REINHOLD ENVIRONMENTAL Ltd.

2019 REINHOLD Round Table Presentation

June 24 & 25, 2019, in Birmingham, Alabama / Hosted by Southern Company

ZLD Design and O&M Best Practices

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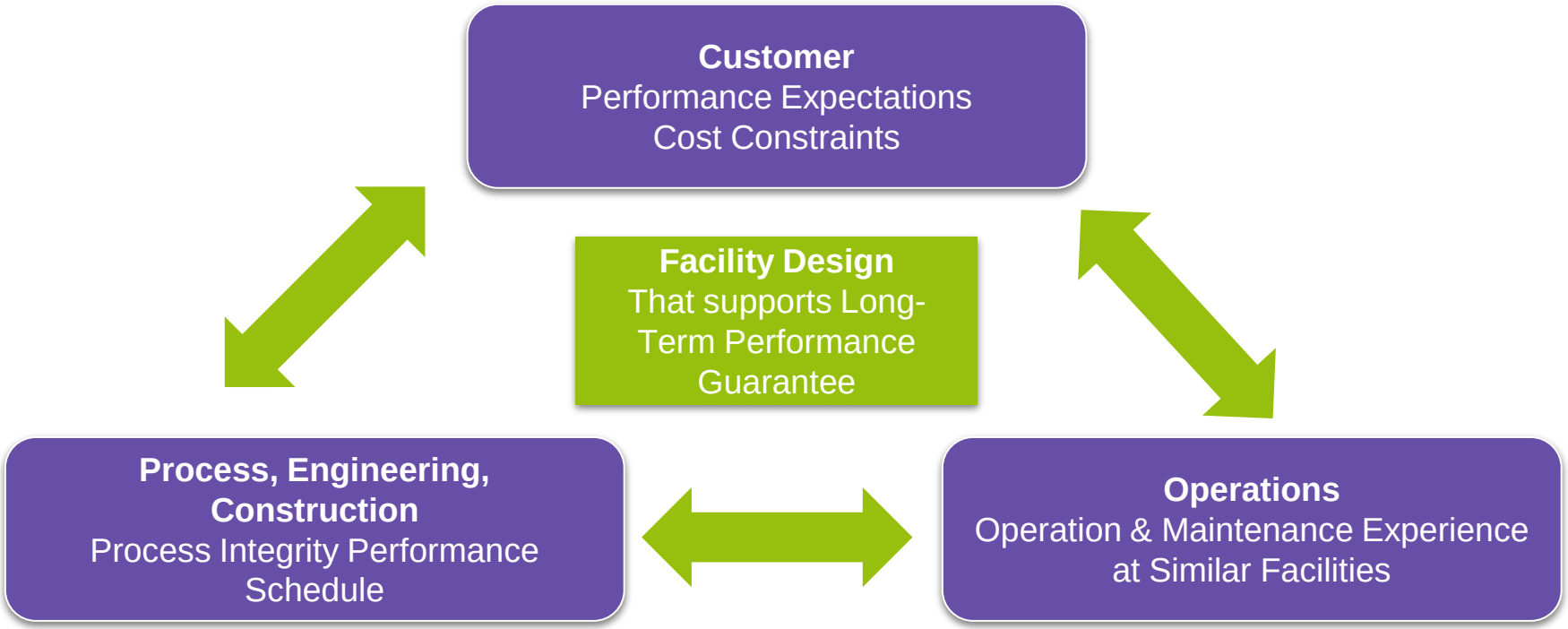
ZLD Design and O&M Presentation Overview

- Experience Summary
  - *20 plus years operating: Pretreatment, precipitation softening, I/X, microfiltration, UF, MMF, high pH, RO, evaporators, crystallizers*
- Design Build Operate (DBO) and Engineer Procure Operate (EPO)
  - *Influent flow and loading variation*
  - *Treatment objectives and availability requirements*
  - *Where do you "draw the box?"*
  - *Tankage, redundancy and catch-up capacity*
  - *Critical spares*
- Operations lessons learned
  - *Process control - Sampling, analysis, field and on-line data all get married*
  - *Asset Management – are you managing the assets or vice versa?*
  - *Managing downtime and the "bad actors"*
- Recommendations
  - *Design*
  - *O&M*

Summary of Experience – Project overview

- HPD ZLD -- Harquahala and Red Hawk
- 11 years - Metals precipitation, filtration, crystallization with product recovery
- 7 years - Softening, MMF, RO, second stage softening, evaporation and crystallization
- 19 years - Softening, filtration, RO, recovery RO, crystallization
- 2 years – Selective Ion removal, multi-effect crystallization
- 30+ years total – 3 systems - high-recovery (high pH) RO systems including softening, filtration, I/X

DBO/EPO Facility Design Collaborative Approach



Collaboration during design and development includes:

Specifications, effluent quality and availability required

Influent variation, equalization and intermediate tankage

Catch-up capacity, Redundancy requirements and critical shelf spares

Customer Always Wins!

Design Considerations

- Influent flow review – how it varies both hydraulically and constituent variability
  - *Upstream tankage – allows accepting influent when production limited*
  - *Add mixing to provide loading equalization – will optimize chemical consumption and RO recovery*
  - *Ponds – good for size but need to manage biological activity*
- Effluent or product– if supplying critical process water evaluate effluent tank with similar approach
  - *12 hours of storage allows short outages without interrupting process*
- Summary
  - *When evaluating system availability to receive influent and provide product water "draw the box" to include influent and product tanks*
  - *Operate with influent tank low and product tank high*
  - *Include catch-up capacity in the design to allow re-establishing desired tank levels in a reasonable time*

ZLD System with 1-day storage tank - 98%

Thermal Design

- Including storage upstream of thermal allows “uncoupling of pretreatment/membrane from thermal
- Designing tank plus catch-up capacity for thermal provides lowest life-cycle cost
- Redundancy and Critical Spares
  - ***Consider redundant:*** *level transmitters, pH meters, salt dewatering, preheaters, transfer pumps, metering pumps*
  - ***Consider complete rotating assemblies for:*** *Recirculation pumps, fans, compressors and centrifuges – include provisions for remove and replace*
- Plan for periodic cleaning: chemically or mechanically based on chemistry and experience
  - *Include access and infrastructure to open heater and platform to hydroblast safely*
  - *Consider Clean-in-place for preheaters – full flowrate during cleaning is best*
  - *Boil-outs can be effective if buildup is water soluble – consider timing and frequency in availability calculations*
  - *Consider buildup on crystallizer walls – spray nozzles or periodic boil-outs*

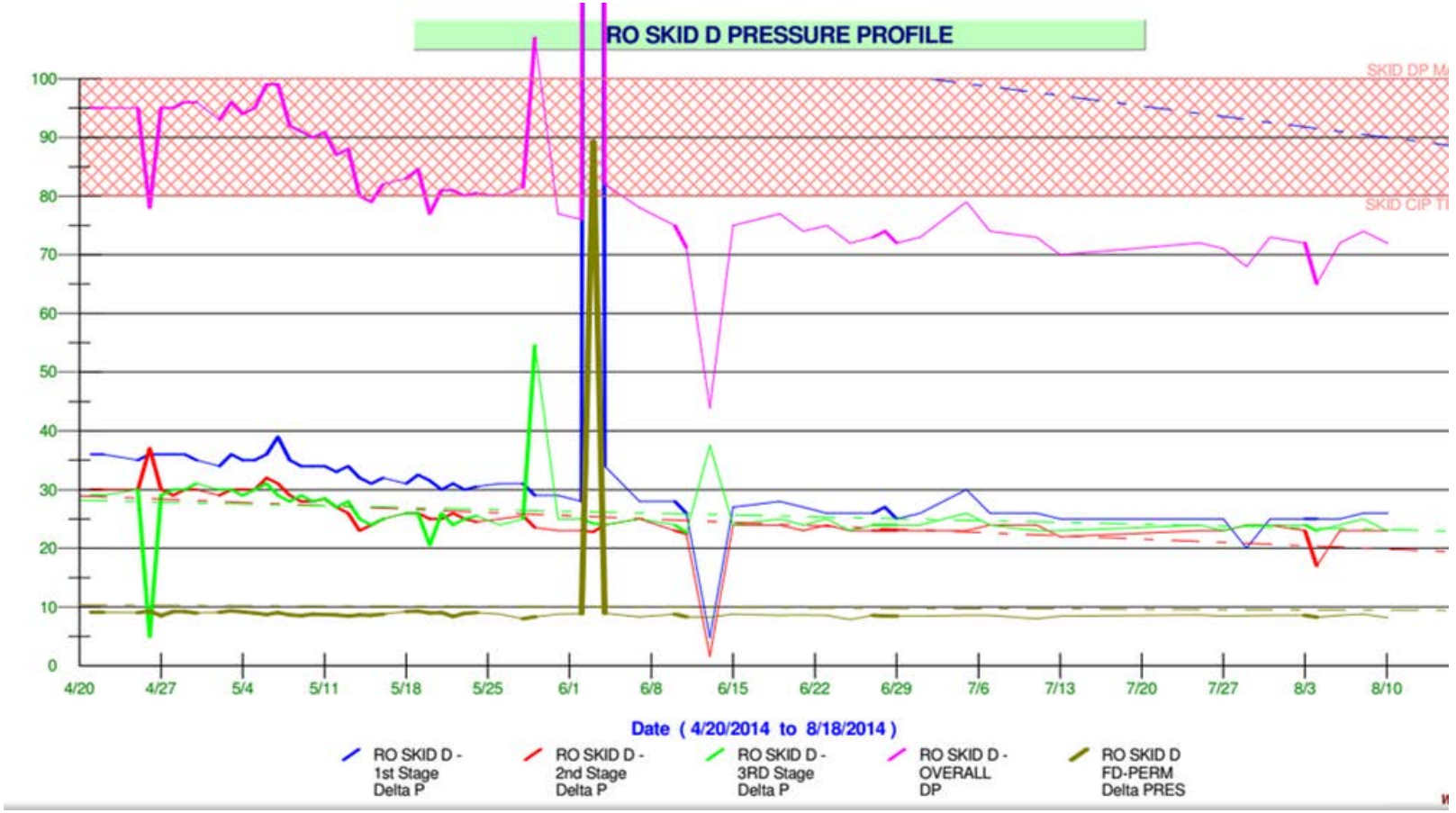
Process Control – Critical!

- **Combine:** sampling, analysis, on-line and field readings in a single database to support calculations trending and key performance indicators (KPI) development
- On-line instruments are great – but must be calibrated and validated
- Sampling and analysis always required
- Hardness, alkalinity, silica, and pH are key in pretreatment

Process Control – Critical!

- RO normalization and stage dP provides early detection to problems
- Confirm all metering pumps, anti-scale etc are delivering with field checks
- Heat Transfer Coefficients and Boiling Point Rise for thermal – online
- Crystal inventory or Apparent Settled Volume and pH – sample it!

Process Control Example Membrane Performance Trending



Clean-in-place occurred on June 3rd based on 1st stage high dP

Process Control Example – Crystallizer Control

- Key aspects of crystallizer control:
  - *pH for corrosion control*
  - *ASV for tube fouling and recirc pump amps*
  - *CO3 for scaling*
  - *BPR for capacity*
  - *Fines control*
  - *Periodic mini-flushes, wall washes for growth control*

#	Parameter	Units	Average Over Date Range	Flag	Sample	08/10/14	08/11/14	08/12/14	08/13/14	08/14/14	08/15/14	08/16/14
2117	Crystallizer Recirculation Pump P-3063 A	AMPS			0							
2008	Crystallizer VB Pressure PIC 3061A	PSIG	0.55		27	0.40	0.55	0.60	0.53	0.53	0.60	0.63
2124	Crystallizer Vapor Body Temperature	DEG F	234.15		27	235.00	233.75	233.50	234.00	234.00	234.00	234.67
2119	Crystallizer Specific Gravity Vapor Body		1.28		27	1.28	1.28	1.29	1.29	1.28	1.28	1.28
2126	Crystallizer HTC	BTU/scft/F	923		27	911	877	820	886	989	1,017	1,007
2012	Crystallizer Boiling Point Rise BPR 3062	DEG F	22		27	22	21	22	22	22	22	22
2015	Crystallizer Fan IGV #1 HV 3065	%	33		27	35	33	32	32	32	32	32
2016	Crystallizer Fan Amps #1 II3068	AMPS	66.26		27	69.25	66.50	66.50	65.50	65.25	65.00	66.00
2019	Crystallizer Fan IGV #2 HV 3071	%	30.63		27	33.00	30.75	30.00	30.50	30.00	30.00	30.00
2020	Crystallizer Fan Amps #2	AMPS	65.11		27	69.50	65.25	64.50	63.00	64.25	64.00	65.00

Asset Management – Keep It Simple

The purpose of the Asset Management program is to aid the project in managing the assets, including:

1	Document all maintenance performed on equipment (planned, unplanned, repeat, project, etc.) including technician notes, measurements, observations, actions, etc...
2	Document maintenance costs and man-hours required – supports repair/replace/upgrade evaluations
3	Schedule and track Preventative Maintenance and Predictive Maintenance activities (time directed, condition directed and failure-finding)
4	Support all internal, environmental, safety, warranty and Customer reporting requirements
5	Track critical spares inventory
6	“If it’s simple – they will use it”

Asset Management Report Example

VEOLIA

Work Order Report

4/14/2016

WO Number	Work Type	PM Number	Equip Desc	Request	Comp Remark	Target Date	Comp Date
83750	CMP		U-2240 Soda Ash Silo	SODA ASH RUBBER BOOT FROM FEEDER LEAKING NEED TO REPLACE CURRENT BOOT WITH NEW RUBBER BOOT.	Shut silo down 2 hours and repaired feed tube.	2/26/2016	3/1/2016
83885	CMP		U-3081B CHRYSTALLIZER CENTRIFUGE	Feed tube Flush is leaking distillate, it appears to have a cracked sight glass.	done during processing no downtime Replaced flow indicator.	2/29/2016	3/1/2016
83892	CMP		P-2223 B1 Silo 2 Lime feed pump A	Pump needs re-packed, almost out of adjustment. Only operational pump in Lime Silo B	EQUIPMENT IS SPARED SO NO DOWNTIME Added ring of packing and adjusted.	3/4/2016	3/1/2016
83728	PM	2125	A-2210; Polymer Mix Tank Agitator	Dry Polymer System Monthly Maintenance/Inspection	done during processing no downtime Inspected polymer system.	1/16/2016	3/1/2016
83729	PM	2129	F-3005 Automatic self Backwashing Strainer	F-3005; MONTHLY STRAINER INSPECTION/LUBRICATION	done during processing no downtime Strainer has been serviced. Hours 114.8	12/20/2015	3/1/2016
83730	PM	2144	P-2031A MMF FEED PUMP	P-2031A; MOTOR LUBE, MMF FEED PUMP	EQUIPMENT IS SPARED SO NO DOWNTIME Motor has been lubricated. Hours 23,380.3	1/29/2016	3/1/2016
83731	PM	2145	P-2031B FILTER FEED PUMP	P-2031B; MOTOR LUBE, MMF FEED PUMP	EQUIPMENT IS SPARED SO NO DOWNTIME Motor has been lubricated. Hours 9,526.3	1/29/2016	3/1/2016

Heads up on potential bad actors – We have seen them all

- Lime delivery
- Polymer dosing
- Biological fouling on membranes and cartridge filters
- RO recovery too optimistic for long-term reliability
- Post precipitation downstream of softening reactors
- Dewatering and solids logistics – don’t skimp here
- Scale inhibitors interfering with desired precipitation
- Thermal startup and shutdown time is significant
- Preheater scaling and plugging

Heads up on potential bad actors – We have seen them all

- Slurry piping reliability
- Centrifuge reliability including washing provisions that do not compromise salt moisture
- Maintaining correct crystal inventory, pH and BPR in crystallizers and evaporators
- Hydroblasting timing and equipment requirements
- Process vapor quality and carry-over considerations for fans and compressors
- Vapors from thermal vents, centrifuge and tanks cause external corrosion and safety risk
- Startup resource requirements and ramp-up times

Recommendations

- Establish solid design basis – flow loading and variability – consider the future
- Draw the box around the entire system including tankage and confirm system meets production, availability and quality requirements
- Consider critical spares, catch-up capacity, maintenance and process interruptions, accessibility when calculating system availability and production potential

Recommendations

- Leverage actual long-term experience to mitigate process and O&M risk whenever possible – visit reference sites – minimize “World’s first of its kind” unit ops
- Expect and facilitate reasonable Performance Demonstration from EPC provider
- Use process control and asset management to be proactive rather than reactive. In ZLDs, often once ROs and heaters are limiting – it’s too late
- If in doubt – consider DBO/EPO – the customer always wins!

Thank You!

Questions?