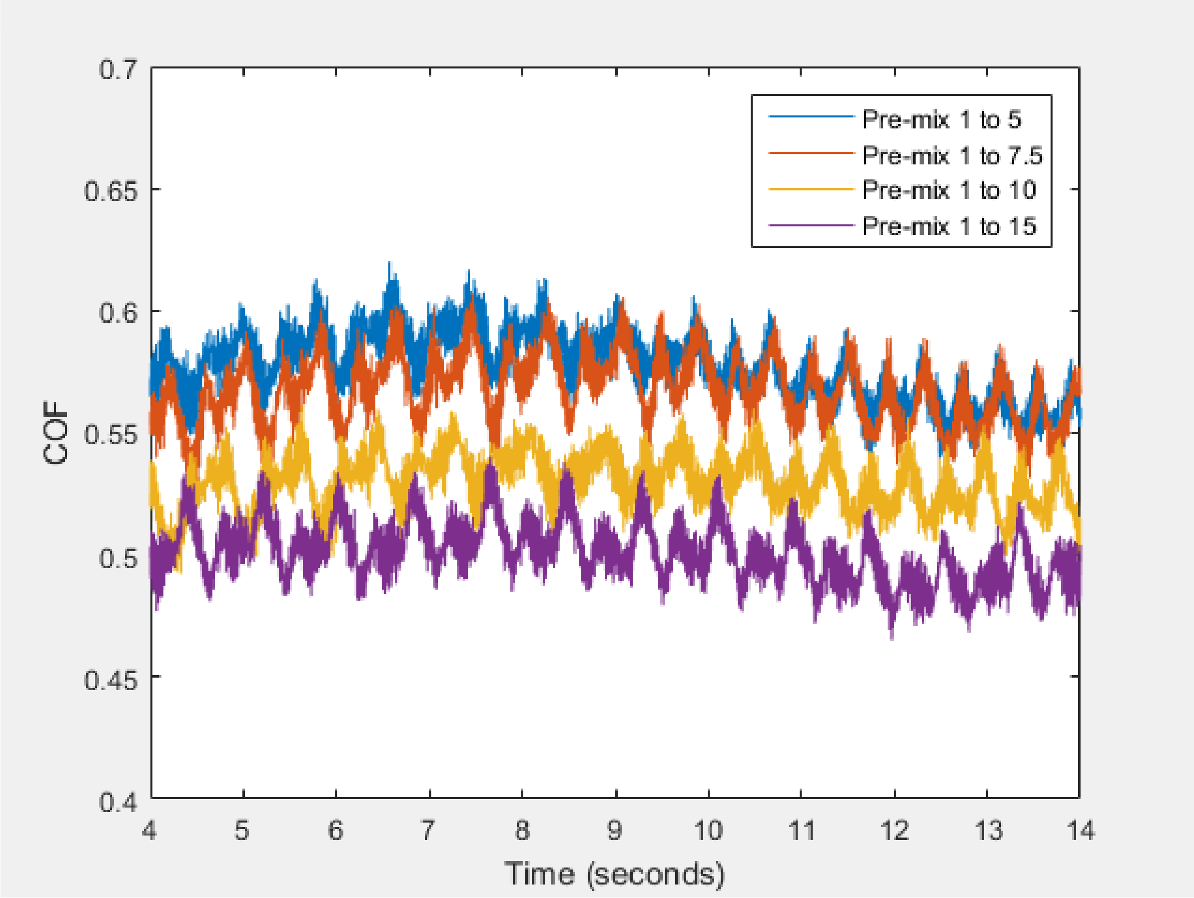


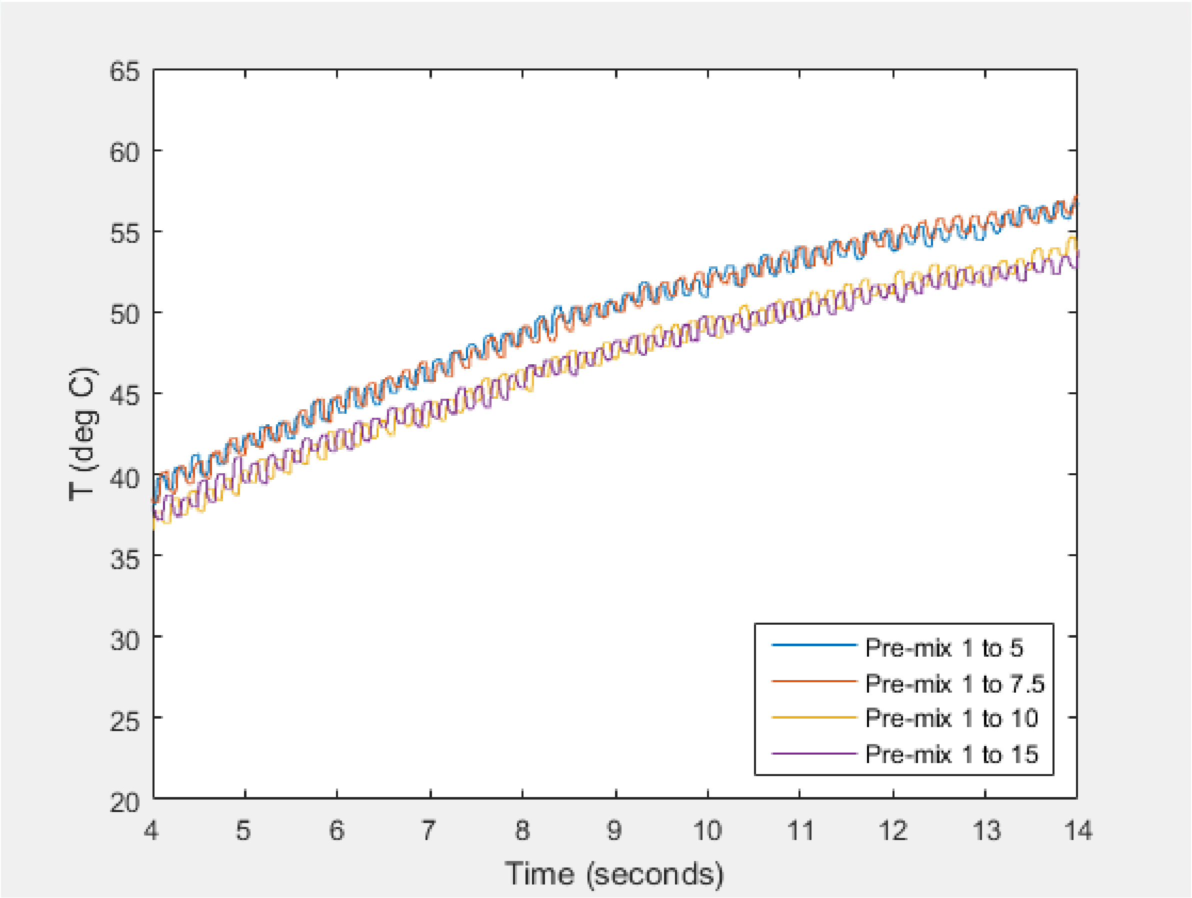
Ceria RR with "Pre-Mixing" Method

- Slurry and water are pre-mixed in a single tank at each dilution ratio prior to each run.
- Pad is rinsed between each run and then air-dried to remove residual water.
- RR increases with addition of UPW up to a slurry-to-UPW ratio of 1:7.5 owing to increasing presence of Ce^{3+}
- Further dilution does not affect RR.
- The ceria binding mechanism is taken over by mechanical limitations past a ratio of 1:7½ (next page)

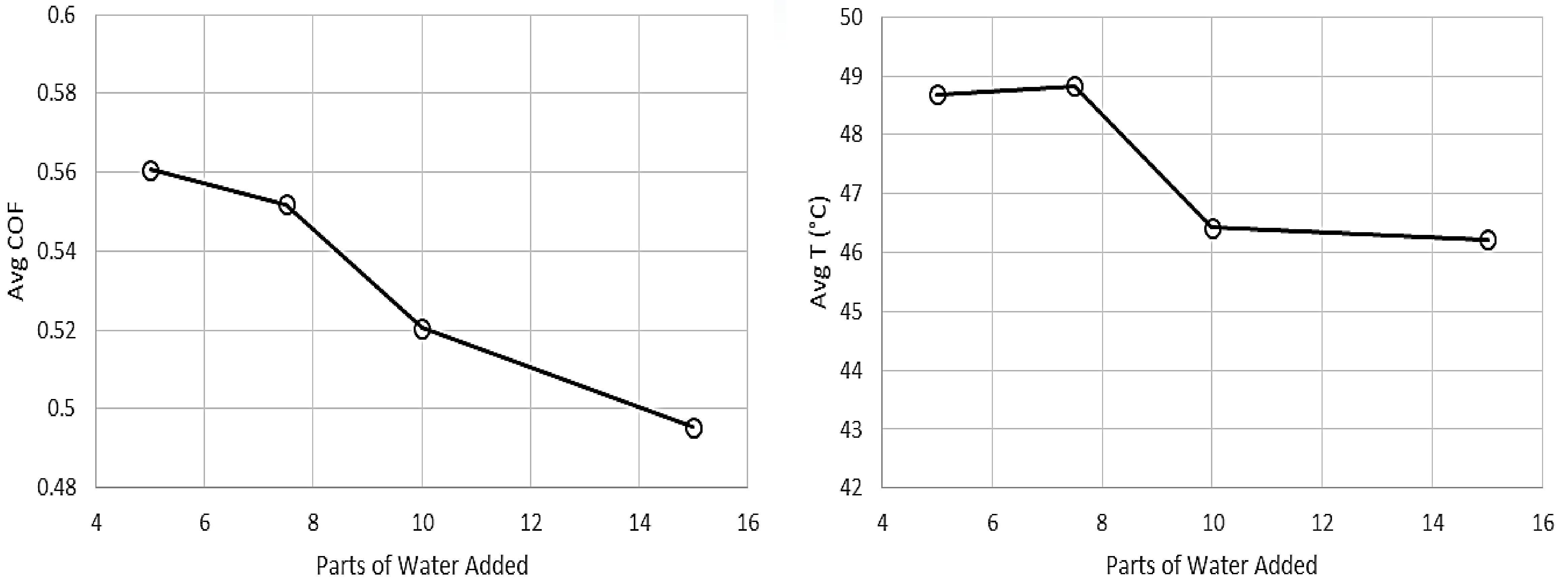


COF &Temperature with "Pre-Mixing" Method



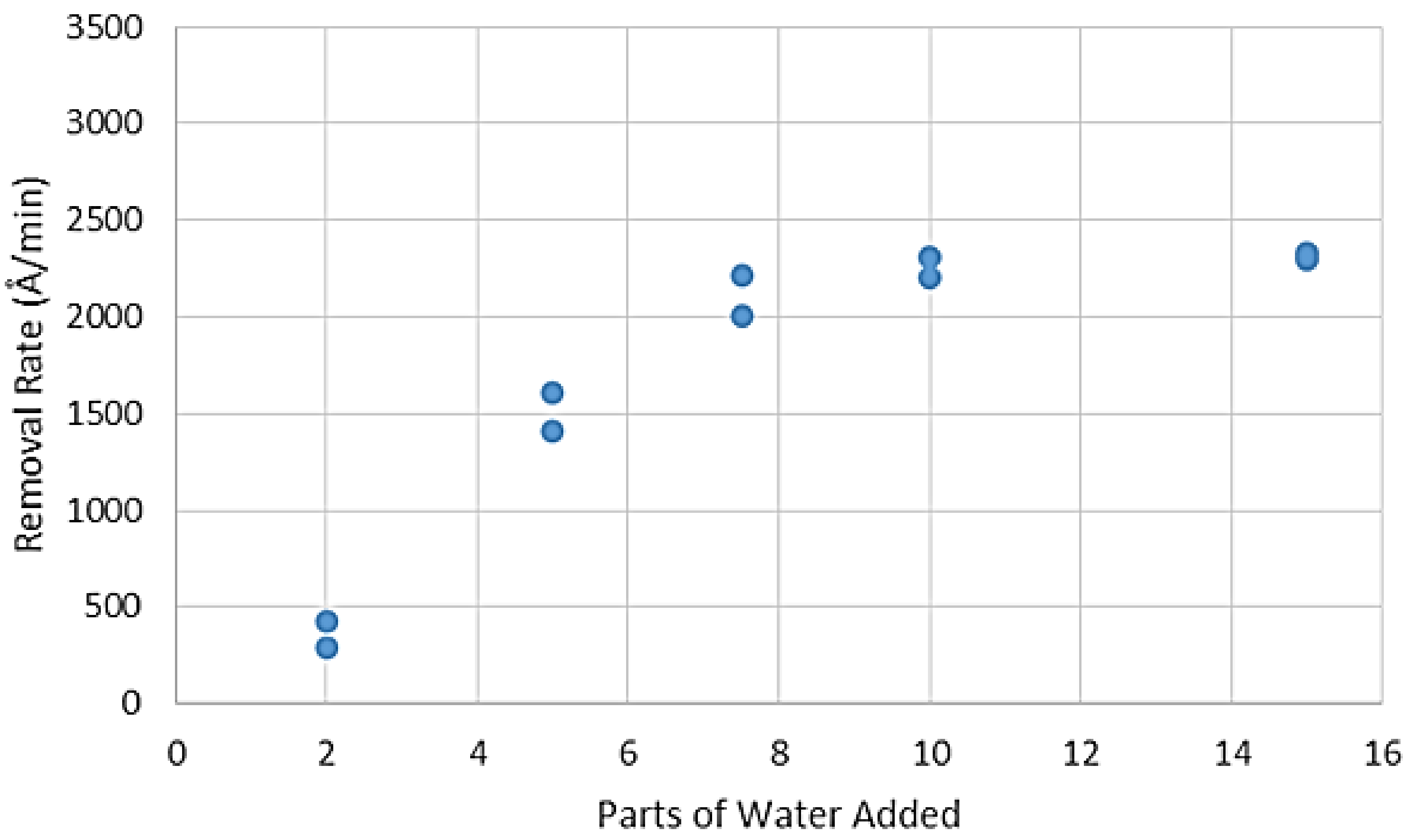


Average COF & Temperature with "Pre-Mixing" Method



Ceria RR with “Point-of-Use” Method

- Slurry and water are kept in separate tanks and individually pumped to a T-valve at the dispense nozzle.
- Pad is rinsed between each run and then air-dried to remove residual water.
- Similar trend to pre-mix case, but at higher RRs for each dilution ratio.
- Likely cause for higher RR: No pre-mixing means FRESH SLURRY; prevents slurry from equilibrating; particles are less agglomerated.



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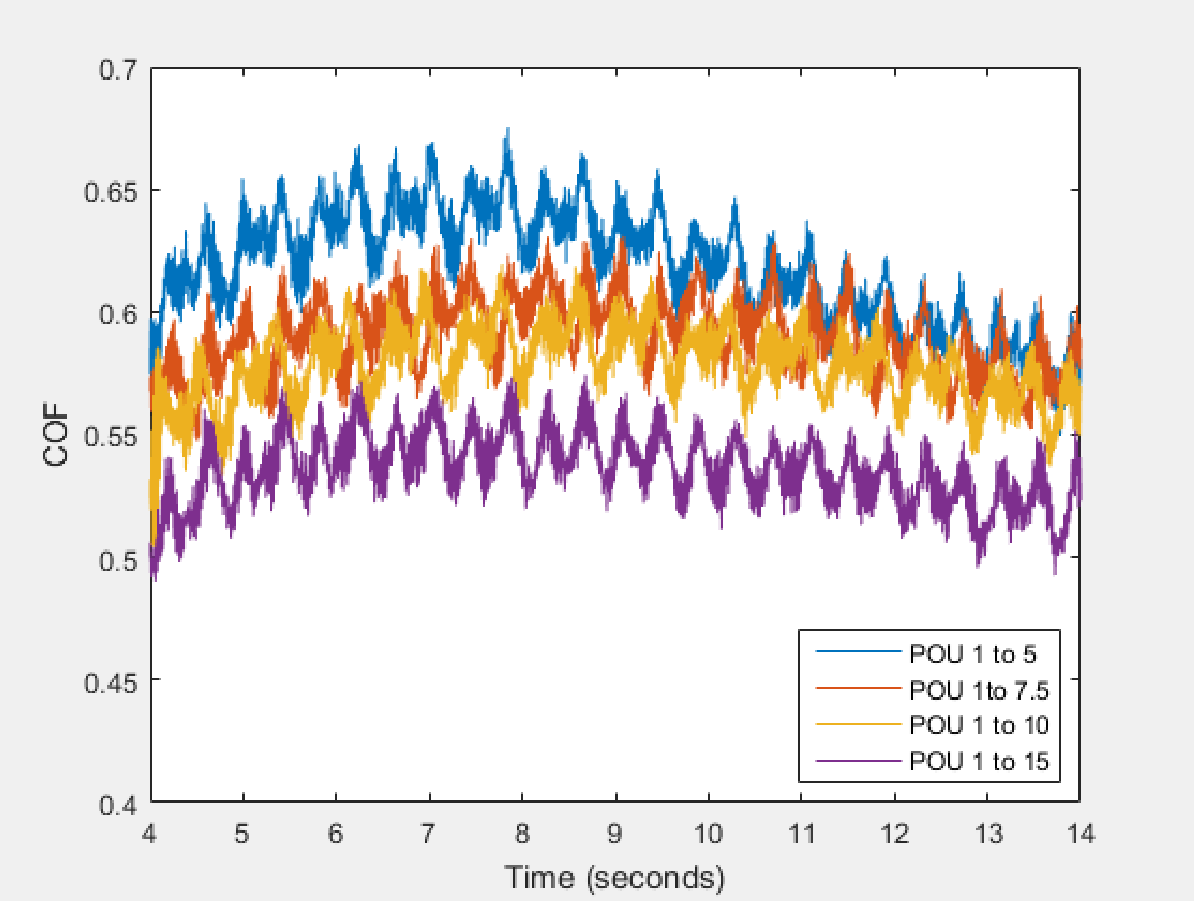

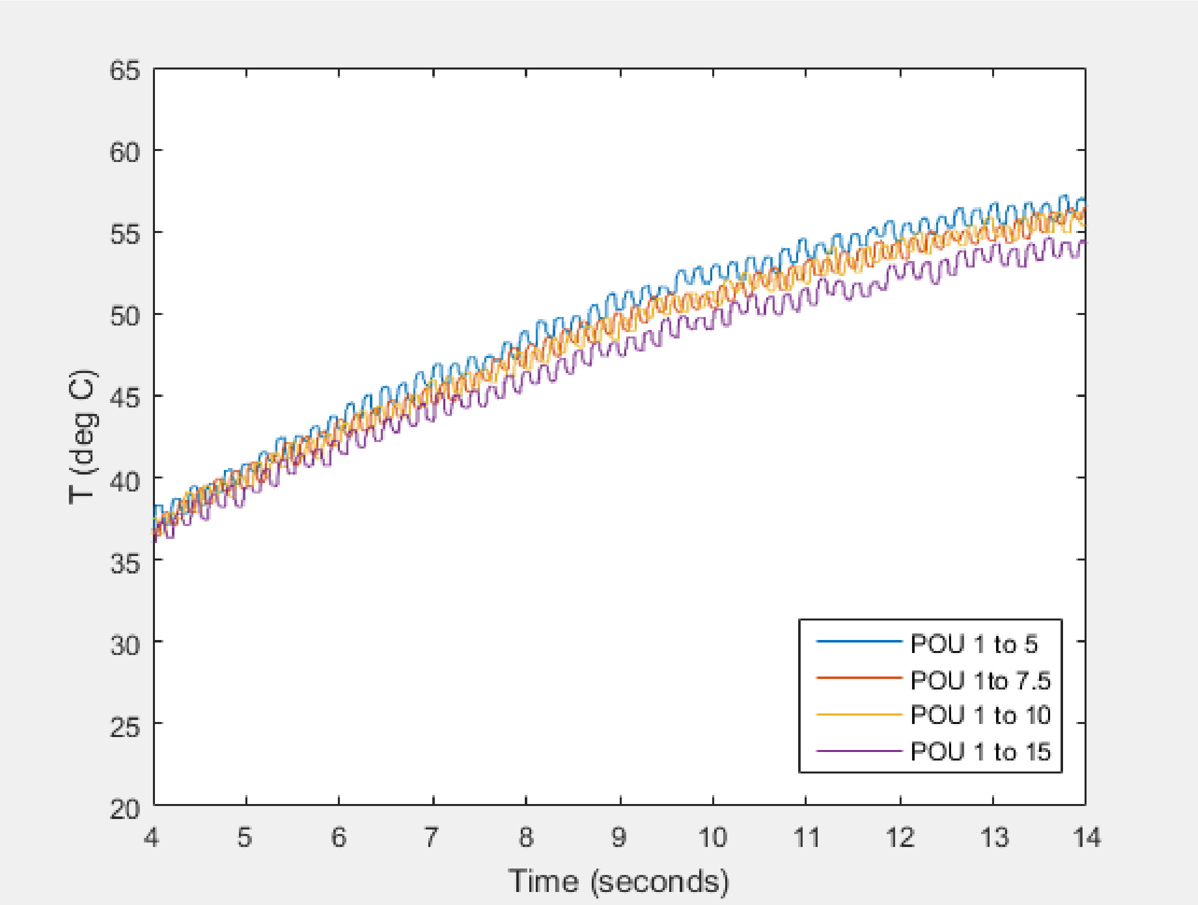

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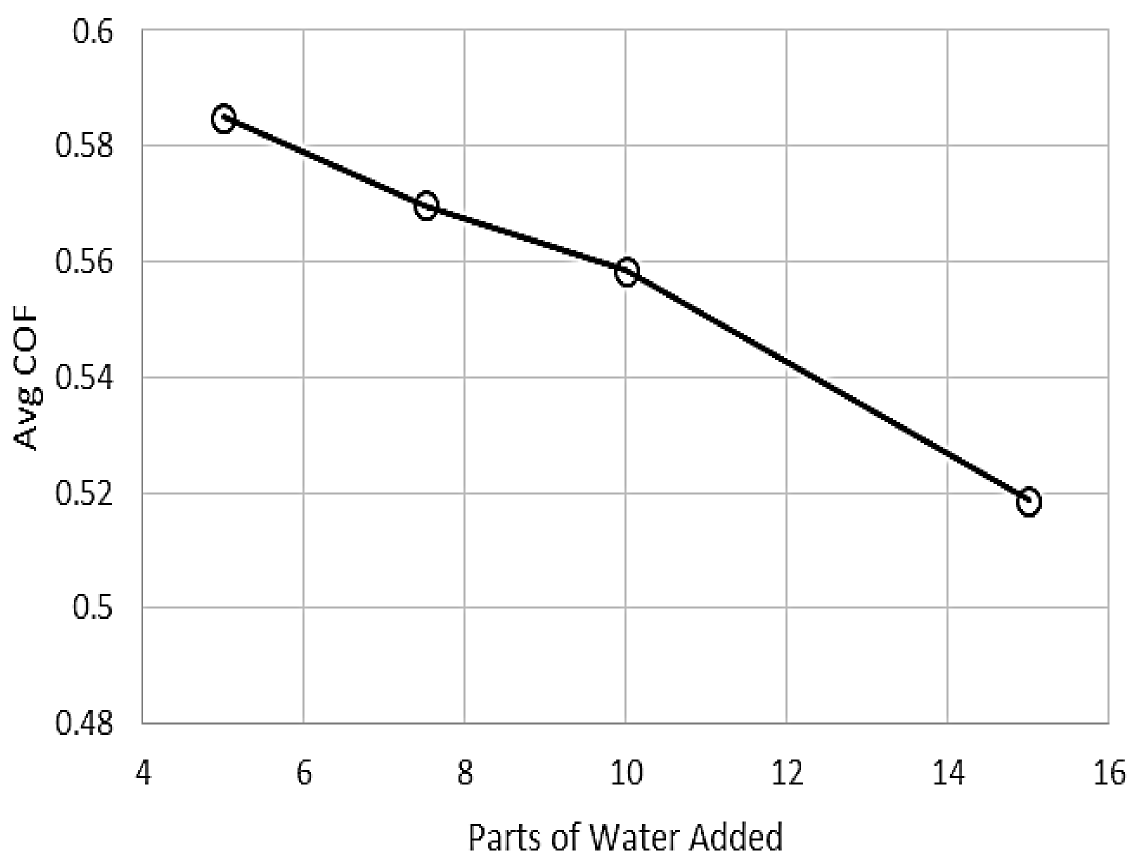
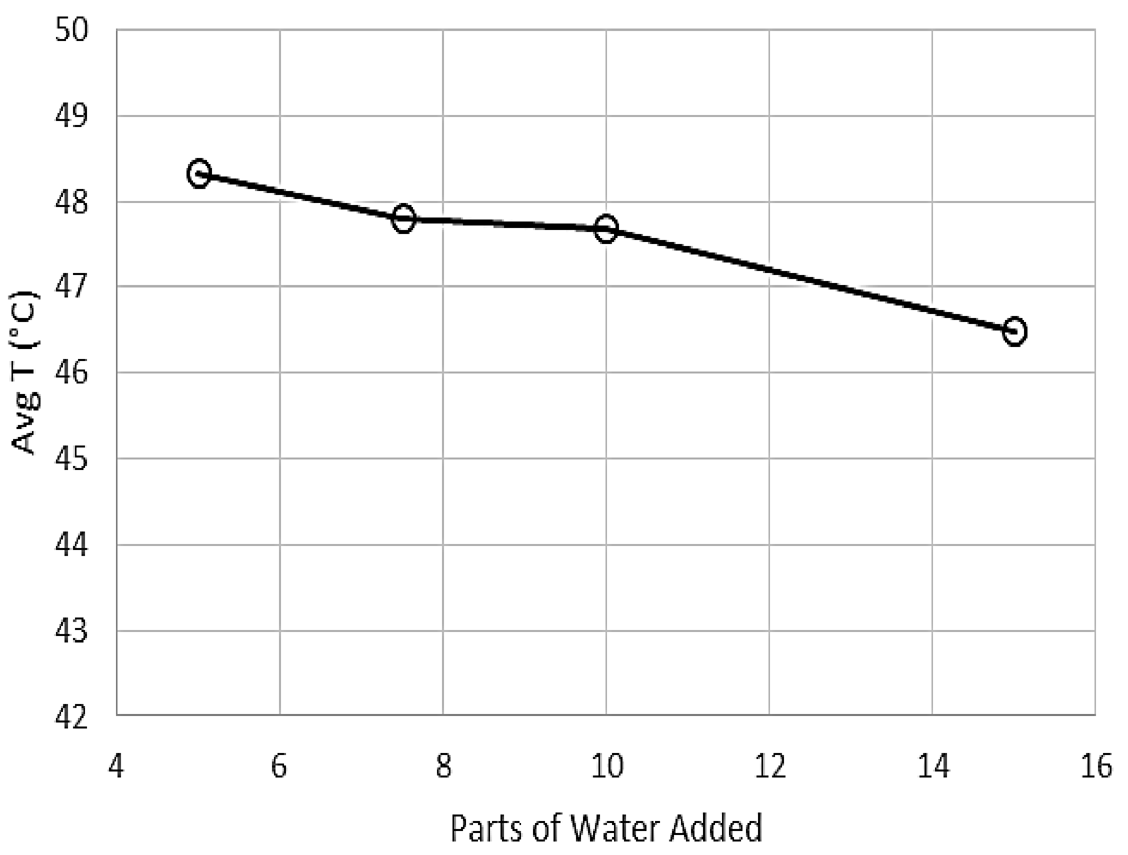
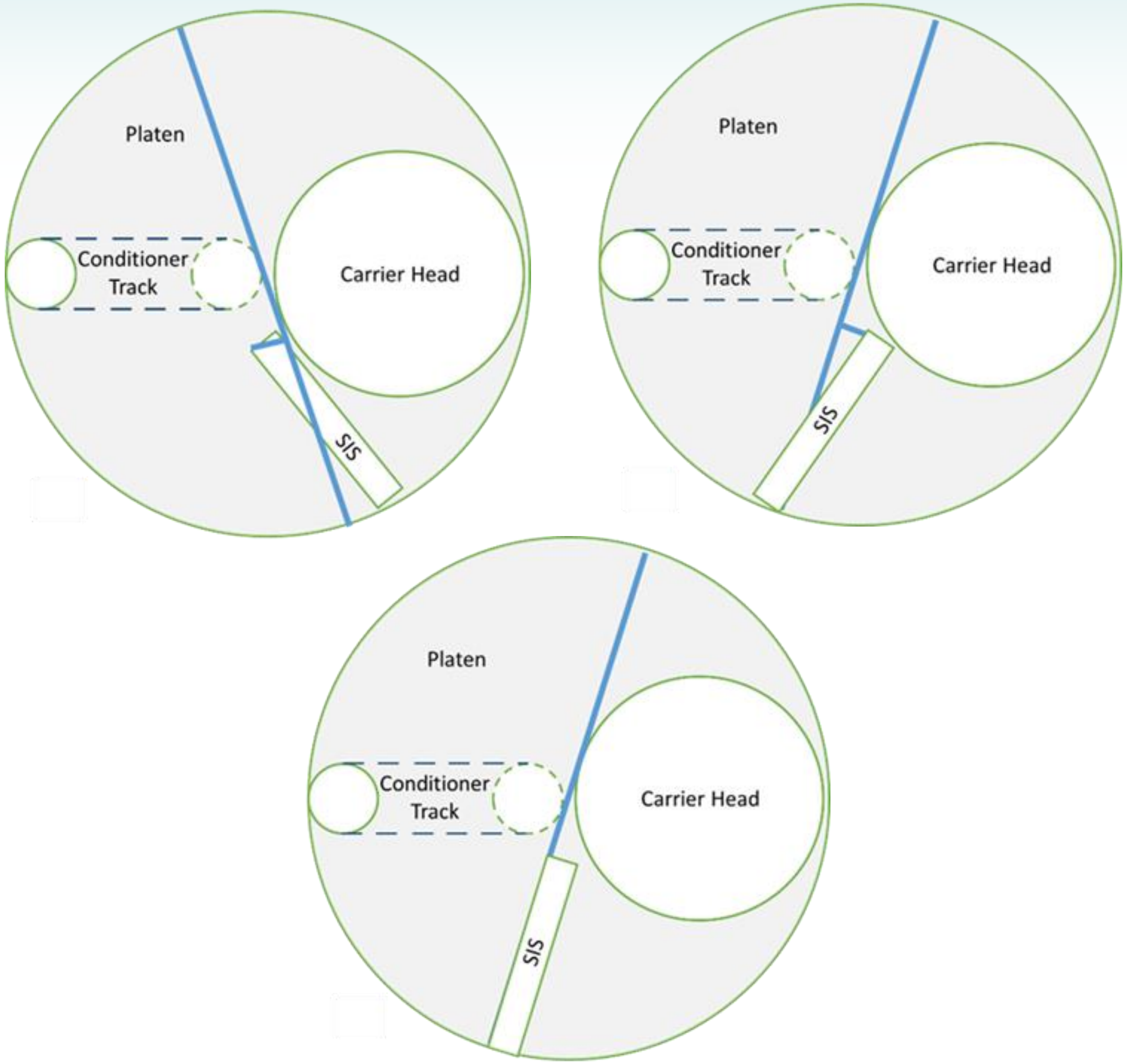




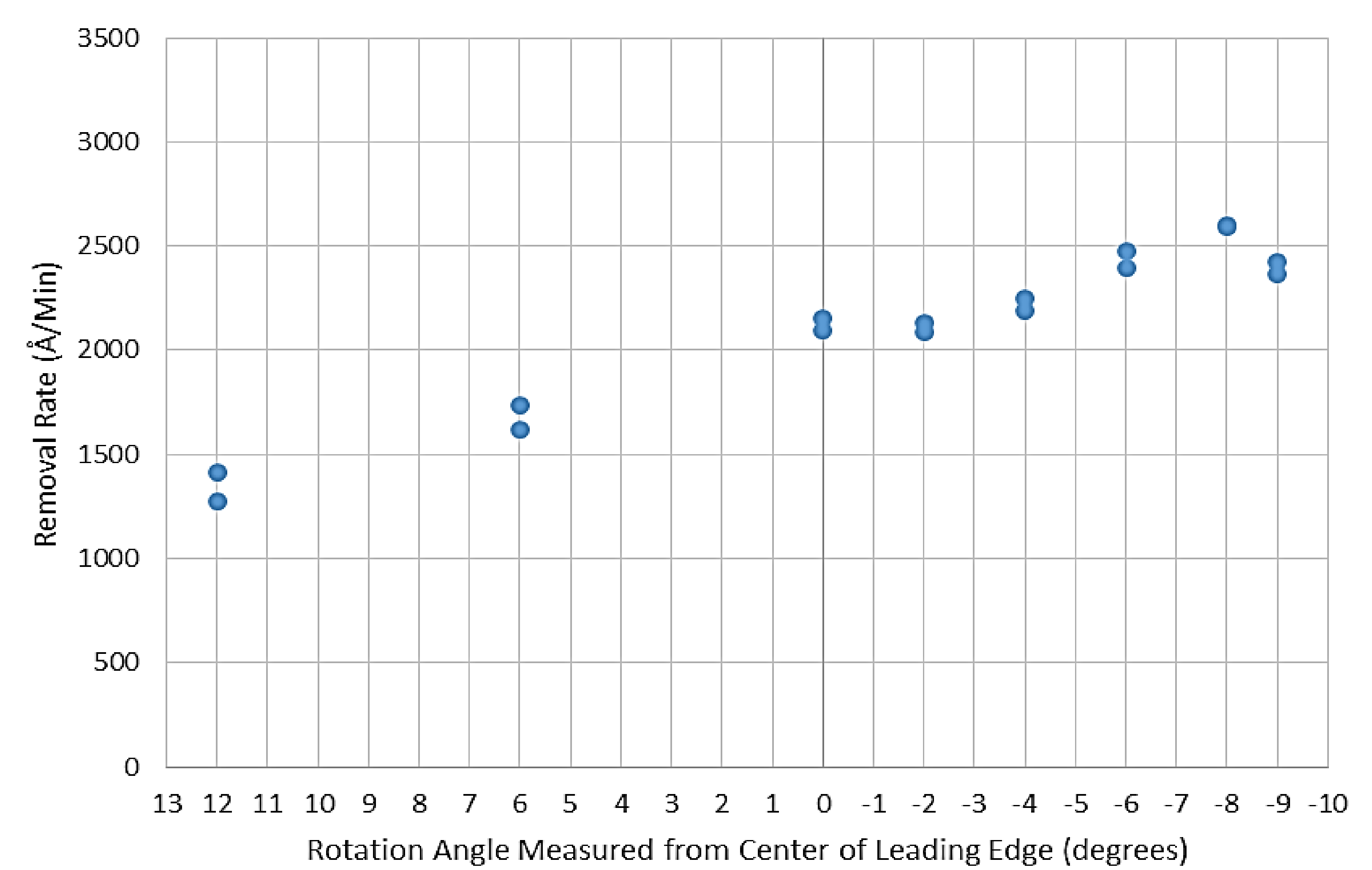
SIS Angle Study – Orientation Schematics

- **SIS was rotated to different angles as measured from the center-point of the leading edge.**
- **Maximum positive rotation angle of 12° (top left).**
- **Maximum negative rotation angle of -9° (top right).**
- **The 0° reference point (bottom).**

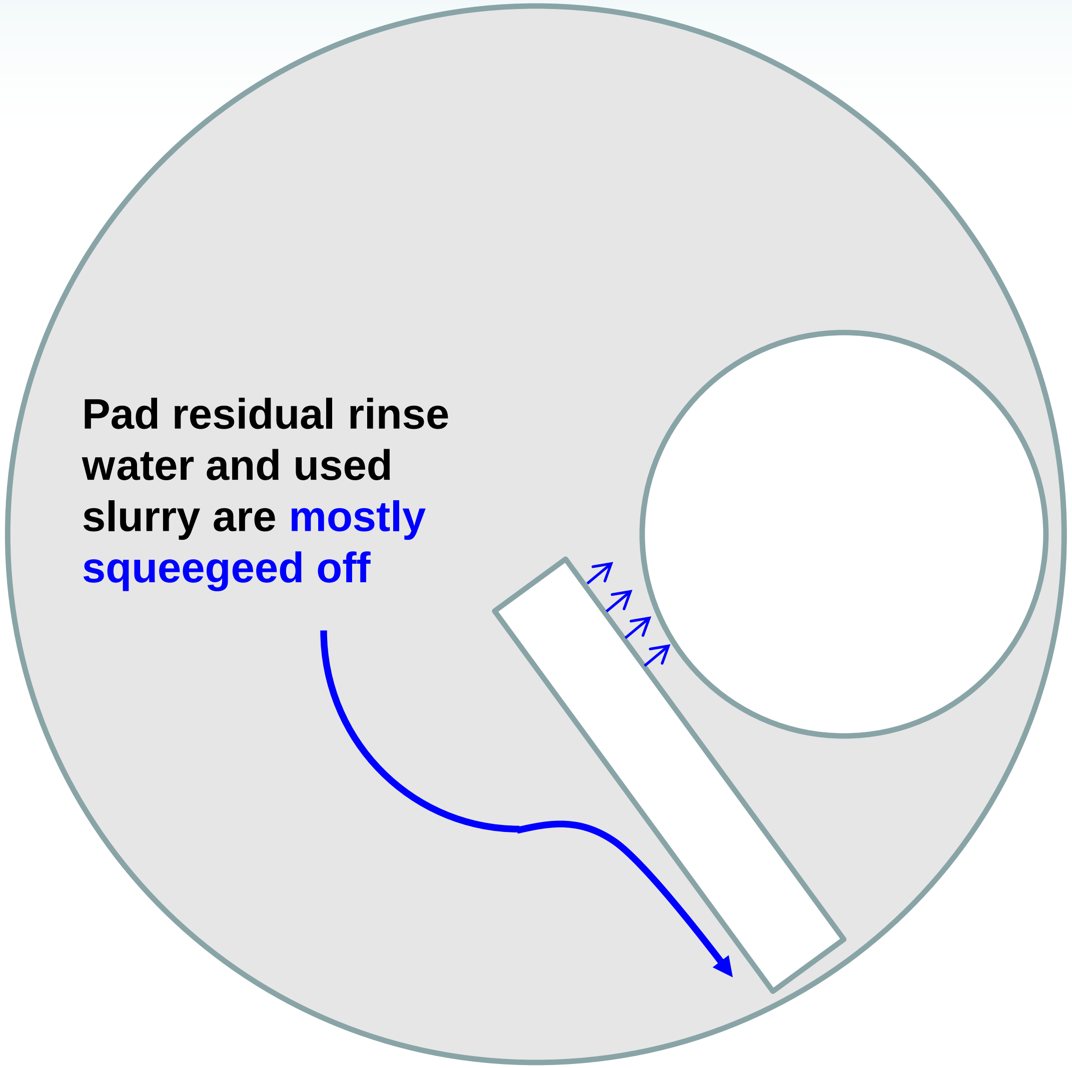


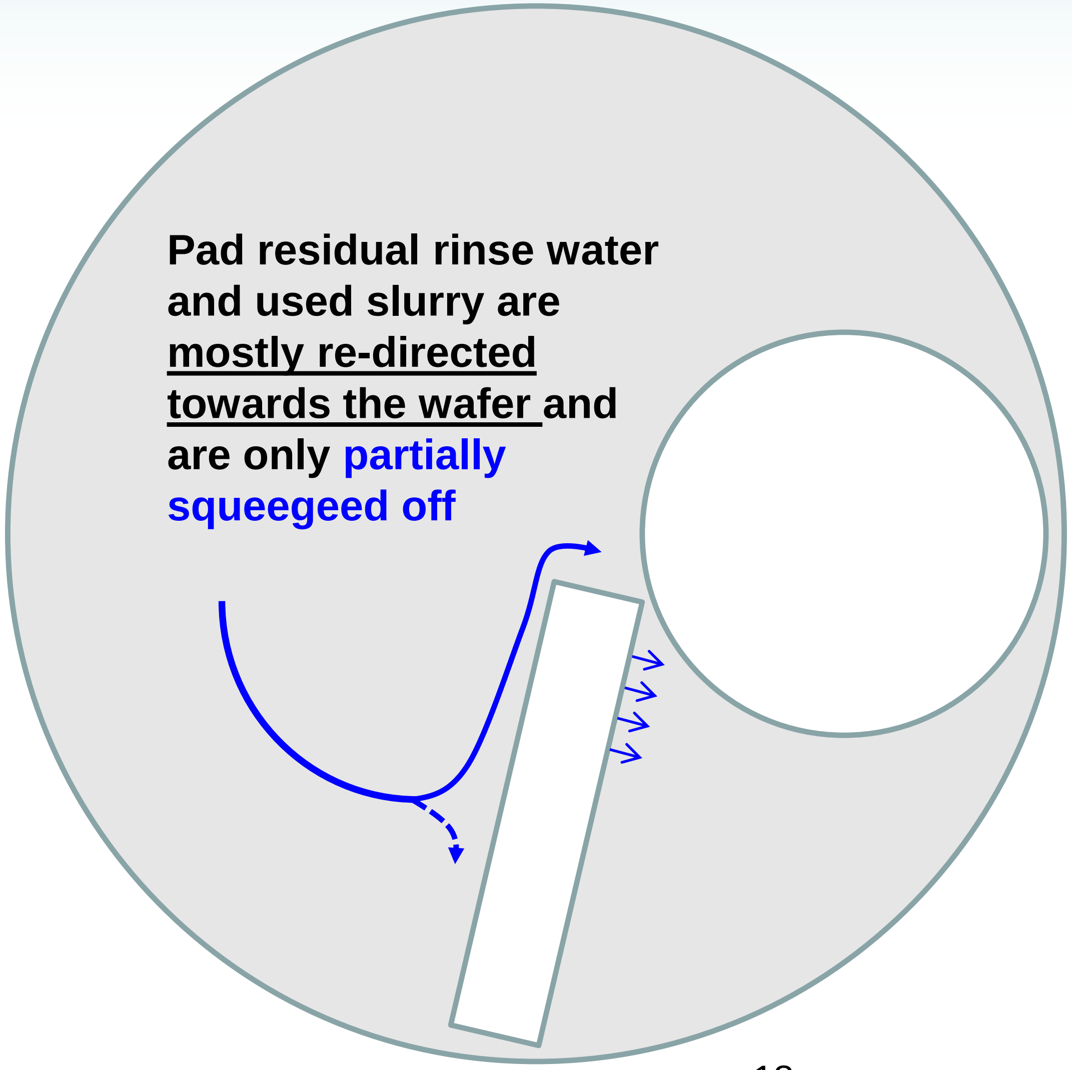
SIS Angle Study – Removal Rates

- **Pad is rinsed between each run and IS NOT air-dried to remove residual water.**
- **RRs increase with increasingly negative angles.**
- **-8° produces average RR of 2,595 Å/min**
- **-9° produces average RR of 2,397 Å/min**



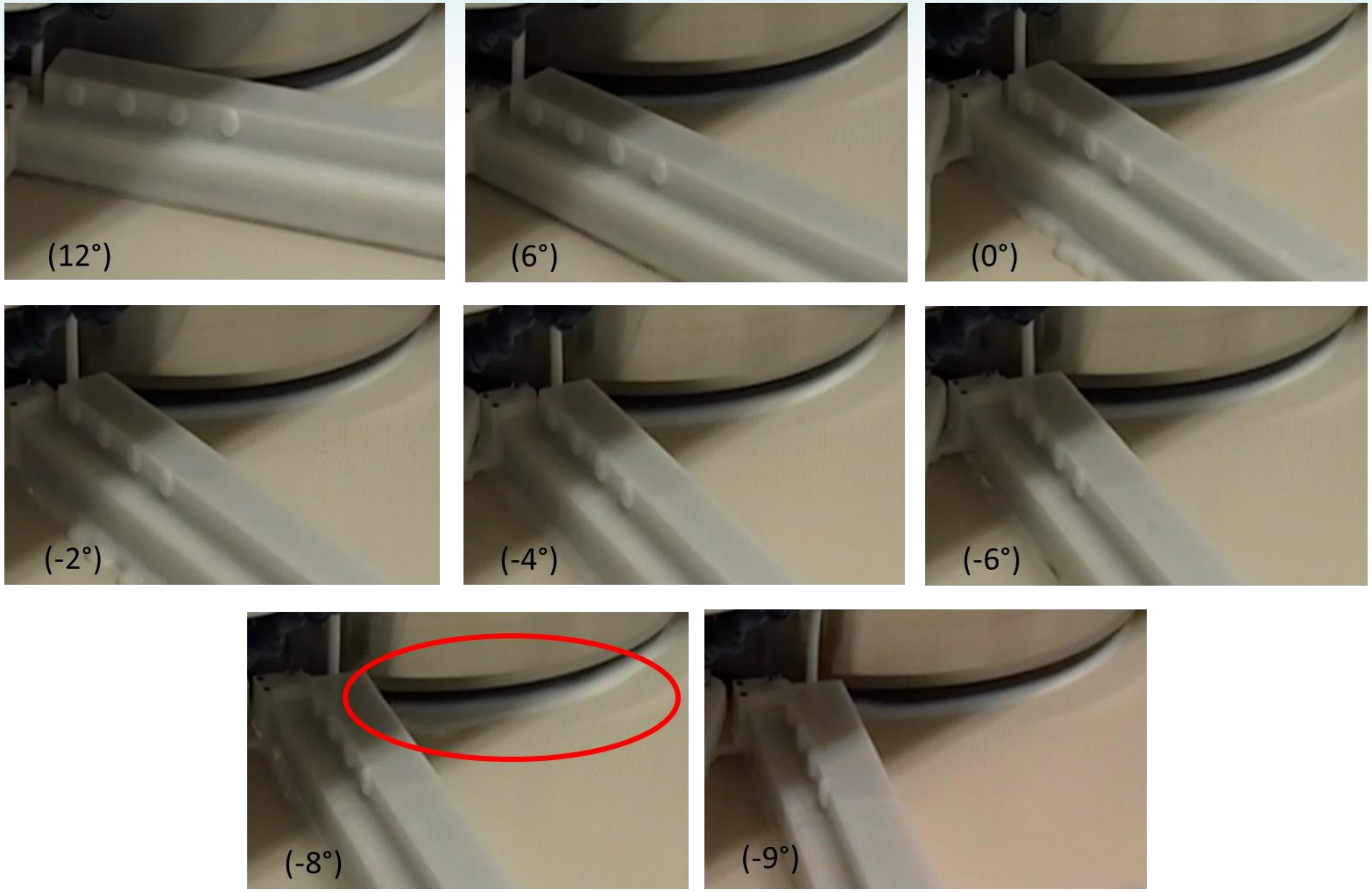
SIS Orientation Effects





SIS Angle Study – Bow Wave Screenshots

- All screenshots taken 7 seconds after ramp-up phase.
- SIS at -8° has a thick retaining ring bow wave that persists longer than other angles.
- Bow wave serves as continual dilution source (i.e. longer persistence means continual dilution).

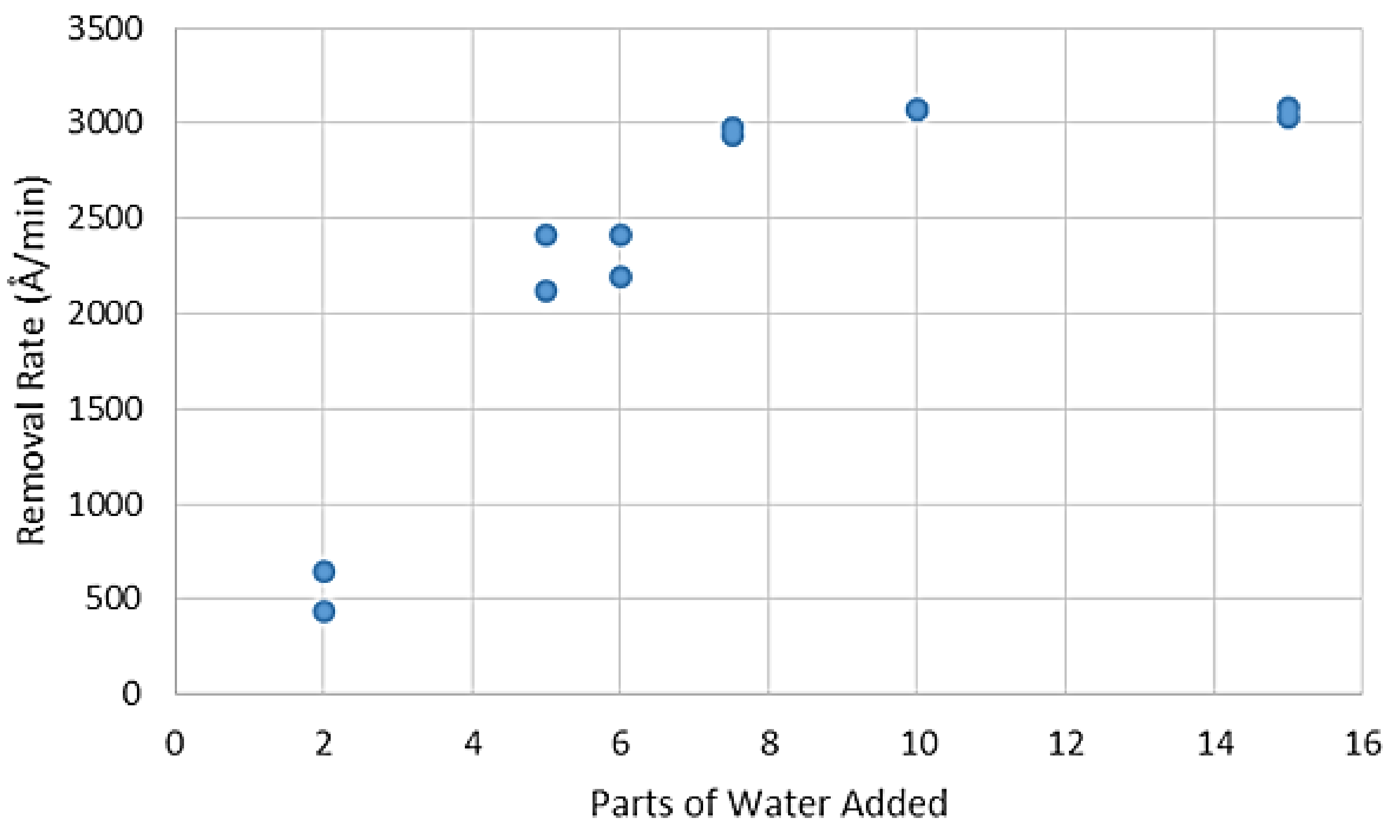


Ceria RR with Point-of-Use (SIS at -8 degrees)

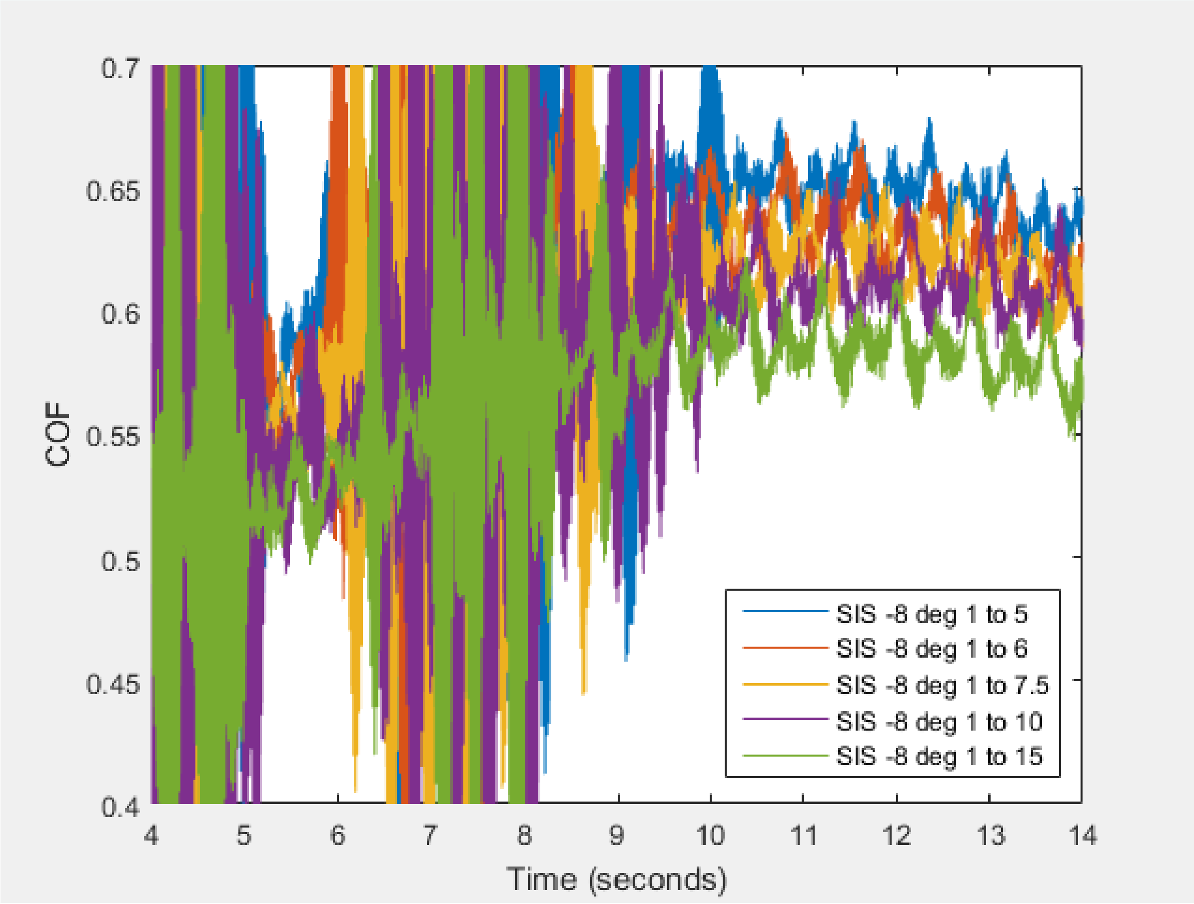
- Slurry and water are kept in separate tanks and individually pumped to a T-valve at the SIS inlet

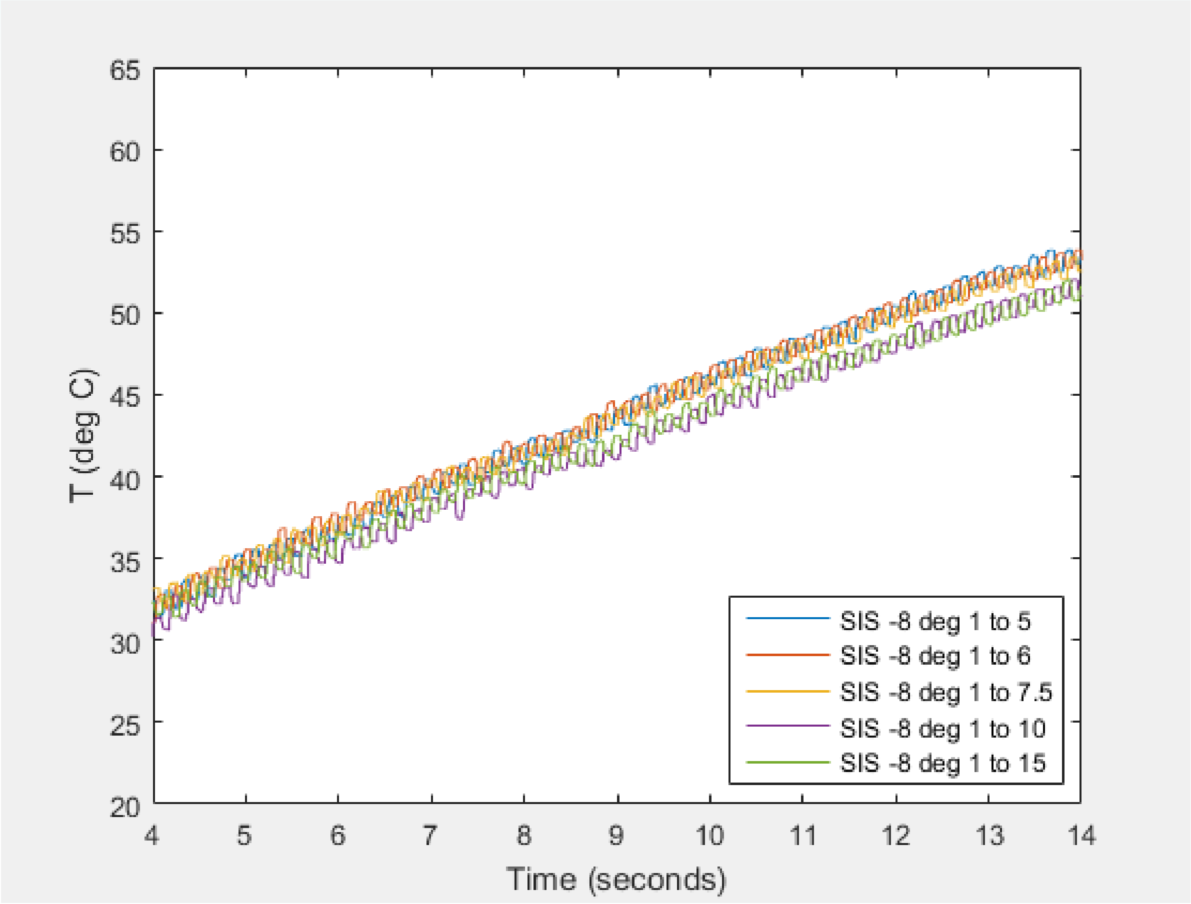
- Pad is rinsed between each run and then air-dried to remove residual water.

- Similar trend to pre-mix case and pad-center POU, but at higher removal rate for each dilution ratio

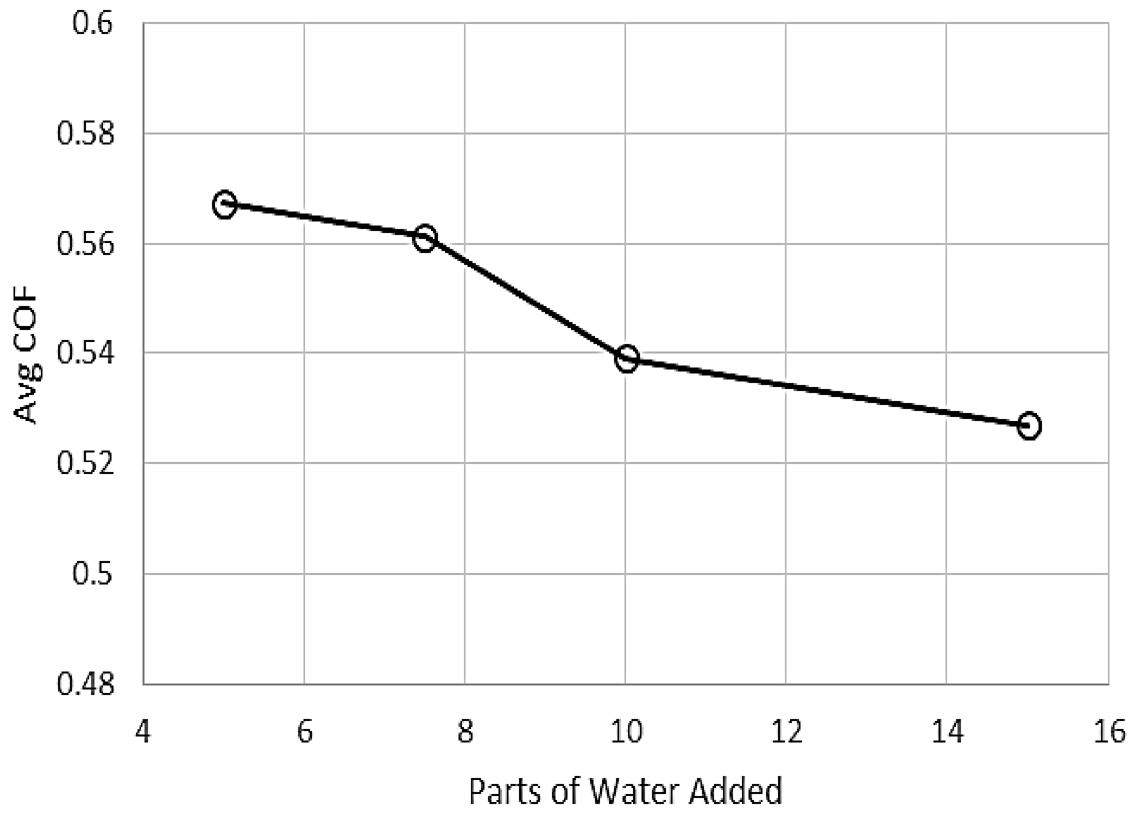


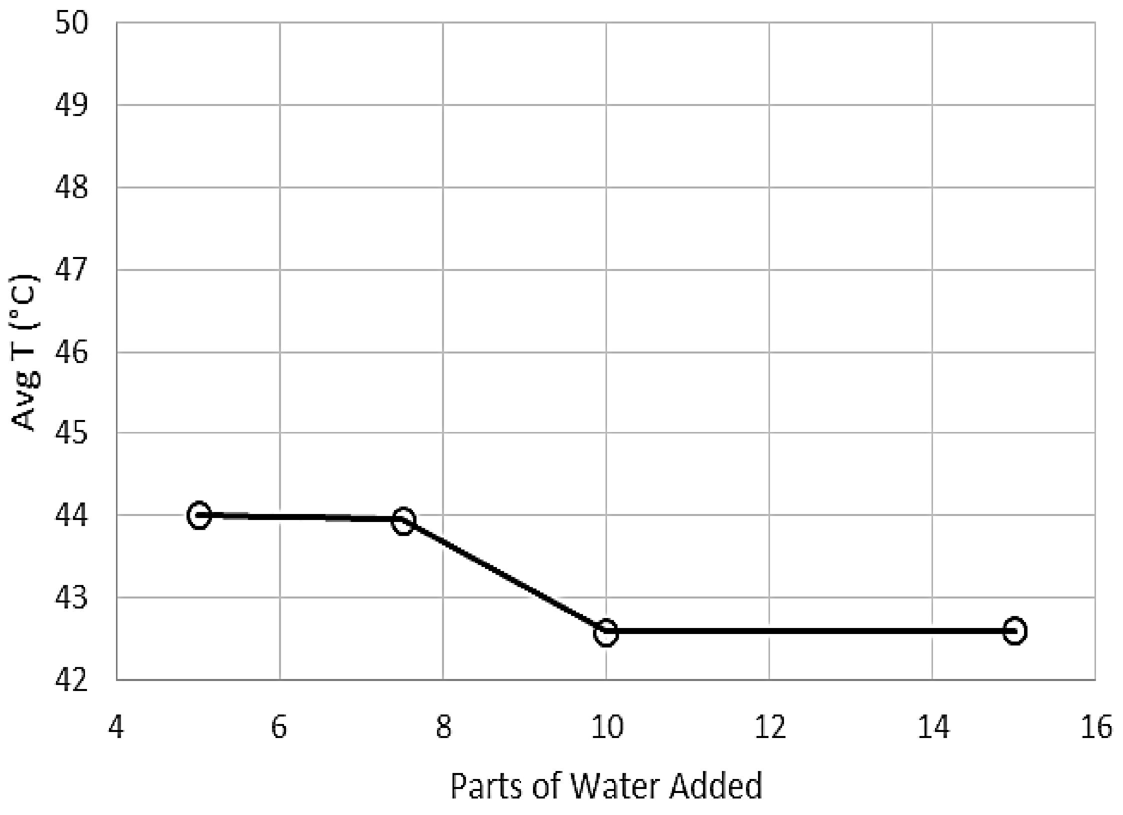
COF & Temperature for "Point-of-Use" with SIS at -8 degrees





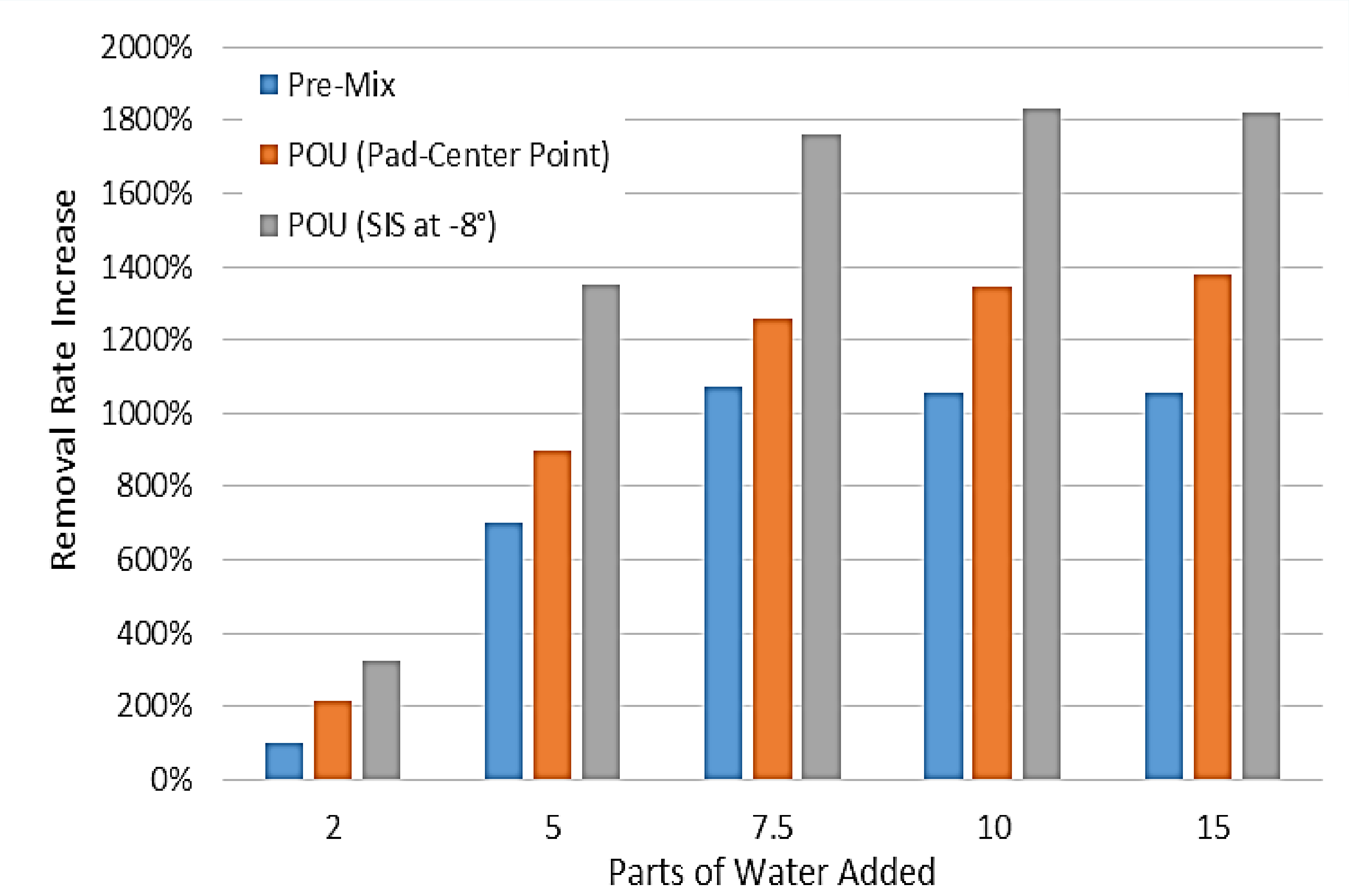
Average COF & Temperature for "Point-of-Use" with SIS at -8 degrees





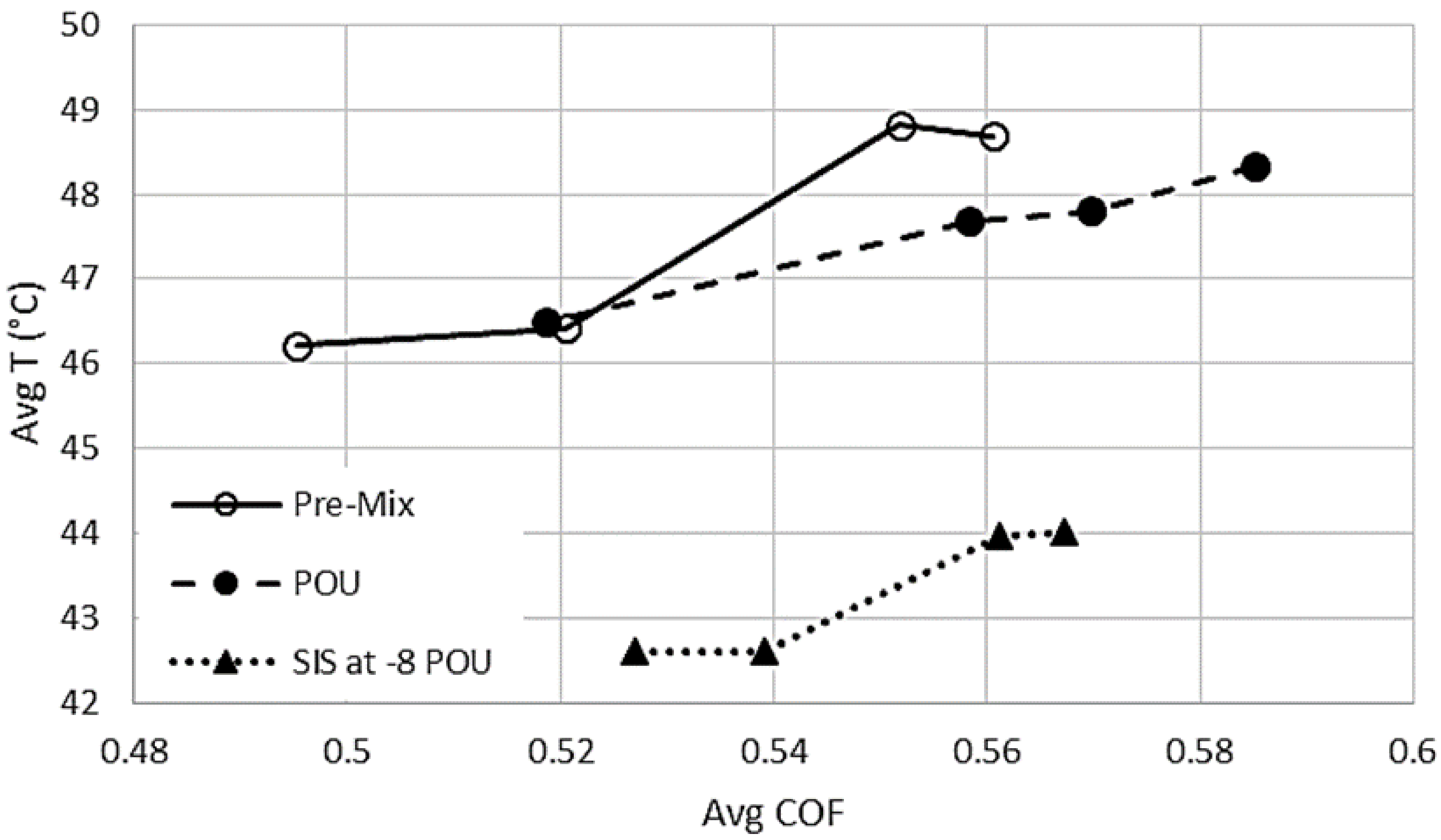
Potential Slurry Savings

- **Over 1800% increase in RR over manufacture's specifications**
- **Using POU with the SIS at -8 degrees consistently yields 1.5X to 3X higher RRs compared to "Pre-Mixing".**
- **Allows IC producers to lower polishing times or the amount of slurry used (cost savings and reduced EHS concerns).**



Average Temperature vs. Average COF for All Dispense Methods

- **Data shown for highest dilution ratios (1:5, 1:7½, 1:10 and 1:15).**
- **SIS runs at a cooler temperature than both pre-mix and POU.**
- **Despite this, SIS yields the highest RR possibly owing to the increased slurry utilization efficiency.**



Summary

- RRs increase with increasing dilution until mechanical removal mechanisms become dominant.
- Method of mixing has appreciable effects on RR.
- SIS angles produce different retaining ring bow waves, yielding different extents of dilution and therefore RRs.
- Combining the benefits of the SIS with POU mixing led to the highest attainable RRs.
- Slurry as well as polishing time savings could be of tremendous benefit to overall COO while also avoiding large environmental, health, and safety issues.