Guidelines for the Selection of a Waterflood Deoxygenation Strategy

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Recommended Strategy for Deepwater Waterflood Deoxygenation:

- Design for full chemical oxygen scavenger as a base case
  - Provide sufficient residence time for scavenger reaction
    - may require a retention vessel
    - required dose depends on temperature, mixing and scavenger concentration
    - w/o sulfate membranes: use catalyzed scavenger & provide 3 minutes to react
    - w/ sulfate membranes, can't use catalyst so provide 5 minutes to react
  - Select appropriate metallurgy for poor scavenging & MIC control
  - Provide sufficient storage for 10 days

- Add mechanical deoxygenation in order to reduce OPEX
  - Required dose for chemical may be excessive in cold water
  - For Basis of Economics:
    - use historical / real uptime data (see below)
    - use real operating costs including Minox catalyst and other chemical costs

Historical Involvement in Compact Deoxygenation:

SeaJect - Extensive field trials

- Developed initially by Norsk Process Inc. in 1980's
  - Initial funding / interest by Conoco
- 1990 Shell testing on shore
- 1990 One week pilot field test on Cognac
- 1992/1993 One year Bullwinkle field trial in parallel train
  - review report - many problems, excessive downtime
- 1994 - 2001 Shell Ram-Powell waterflood - SeaJect on-line
  - many problems, excessive downtime
  - relying on chemical oxygen scavenger
  - extensive well tubing corrosion
- 1998 Axsia Serck Baker acquires SeaJect
- 2001 Shell selects SeaJect for Bonga
- 2001 Shell decommissions SeaJect on Ram-Powell

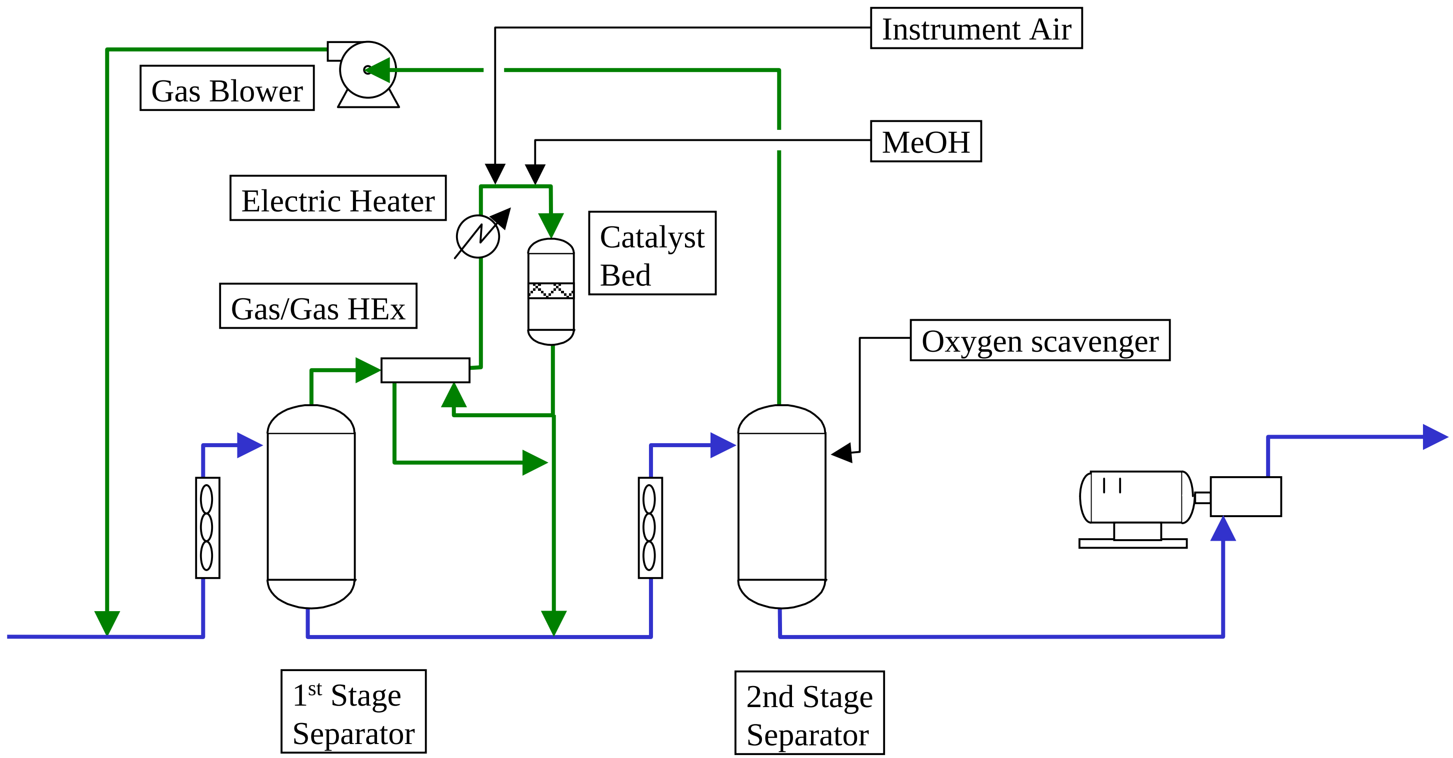
Historical Involvement in Compact Deoxygenation:

2001 / 2002 Pivotal Years:

- SeaJect selected for Bonga & GA approved for construction
  - But operations raise strong objections
- Mars WF approved assuming compact deoxygenation
  - GA, weight & space constrained
- Shell acquires Enterprise, inc Bijupira-Salema
  - Minox selected by Modec / Alliance Engineering, designed by Minox
- Shell & BP (Mars partner) share their experience:
  - BP initial good experience with Minox
  - Minox selected for several more BP waterfloods
  - Not much industry experience available regarding Minox

Shell selects Minox for both Mars and Bonga

WF DeOx System – Common to all 3 DW WF:



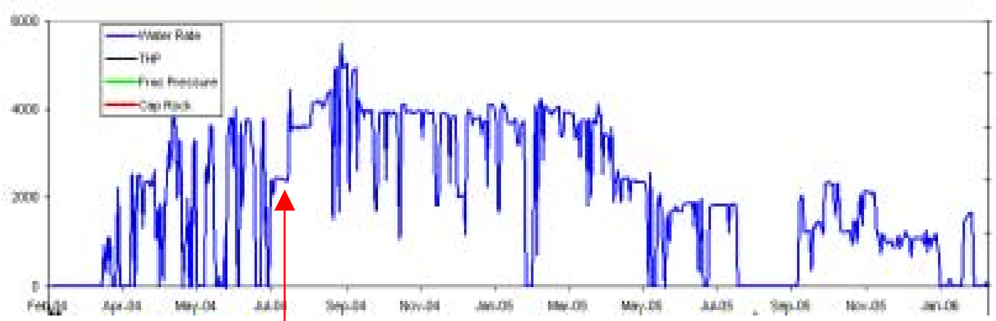
- ➢Overall nitrogen / seawater flow is counter-current

- ➢Local nitrogen / seawater flow is co-current
  - nitrogen / seawater mixing in static mixers

- ➢High efficiency from:
  - small bubble size (high surface area, short gas diffusion length)
  - 2-stage counter-current process

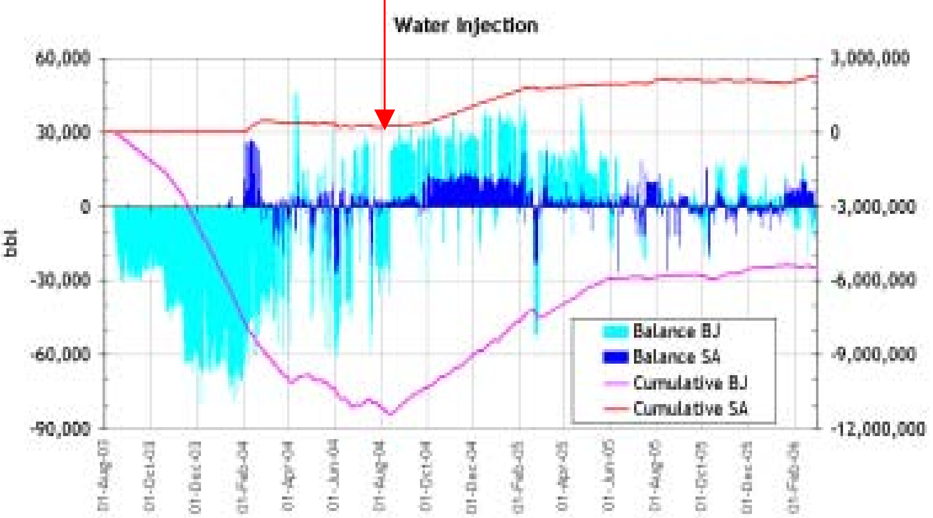
Shell Brazil Bijupira-Salema water injection performance

Water injection rate
(cubes / day)

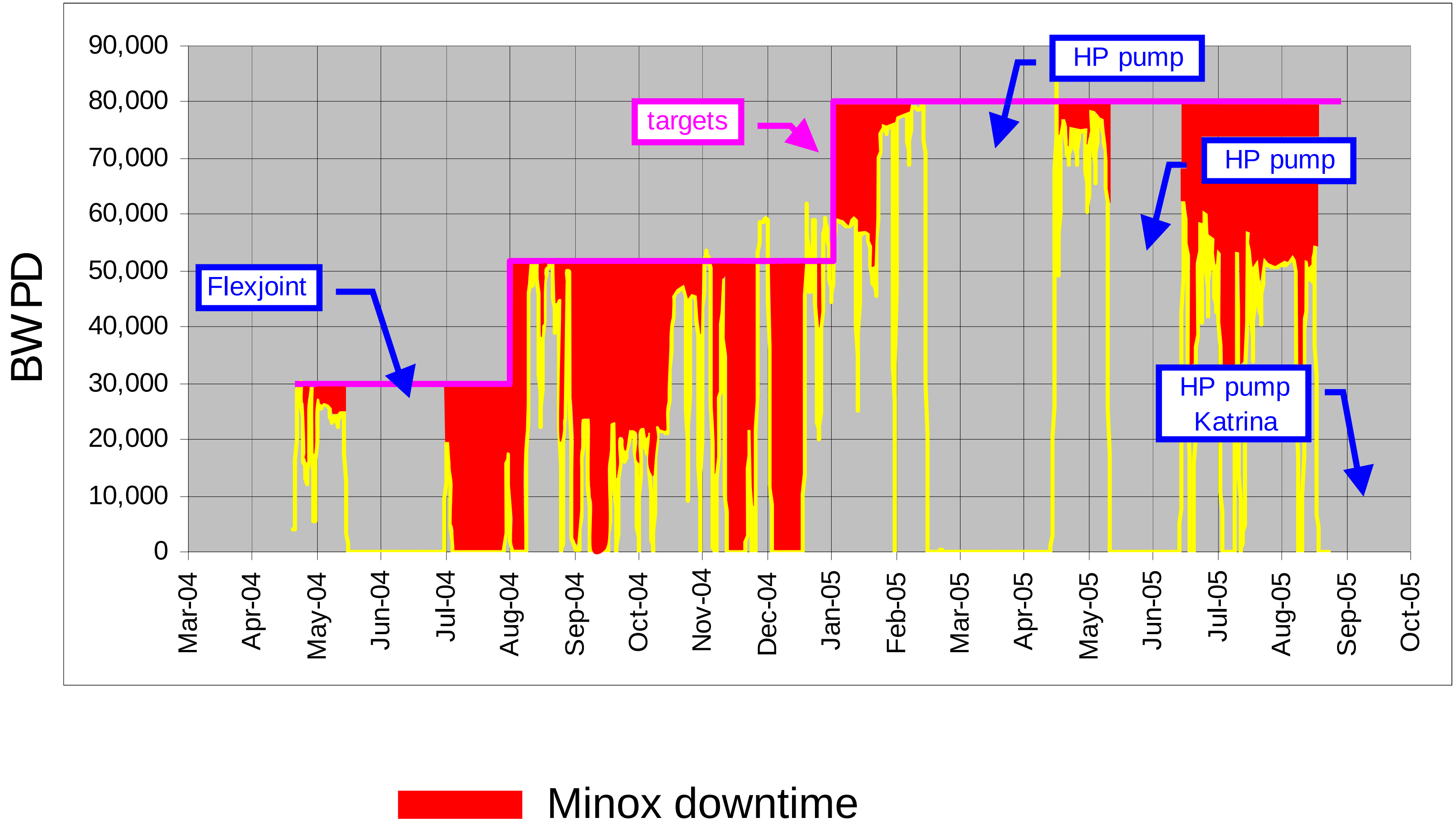


Bypass Minox –
Using full chemical scavenger instead
Dramatic Uptime Improvement

Voidage Replacement
(cubes / day)



Mars topsides performance



Minox: 40 % average downtime

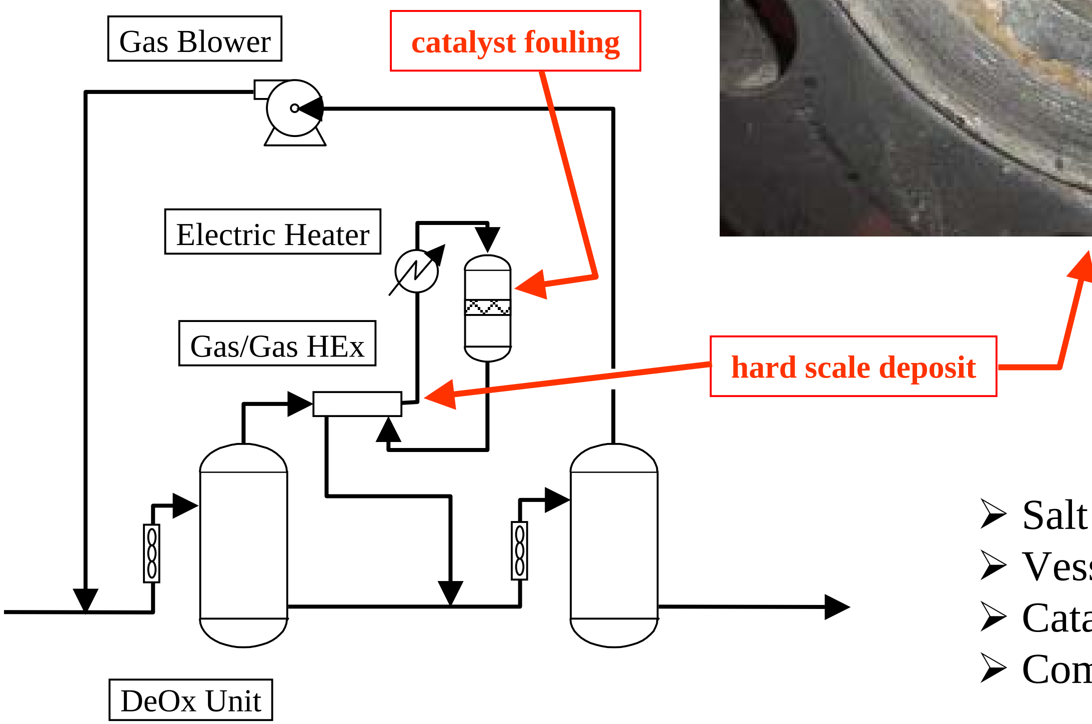
Project	Company	Mark	Date Installed	Capacity kBWPD	Working Effectively	Comments
Snorre	Saga		1991	375		
Foinaven	BP	Mark 1	1995	165	Y	Minox unit very successful here - single stage, using the catalyst reactor. Static mixer & stripping tower contactor / separator.
Schiehallion	BP	Mark 1	1996	280	N	76% injection against target - single stage, using the catalyst reactor. Static mixer & stripping tower contactor / separator.
Vigdis (Snorre)	Saga		1996	136		
Masa	Petronas		1998	25		
Siri	Statoil		1998	81.5		
Statfjord	Statoil		1998	790		Conversion of fuel gas stripping tower
Gabon	Marathon		1999	45	-	Not installed
Pogo 1 (Thailand)	Chevron		1999	20	N	Not operating
Pogo 3 (Thailand)	Chevron		1999	40	N	Not operating
Glitne (FPSO)	Statoil PGS		2000	65		
Pogo 2 (Thailand)	Chevron		2000	20	N	Not operating
ValHall	BP	Two stage	2000	220	N	
Halfdan	Maersk		2001	220	Y	Fixed by NATCo
Heidrun	Statoil		2001	200		
Bijupira Salema	Shell	Mark 3	2002	100	N	Minox currently by-passed. Relying on oxygen scavenger.
Mars	Shell	Mark 2	2003	94	Y	Shell design
Balam GOM	Pemex		2005	30		
Clair	BP	Two stage	2005	100	Y	Requires 80 kbwpd. T. Marsh note of 29/6 says best achievable through Minox is 35 kbwpd
Holstein	BP	Mark 3	2005	100	N	
P 18 (Brazil)	Petrobras		2005	150		
Thunderhorse GOM	BP	Two stage	2005	200		
Bonga	Shell	Mark 3	2005	400	N	Minox in permanent bypass due to blower bearing problems. Relying on Oxy Scavenger injection.
Agbami (W. Africa)	Chevron		2006	450	-	Under installation 10/06
Atlantis GOM	BP	Two stage	2006	75		
Ursa (future)	Shell	Mark 2	2008		-	Shell design with large vessels, internals and scrubbers (SRM: cannot inject de-foamer)

Problems w/

Mars

Bijupira-Salema

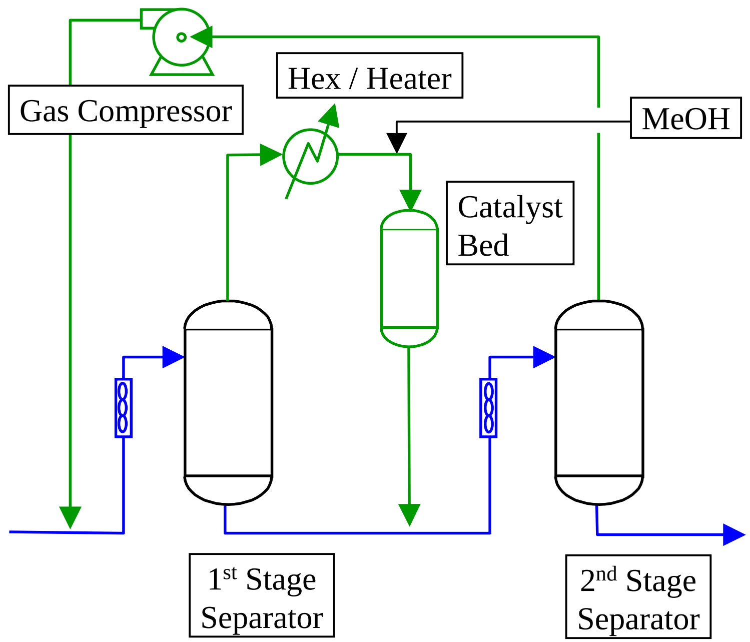
Bonga



- Salt deposits
- Vessels full of foam
- Catalyst fouling / short catalyst life
- Compressor fouling / high maintenance

G/L Separation Design
& differences system to system:

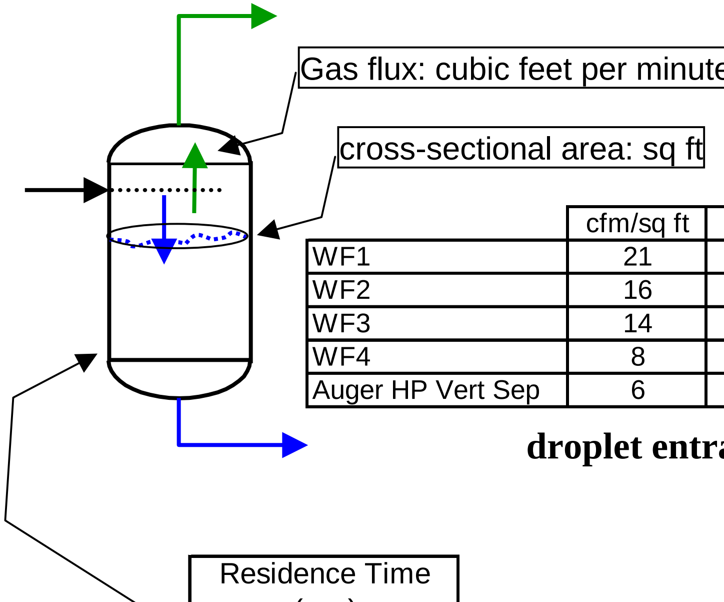
Typical Minox Unit:



Almost all conventional HC G/L systems have scrubbers U/S of compressors, yet this system has:

- No scrubbers
- Limited coalescing filters
- No membrane filters

Carry-Over & Carry-Under:



	cfm/sq ft	cm/hour/sq m
WF1	21	382
WF2	16	288
WF3	14	257
WF4	8	143
Auger HP Vert Sep	6	110

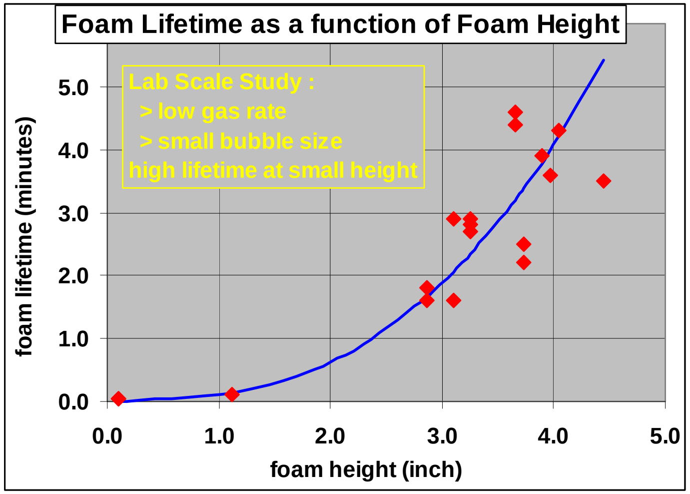
droplet entrainment

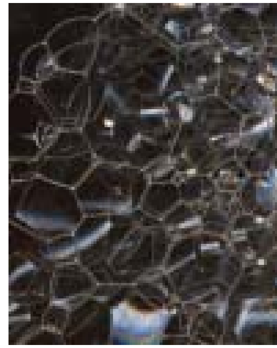
	Residence Time (sec)
WF1	19
WF2	25
WF3	30
WF4	91

carry-under

note variation

Minox Separator Vessel Sizing
Should Account for Foam Height





When upper layers burst, liquid drains into lower layers making them stronger. Thus, a tall foam is a strong foam.

Vessel Design should include Foam Height:

$$H_V = H_O + \underline{H_F} + H_G$$

H_O = height of oil section (retention time = 1 minute)

H_F = height of foam section

H_G = height of gas section (Shell spec)

$$H_F = V_F / A_V$$

$$V_F = k_1 k_F E_F F_o$$

k_1 = constant

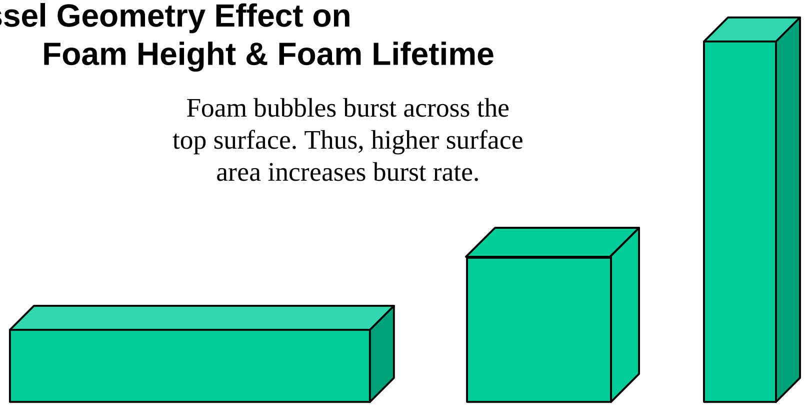
k_F = Foam Height Geometry Factor (dimensionless)

E_F = intrinsic Foam to Oil ratio (ft^3 foam/BPM)

F_O = oil flow rate(BPM)

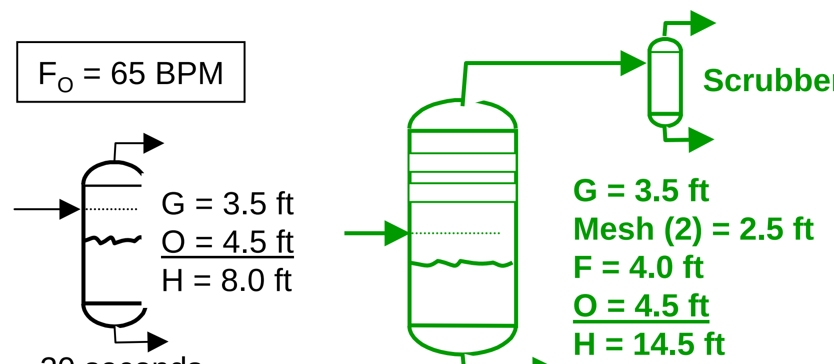
Vessel Geometry Effect on Foam Height & Foam Lifetime

Foam bubbles burst across the top surface. Thus, higher surface area increases burst rate.



Foam Volume (ft^3):	**54**	**54**	**54**
Surface Area (ft^2):	**36**	**18**	**9**
Foam Height (ft):	**1.5**	**3**	**6**
Foam Lifetime (minutes):	**0.5**	**3**	**17**

F_O = 65 BPM



20 seconds water retention ID = 6 ft

60 seconds water retention ID = 10 ft

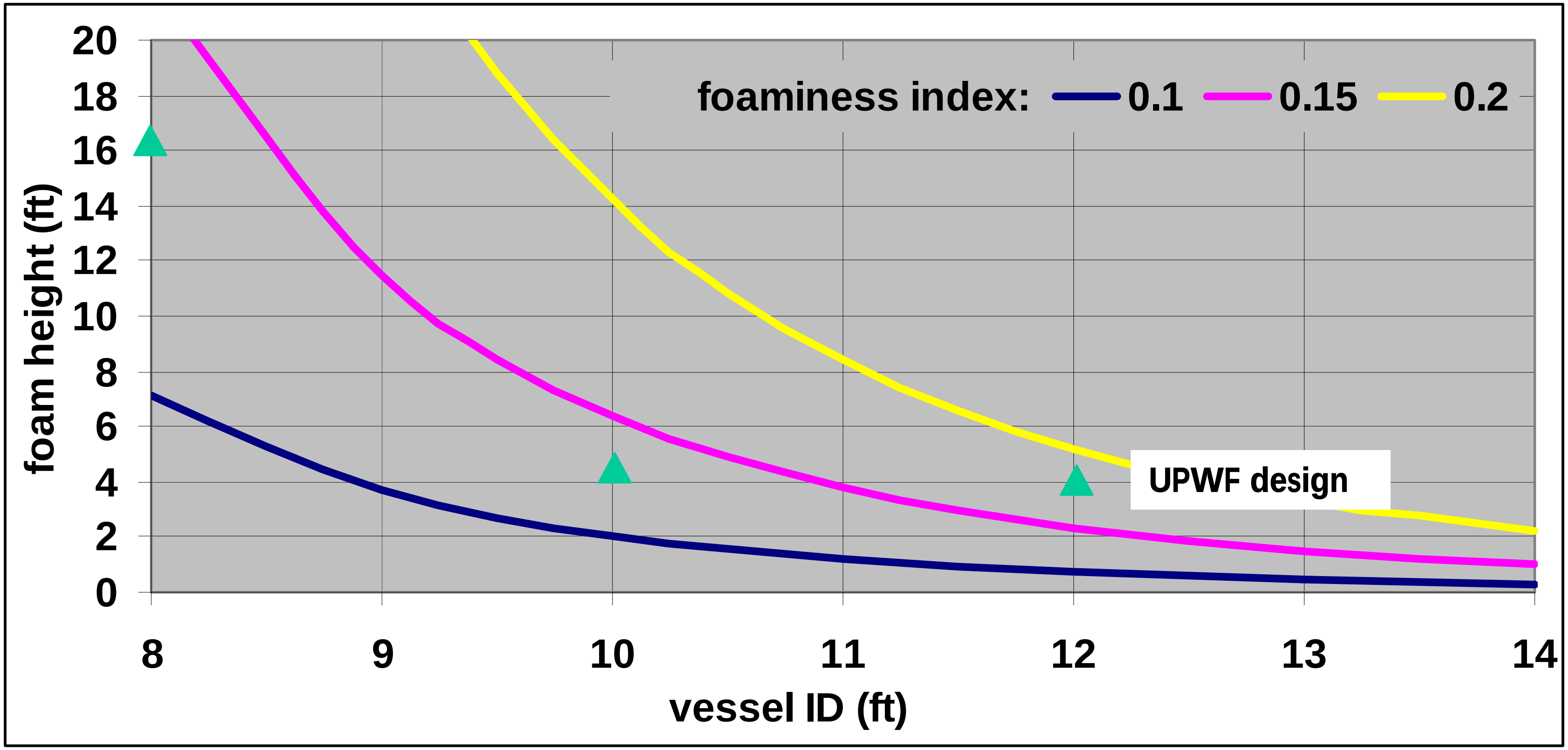
Deuel, Walsh: Deoxygenation Guidance

Seawater / Nitrogen Foam Height Design Curves:

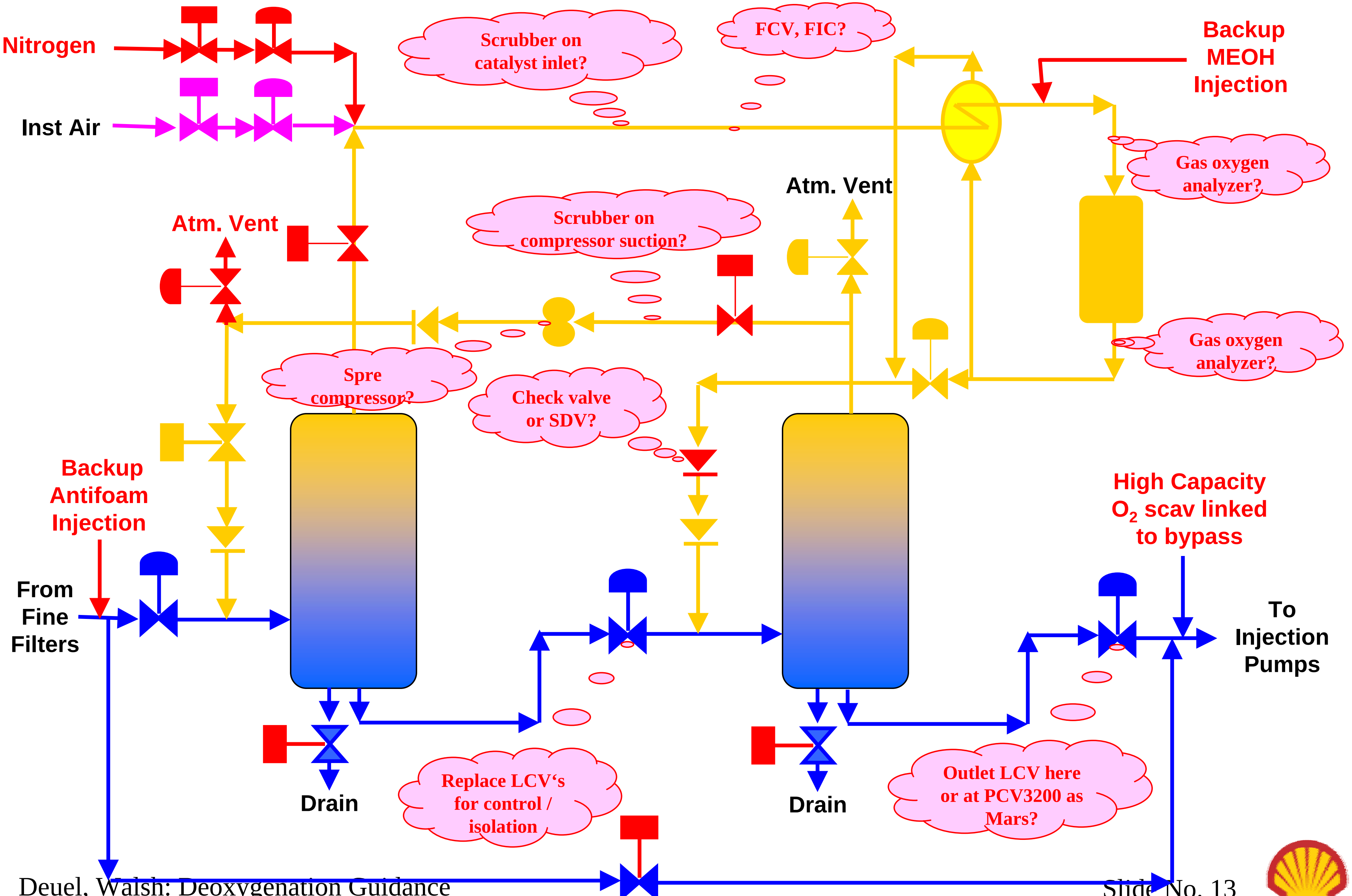
Calibration using Bonga Data:

	Bonga	
Foaminess Index	0.134	cu ft / BPM
Vessel ID	8.43	ft
Liquid flux rate	1.9	BPM / sq ft
Foam height	3.30	ft

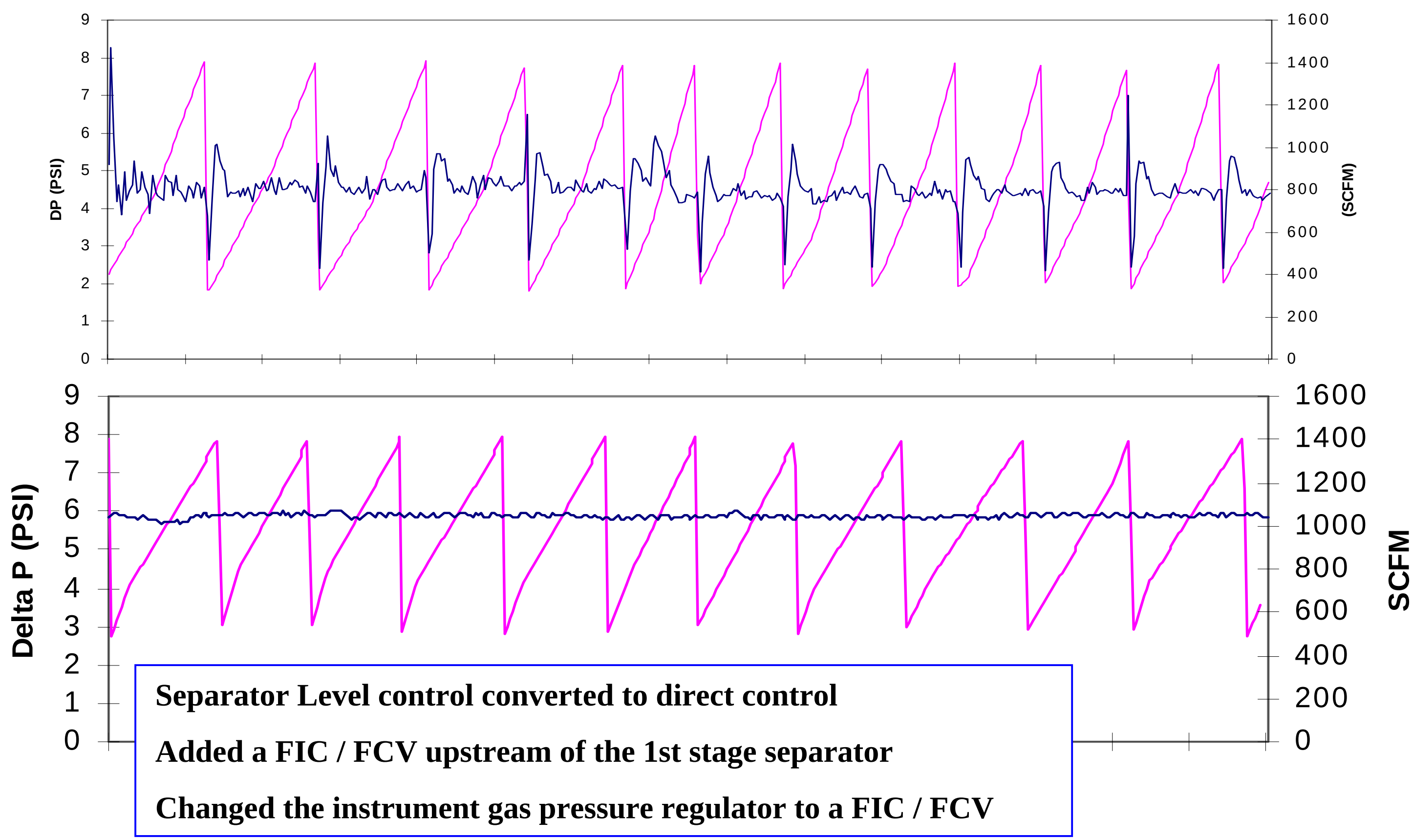
Foam height as a function of vessel ID and foaminess index for the UPWF Minox separators:

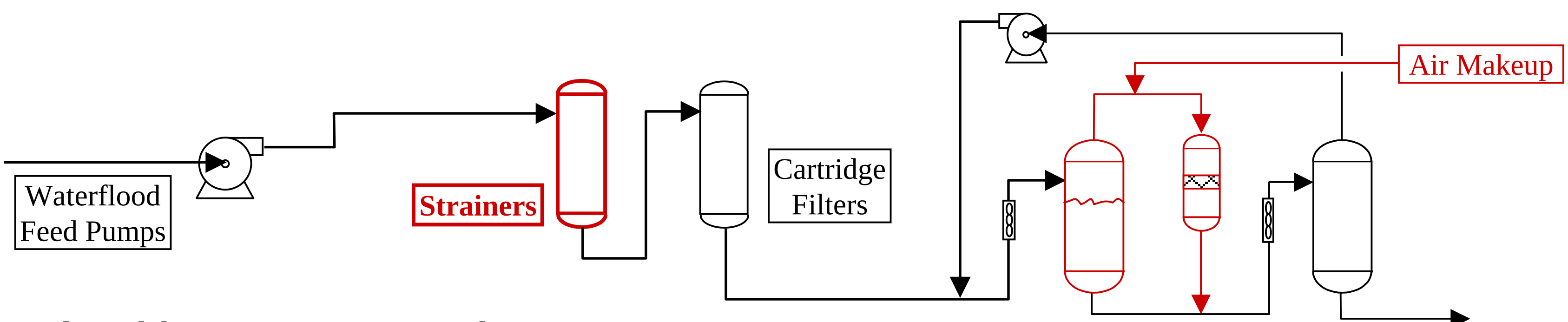


Minox System. Possible Upgrades shown in red



WF2 Complex Oxygen Control Response

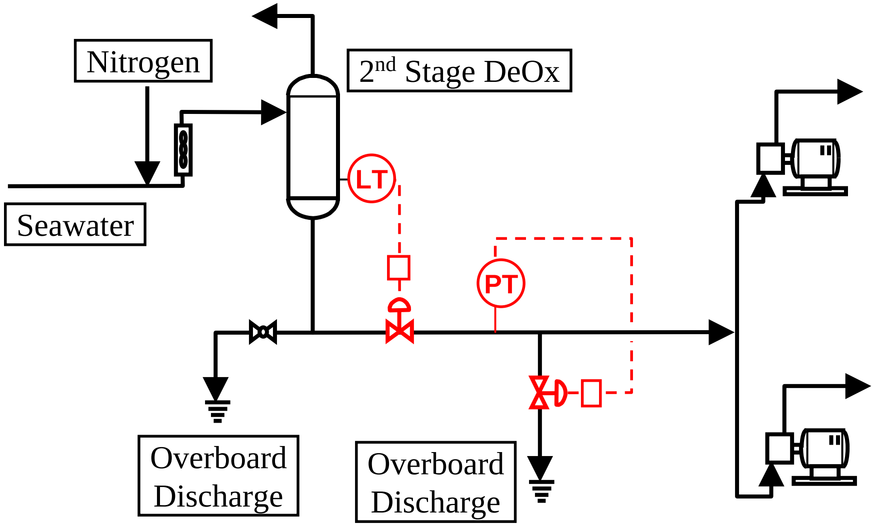




Level / Flow Control for the DeOx / High Pressure Pump system

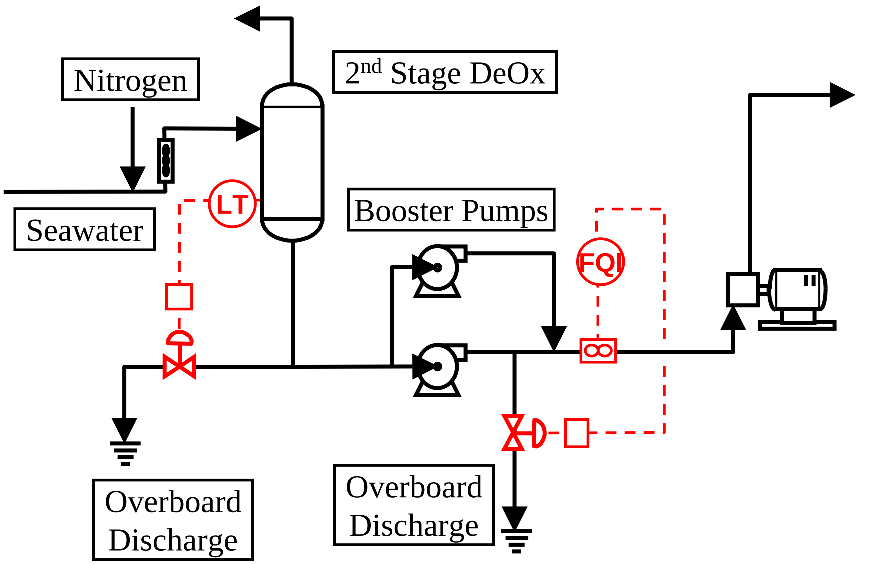
WF1-problems

- Operating experience: frequent trips on startup of HP pumps
- PIT instead of a FIT – sensitive dP / Q relation but too nonlinear



WF2-successful

- Operating experience: no trips on startup of pump systems
- LIC / LCV tied to overflow / discharge line – effective for rapid flow control / response
- Flow sensor tied to overflow / discharge line – effective over broad range of startup & normal operating conditions



Third-Party Review:

- sealing and salt deposition problems in the nitrogen blowers
- inability of the system to respond automatically to flow or temperature changes
- high degree of operator intervention required
- lack of engineering and service capability within Minox Technology
- In addition to the above, doubts remain about the capability of the separators to achieve adequate separation without making them substantially larger.

Holstein Upgrades:

The Minox unit for Holstein as delivered from Kvaerner Process Systems required instrumentation upgrades and de-bottlenecking. These upgrades included:

1. oxygen gas phase analyzers installed on inlet and outlet of the deoxidizer,
2. temperature indicators installed in the same locations as the gas phase oxygen analyzers,
3. methanol flow measurement and control,
4. instrument air flow measurement and control,
5. instrument air coalescing filters,
6. replacement of a Big Joe regulator to a PCV on second stage separator,
7. single 16” static mixer on separator inlets versus two mixers (10” and 12”) in parallel for turn down,
8. changed 50 hp to 60 hp blower driver,
9. increase deoxidizer catalyst bed volume,
10. installed methanol atomizing quill,
11. automated Minox inlet and by pass valves,
12. installed methanol and Instrument air mixing orifice,
13. made logic changes from sea water level to flow control
14. Tie-in of all Minox system input / output into the platform Honeywell DCS.

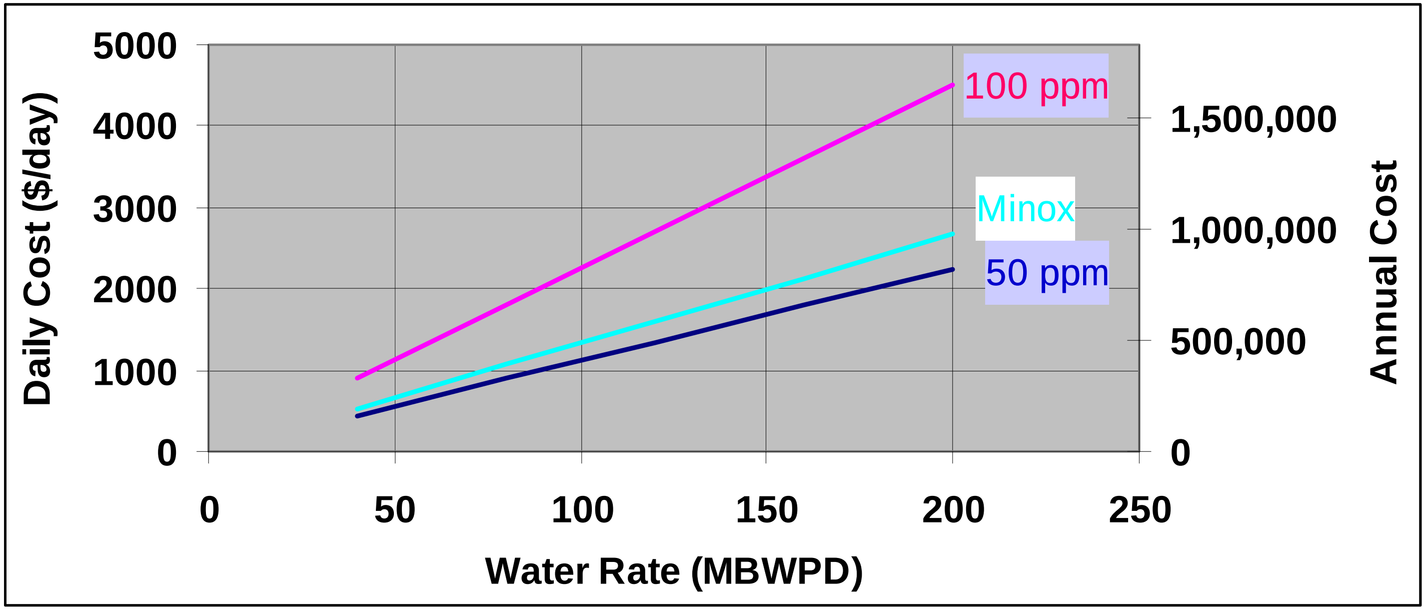
Opex Cost Considerations:

Scavenger: ppm rate depends on water T and source depth

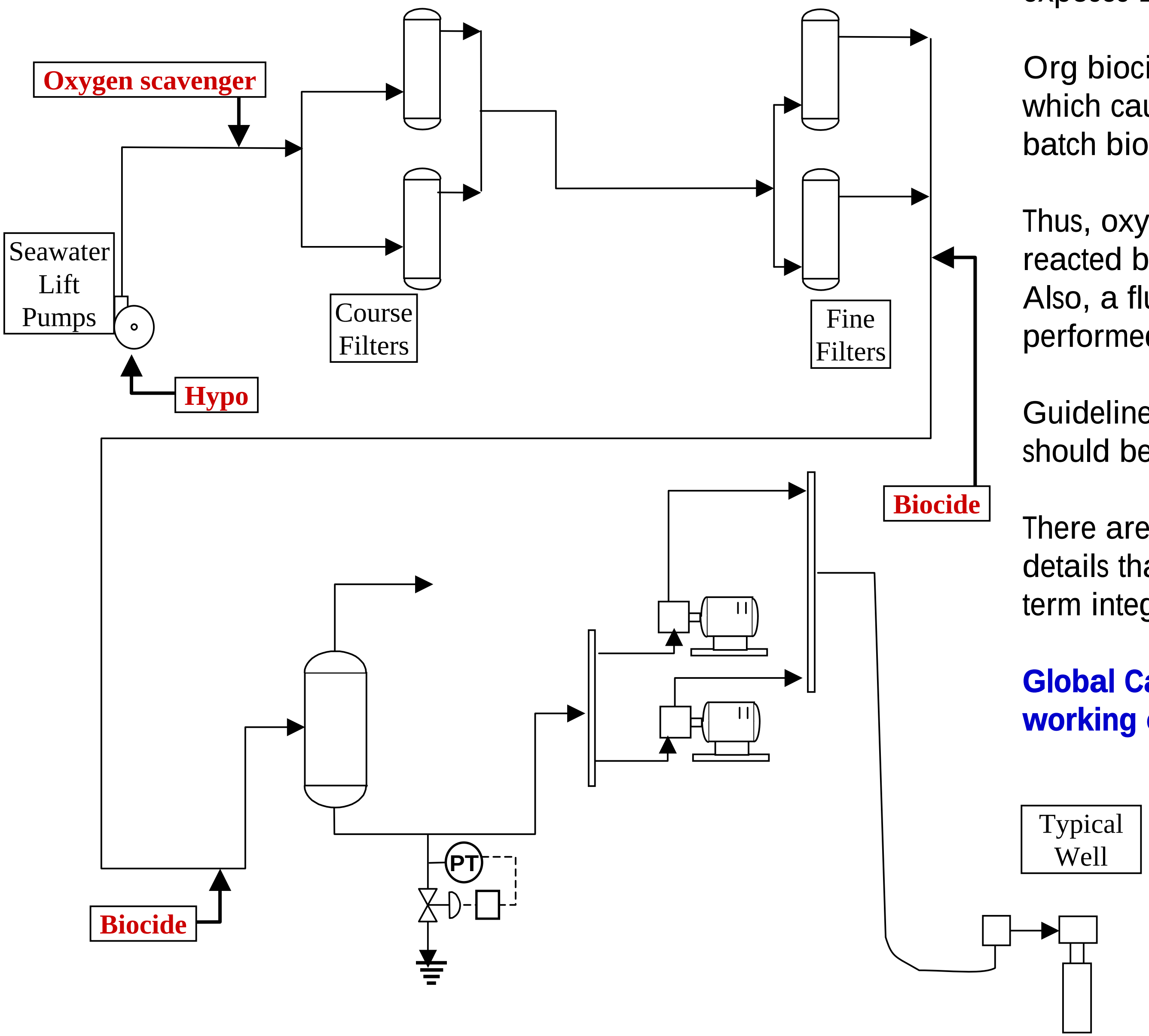
- Holstein: 50 ppm (-650 feet from NSL)
- Bonga: 55 ppm (warm water)
- Brazil: 45 ppm (warm water)
- Mars: 80 ppm

Minox:

- MeOH
- polishing scavenger
- defoamer
- catalyst replacement cost



Hypo / Oxygen Scavenger / Biocide Injection:



Oxy scav is incompatible w/ hypo, which exposes D/S piping to biofilm.

Org biocide is incompatible w/ oxy scav which causes an oxygen excursion when batch biocide is performed.

Thus, oxy scav must be nearly fully reacted before batch biocide addition. Also, a flush biocide treatment can be performed during S/D.

Guidelines for Biomonitoring & Control should be followed.

There are other small but important design details that must be incorporated for long term integrity using chemical.

Global Category Management is working on this Guideline.

Other options:

Stripping tower

Vacuum tower

Even with these, break dependence on production uptime for power, gas, etc need to switch to chemical to achieve waterflood uptime

However with chemical only systems, need to have high quality injection equipment plant uptime, sparing, automated flow control, alarm measurement, etc.,
Need residence time, and tanks

Weight space cost comparisons logistics storage uptime vs Brazil & Bonga uptime 95% +