Reducing Maintenance-Water Consumption in Evaporative Cooling Equipment

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June 25, 2013
Seminar 24
ASHRAE Summer Meeting

WESTERN COOLING EFFICIENCY CENTER

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Learning Objectives

* Explain why calcium and magnesium behave differently in the production of scale in evaporative cooling equipment
* Describe how proper maintenance of scale production can actually reduce water consumption
* Provide estimates of water use savings for different supply water characteristics

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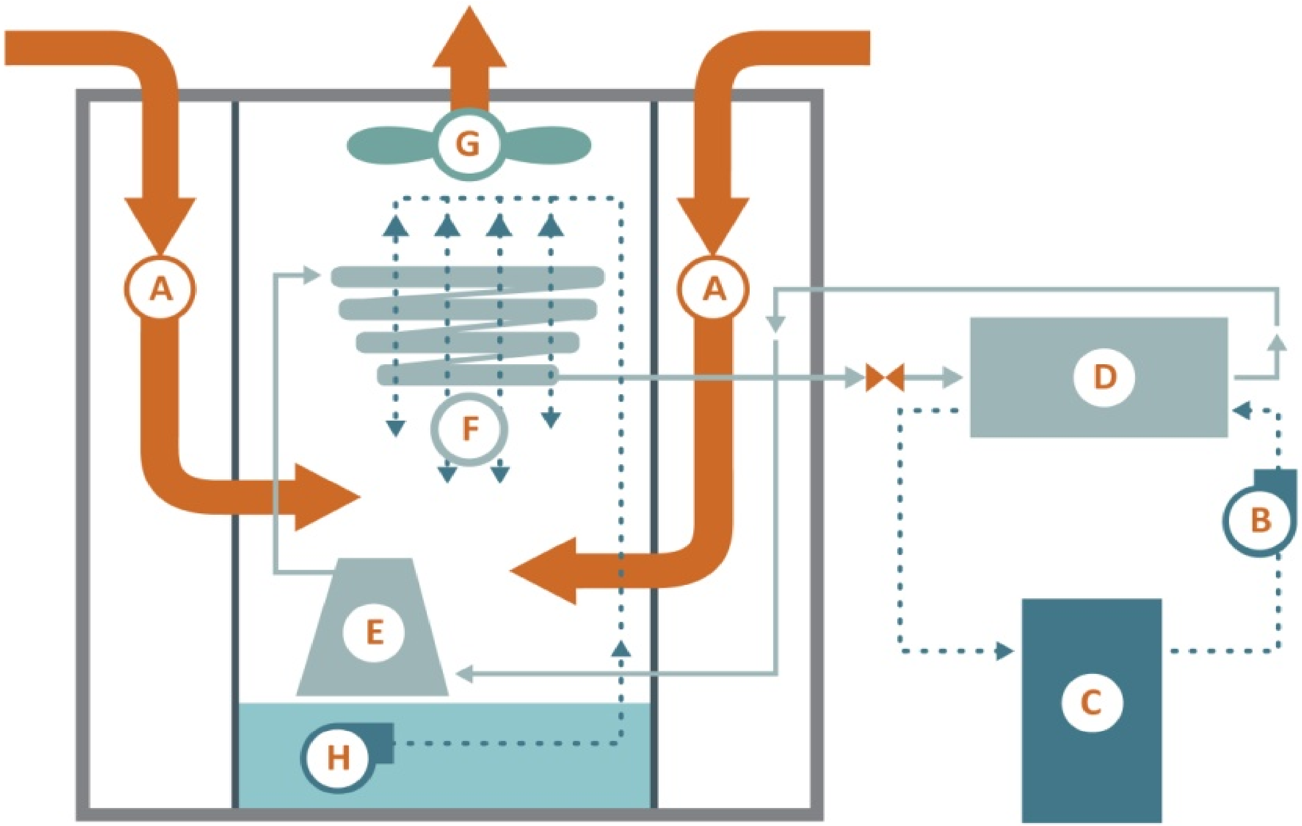
Acknowledgements

* WCEC Contributors include Theresa Pistochini, Erica R. McKenzie, Curtis Harrington and Peter Breyfogle
* Research funded by Southern California Edison under the Emerging Technologies Program

Project Objectives

* Understand impact of water management and treatment strategies on longevity of residential evaporative condenser
* Develop optimized water management strategies (i.e. bleeds and/or treatment devices)

Evaporative Condenser Schematic



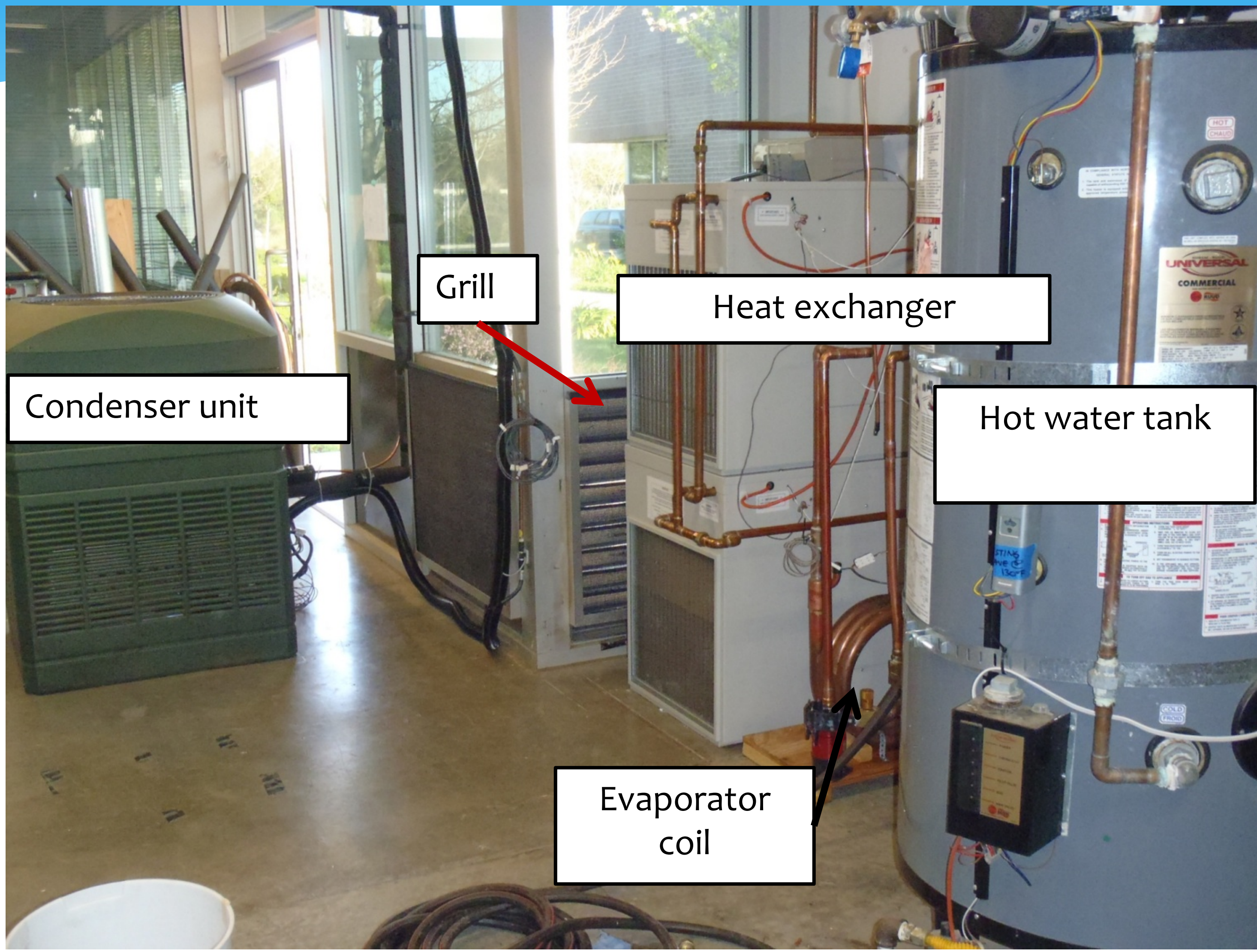
- **A** Plenums with 95°F airflow at neutral pressure
- **B** Pump
- **C** Water heater
- **D** Water to refrigerant HX
- **E** Compressor
- **F** Condenser coil
- **G** Exhaust blower
- **H** Sump pump

Full Scale Experimental Design

Measurement/Control

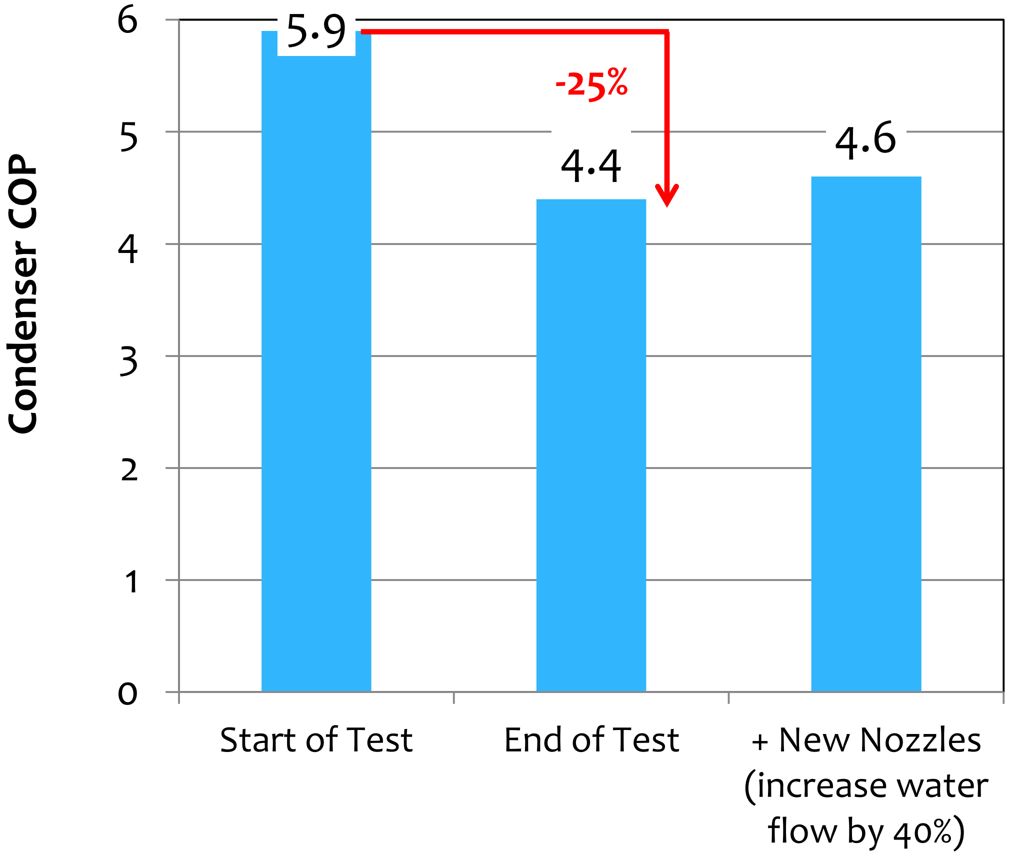
* Temperature and %RH of input air
  * Controlled to 95°F
* COP
  * Capacity of the system
    * Water-refrigerant heat exchanger
    * Water flow rate and ΔT
  * Total Power
* Bleed-water removal rate
* Make-up water supply rate and electrical conductivity
* Evaporation rate
  * Difference between supply and bleed
* Water conductivity in sump

Full Scale Experimental Design



Full-Scale Evaporative Condenser Results

* 2075 hours of operation
* 11,000 gallons of water
* Maintenance Performed
  * Two pump failures
  * Cleaned filter basket

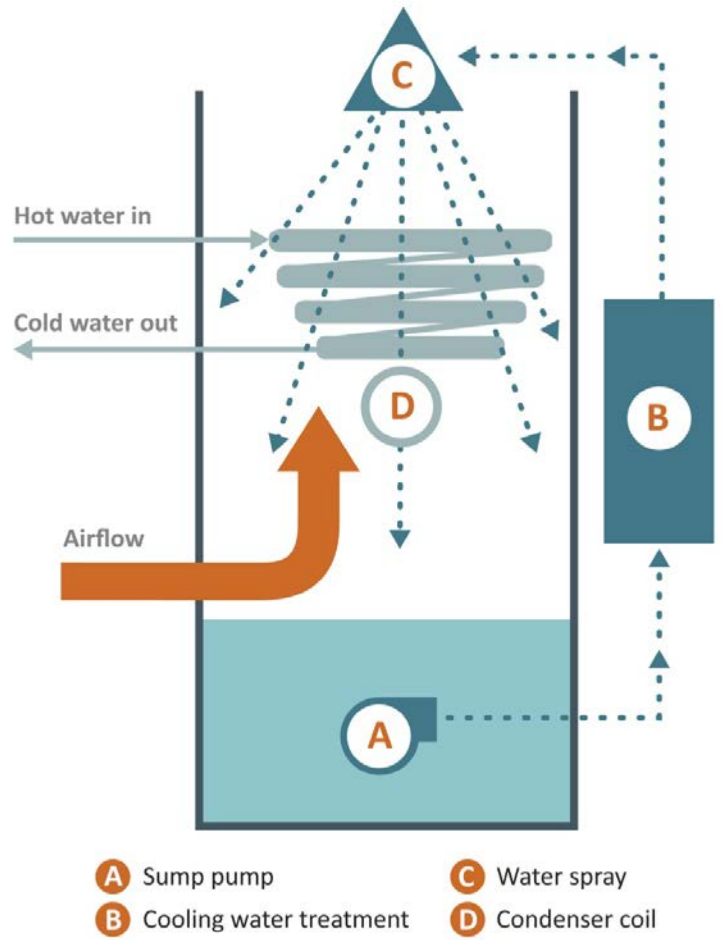


Small Scale Experimental Design

Small Scale Experimental Design

Measurement/Control

- Temperature and %RH of input air
  - Controlled to 95°F
- Capacity of coils
  - Hot-water flow rate and ΔT
- Air pressure differential across coils
- Bleed-water removal rate
- Make-up water supply rate and electrical conductivity
- Evaporation rate
  - Difference between supply and bleed
- Water conductivity in sumps
- Periodic water analysis
- Deposit analysis

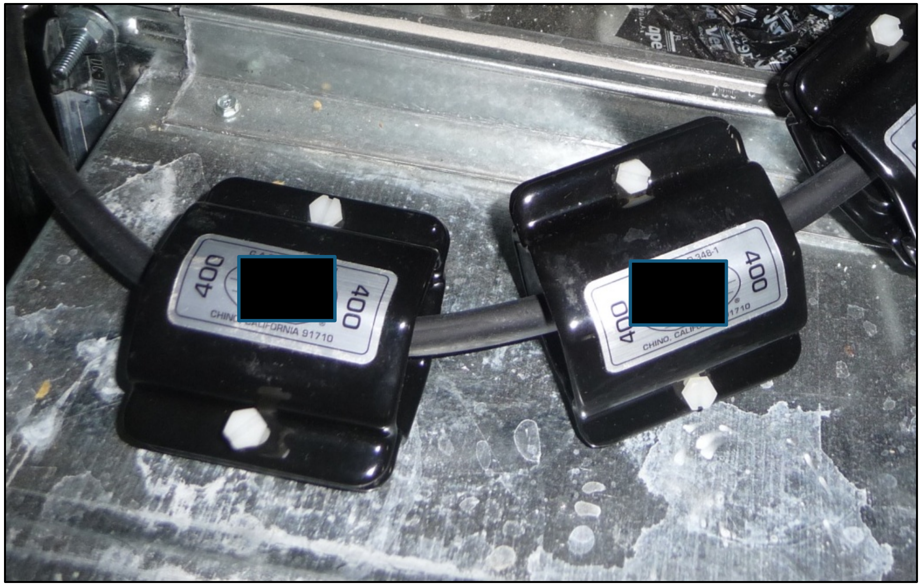


Evaporative Condenser Impacts on Water

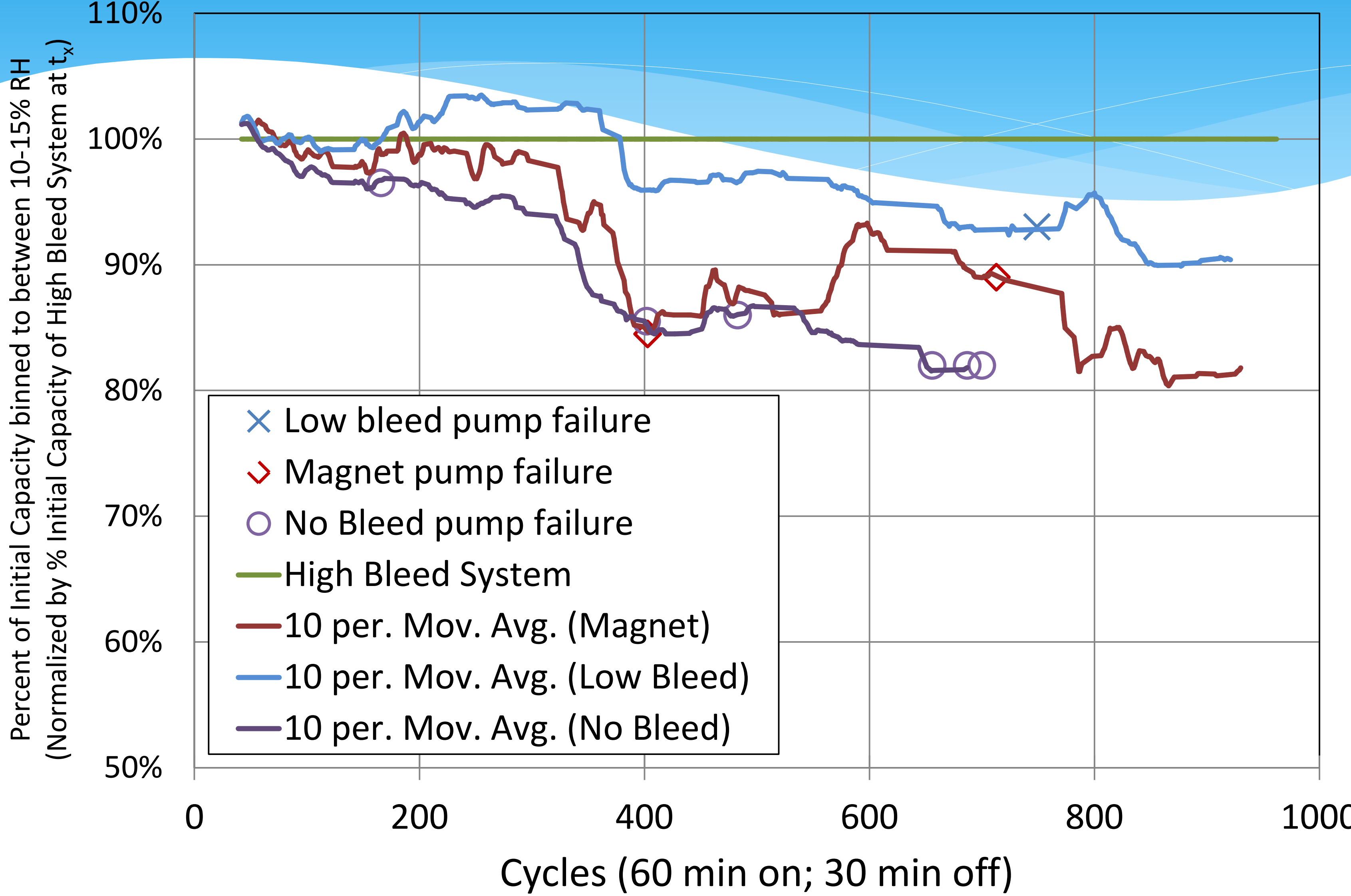
- **Concentration of mineral solutes**
  - Scale-forming constituents (Ca and Mg)
  - Salinity and carbonate concentrations
- **Increase in pH**
  - High pH decreases solubility of Ca and Mg
- **Temperature changes that impact $CaCO_3$ solubility**
  - Solubility is lower at higher temperatures

Small-Scale Test Results – Round 1

- Chamber 1 – Low Bleed (+8% water use)
- Chamber 2 – Permanent magnets
- Chamber 3 – High Bleed (+40% water use)
- Chamber 4 – Baseline



Small-Scale Results – Round 1



Small-Scale Tests: Water Chemistry

System	pH	Calcium			Magnesium			Coil scale mass/cycle (g)
		Sump (mM)	Precipitated		Sump (mM)	Precipitated		
			(mols)	(%)		(mols)	(%)	
Influent (tap)	8.11	0.85	-	-	1.97	-	-	-
Control - no bleed	9.46	0	1.13	100	11.04	2.57	98.4	0.22
Magnets - no bleed	9.56	0	1.13	100	8.73	2.58	98.7	0.22
Low bleed +8% water	9.19	0.40	1.17	95.4	14.41	1.23	43.4	0.13
High bleed +40% water	8.99	0.21	1.29	81.1	7.64	0.00	0.0	0.11

- Primary finding – **increased bleed rate**
  - ⇨ significantly **decreased magnesium** precipitation
  - ⇨ somewhat **increased calcium** precipitation

Water Chemistry: Dissolved Solid Solubility

* Preliminary results from small-scale tests at different bleed rates

* Calcium and Magnesium are not equivalent

Ca => $CaCO_3$ (calcite)	K_{sp}=3.36e-9
Mg => $MgCO_3$ (magnesite)	K_{sp}=6.82e-6

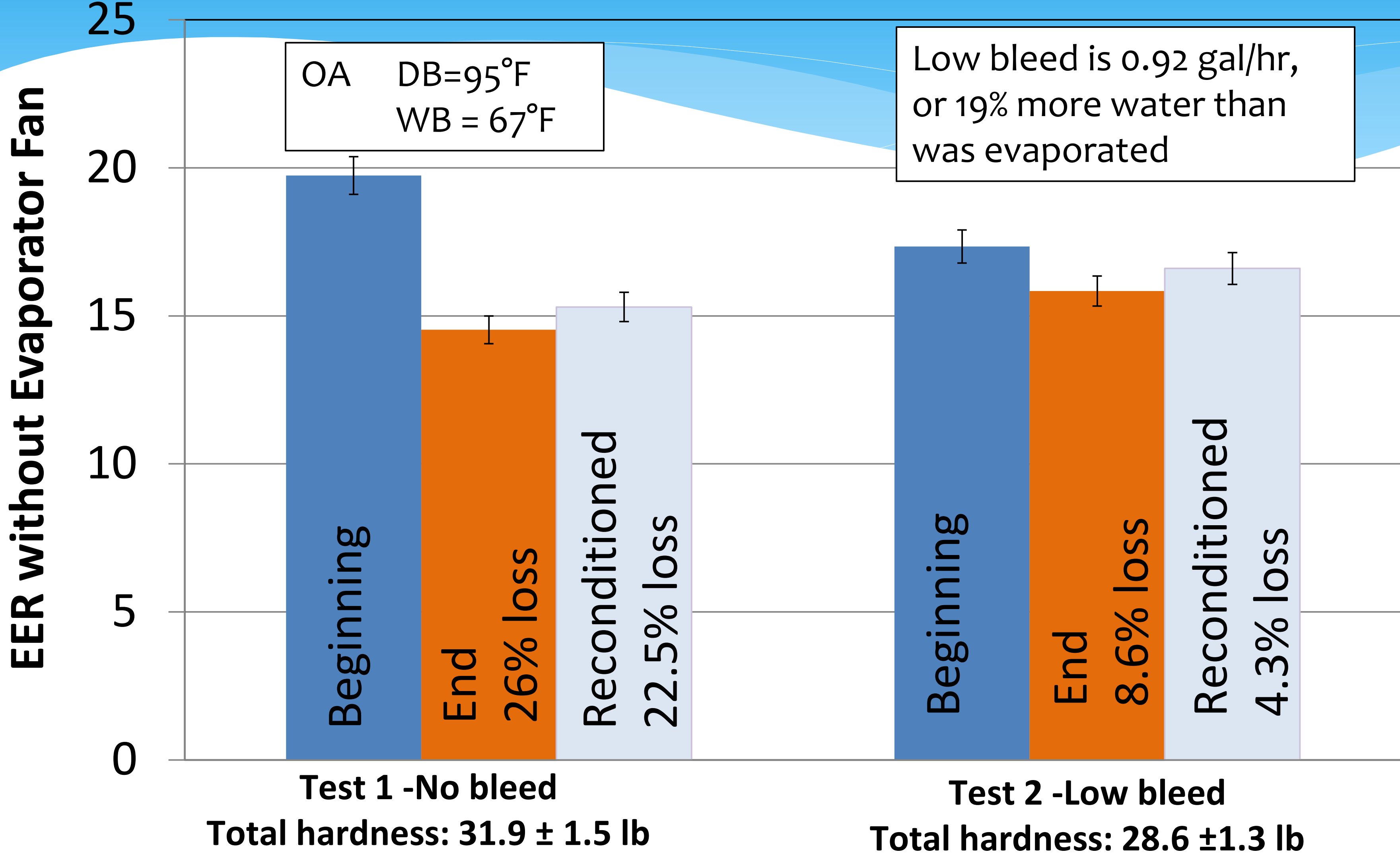
⇨ calcite is less soluble than magnesite

Follow-Up Full-Scale Test

No Bleed

Low Bleed (+19%)

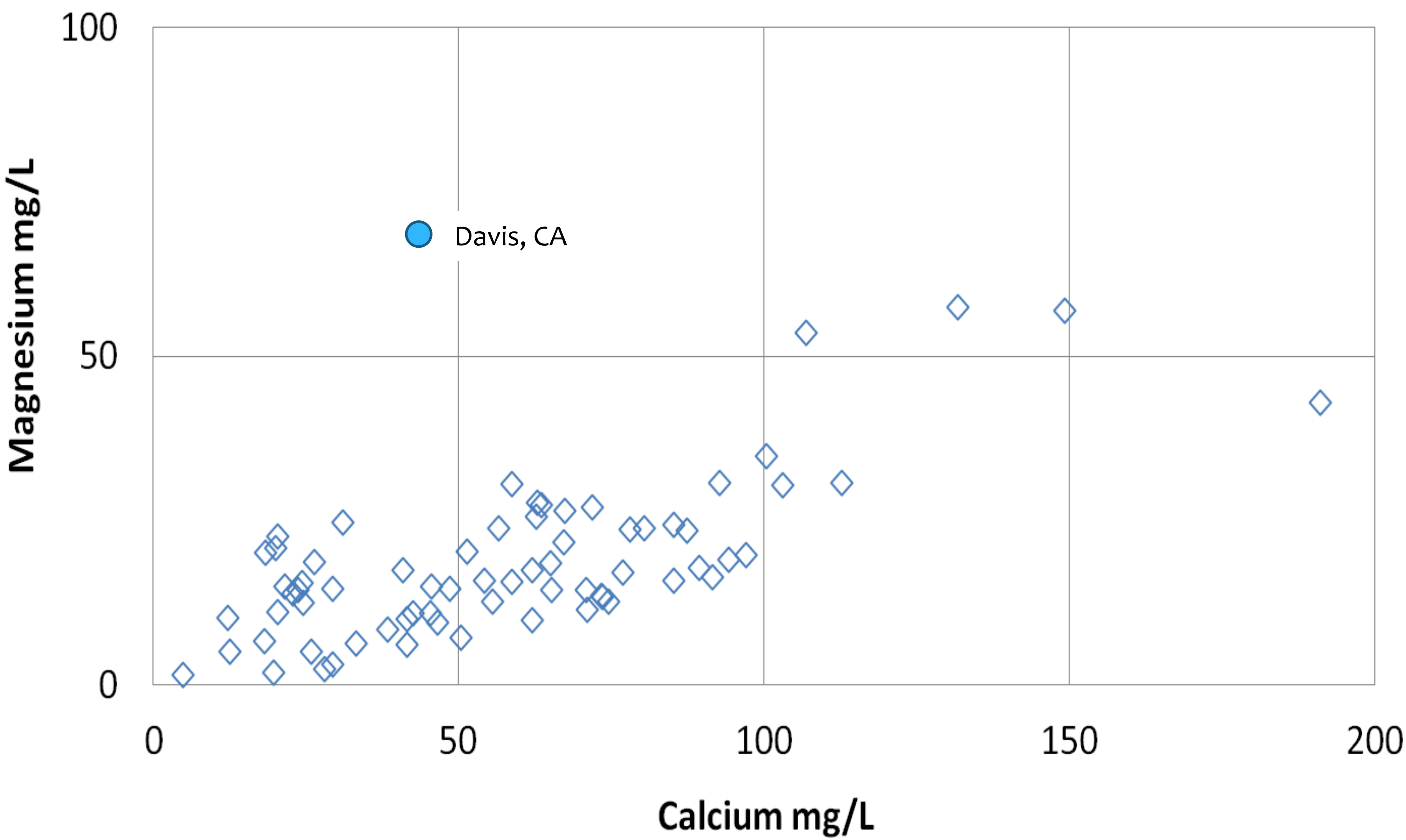
Follow-Up Full-Scale Results



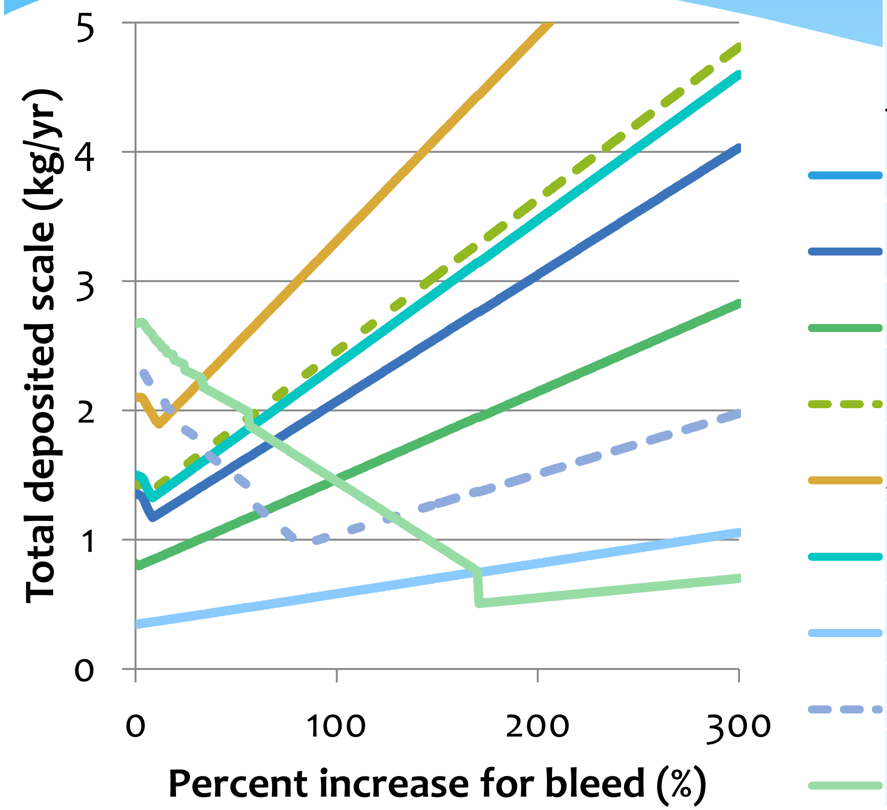
Follow-Up Full Scale Results

* **No Bleed Test**
  * ~362 ppm average hardness tap water
  * 30% Reduction in water flow due to clogged nozzles
  * ~30lb of scale on coil, and two failed pumps
* **Low Bleed Test (+19% water)**
  * ~254 ppm average hardness tap water (30% lower)
    * Same run hours, but only 10% less mineral introduction (due to minerals brought in by make-up for bleed water)
  * Some nozzles blocked, negligible water flow reduction
  * Negligible deposition on coil and no pump failures

Calcium/Magnesium in CA Water



(Semi) Optimized Bleed Rates



Location	Mg (mg/L)	Ca (mg/L)	Lifespan (yr)
Riverside	17	70	10
Eastern	17	62	12
Irvine	11	45	17
Santa Ana	14	73	10
Anaheim	20	97	7
Los Angeles	17	70	10
Long Beach	2	20	39
Davis	53	33	14
Hypothetical	70	15	27

- % increase for bleed = $V_{bleed}/V_{evaporation}*100\%$
- Use bleed to eliminate magnesium precipitation

Conclusions

* **Thermal degradation is modest**
  * System performance robust even with scale build-up
  * Pumps appear to fail before significant thermal degradation
* **Bleed rate affects many water quality parameters**
  * Ca and Mg concentrations, pH, Salinity
* **Calcium and Magnesium behave differently**
  * Different solubility limits
  * Need to consider local water conditions
  * Lower bleed rates should be considered, and could improve performance in some circumstances
* **Manufacturer Specifications**
  * Often inconsistent with these research results