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Desalination of Oilfield Produced Water at the Chevron San Ardo Water Reclamation Facility, CA

VEOLIA WATER
Solutions & Technologies

Project Background

- Oil field located in Central California near the town of San Ardo
- Produced about 500 million barrels of oil since field discovery in 1947
- Production is limited by waste water capacity of Class II disposal wells
- Dewatering the field will increase oil production by reducing the formation pressure
- Dewatering the field will require treatment of produced water for discharge to the fresh water aquifer

Produced Water

- Produced water comes to surface as a part of the oil extraction process
- Generation rate - approximately 10 to 15 bbl of water per bbl of oil produced
- Characterization
  - High Temperature
  - High Free & Dispersed Oil Droplets
  - High Organic Compounds (soluble oil, organics, etc)
  - High Dissolved Inorganic Compounds (total hardness, sodium, chloride, sulfate, silica, boron, metals, etc)
  - High Dissolved Gases (hydrogen sulfide, ammonia, etc)

San Ardo Water Quality

Constituent	Feed	Discharge to Aquifer
TDS, mg/l	7,000	< 600
Sodium, mg/l	2,300	< 100
Chloride, mg/l	3,400	< 150
Sulfate, mg/l	133	< 150
Nitrate, mg/l	10	< 5.0
Boron, mg/l	26	< 0.75
Total Hardness, mg/l as $CaCO_3$	170	-
T.Alkalinity, mg/l as $CaCO_3$	670	-
T. Ammonia, mg/l as N	25	-
T. Sulfides, mg/l as S	20	
Silica, mg/l	240	-
TOC, mg/l	80	-
Free Oil, mg/l	20 ~ 30	-
pH, standard units	7.0	6.5 ~ 8.4
Temperature, deg F	185	-

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Treatment Technologies Evaluated

Membrane based Technologies

- Requires pretreatment to minimize scaling by calcium salts, metal salts, etc.
- Requires operation of membrane @ elevated pH to facilitate boron removal and mitigate organic fouling & silica scaling
- Low power consumption (10 to 12 KWH/K-Gal)

Evaporation

- Requires pretreatment to control silica scaling (e.g., aluminum silicate, magnesium silicate, iron silicate)
- Distillate quality with TOC & NH_3 requiring further treatment
- High alloy metallurgy requirements to prevent corrosion
- High power consumption (60 to 75 KWH/K-Gal)

San Ardo Project Goals

- Project Goals
  - Discharge of permit-compliant treated water to local freshwater aquifer
- System Capacity
  - De-oiling and solids filtration : 150,000 bpd
  - OPUS technology : 71,400 bpd
- System Recovery Requirements
  - Minimum 75% overall system recovery
- Focus on Life Cycle Cost

Membrane Technology – Treatment Challenges

- Membrane Scaling Potential
  - Silica
  - Calcium carbonate
  - Iron precipitates
- Membrane Fouling Potential
  - Organics
  - Particulates (suspended solids, free oil, etc)
- Gas Emission Potential
  - Hydrogen sulfide
- High Feed Water Temperature
  - Membrane limit – 113F

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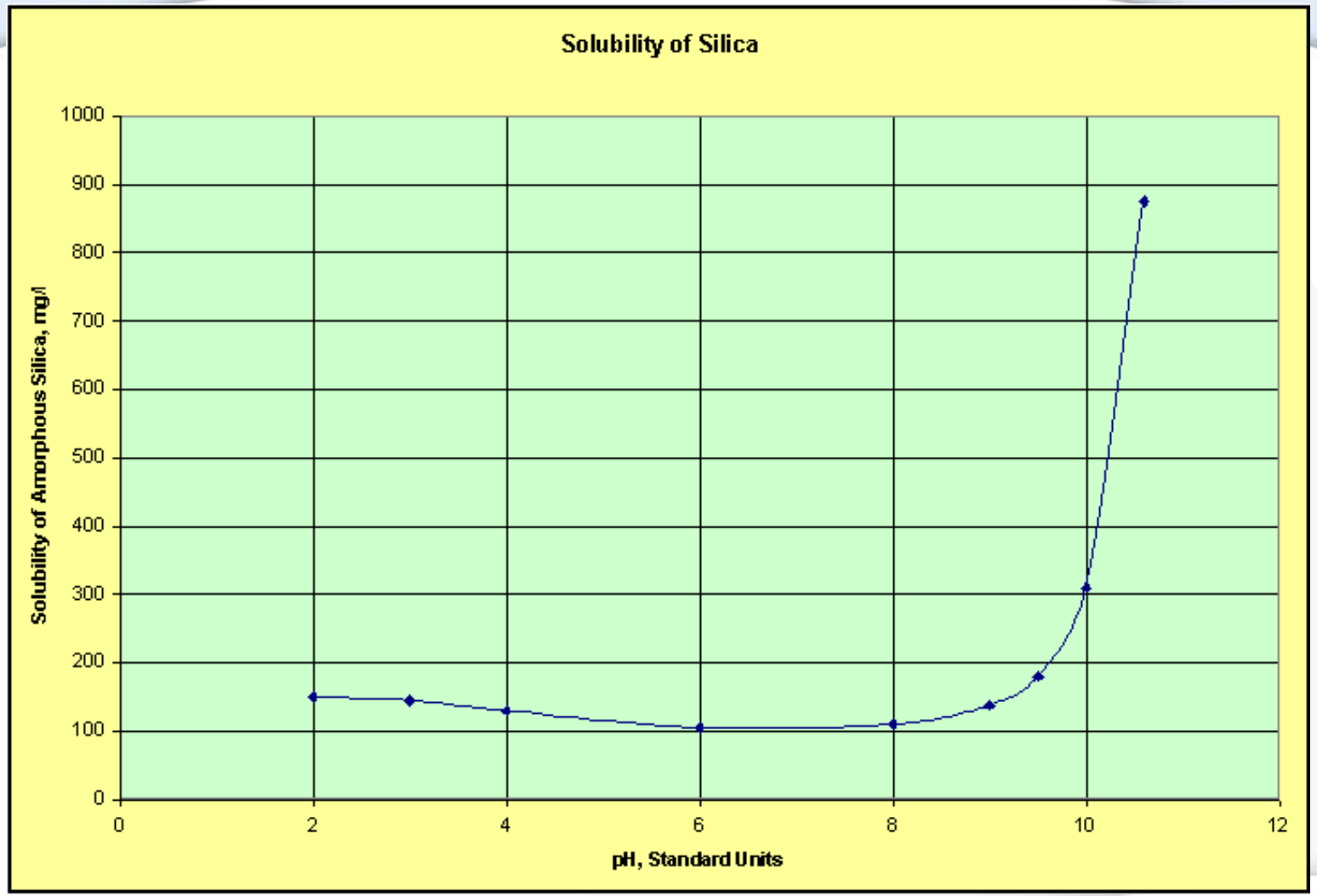
Silica Solubility - Function of pH



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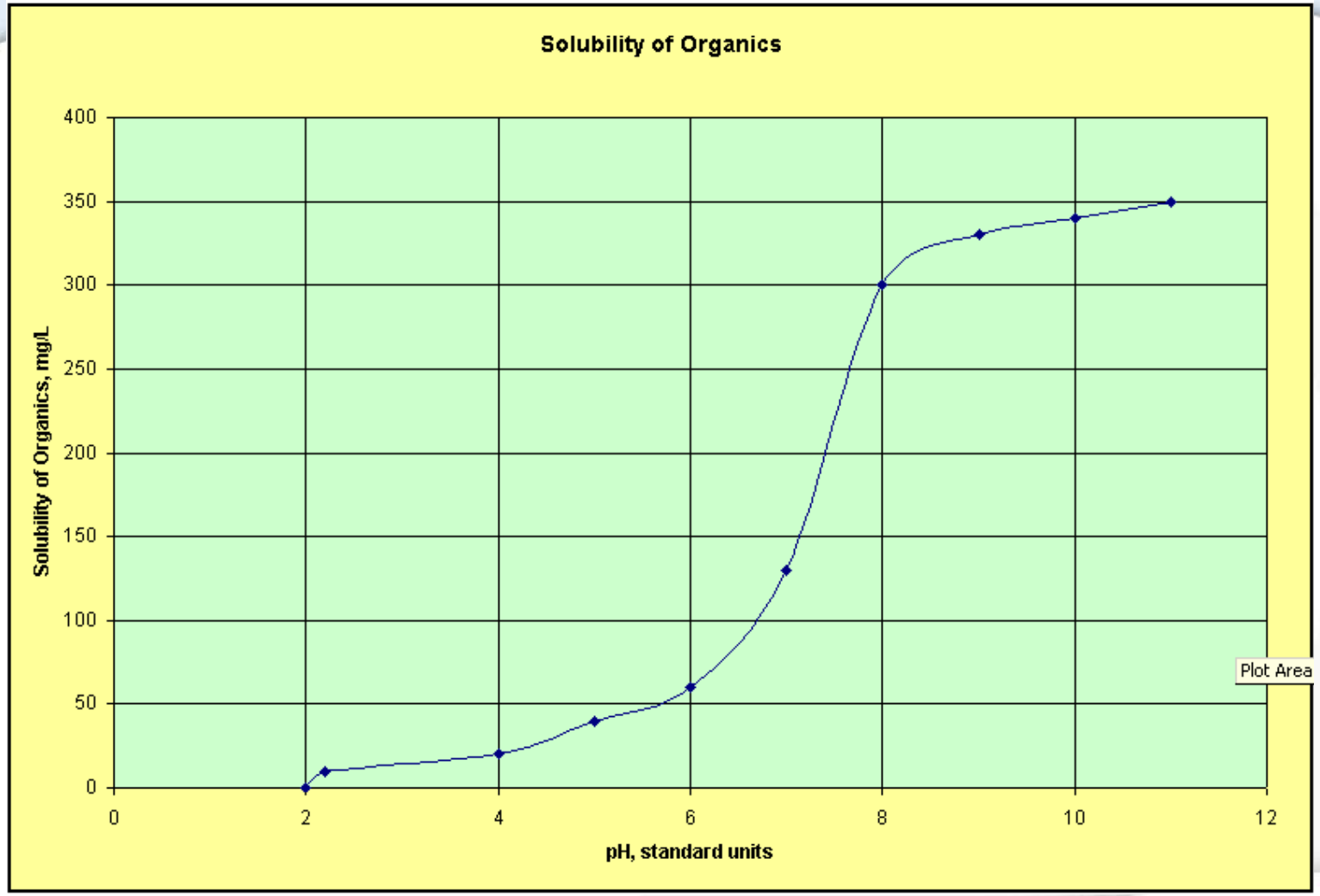
Organics Solubility – Function of pH



Above graph is the data collected from similar Produced Water Facility for Napthenic Acid.
Solubility will vary depending on nature of the organics

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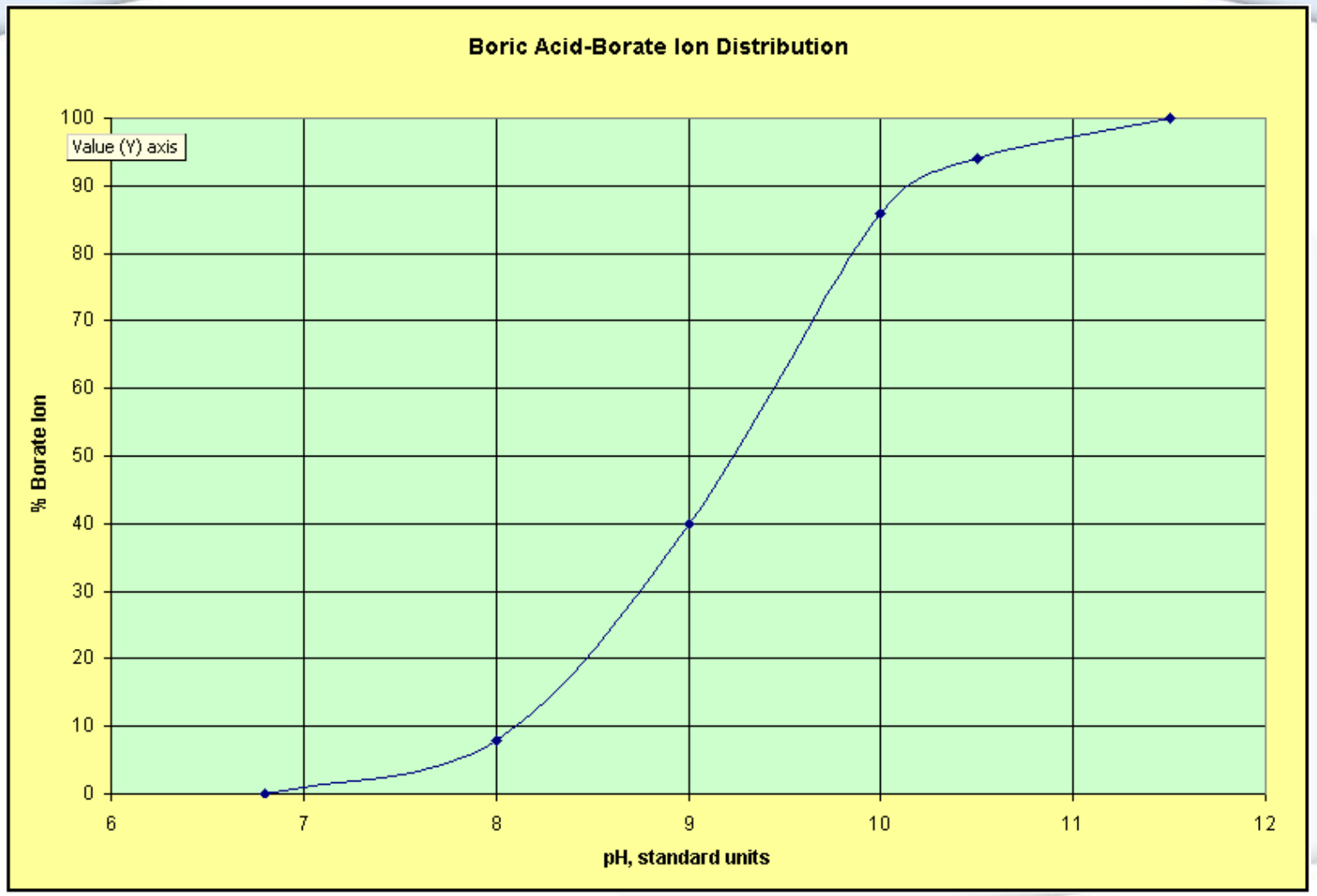
Boric Acid - Borate Ion Distribution



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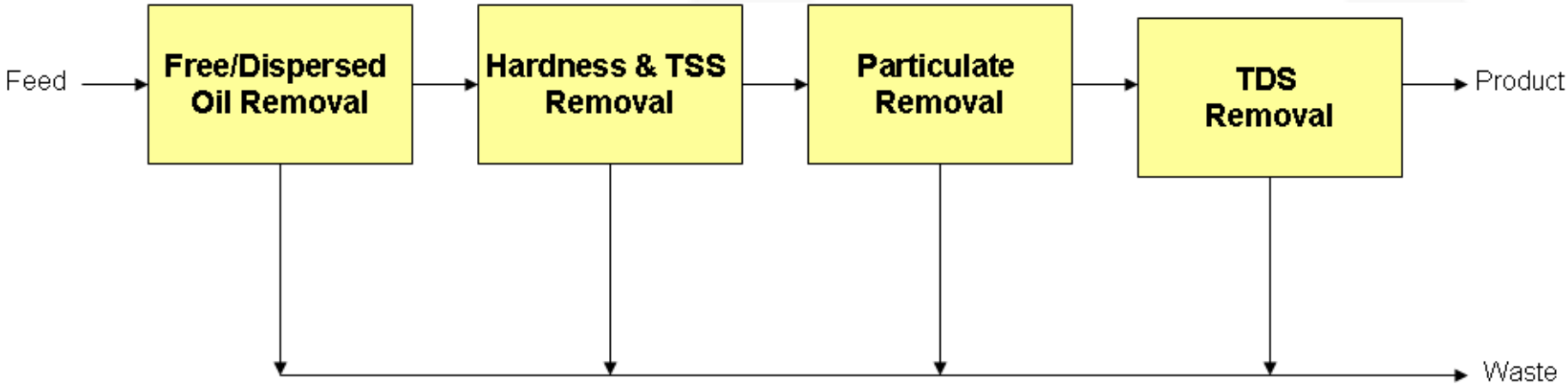
Membrane Pretreatment Requirements

To Operate at High pH Condition



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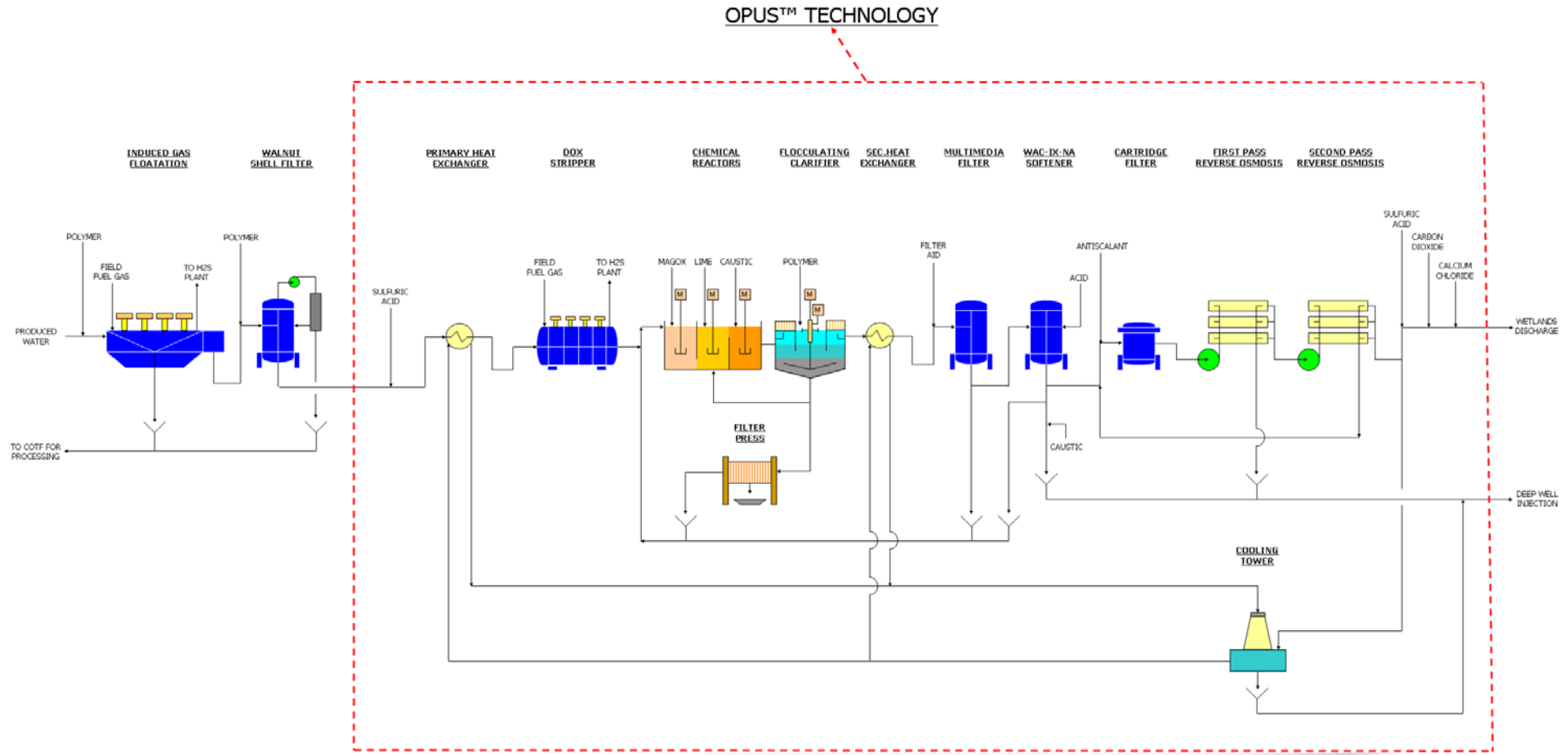
OPUS™ Technology

What is OPUS ?

- Optimized Pretreatment Unique Separation Process
- A unique membrane desalination process involving RO operation at elevated pH condition
- An optimized pretreatment approach ahead of the RO to minimize membrane fouling / scaling issues
- Highly Suitable for high fouling / high scaling applications which require pretreatment ahead of RO
- Key advantage: High system recovery rates with low waste volumes

Treatment Process – OPUS™ Technology



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San Ardo Facility

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Free/Dispersed Oil Removal

- Induced Gas Flotation
- Free Oil Removal
- Froth Flotation Process
- Mechanical Gas Induction
- 90 ~ 95% Removal Efficiency
- Effective De-Oiling Process
- Low Retention Time (5 min.)
- Effluent Oil - < 2.0 ppm
- Polymer - 2.0 ppm

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Free/Dispersed Oil Removal (cont.)

- Walnut Shell Filtration
- Free Oil Removal
- Media – Nutshell Media
- 95%+ Removal Efficiency
- External Scrub Process
- Deep Bed Filters (60”)
- High Oil Loading Capacity
- Effluent Oil – < 1.0 ppm
- Polymer – 1.0 ppm

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Degassification

- DOx Stripper – Depurator
- First Oil Field Application
- Fuel Gas Scrubbing
- CO_2 & H_2S Removal
- No Off Gas Emissions
- Product Water Quality
  - CO_2 Levels < 50 ppm
  - H_2S Levels < 5 ppm

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Warm Lime Softening

- Multistage Softening
- Flocculating Clarifier
- Softening Chemistry
  - Lime, MgO, NaOH
  - Cationic Polymer
- Product Water Quality
  - Hardness < 5 mg/l as $CaCO_3$
  - Turbidity < 5 NTU
- Sludge Concentration
  - 15 ~ 25% w/w Conc.

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Media Filtration

- Type: Multimedia
  - Anthracite (0.6 ~ 0.8 mm)
  - Sand (0.45 mm)
  - Garnet (0.25 mm)
- Filter Internals
  - Underdrain - Hub-Radial
  - Air Scour - Header-Lateral
- Filter Aid
  - Organic Coagulant
- Product Water Quality
  - Turbidity : 0.1 ~ 0.2 NTU
  - SDI : 2 ~ 3

Ion Exchange Softening

- Type: Weak Acid Cation
  - Sybron CNP-80 Resin
  - Sodium Form Operation
  - High TDS Softening
- Softener Internals
  - Underdrain - Strainer Plate
  - Regen. Dist - Header-Lateral
- Regenerants
  - Hydrochloric Acid
  - Caustic
- Product Water Quality
  - Hardness : < 0.1 ppm as $CaCO_3$

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Reverse Osmosis

- First Pass RO
  - Pressure Rating - 600 psig
  - Enhanced Brackish Membranes
  - Operation pH - 10.7
- Second Pass RO
  - Pressure Rating - 450 psig
  - High Salt Rejection Membranes
  - Operation pH – 11.1

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System Performance

CONSTITUENT TYPE	PRODUCED WATER	SECOND PASS PERMEATE	FINAL TREATED EFFLUENT	EFFLUENT SPECIFICATION
TDS, PPM	7,000	76	120	600
SODIUM, PPM	2,300	43	43	100
CHLORIDE, PPM	3,400	Non-Detect	11	150
SULFATE, PPM	133	Non-Detect	120	150
NITRATE, PPM	10.0	Non-Detect	Non-Detect	5.0
BORON, PPM	26.0	0.24	0.24	0.75
pH, NO UNITS	7.5	10.7	7.8	6.5 ~ 8.4

Operational Challenges Faced

- Effect of Temperature on pH Measurement
  - Challenges with high temperature pH measurement
  - Temperature Correction factor issues for online probes
- Effect of Organics on Salt Rejection
  - Increase in pH on RO permeate vs. decrease in pH
- Oil Field Fines
  - Iron Sulfide fines in the feed water caused plugging of HX
- Cooling of Produced Water
  - Necessity for pre-strainers ahead of Heat Exchangers
  - Accounting for variation in evaporative losses
- Maintenance Requirements on Chemical Feed Systems

System Operation Summary

- Complex Feed Water Source
- First Membrane-based Produced Water Desalination Facility in the World
- 72 hour Performance + 60 day Reliability Test
- Successful Plant in Operation for the past 15 Months
- Consistent Performance & Product Water Quality
- RO CIP Data
  - High TOC Feed Water : 50 ~ 80 ppm, 80% Recovery
  - CIP Frequency : Once in 4 to 6 months
- Sludge Cake : 50% Non-Hazardous Cake
- Power Consumption: 513 KWH/K-bbl (12 KWH/K-Gal)

OPUS™ Technology - Benefits

- High “System” Recovery Rates
  - 90%+ depending on TDS, NO limitation due to scaling/fouling
- Effective Fouling Control
  - Bio-Fouling, Organic Fouling, Particulate Fouling
- Effective Scaling Control
  - Silica, Calcium Salts, Metal Salts
- Ability to Handle Variations in Feed Water Quality
  - TSS, Total Hardness, Silica, etc
- High Salt Rejection
  - Silica > 99.9%, Boron > 99.4%, TOC > 99%
- Continuous CIP Process
  - Low CIP Costs, High Cleaning Intervals
- Reliable Operation with Minimal Downtime

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Questions

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