Cobalt Buff Step CMP for MOL Applications and Reduction in Slurry Consumption Using a Novel Slurry Injection System

C. Stuffle[1], R. Han[1], Y. Sampurno[1, 2], S. Theng[2], W. Tseng[3] and A. Philipossian[1, 2]

[1] University of Arizona, Tucson, AZ, USA
[2] Araca Inc., Tucson, AZ, USA
[3] GlobalFoundries, Malta, New York 12020, U.S.A.

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    - ❖ Simulation
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    - ❖ Polishing
    - ❖ Simulation
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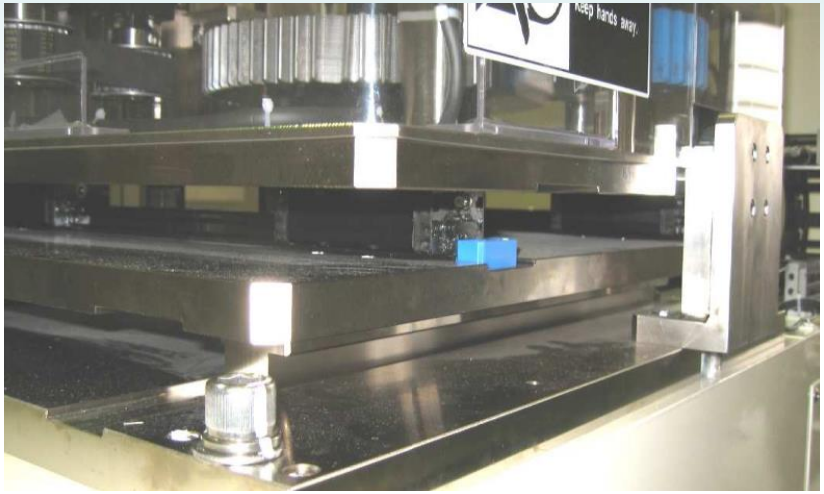
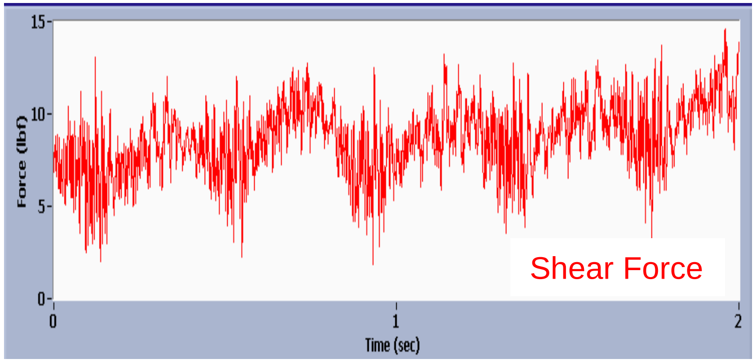
Introduction

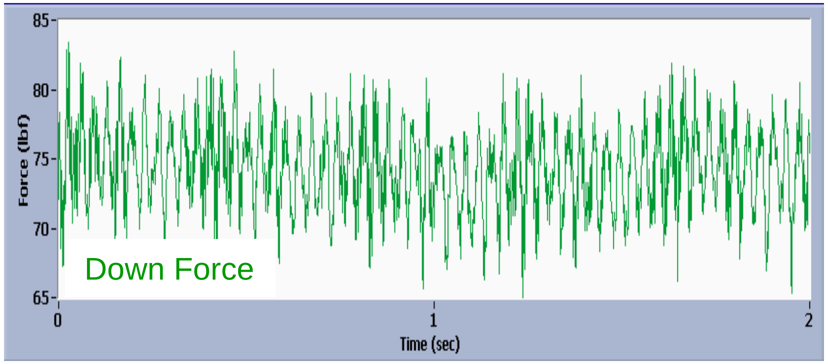
- **Cobalt is making its way into MOL metallization, replacing tungsten:**
  - ❖ **No need for a nucleation layer as is the case for W CVD → More room for bulk cobalt**
  - ❖ **Can be annealed at reasonable temperatures → Allows for reflow and grain growth**
  - ❖ **No fluorine containing precursors → Can use Ti as liner without needing TiN**
- **Motivation – Focusing on Step-2 polish, investigate how this “buff” step affects the removal of the surrounding dielectric.**

Experimental Apparatus and Conditions

Araca APD-800 300-mm Polisher and Tribometer





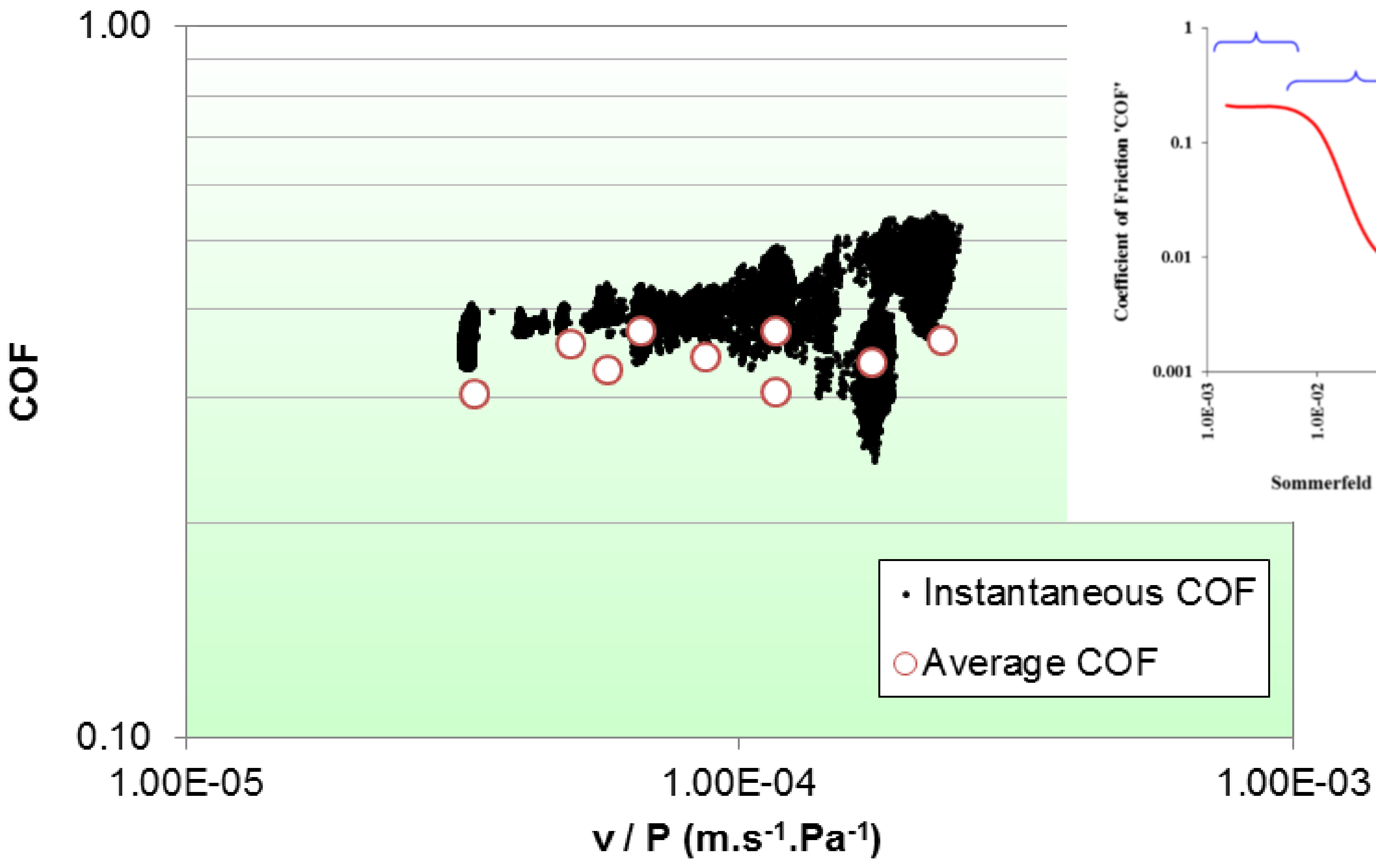


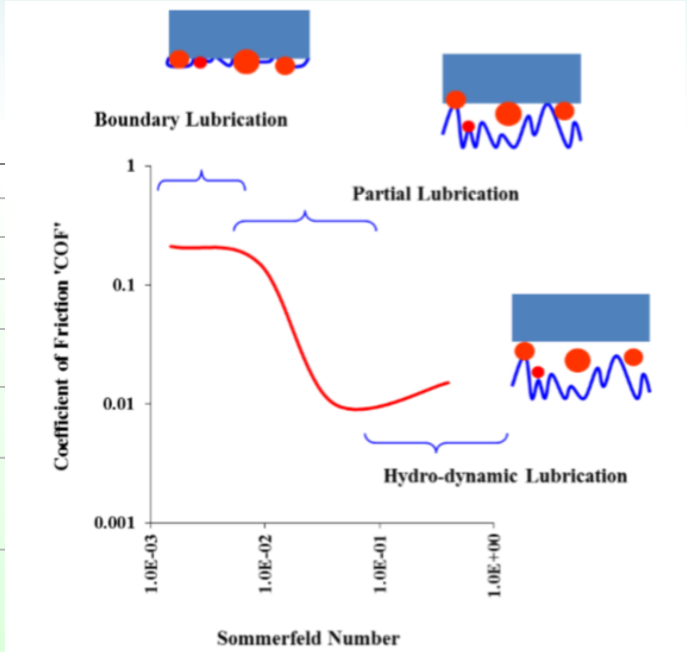
Experimental Conditions

- Pad = Fujibo H800-CZM
- Wafer = 300-mm blanket PETEOS
- Slurry
  - ❖ Proprietary HVM Co slurry
  - ❖ Flow rate: Part 1 – 200 mL/min Part 2 – 100, 150, 200 mL/min
- Controlled Rinse
  - ❖ DI H_2O flow rate = 1,000 cc/min at a platen velocity of 1.6 m/s
- Diamond Disc
  - ❖ Saesol CLC-S1-SA5C rotating at 36 RPM, conditioning down force of 2 kg_f and a disc sweeping schedule of 13 times/min
- Polishing Conditions
  - ❖ Time = 1 minute with 10 sec *ex-situ* conditioning
  - ❖ Part 1
    - ✓ Polishing pressure = 1, 2 and 3.5 PSI
    - ✓ Sliding velocity = 0.8, 1.2 and 1.6 m/s
  - ❖ Part 2 – SIS vs PA
    - ✓ Polishing pressure = 2 PSI
    - ✓ Sliding velocity = 1.2 m/s

Part I – Characterization of Cobalt "Buff" Step – Experimental and Simulation Work

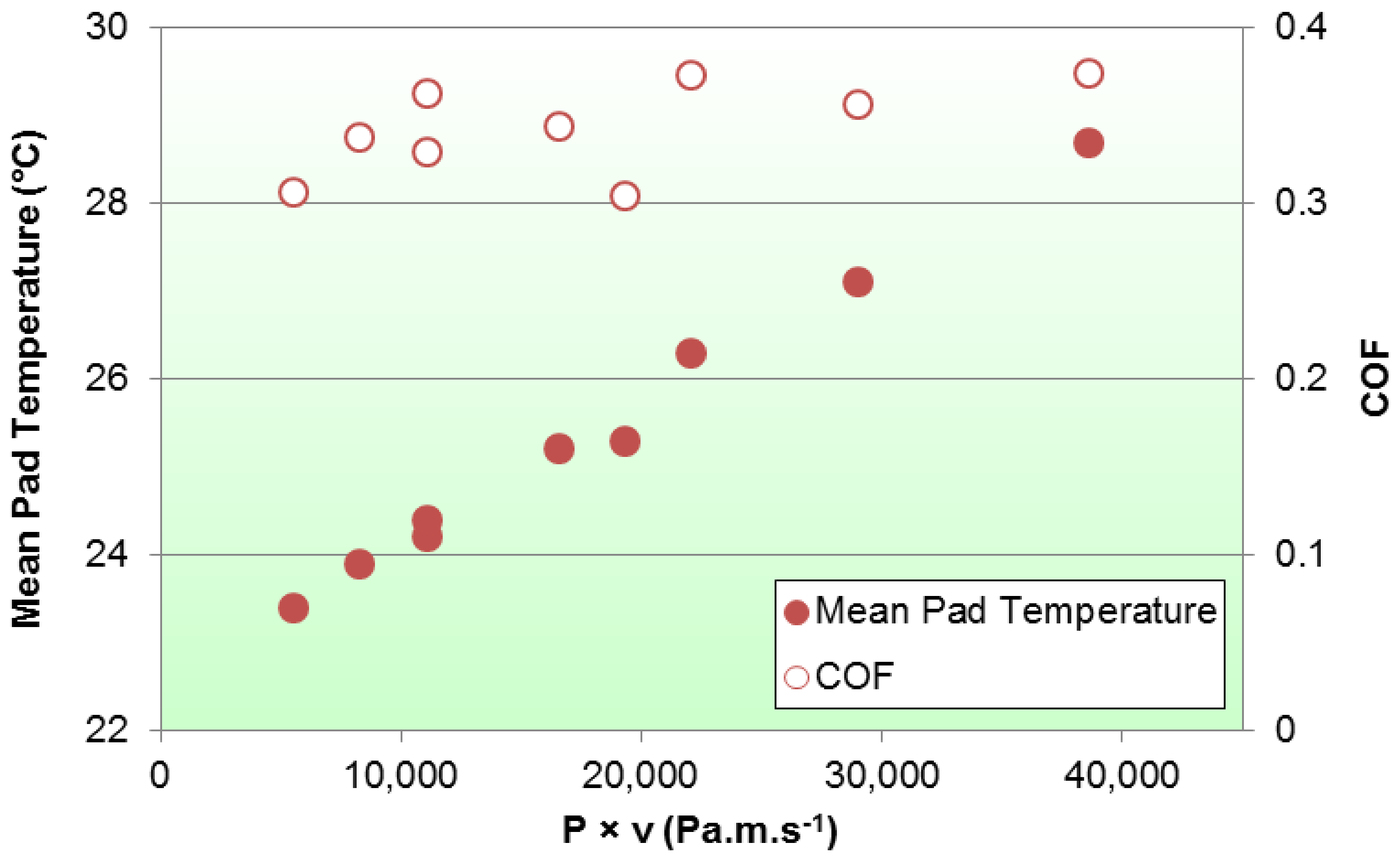
Part I – Polishing Results
Stibeck and Stribeck+





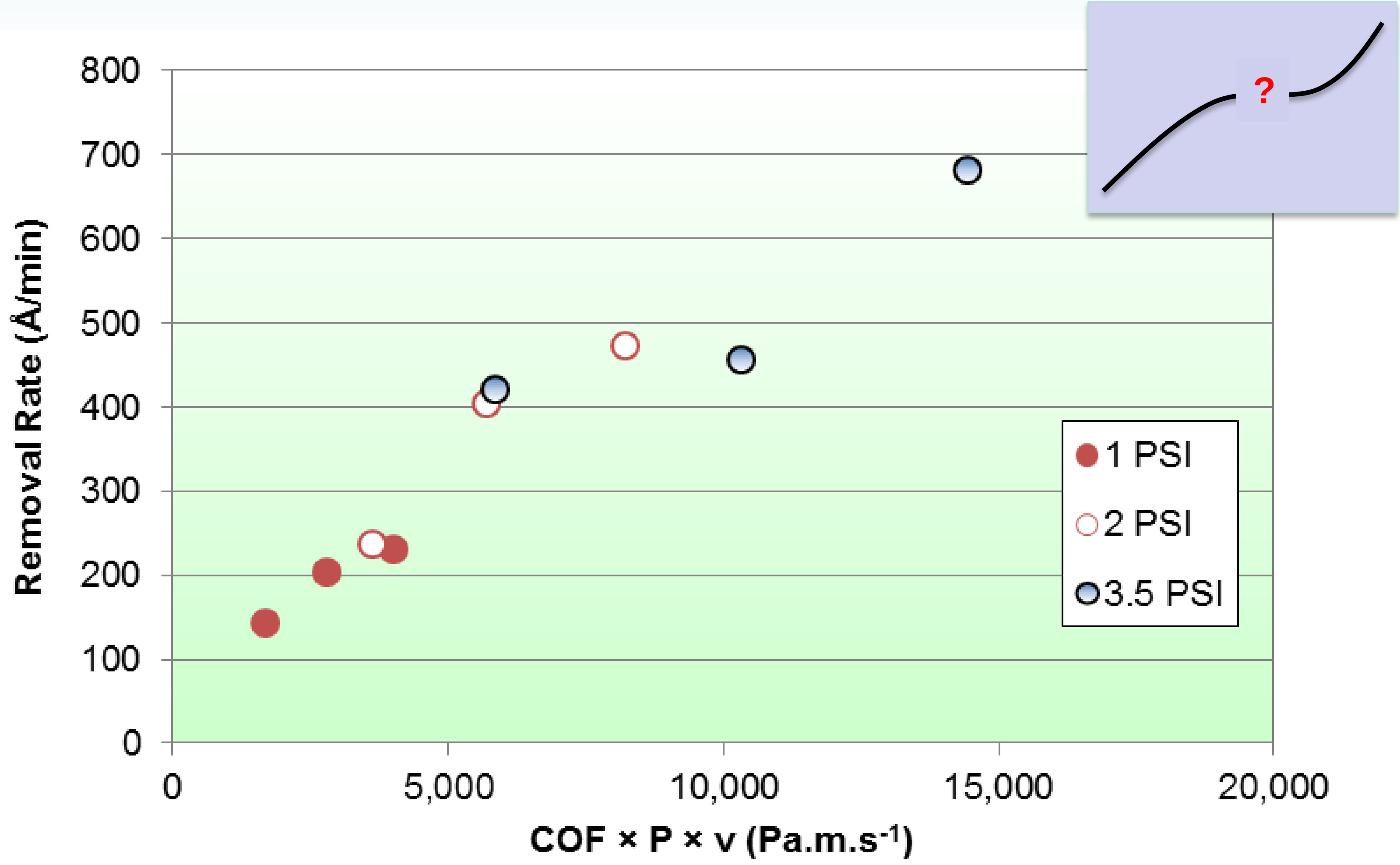
Part I – Polishing Results

Mean Pad Temperature and COF



Part I – Polishing Results

Removal Rate



Removal Rate Model

- **Modified Langmuir-Hinshelwood (L-H) model:**

  - **n moles of reactant R in the slurry react at rate k_1 with silicon dioxide film on the wafer to form a product layer L on the surface**

$$S + nR \xrightarrow{k_1} \underline{L}$$

$$k_1 = A \times \exp(-E_a / kT)$$

$$T = T_p + \frac{\beta}{V^{0.5+e}} \times COF \times P \times v$$

  - **Product layer $\underline{L}$ is subsequently removed by mechanical abrasion with rate k_2**

$$\underline{L} \xrightarrow{k_2} L$$

$$k_2 = C_p \times COF \times P \times v$$

  - **Abraded material *L* is carried away by the slurry**

- **RR in this sequential mechanism therefore is a function of both chemical and mechanical attributes of the process**

$$RR = \frac{M_w}{\rho} \frac{k_1 k_2}{k_1 + k_2}$$

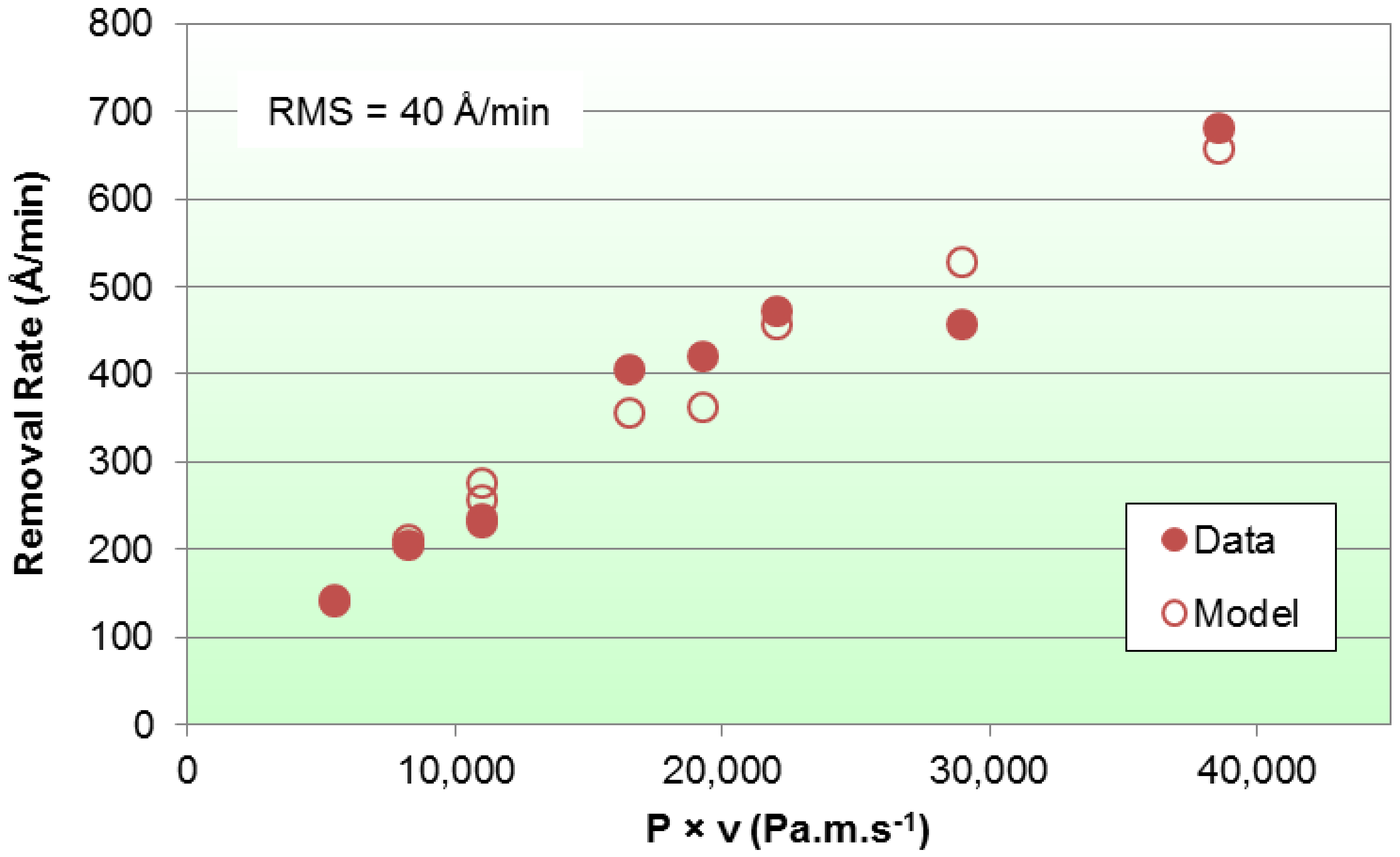
Fitting Parameters and Optimized Values

E_a	Activation Energy (eV)	0.5
A	Pre-exponential factor of chemical rate constant (mole $\times$ m^{-2} s^{-1})	2.71E+04
C_p	Proportionality constant for the mechanical rate constant (mole/J)	6.04E-09
e	Exponential factor for sliding velocity derived from pad heat partition fraction	4.98E-10
β	A constant that mainly depends on wafer size, tool geometry and pad surface and bulk properties $(K/Pa(m/s)^{0.5-e})$	1.23E-05

Simulation was done by floating the parameters: A, Cp, e and β.

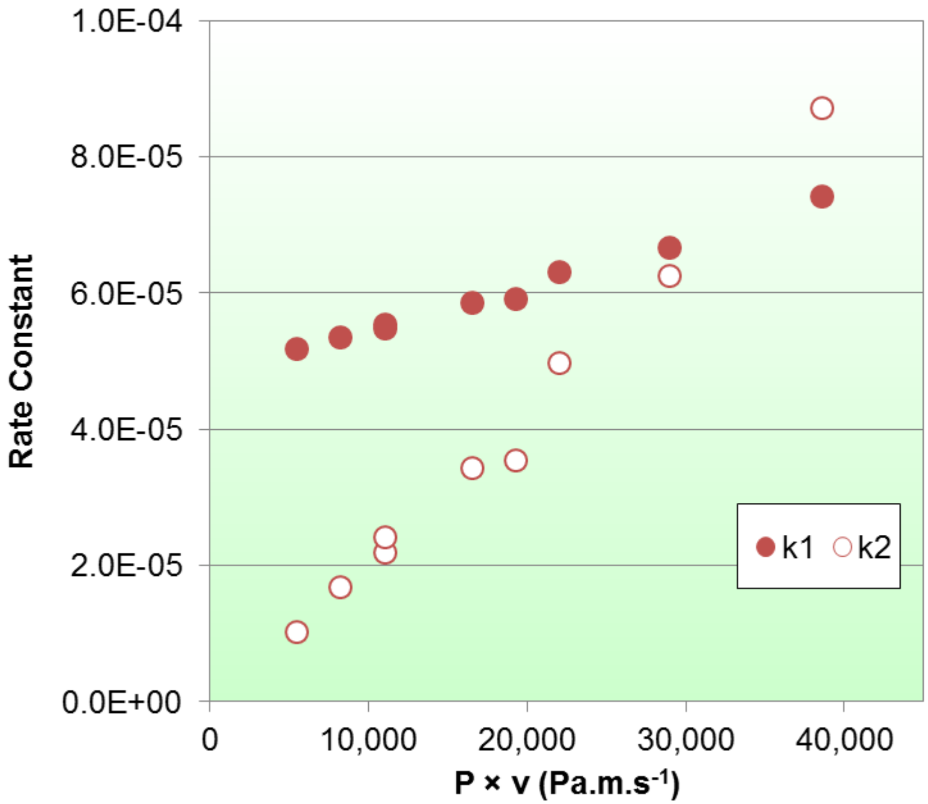
Part I – Simulation Results

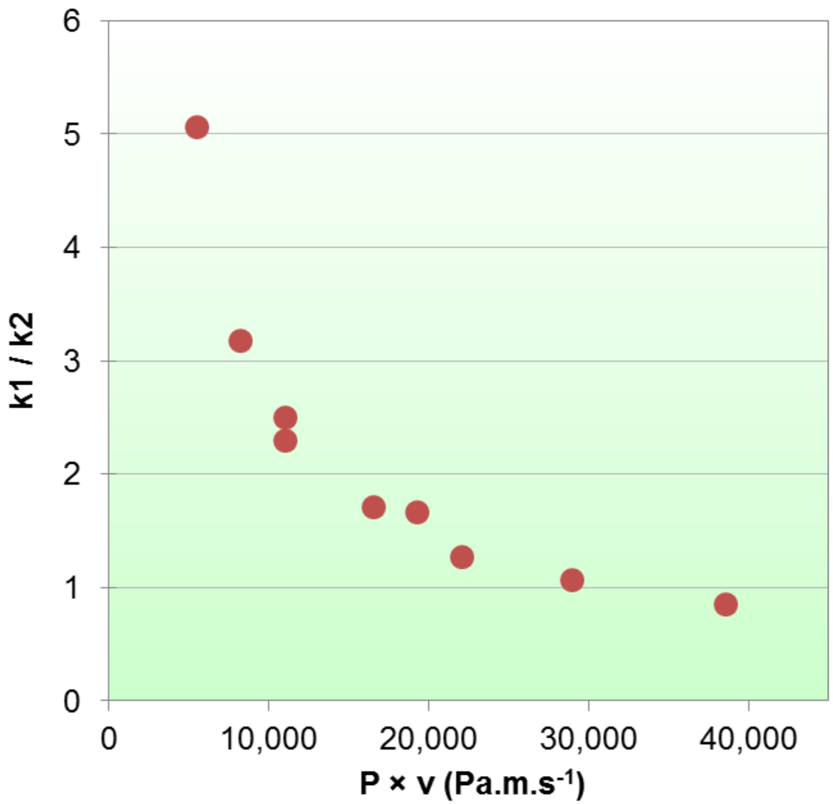
Removal Rate



Part I – Simulation Results

Chemical and Mechanical Rate Constants

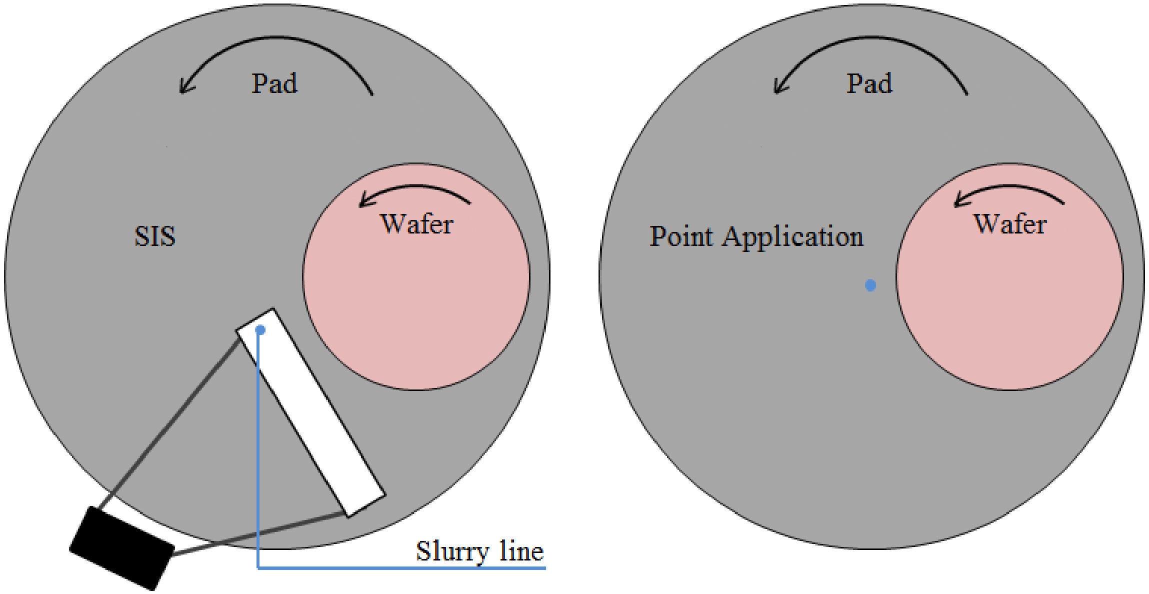




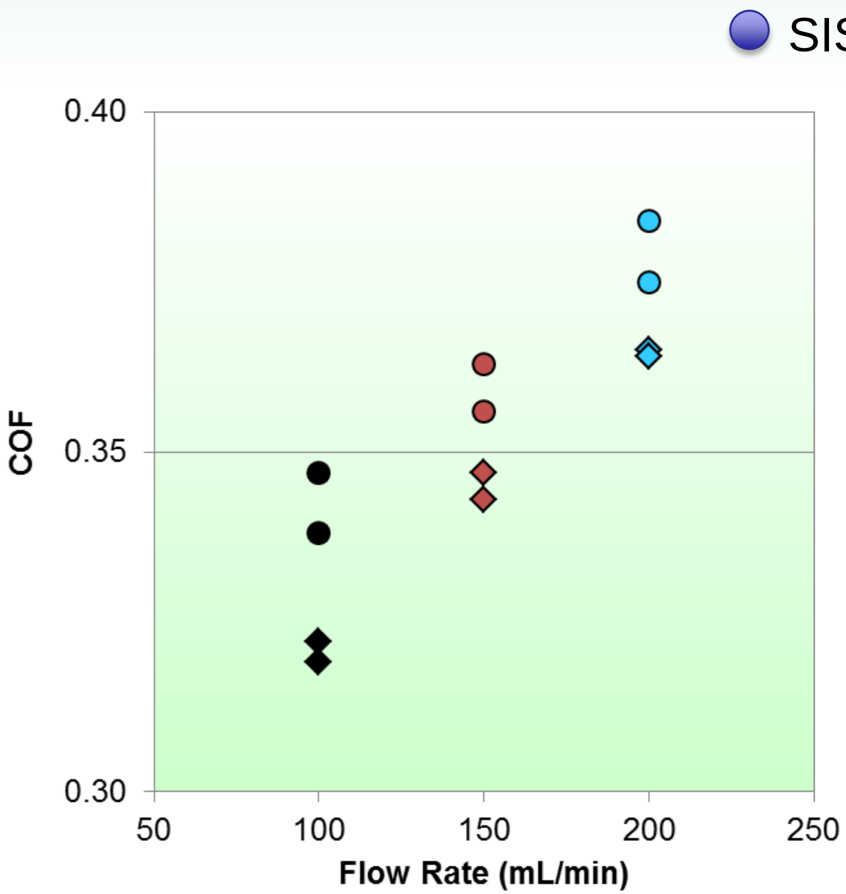
Part II – Application of the Novel Slurry Injection System – Experimental and Simulation Work

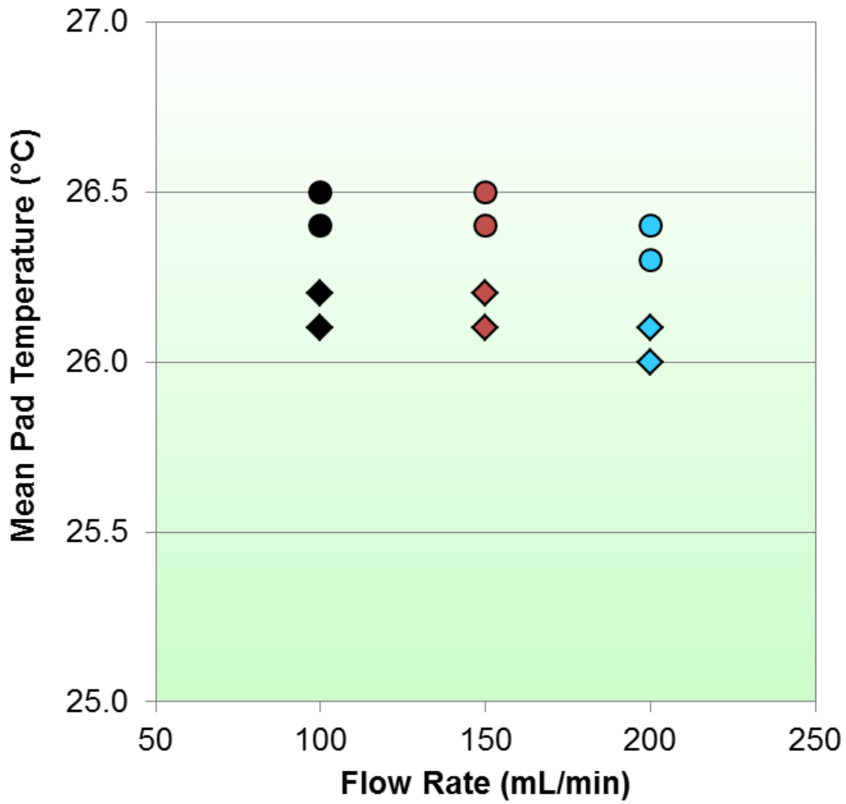
Application of SIS

- SIS can be used to mitigate slurry dilution
- Sits on the pad surface to apply fresh slurry and block residual rinse water and spent slurry. Since in the case of our cobalt slurry dilution reduces RR, reducing residual water should increase RR.
- Motivation – Reduce consumption of slurry to address cost and EHS concerns



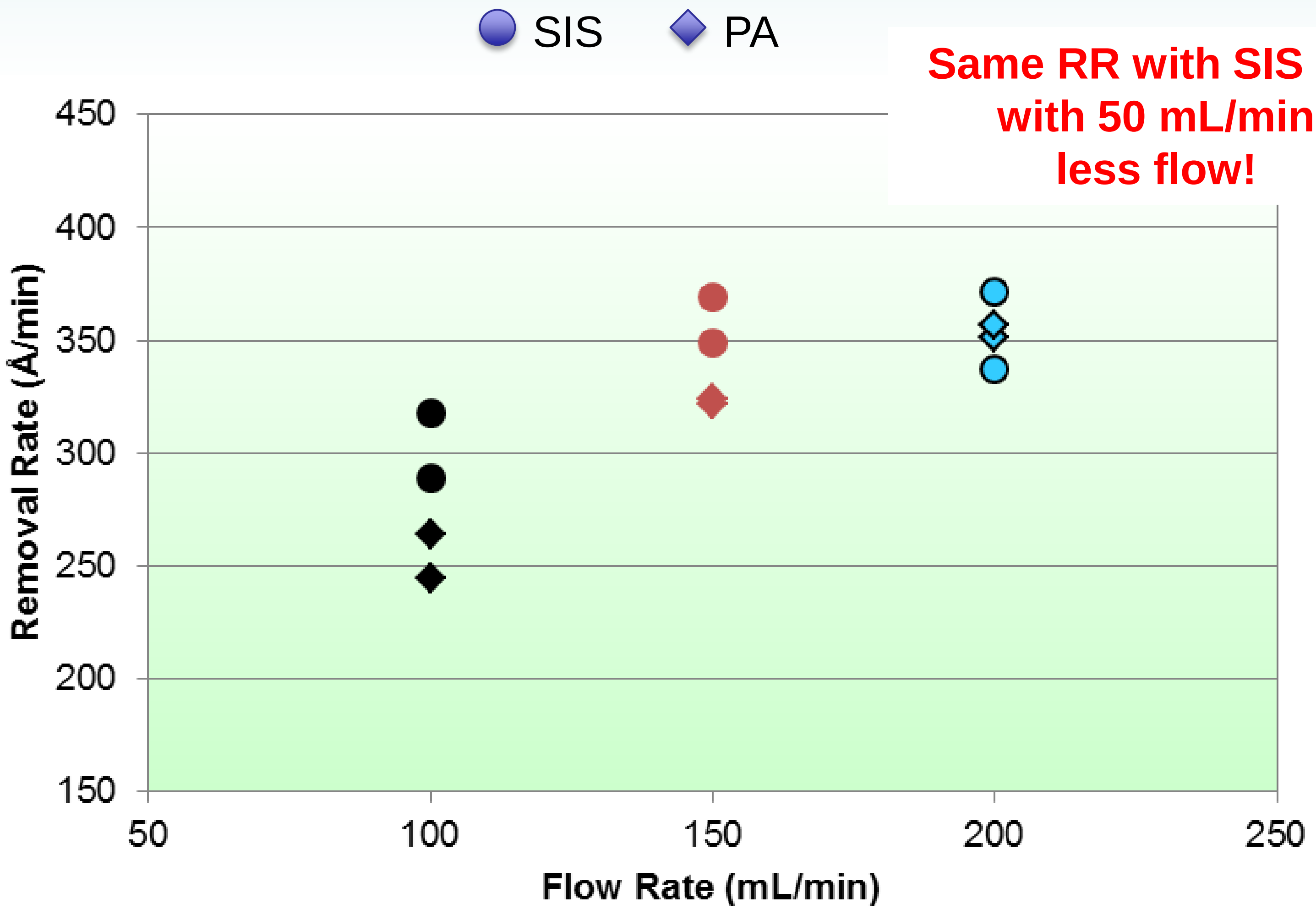
Part II – Polishing Results
COF and Mean Pad Temperature





Part II – Polishing Results

Removal Rate

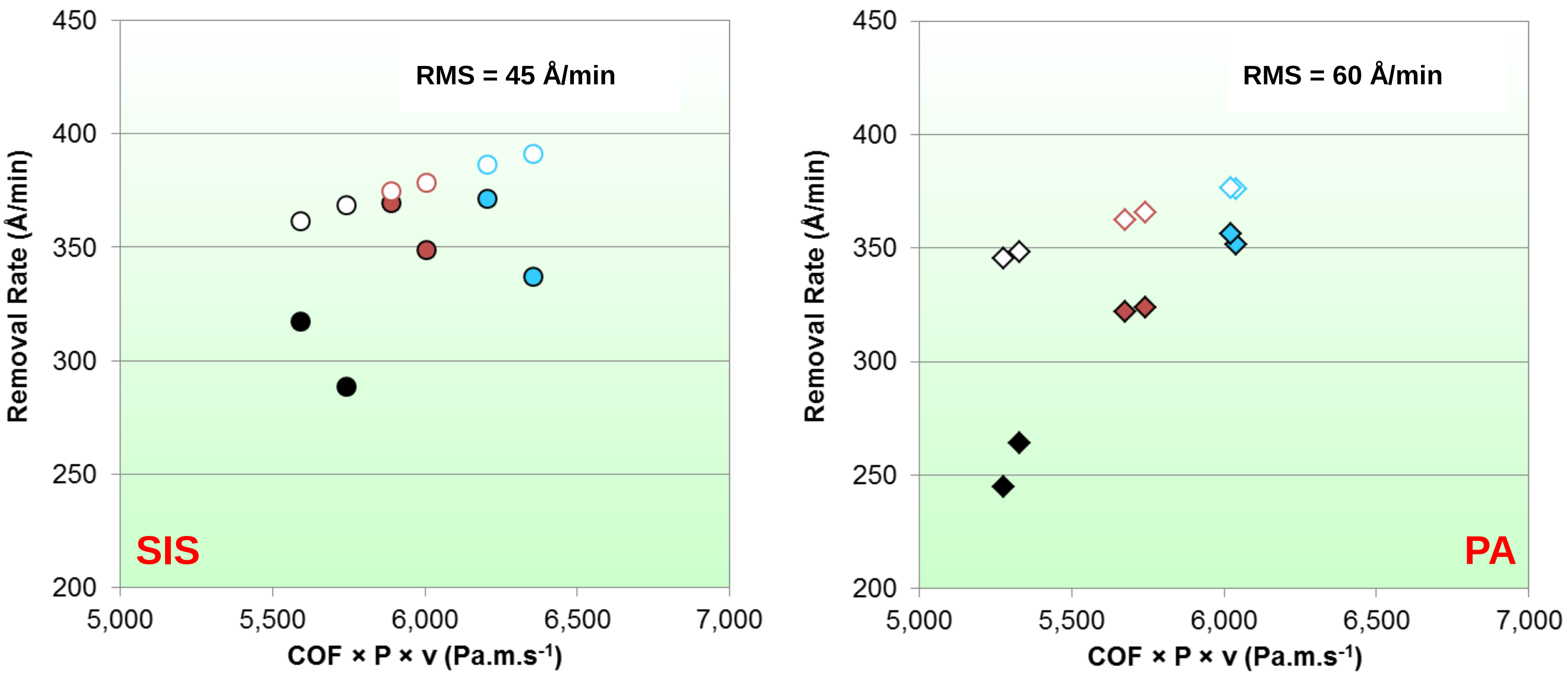


Same RR with SIS but with 50 mL/min less flow!

Part II – Simulation Results

Removal Rate – With Fixed "A" and other Optimized Parameters

$$k_1 = A \times \exp(-E_a / kT)$$



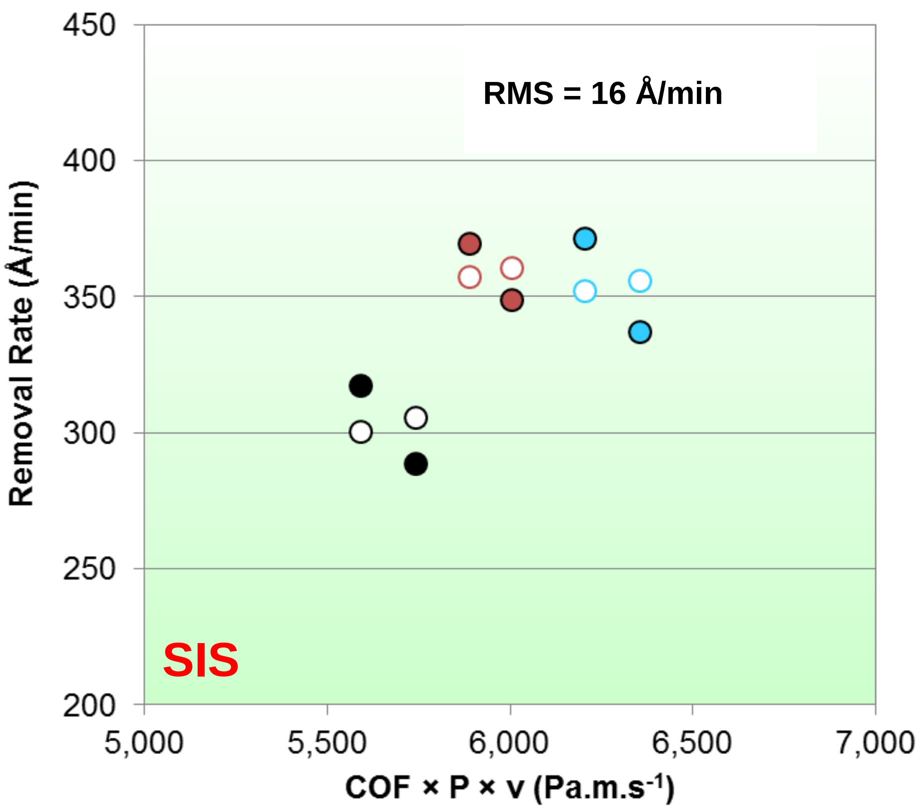
Optimized Pre-Exponential Factor

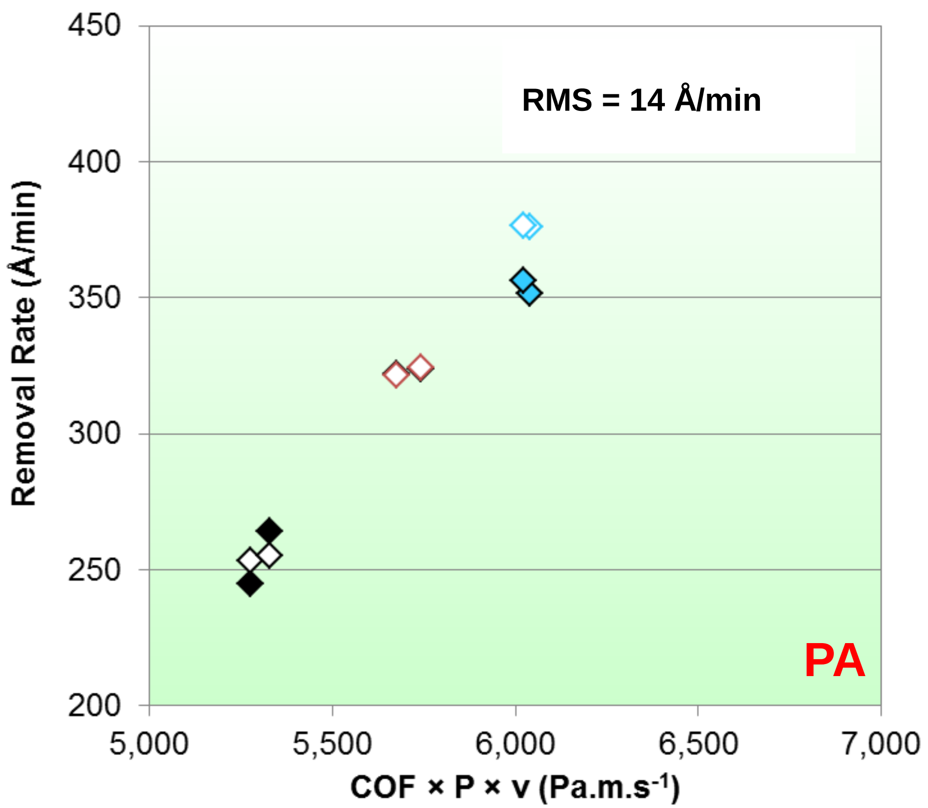
Accounting for Less Water Dilution due to Flow Rate and Use of the SIS

Application Method	Flow Rate	A (mole $\times$ m^{-2} s^{-1})
SIS	200	2.14×10^4
SIS	150	2.38×10^4
SIS	100	1.71×10^4
PA	200	2.71×10^4
PA	150	1.99×10^4
PA	100	1.30×10^4

Part II – Simulation Results

Removal Rate – With Fitted "A"





Concluding Remarks

- **Process is tribologically robust – Boundary lubrication.**
- **Mean pad temperature – No surprises! Increases with P×v and remains constant with COF×P×v.**
- **Removal rate – Initially Prestonian, followed by gross non-Prestonian behavior at moderate to high values of COF×P×v .**
- **Simulation yields respectable RMS values → Extracted rate constants indicate that:**
  - ❖ **At low P×v values, the process is mechanically-limited (i.e. very sensitive to slight shifts in pressure, velocity and possibly pad properties as the pad ages).**
  - ❖ **At high P×v values, the process is chemically and mechanically balanced (i.e. sensitive to temperature, concentration and mechanical parameters)**
- **With the SIS, the same RR as POR could be achieved with up to 33 percent reduction in slurry flow rate. Simulation with constant "A" failed → Critical change was introduced by taking into account the effect of dilution on "A".**

Thank You!