Application of pulse spark discharges for scale prevention and continuous filtration methods in coal-fired power plant

U.S. DEPARTMENT OF ENERGY
National Energy Technology Laboratory

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New Scale-Prevention Technology

Use electrical pulse spark discharges in water

→to precipitate dissolved mineral ions.

→ Remove them using a self-cleaning filter from cooling water.

Specific objectives of the proposed work

1. Determine whether the spark discharge can promote the precipitation of mineral ions in cooling water.

2. Determine whether the proposed technology can increase the COC through a continuous precipitation of calcium ions and removal of the precipitated salts with a self-cleaning filter.

3. Demonstrate that mineral scale on condenser tubes can be prevented or minimized at COC of 8 or zero blowdown.

TASKS TO BE PERFORMED

Task 1 – Precipitation of dissolved calcium ions using spark discharge

Task 1 attempts to achieve 50% reduction in calcium hardness in circulating cooling water by precipitating dissolved calcium ions with spark discharges and removing them instead of blowdown.

Task 1 – Precipitation of Dissolved Calcium Ions using Spark Discharge (Preliminary data)

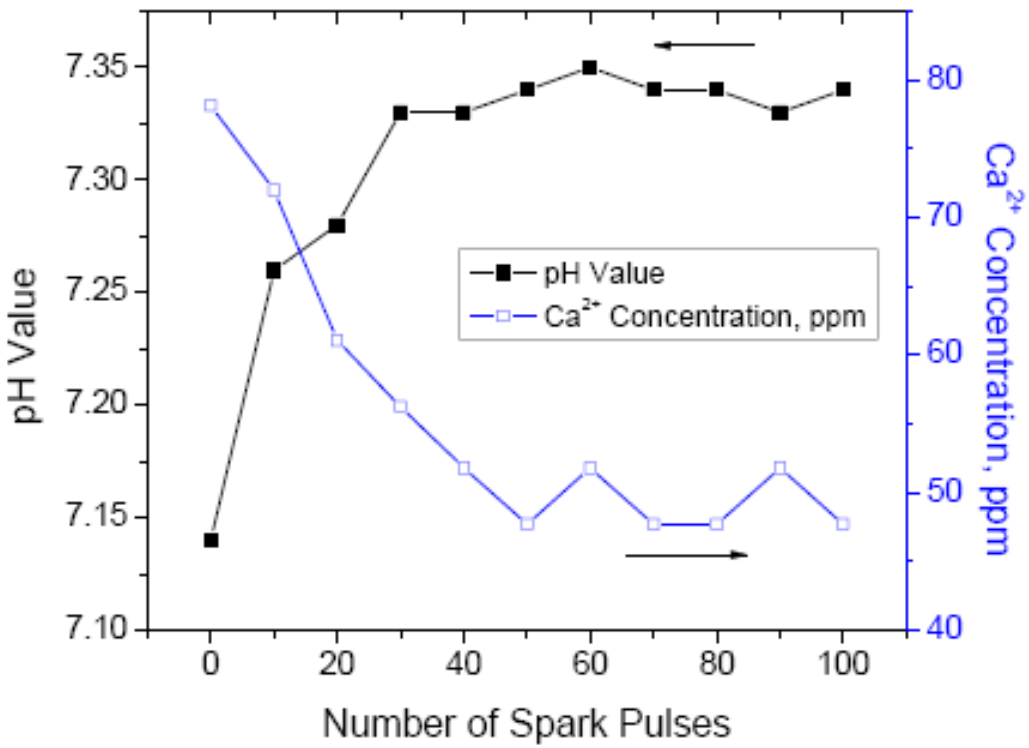
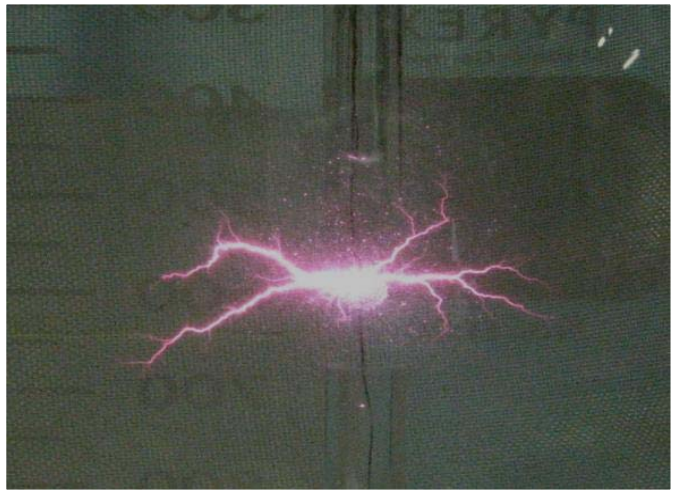
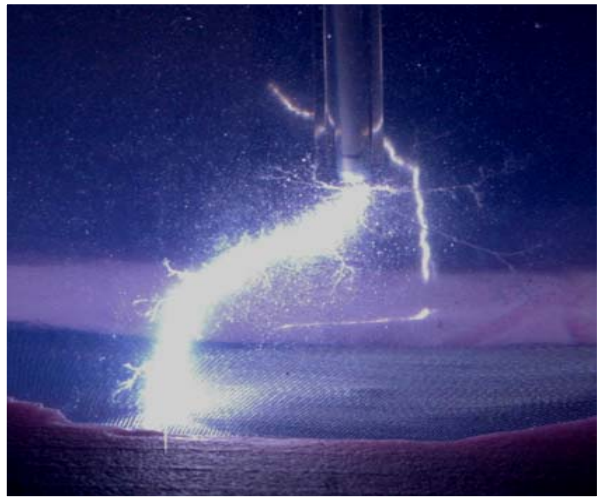


Figure 1 - Validation test for the concept of Ca^{2+} precipitation using spark discharges in water [unpublished data, Drexel University]

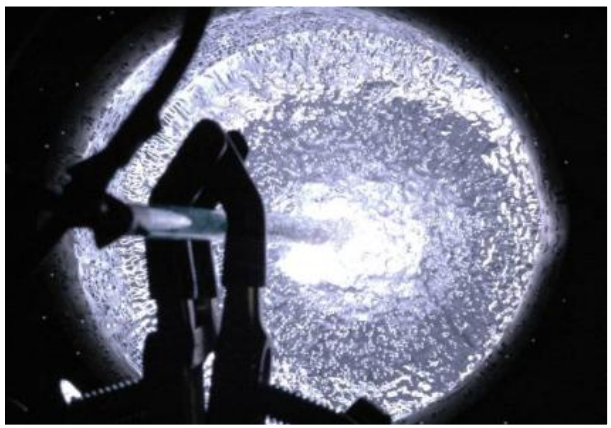
Plasma Discharges in Water (Drexel University)



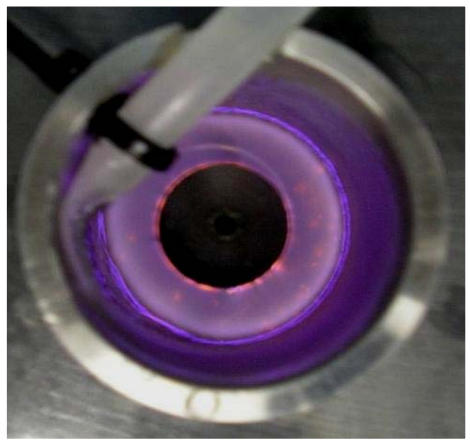
Pulsed Corona in water



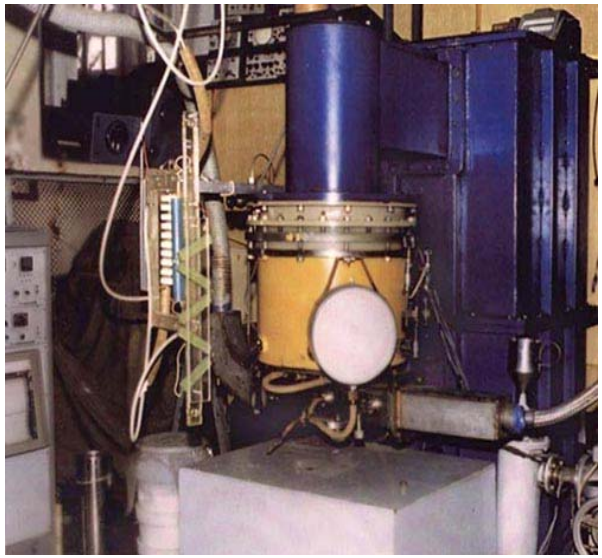
Spark Discharge in water



Spark Discharge in water



Gliding Arc in water

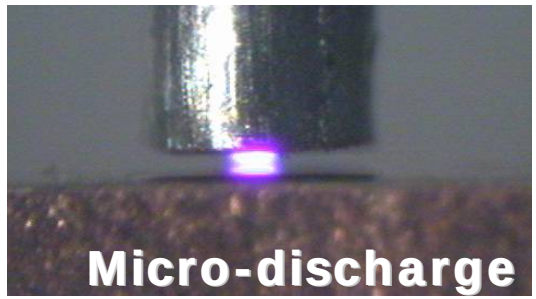


Electron Beam

SuperSonic flame plasma

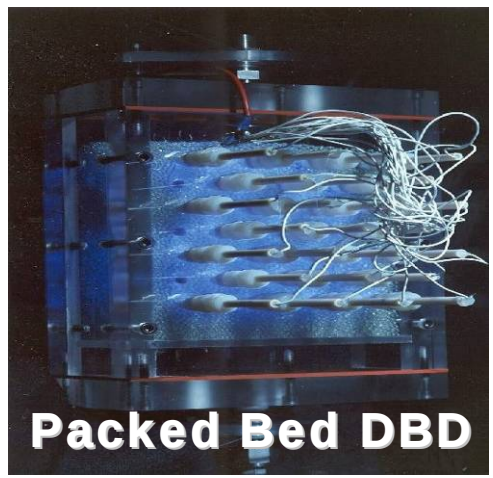
Gliding Arc

Plasma Torch



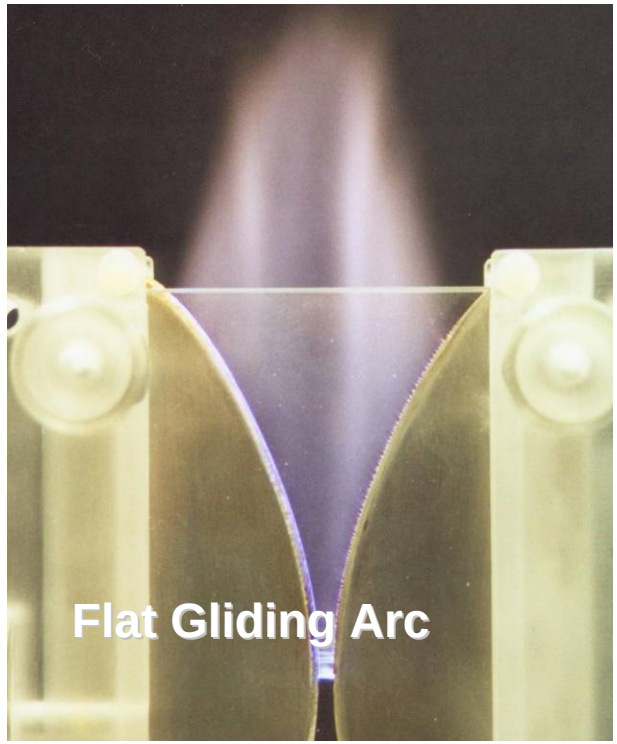
Micro-discharge

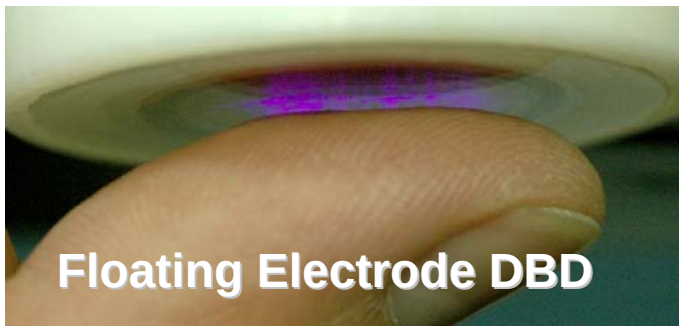
10kW Pulsed Corona

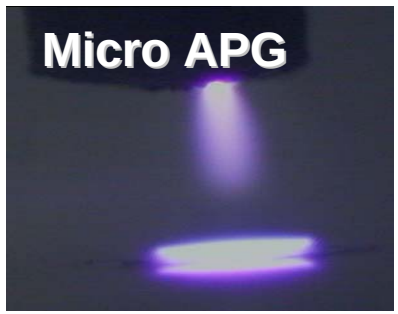


Packed Bed DBD

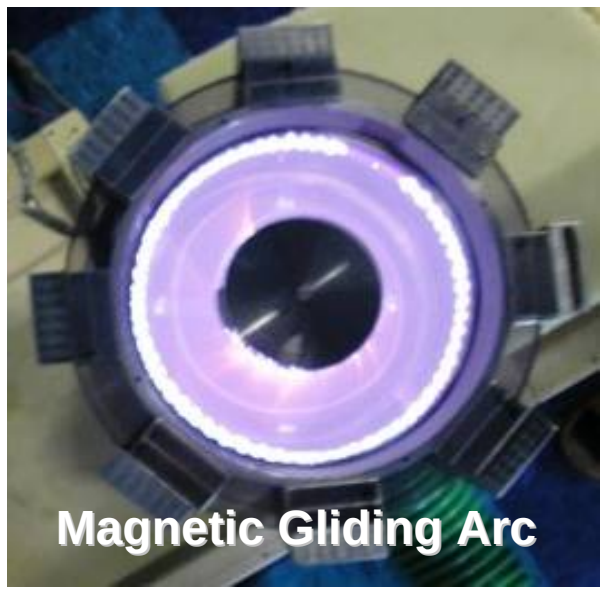
Pulsed Corona


Flat Gliding Arc


Floating Electrode DBD


Micro APG

Dielectric Barrier Discharge


Magnetic Gliding Arc

Task 1 – Precipitation of Dissolved Calcium Ions using Spark Discharge

Subtask 1.1 Modeling of Ca^{2+} precipitation process using water-related variables

Different cooling water conditions;

Modeling of the precipitation process.

Subtask 1.2 Parametric study of Ca^{2+} precipitation process using power-related variables

Different spark configurations

Subtask 1.3 Optimization of electrode configuration for most efficient spark discharges

Effects of electrode materials and geometry

SUCCESS CRITERIA AND DECISION POINTS

Criteria for success for Task 1

If the proposed spark discharge technology can reduce the concentration of calcium ions by more than 50% for different levels of hardness of cooling water.

TASKS TO BE PERFORMED

Task 2 – Validation experiments to increase COC

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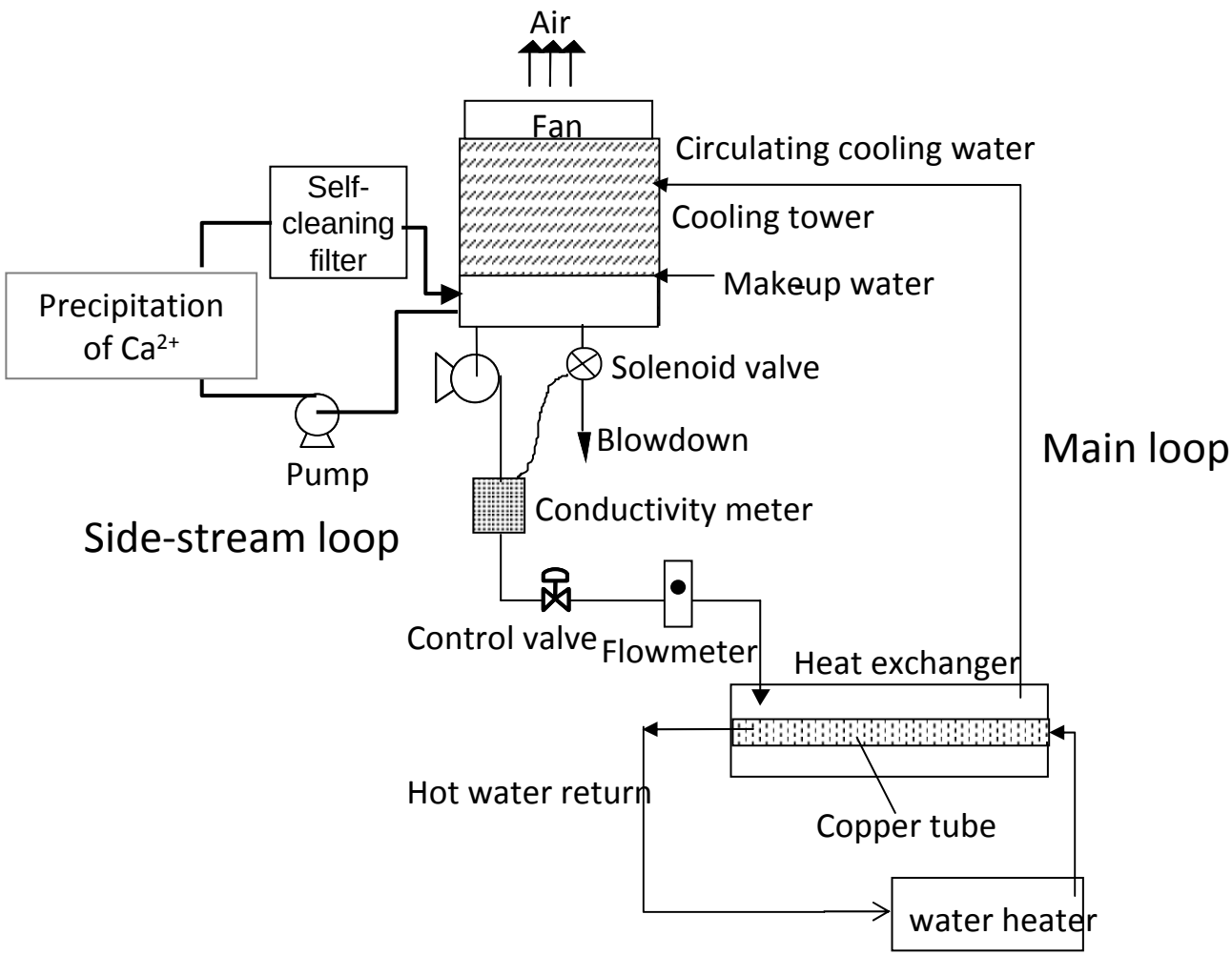


Figure 2 - Schematic diagram of a laboratory cooling tower test facility for the proposed study

Task 2 – Validation Experiments to Increase COC

Subtask 2.1 Tests with COC of 4

to investigate whether the proposed spark discharge system can increase the COC, starting at a COC of approximately 4.

Subtask 2.2 – Tests with COC of 6

Subtask 2.3 Tests with COC of 8

Subtask 2.4 Tests with zero blowdown

Subtask 2.5 Tests with bulk heating for COC of 4

Task 2 – Validation Experiments to Increase COC (Sample data from the previous study)

	Makeup	Baseline (Day 11)	PWT-S (Day 12)
Total alkalinity (ppm)	120	260	240
Chloride (ppm)	125	1,240	1,320
Total hardness (ppm)	190	1,720	1,680
Calcium (ppm)	170	1,360	1,240
Magnesium (ppm)	20	360	440
pH	6.8	6.9	7.2
Conductivity (micromho/cm)	445	4,600	4,550

Table 1 – Previous water analysis conducted at Drexel University

SUCCESS CRITERIA AND DECISION POINTS

Criteria for success for Task 2

If the proposed spark discharge technology at least doubles the COC of the present practice.

TASKS TO BE PERFORMED

Task 3 – Validation experiments for scale prevention (Year 3)

To investigate whether the proposed spark discharge technology can prevent or minimize scale deposits on the condenser tubes.

Task 3 – Validation experiments for scale prevention (Year 3)

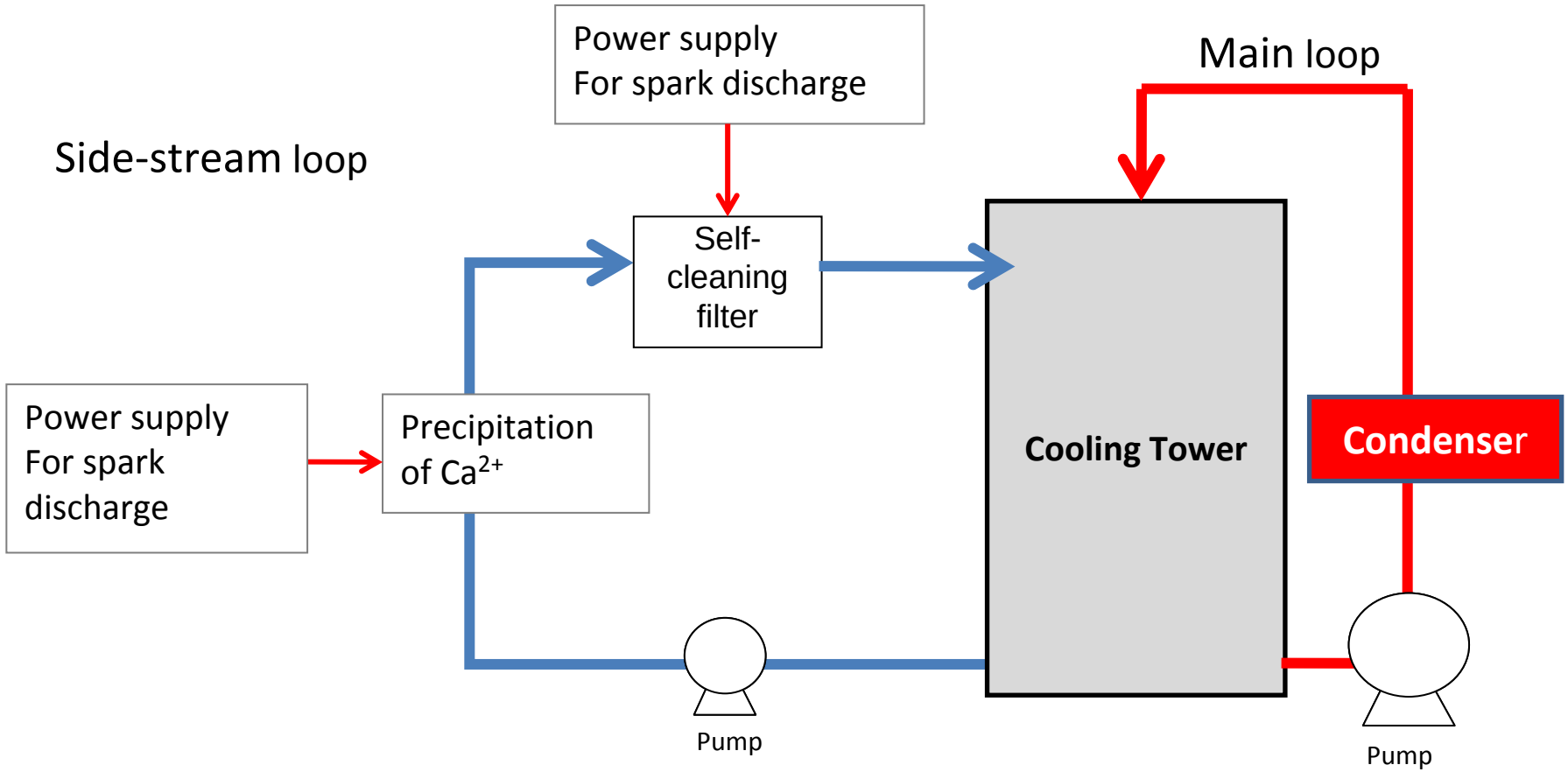


Figure 4 - Schematic diagram of the side-stream loop in a laboratory cooling tower test facility for the proposed study

Task 3 – Validation experiments for scale prevention (Year 3)

Subtask 3.1 Tests with COC of 4

This task will deliver fouling test data, in terms of fouling resistance over time,

for the baseline (no treatment) case, and

for the proposed spark discharge technology.

Subtask 3.2 – Tests with COC of 6

Subtask 3.3 Tests with COC of 8

Subtask 3.4 Tests with zero blowdown

Task 3 – Validation experiments for scale prevention (Year 3) (Sample data from the previous study)

The fouling resistance

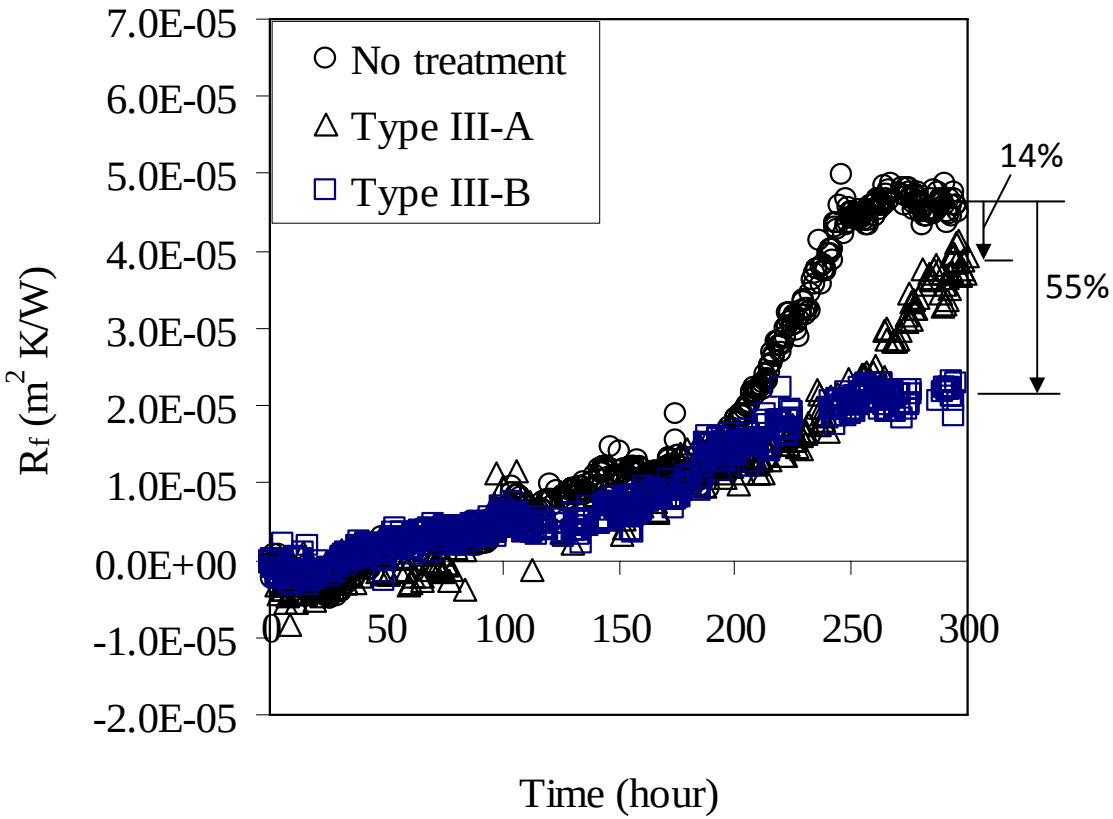


Figure 6 - Previous fouling test results obtained at Drexel University using two different types of permanent magnets [18]. R_f = fouling resistance; Zero fouling resistance means a perfectly maintained condenser tube.

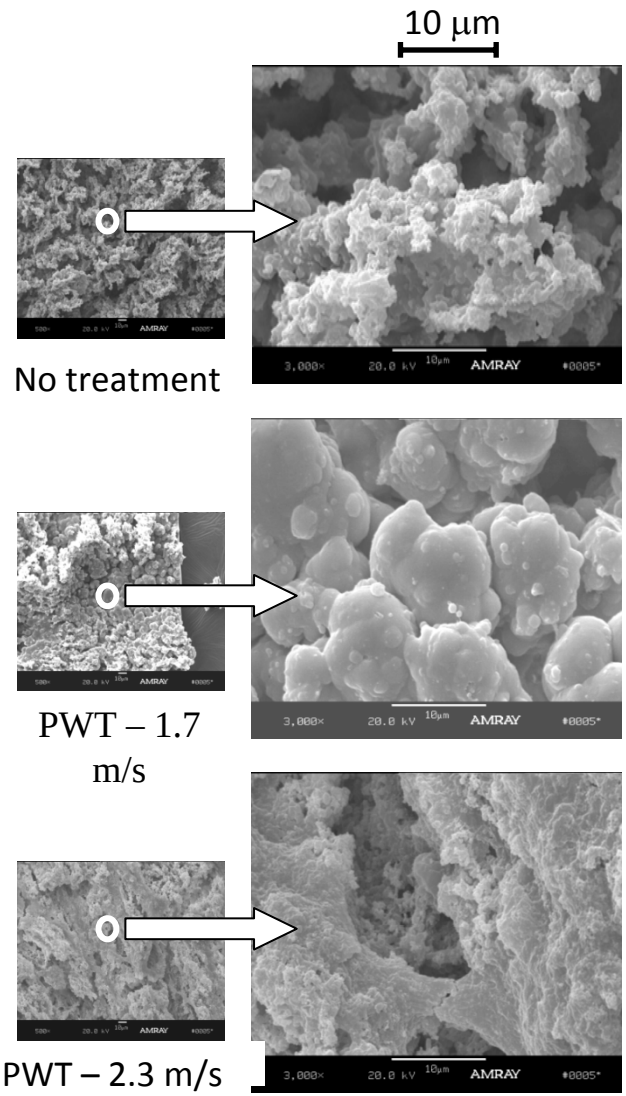
Block diagram of parameters that may affect the outcome of fouling tests

COC (Hardness)
COC = 4
COC = 6
COC = 8
No Blowdown

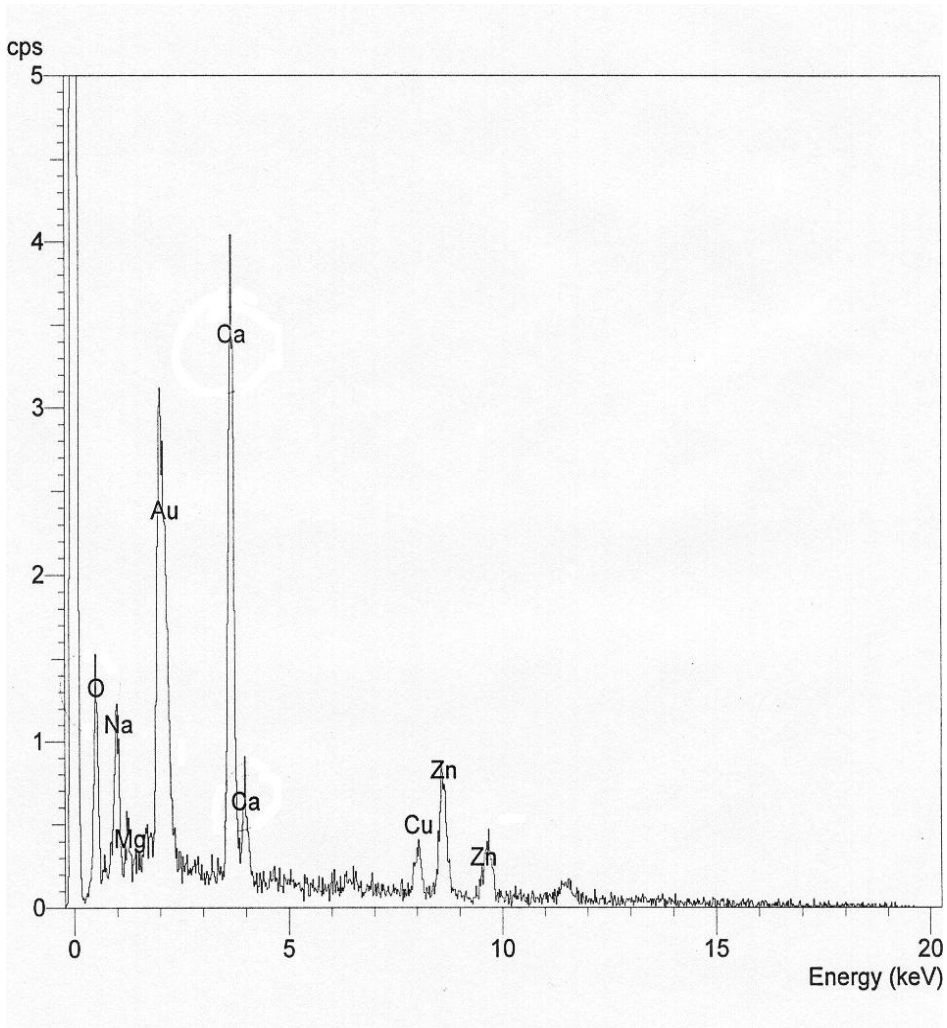
Spark discharge for Precipitation of Ca^{2+} Variables
Frequency and strength of spark discharge
Electrode geometry, material
Flow velocity around electrode

Self-cleaning filter Variables
Frequency and strength of spark discharges

SEM photographs of $CaCO_3$ Deposits on Condenser Tubes (Sample data from the previous study)



Energy Dispersive Spectrum (EDS) of CaCO3 Deposits on Condenser Tubes (X-ray diffraction)



SUCCESS CRITERIA AND DECISION POINTS

Criteria for success for fouling test

If the proposed spark discharge technology can reduce the fouling resistance by at least 90% compared to those obtained from the baseline test for COC = 4.

For higher COC cases (i.e., COC = 6 and 8, and no blowdown case), the improvement may be less than 90%, but still greater than 75%.

Energy Requirement

The power of the spark discharge is approximately 2 J/pulse and about 10-20 pulses are needed for a volume of 0.5-L water for an effective removal of impurities from the filter membrane.

Hence, approximately 80 J/L of electric energy were consumed in laboratory tests.

The proposed spark discharge requires only 5 KW of electrical energy to treat water at a flow rate of 1,000 gpm.

The power needed to treat the cooling water in the 1000-MW power plant will be 200 KW, which is only 0.02% of the full capacity of 1000 MW.

Risk Management - Energy Requirement

Plasma Discharge in Water Comparison Chart			
	Gliding Arc Discharge	**Pulsed Spark Discharge (Drexel)**	**Pulsed Corona Discharge (Max)**
Energy per Liter for 1 log reduction in E. Coli (J/L)	860	77	150000
Power requirement for household water consumption at 6 gpm (kW)	0.326	0.029	56.8
Power requirement for village water consumption at 1000 gpm (kW)	54.3	4.9	9463.5
Efficiency of power supply required	Excellent	Excellent	Poor
Maximum Water throughput based on Maximum power (gpm)	95	2058	0.03
Central lethal biological agent of discharge	UV and Chemical Radicals	UV	Chemical Radicals (OH, H_3O+, H_2O_2)

PROJECT TIMELINE

	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1 – Precipitation of dissolved calcium ions using spark discharge												
Subtask 1.1 Modeling of Ca^{2+} precipitation process	↔	↔										
Subtask 1.2 Parametric study of Ca^{2+} precipitation process in power supply side		↔										
Subtask 1.3 Optimization of electrode configuration for most efficient spark discharges			↔	↔								
Task 2 – Validation experiments to increase COC (Year 2)												
Subtask 2.1 Tests with COC of 4					↔							
Subtask 2.2 Tests with COC of 6						↔						
Subtask 2.3 Tests with COC of 8							↔					
Subtask 2.4 Tests with zero blowdown								↔				
Subtask 2.5 Tests with bulk heating for COC of 4								↔				
Task 3 – Validation experiments for scale prevention (Year 3)												
Subtask 3.1 Tests with COC of 4									↔			
Subtask 3.2 Tests with COC of 6										↔		
Subtask 3.3 Tests with COC of 8											↔	
Subtask 3.4 Tests with zero blowdown												↔
Task 4 – Project Management, Planning, and Reporting	←	—	—	—	—	—	—	—	—	—	—	→

What do we expect at the end of the project?

A New Water Technology using Pulsed Spark Discharge in Water

1. Precipitates dissolved calcium ions in water.
2. Calcium salt is removed using a self-cleaning filter
3. Scale prevention in condenser tubes without scale inhibitors
4. Effective biofouling control without biocides
5. True mechanical water softener with minimal energy consumption
6. Widely applicable: RO, desalination, wastewater treatment, general household applications