

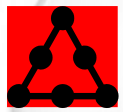
Fehr Solutions, LLC

Water Treatment Services and Consulting

CONVERSION FROM TRADITIONAL BIOCIDE TO MIOX ON-SITE GENERATION AT NRG PHOENIX CHILLED WATER PLANT

MICHAEL FEHR, PH.D.

FEHR SOLUTIONS, LLC



BACKGROUND ON BIOLOGICAL CONTROL

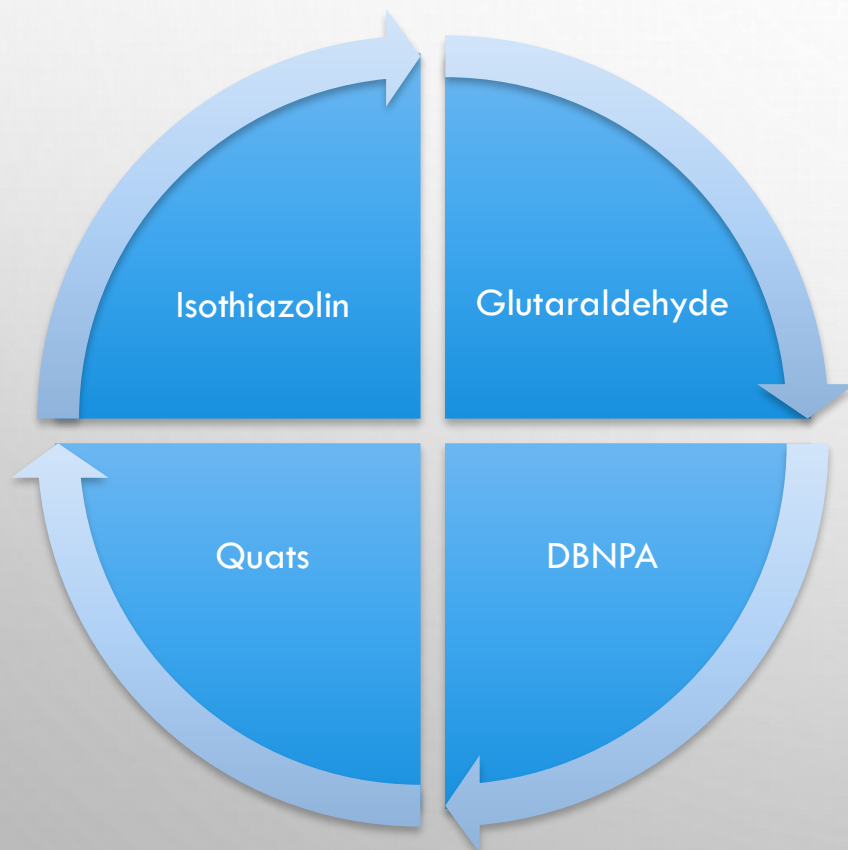
- BIOLOGICAL CONTROL WITHIN COOLING TOWERS HAS ALWAYS BEEN IMPORTANT FROM A PERFORMANCE AND SAFETY STANDPOINT.
- IT HAS BECOME EVEN MORE IMPORTANT WITH THE ASHRAE 188-2015 STANDARD BEING ISSUED
- COOLING TOWERS FOR DISTRICT ENERGY SYSTEMS ARE ALMOST BY DEFINITION LOCATED IN HIGHLY POPULATED AREAS
 - INCREASES POTENTIAL EXPOSURE
- THE TECHNOLOGY USED TO CONTROL BACTERIAL GROWTH HAS STAGNATED



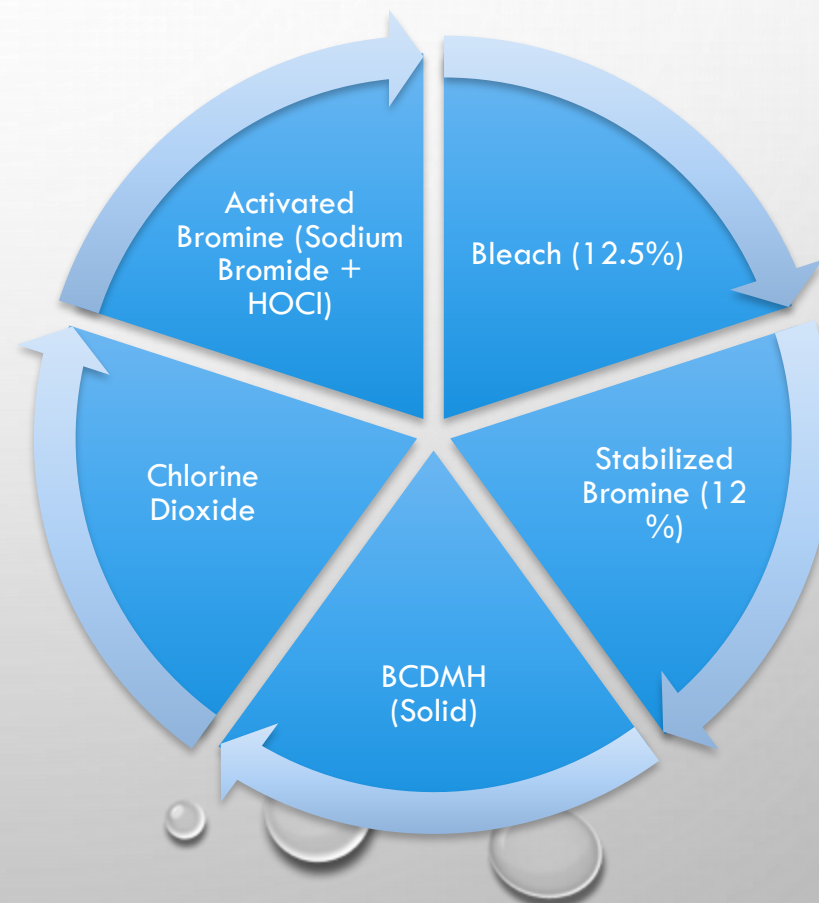


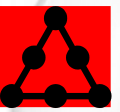
THE “BIOLOGICAL CONTROL” PLAYERS

Non-Oxidizers (slow acting)



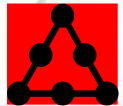
Oxidizers (fast acting)





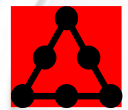
THE FEED AND CONTROL STRATEGIES

- CONTINUOUS
 - MAINTAIN CONTINUOUS RESIDUAL
- SLUG FEED
 - SLUG FEED ON REGULAR BASIS ON A REPEATING CYCLE
 - OFTEN OVERLAID WITH REGULAR NON-OXIDIZER USAGE
- CONTROL
 - ORP
 - FREE CHLORINE ANALYZERS
 - REAGENT TYPE
 - MEMBRANE TYPE



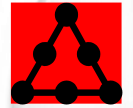
THE HANDLING PROBLEM

- BIOCIDES ARE GENERALLY THE MOST HAZARDOUS MATERIALS IN A FACILITY
 - THEY ARE DESIGNED TO KILL BACTERIA AND ALGAE
- BLEACH/STABILIZED BROMINE/ACTIVATED BROMINE
 - VERY HIGH PH, PRONE TO QUILL PLUGGING
 - VERY HARD ON PUMPS AND FITTINGS
 - FED UNDER PRESSURE
- CHLORINE DIOXIDE
 - PRECURSORS CAN BE EXPLOSIVE (IF DRIED)
 - OSHA LIMIT ON ClO_2 GAS
- BCDMH
 - DUST IS IRRITATING AND HAZARDOUS
 - IF MIXED IMPROPERLY OR ACCIDENTALLY THEY CAN CAUSE EXPLOSION WITHIN FEED SYSTEM



THE VOLUME PROBLEM

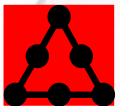
- UNLIKE SCALE AND CORROSION INHIBITORS THEY ARE GENERALLY NOT BLENDED AT MORE DILUTE CONCENTRATIONS AND THEREFORE CANNOT BE DILUTED:
 - BLEACH (12.5%)
 - BALANCE (~87.5% WATER)
 - STABILIZED BROMINE (12.5%)
 - BALANCE (~87.5% WATER)
 - BCDMH (BROMO-CHLORO-DIMETHYL-HYDANTOIN)
 - PROVIDES BOTH HYPOBROMOUS AND HYPOCHLOROUS
 - ABOUT 58% ACTIVE (AS MEASURED BY FREE AVAILABLE CHLORINE)



SELECTING AN OXIDIZING BIOCIDES AT NRG PHOENIX

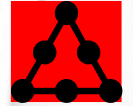
- SYSTEM OPERATES WITH SOFT WATER AT A PH OF 9 TO 9.3
- 2014 WATER USAGE OF 250,000,000 GALLONS PER YEAR
 - IF WE DOSE 12.5% BLEACH TO MAINTAIN 0.75 PPM FREE CHLORINE RESIDUAL
 - ASSUME 20 PPM OF PURE BLEACH TO GET 0.75 PPM OF FREE RESIDUAL AT 3.0 CYCLES OF CONCENTRATION
 - LOSSES DUE TO EVAPORATION, CONSUMPTION
 - WE WOULD NEED OPTIMISTICALLY 150 - 55 GALLON BARRELS OF BLEACH
 - ABOUT 8,200 GALLONS A YEAR.
 - ASSUMING NO LOSS IN ACTIVITY





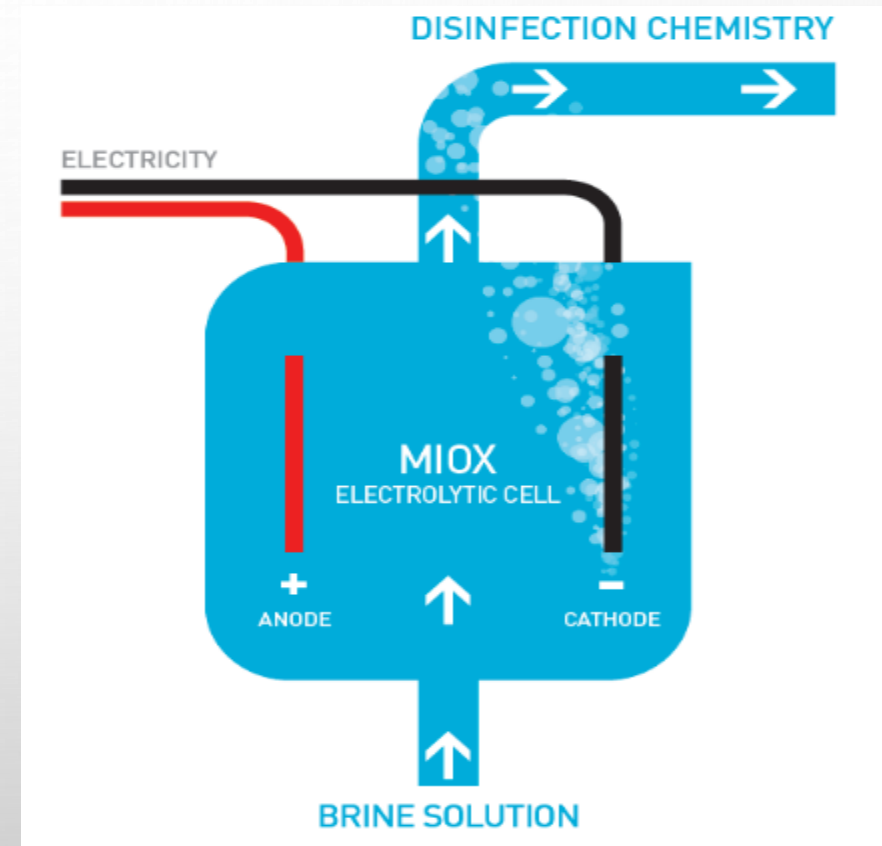
SELECTING AN OXIDIZING BIOCIDES AT NRG PHOENIX

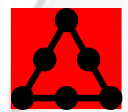
- STABILIZED BROMINE
 - FACILITY WAS CURRENTLY USING
 - RESULTS WERE MEDIOCRE
 - ACTUAL USAGE FOR THESE RESULTS WERE 5,200 GALLONS A YEAR
 - COST IS AN ISSUE
 - \$2.00/LB AT 52,000 LBS/YEAR ADDED \$104,000 OF OPERATING EXPENSE PER YEAR
 - STILL A TREMENDOUS BURDEN ON HANDLING MATERIAL
- BCDMH
 - ESTIMATED BASED ON STABILIZED BROMINE THAT 18,000 TO 20,000 LBS PER YEAR WOULD BE NEEDED
 - STILL COSTS \$67,000 PER YEAR AT COMMODITY COSTS
 - SOMEONE HAS TO LOAD THE FEED SYSTEM
 - NOT EASY TO ACCURATELY CONTROL DOSAGES



SELECTING AN OXIDIZING BIOCIDES AT NRG PHOENIX

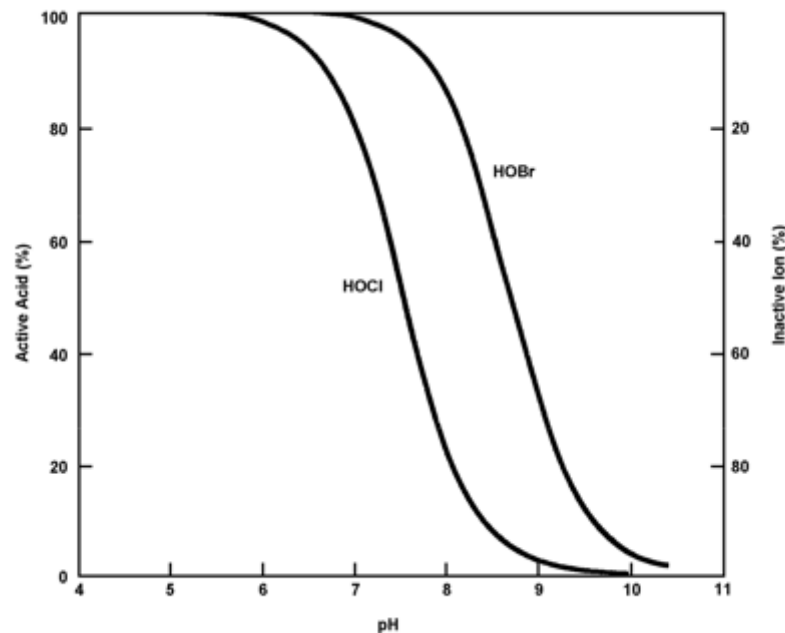
- AN ALTERNATIVE STRATEGY IS TO GENERATE OXIDIZING BIOCIDES ON-SITE USING SIMPLE PRECURSORS
 - SODIUM CHLORIDE
 - NACL
 - ELECTRICITY
 - WATER
- REACTIONS
- $\text{NACL} + \text{H}_2\text{O} \rightarrow \text{NAOCL} + \text{H}_2 + 2 \text{E}^-$
- $2\text{OH}^- \rightarrow \text{H}_2\text{O}_2 + 2 \text{E}^-$





BUT THE PH IS TOO HIGH FOR CHLORINE TO BE EFFECTIVE.....

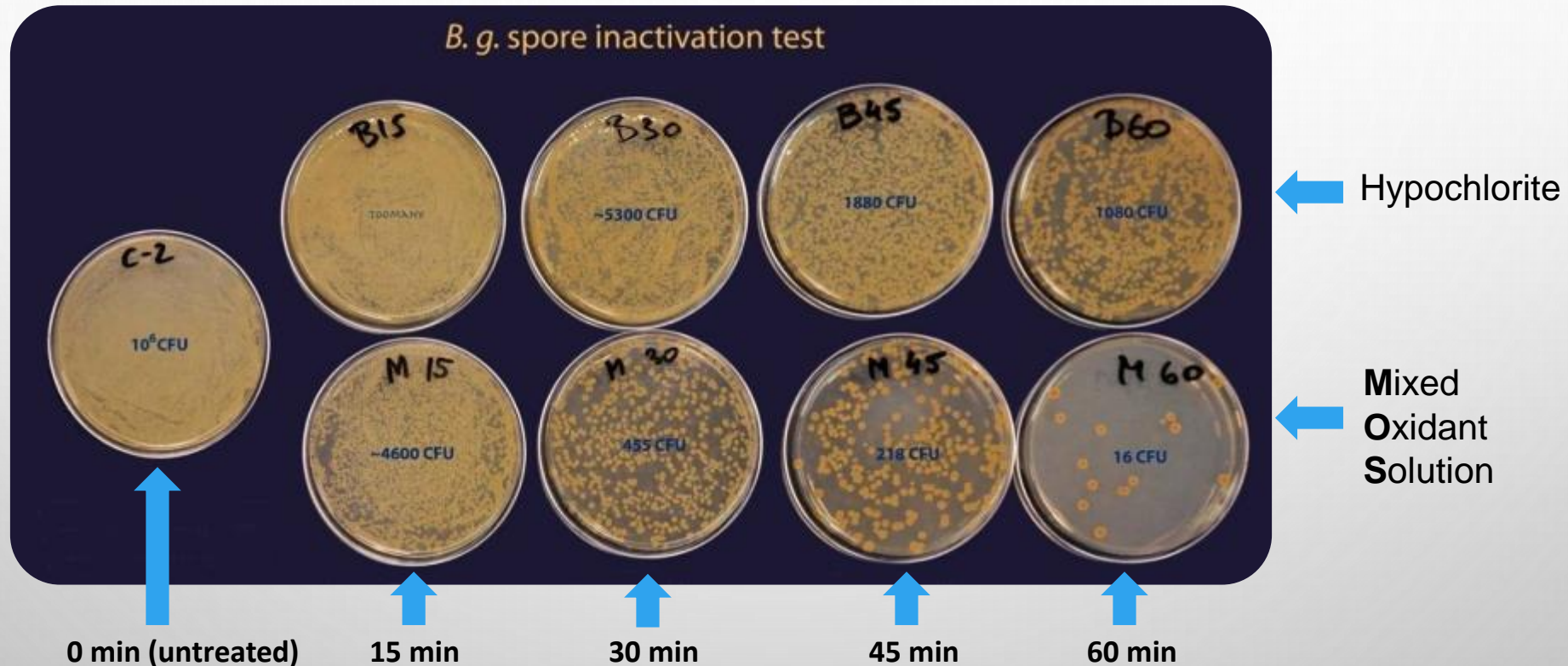
Figure 1: Dissociation Curves of Hypobromous and Hypochlorous Acids



- THIS CHART (FROM THE ENVIROTECH BCDMH TECH BOOKLET) SHOWS THE RELATIVE PERCENTAGE OF AVAILABLE CHLORINE AND BROMINE AS A FUNCTION OF PH
- NRG PHOENIX COOLING TOWER OPERATES AT 9.0 TO 9.3
 - AT THIS PH - ACCORDING TO THIS CHART – THERE IS VERY LITTLE FREE CHLORINE AVAILABLE.
 - HOWEVER THIS CHART “ASSUMES” THAT THE EQUILIBRIUM BETWEEN HOCL AND OCL⁻ IS STATIC
 - IT IS NOT AND AS HOCL IS CONSUMED IN THE OXIDATION PROCESS IT IS REPLENISHED.
 - HOBR CAN BE A FASTER DISINFECTANT BUT THAT DOESN'T MEAN IT IS BETTER (OR MORE COST EFFECTIVE)
 - IF A CONTINUOUS RESIDUAL IS MAINTAINED THERE IS ALWAYS ENOUGH FREE CHLORINE AVAILABLE.

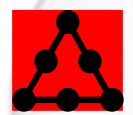
THE MIXED OXIDANT SOLUTION HAS BEEN SHOWN TO BE SUPERIOR TO BLEACH

CDC Study - Inactivating *Bacillus globigii* (B.g.)



30+ Peer Reviewed Publications

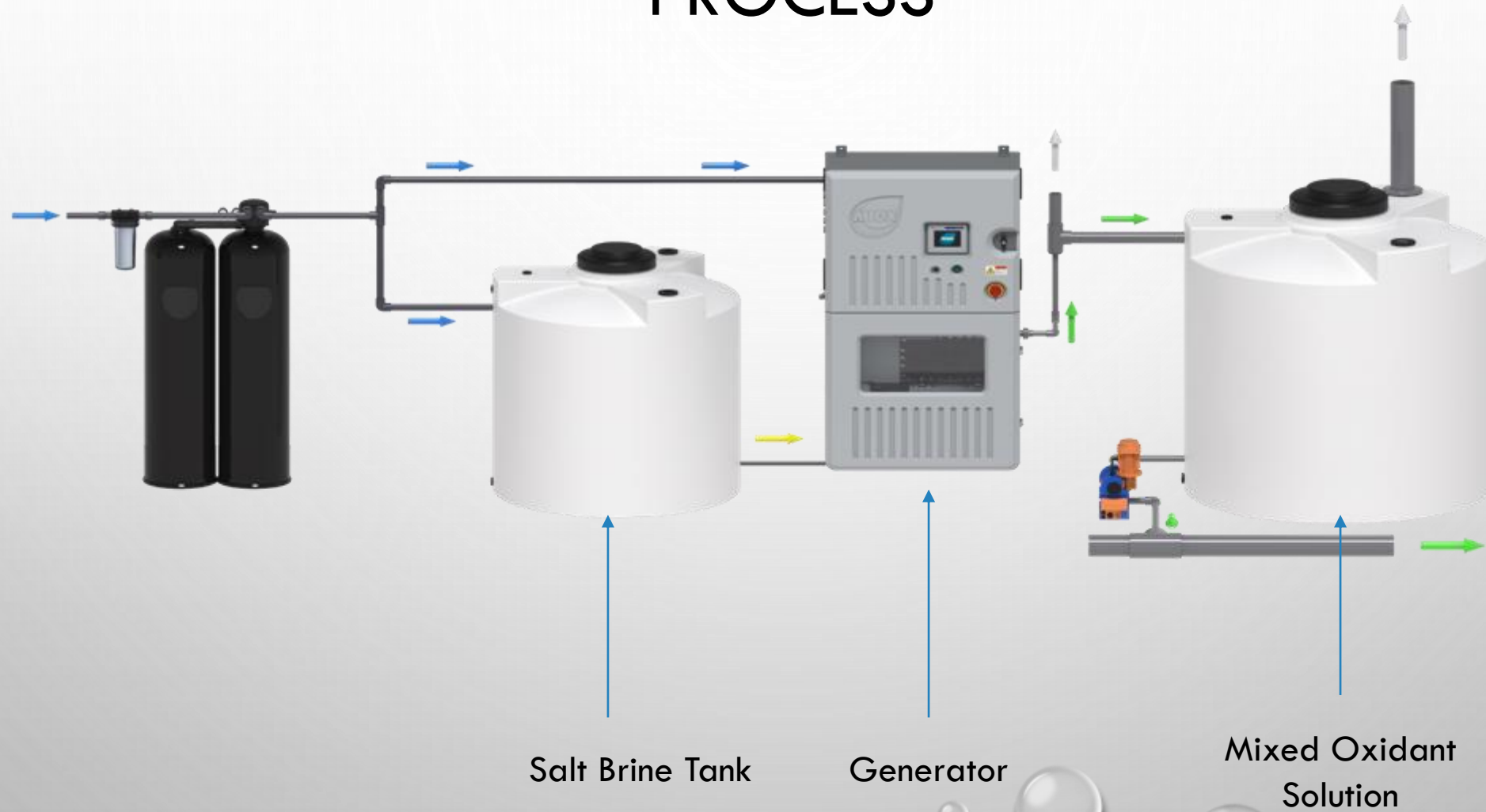
Visible Effect of Trace Hydrogen Peroxide with Hypochlorite

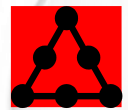


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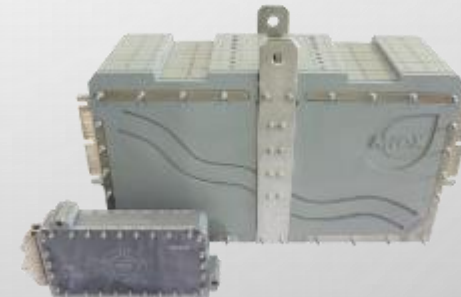
PROCESS

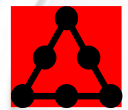




ECONOMICS OF GENERATION

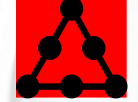
- FOR EACH POUND OF FREE AVAILABLE CHLORINE (FAC) THE SYSTEM REQUIRES
 - 3 LBS OF SALT
 - 3 KW-HR
- WE ESTIMATED THAT IT WOULD REQUIRE 20 LBS PER DAY OF FAC (AVERAGE)
 - 21,900 LBS OF SALT (ABOUT 9 PALLETS)
 - \$2,500 @ \$.11 /LB OF SALT
 - 21,900 KW-HR
 - \$2,500 @ \$.11 /KW-HR
- TOTAL OPERATING COST OF ABOUT \$5,000/YEAR AT 20 LBS OF FAC AVERAGE
- ROUGH SAVINGS OF \$50K TO \$90K PER YEAR OVER STABILIZED BROMINE OR BCDMH





INSTALLATION REQUIREMENTS

- WATER PRESSURE
 - 35 TO 100 PSIG
 - 25 PSIG AT THE UNIT INLET
- WATER TEMPERATURE
 - 50 DEGREES TO 90 DEGREES F
 - PHOENIX WATER CAN GET ABOVE 90 DEGREES F SO A HEAT EXCHANGER WAS INSTALLED TO COOL WATER IF NECESSARY
 - THIS HAS NEVER BEEN USED
- SALT PURITY
 - >99.5% "PURE" IS RECOMMENDED
 - AVOID ROCK SALT OR SALTS WITH HIGH CALCIUM LEVELS
- HYDROGEN VENTING
 - SMALL AMOUNT OF HYDROGEN GAS IS GENERATED DURING ELECTROLYTIC PROCESS
 - MUST BE SAFELY VENTED THROUGH A PASSIVE VENT OUT OF BUILDING
- ELECTRICAL REQUIREMENTS
 - DEPENDS ON UNIT – THE 30 LB PER DAY MODEL NEEDED
 - 208 SINGLE PHASE
 - 90 AMP BREAKER



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INSTALLATION AT PLANT 2

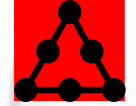
Vent Line

Mixed Oxidant
Solution Product
Tank

Salt Brine Tank



Generator



NRG PHOENIX PLANT 2 SPECIAL INSTALLATION CONSIDERATIONS

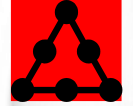
- INSTALLATION WAS IN A BASEMENT
 - UNDER THE STREET
 - VENTING WAS DIFFICULT
- VENTING WAS MADE TO A VENTILATION DUCT CARRYING AIR TO THE OUTSIDE
 - VENT OPERATION IS TIED TO THE MIOX UNIT
 - IF VENT STOPS WORKING THEN THE MIOX SHUTS OFF
- DOOR WIDTHS LIMITED THE SIZE OF THE PRODUCT TANK
 - CONSIDERED TWO TANKS INTERCONNECTED BUT HAVE NOT HAD ISSUES KEEPING UP WITH DEMAND.



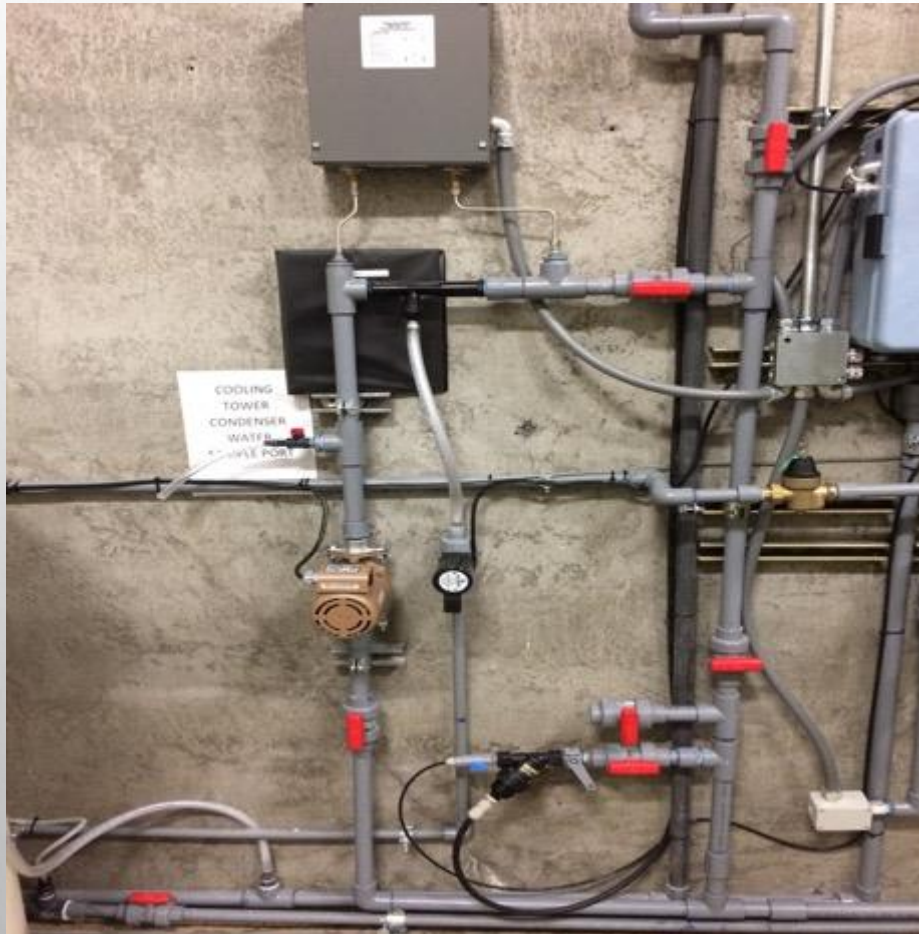
NRG PHOENIX MIOX FEED AND CONTROL STRATEGY

- FEED STRATEGY
 - CONTINUOUS MAINTENANCE OF A 0.5 TO 1.0 PPM
 - DOSAGE IN TOWER WATER MEASURED BY HACH CL-17
 - USES SAME TECHNOLOGY AS THE DPD FREE CHLORINE TEST THAT OPERATORS USE
 - NO NEED TO CORRELATE TO ARBITRARY ORP VALUES
 - NO NEED TO CORRELATE PH TO FREE CHLORINE
 - BUFFER AND REAGENT SOLUTION CHANGED OUT MONTHLY

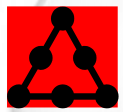




FEED OF MIXED OXIDANT PRODUCT



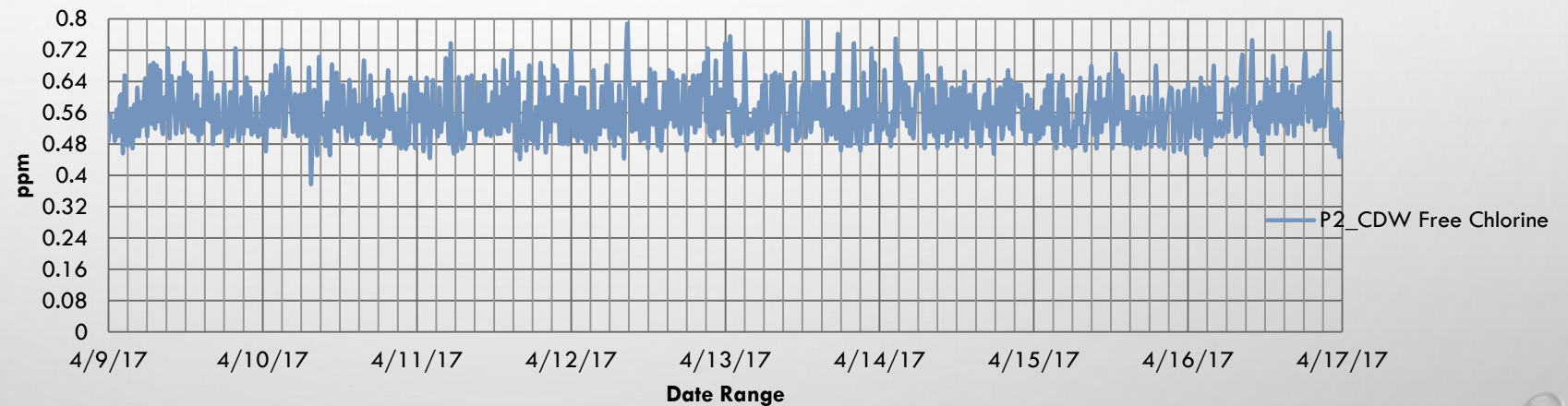
- THE MIXED OXIDANT SOLUTION IS ONLY 0.45% ACTIVE – SO FEED RATES ARE HIGHER VERSUS OTHER PRODUCTS. NEED TO ACHIEVE 40 TO 60 GALLONS PER HOUR
 - AT THIS FACILITY THE SOLUTION IS “SUCKED” INTO THE CONDENSER WATER USING A MAZZEI INJECTOR AND A SMALL BOOSTER PUMP.
 - CAN ALSO BE ACCOMPLISHED WITH POSITIVE DISPLACEMENT PUMPS
- THE SOLUTION ONLY HAS A PH OF ~ 9.0 SO AND IS DILUTE SO INJECTION QUILL PLUGGING IS NOT AN ISSUE
- CPVC IS PREFERRED TO FEED PRODUCT

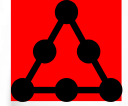


FREE CHLORINE LEVELS ARE MONITORED ON A CONTINUOUS BASIS

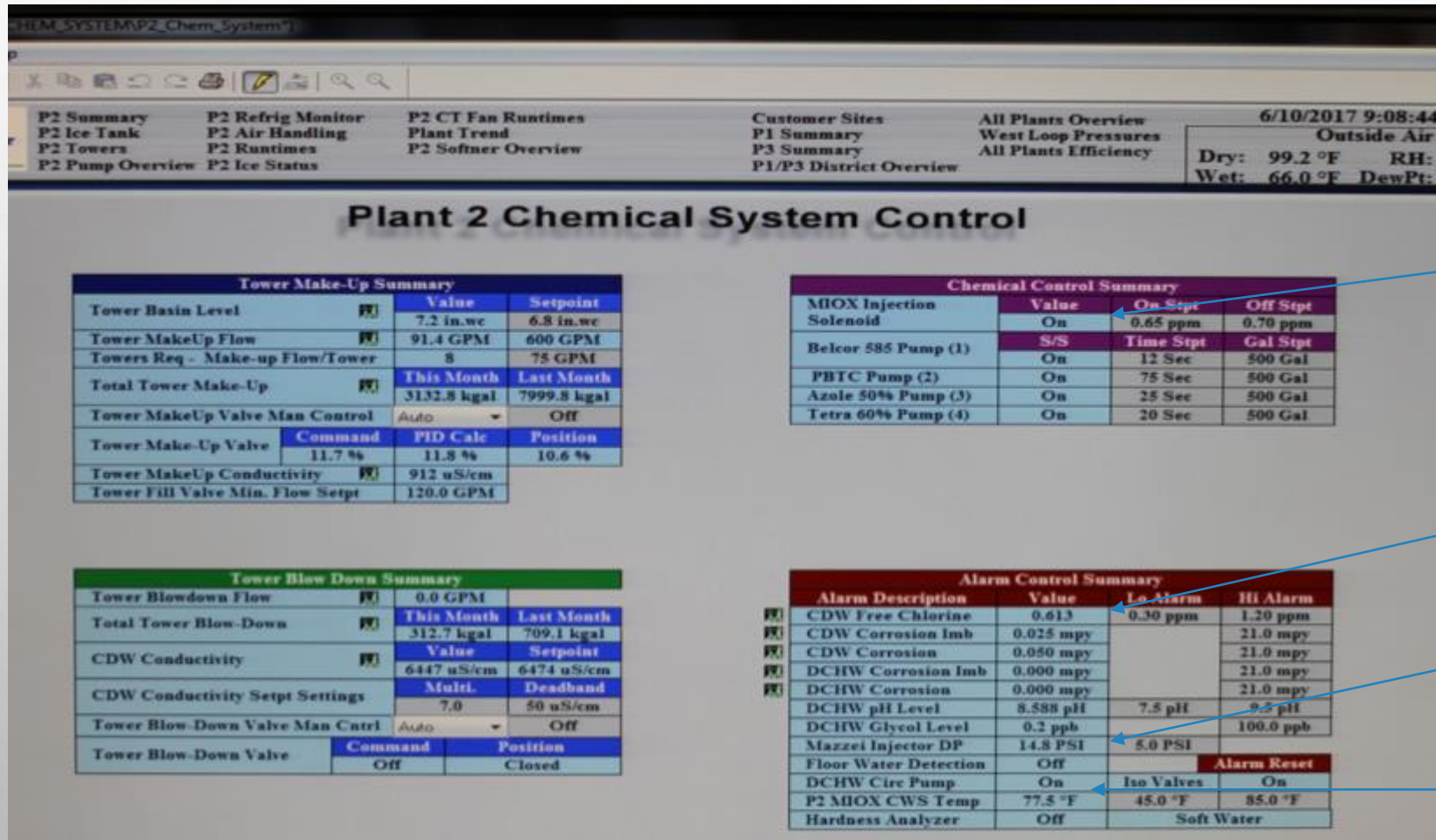
- SIGNAL FROM HACH CL 17 GOES TO PLANT PLC AND CONTROLS A RELAY THAT OPENS A SOLENOID VALVE THAT ALLOWS THE MIXED OXIDANT TO BE SUCKED INTO SYSTEM

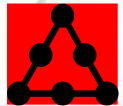
Plant 2 Free Chlorine Level - 8 Days





ALL OF THIS INFORMATION IS AVAILABLE TO THE OPERATORS VIA THIS SCREEN





NRG PHOENIX RESULTS

- MIOX TECHNOLOGY HAS BEEN IN CONTINUOUS OPERATION SINCE DECEMBER OF 2014
 - HAS OPERATED FOR 6,365 HOURS
 - CORRELATES TO AN AVERAGE CHLORINE PRODUCTION OF 7.6 LBS/DAY
 - VERSUS ESTIMATE BASED ON BLEACH/STABILIZED BROMINE OF 20 LBS/DAY
 - NO UNSCHEDULED DOWNTIME DURING THIS PERIOD
 - BASINS HAVE BEEN FREE OF ALGAE AND BACTERIAL FILMS

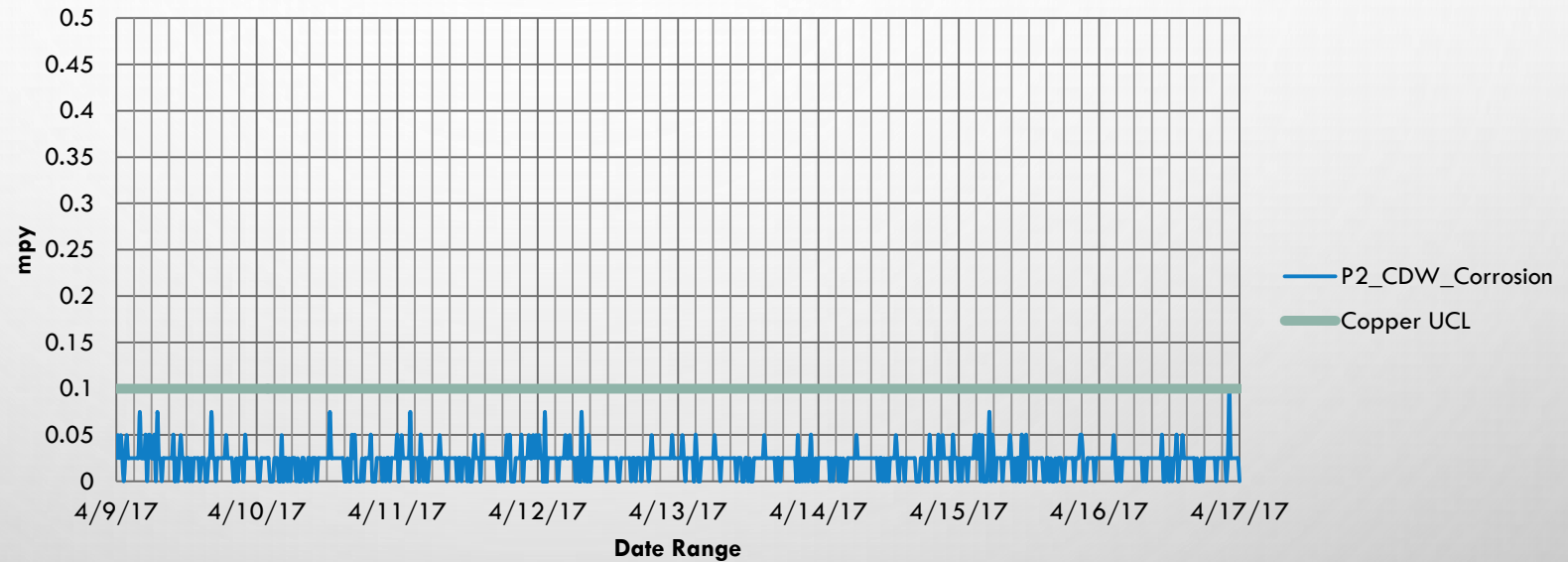


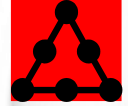


NRG PHOENIX RESULTS

Plant 2 General Corrosion Rate (Copper) - 8 Days

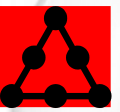
- MIOX TECHNOLOGY HAS BEEN IN CONTINUOUS OPERATION SINCE DECEMBER OF 2014
 - CORROSION RATES ON COPPER AVERAGE 0.03 MPY





NRG PHOENIX RESULTS

- BULK BACTERIA LEVELS CONSISTENTLY UNDER 100 CFU/ML
- SESSILE BACTERIA LEVELS CONSISTENTLY UNDER 10,000 CFU/CM²
- LEGIONELLA BACTERIA NON DETECTABLE (QUARTERLY TESTING)
- NO INCREASE IN CONSUMPTION OF AZOLE OR ORGANIC PHOSPHONATES
- ANY ADDITIONAL WORK LOAD DUE TO MIOX TECHNOLOGY?
 - LOAD SALT INTO BRINE TANK
 - ABOUT 200 LBS PER WEEK (4 BAGS)
 - CLEAN CELL ONCE A YEAR
 - 1 HOUR PROCESS
 - CHECK HACH CL 17 AND CHANGE REAGENTS
 - CHECK UNIT 2 X A DAY WITH WET CHEMISTRY
 - CHANGE REAGENTS ONCE A MONTH
 - CHANGE TUBING ONCE A QUARTER

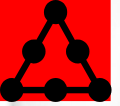


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ECONOMICS

- PAYBACK ON TECHNOLOGY WAS 2.0 YEARS BASED ON CAPITAL COSTS AND INSTALLATION



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QUESTIONS?