

Agenda

- **12h00 – 12h30:**
Arrive, meet and a bite – Sponsored by Magalies Water.
- **12h30 – 13h00:**
Introduction to the Oxidation and Disinfection Division – Chairman - Dr Mias van der Walt.
- **13h00 – 13h30:**
Case Study Slot: Industrial Cooling tower Ozonation - Report and Pilot study work done – Air Products SA - Brendan van Wyk.
- **13h30 – 14h00:**
Supplier / Technology Slot: Three short presentations - Ozone Services Industries, NCP, Ozonic.
- **14h00 – 14h30:**
Theory Slot: Presentation on fundamental understanding and design needs in the market – PDNA & Associates.
- **14h30 – 15h00:**
Open discussion and Questions.
- Exhibition - Ozone / UV Technology (small systems) will be on display.

A very biased look at

Oxidation and Disinfection Engineering

in potable water treatment

Tony Ceronio, PD Naidoo & Associates

Oxidation and Disinfection Division WISA

Quarterly meeting, DBSA Midrand
Thursday, 31 August 2006 at 12:00.

Engineering approach

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- Determination of the purpose of the oxidation/disinfection processes
- Oxidation
 - Alternative strategies
 - Effects
- Disinfection
 - Alternative strategies
 - Effects
- Combination and synthesis of process alternatives
 - Preliminary sizing and design
 - Preliminary costing
- Comparisons of process alternatives
 - Technical and operational requirements
 - Legislative requirements
 - Life cycle costs
- Final selection and design

Determination of the purpose of the oxidation/disinfection processes

- Statistical analysis of raw and recycled water quality
 - **Best water** quality available to the plant
 - Data must be **reliable**
 - Reliable in terms of analysis,
 - Reliable in terms of record keeping,
 - Data must be **representative**
 - Representative in terms of source
 - Representative in terms of record length
- Consideration of water quality trends
 - Water quality data trend
 - Catchment development
- Parameters
 - SANS 241
 - Other: Individual taste and odour compounds, algal toxins, cysts and oocysts

Case study analysis

Parameter	SABS 241		Final Water	Supernatant		Raw water		Comments
	Class 0	Class 1	Avg.	50%	95%	50%	95%	
Colour (mg/l Pt)	15	20	5	21	40	20	38	Removal of colour is good, probably in the flocculation/settling. No special treatment is required.
Chlorophyll a (ug/l)	NS	NS	1	2,7	13,2	17,8	38,8	The chlorophyll a value of the raw water is substantially higher than that of the supernatant and the levels in the raw water warrants DAF as a phase separation unit process
Total dissolved solids (mg/l)	450	1000	293	328	429	299	378	TDS levels in the final water is still below taste threshold of 300 mg/l. The supernatant has higher TDS levels due to the waste being concentrated and Ferric flocs adding to the salinity. Conventional treatment will not remove TDS
TOC (mg/l C) - DOC standards	5	10	5	5,8	9,0	5,8	9,2	The organic content in the water is relatively low if compared to other eutrophic sources like the Hartbeespoort dam and the Rietvlei dam, which has DOC levels of 10-12 mg/l. Should GAC be used for taste and odour removal, exhaustion of the carbon should occur at lower rates than say the GAC used at Rietvlei.
pH	6 – 9	5 – 9,5	8,0	7,9	8,2	8,3	8,6	pH drops a bit due to ferric dosing, water is well buffered
Turbidity (NTU)	0,1	1	0,3	4,1	11,7	4,4	12,6	The turbidity values in the supernatant are lower than that in the raw water and might be used only in a DAF process or even direct filtration. It has also been established that the high peaks of turbidity experienced in 2000 is not reflected in the data and it is known that the raw water turbidity values can exceed 1000 NTU at times. It will be possible to operate the plant without sedimentation only if high turbidity raw waters are diverted away to Vaalkop #2 and 3.
Alkalinity (mg/l CaCO ₃)	NS	NS	107	132	155	122	135	Water is well buffered and will not undergo pH fluctuations due to Ferric dosing.
Fluoride (mg/l F)	0,7	1	0,55	0,42	0,54	0,44	0,61	The final water will require limited fluoride dosing to obtain 0,7 mg/l.
Iron (mg/l Fe)	0,01	0,2	0,02	0,1	0,3	0,1	0,4	The occasional high levels of iron and manganese require special attention in the form of an oxidation step – as is indeed being practised at the raw water pumping station in the form of chlorination.
Manganese (mg/l Mn)	0,05	0,1	0,02	0,01	0,12	0,02	0,10	
Calcium (mg/l Ca)	80	150	33	40	49	33	38	The water can be classified as moderately hard with the supernatant values higher than those in the raw water – this is due to the concentration of waste water and lime added also increase the Ca levels
Magnesium (mg/l Mg)	30	70	18	32	36	25	30	As with Ca parameter. Values are slightly above Class 0 values. This indicates the possibility of slight scaling problems but no health and aesthetic effects.
Chloride (mg/l Cl)	100	200	51	56	70	47	59	Chloride values are higher in the supernatant due to concentration of ferric flocs and release of chloride – still well below SABS 241 limit

Conclusions reached in the case study water quality analysis

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- TOC/DOC is low but can be lower
- Manganese and iron levels are high
- High levels of bacteriological activity in the recycled water
- Cysts and oocysts are a concern (from above and from counts performed on raw water)
- Algal toxins are a concern
- Taste and odours in the raw and recycled water is a concern
- In future the raw water is expected to present:
 - Increased algal loads
 - Increased occurrences of taste and odour events
 - Increased incidents and higher levels of algal toxins

The evaluation showed that many questions could not be answered by the available data and suggested some experimentation and studies

Purpose of oxidation/disinfection in the case study:

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Oxidation

- ✓ Iron and manganese
- ✓ TOC/NOM
- ✓ Organic Taste and odour
- ✓ Algal toxins
- ✓ Algal removal and activity reduction
- Inorganic taste and odour
- Synthetic organic compounds
- Colour removal
- Environmental pollutants

Disinfection

- ✓ General pathogenic organisms
- ✓ Giardia
- ✓ Cryptosporidium
- Control of bio-growth

Treatment technologies other than oxidation were also considered but are not discussed in detail in this presentation

Which oxidation alternatives are available

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	Chlorine	Ozone	Chlorine dioxide	Potassium permanganate
Iron and manganese	√ Complexed?	√ Complexed?	√ Complexed?	√ Complexed?
TOC/NOM		√ with GAC		
Organic Taste and odour	Marginal	With hydroxile formation	Geosmin and 2-MIB?	Marginal
Algal removal and Activity reduction	√ ?	√ ?	√ ?	√ ?
Algal toxins	√ ?	√ with GAC	√ ?	√ ?
With chloramines?		Moderate DBP - high THMFP	High DBP	

Inactivation of pathogens

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- What defines “sufficient care” in pathogen inactivation?
 - Local design guidelines are lacking
- International standards and guidelines:
 - USEPA
 - LT1ESWTR (2002): Control of pathogens and addresses risk trade-offs with DBPs.
 - Stage 2 D/DBP rule (2003): Focusses on DBP compliance
 - LT2ESWTR (2003-2006): Sets *Cryptosporidium* removal levels
 - Australian Drinking Water Guidelines (2004)

USEPA bin classification

TABLE IV.B-1.—BIN CLASSIFICATION TABLE FOR FILTERED PWSs

For PWSs that are:	with a Cryptosporidium bin concentration of . . .	The bin classification is . . .
* * * required to monitor for Cryptosporidium	less than 0.075 oocysts/L	Bin 1.
	0.075 oocysts/L or higher, but less than 1.0 oocysts/L ..	Bin 2.
	1.0 oocysts/L or higher, but less than 3.0 oocysts/L	Bin 3.
	3.0 oocysts/L or higher	Bin 4.
* * * serving fewer than 10,000 people and NOT required to monitor for Cryptosporidium ¹ .	NA	Bin 1.

¹ Filtered PWSs serving fewer than 10,000 people are not required to monitor for Cryptosporidium if they monitor for E. coli and demonstrate a mean concentration of E. coli less than or equal to 10/100 mL for lake/reservoir sources or 50/100 mL for flowing stream sources or do not exceed an alternative State-approved indicator trigger (see section IV.A.1).

Treatment requirements

TABLE IV.B-2.—TREATMENT REQUIREMENTS FOR LT2ESWTR BIN CLASSIFICATIONS

If your bin classification is . . .	And you use the following filtration treatment in full compliance with the SWTR, IESWTR, and LT1ESWTR (as applicable), then your additional treatment requirements are . . .		
	Conventional filtration treatment ¹ , diatomaceous earth filtration, or slow sand filtration	Direct filtration	Alternative filtration technologies
Bin 1	No additional treatment	No additional treatment	No additional treatment.
Bin 2	1-log treatment ²	1.5-log treatment ²	As determined by the State ^{2,4}
Bin 3	2-log treatment ³	2.5-log treatment ³	As determined by the State ^{3,5}
Bin 4	2.5-log treatment ³	3-log treatment ³	As determined by the State ^{3,6}

¹Applies to a treatment train using separate, sequential, unit processes for coagulation/flocculation, clarification, and granular media filtration. Clarification includes any solid/liquid separation process following coagulation where accumulated solids are removed during this separate component of the treatment system.

²PWSs may use any technology or combination of technologies from the microbial toolbox in section IV.D.

³PWSs must achieve at least 1-log of the required treatment using ozone, chlorine dioxide, UV, membranes, bag filtration, cartridge filtration, or bank filtration.

⁴Total Cryptosporidium removal and inactivation must be at least 4.0 log.

⁵Total Cryptosporidium removal and inactivation must be at least 5.0 log.

⁶Total Cryptosporidium removal and inactivation must be at least 5.5 log.

Microbial toolbox credits

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- Watershed control program – 0,5 cr
- Presedimentation with coagulation – 0,5 cr
- 2 Stage lime softening – 0,5 cr
- Bank filtration – 0,5 to 1 cr
- Combined filter < 0,15NTU 95% - 0,5 cr
- Individual filter < 0,15NTU 95% <0,3NTU – 0,5 cr
- Demonstration of performance - based on demonstr.
- Add. Bag and cartridge filters - based on demonstr.
- Membrane filtration - based on demonstr.
- 2nd stage filtration - 0,5 cr
- Slow sand filters - 2,5 cr (3,0 cr)
- Chlorine dioxide, ozone, UV - Tables

Ct-values

TABLE IV.D-3.—CT VALUES FOR CRYPTOSPORIDIUM INACTIVATION BY OZONE¹ (MG/L × MIN)

Log credit	Water temperature, °C										
	≤0.5	1	2	3	5	7	10	15	20	25	30
0.25	6.0	5.8	5.2	4.8	4.0	3.3	2.5	1.6	1.0	0.6	0.39
0.5	12	12	10	9.5	7.9	6.5	4.9	3.1	2.0	1.2	0.78
1.0	24	23	21	19	16	13	9.9	6.2	3.9	2.5	1.6
1.5	36	35	31	29	24	20	15	9.3	5.9	3.7	2.4
2.0	48	46	42	38	32	26	20	12	7.8	4.9	3.1
2.5	60	58	52	48	40	33	25	16	9.8	6.2	3.9
3.0	72	69	63	57	47	39	30	19	12	7.4	4.7

¹PWSs may use this equation to determine log credit between the indicated values: $\text{Log credit} = (0.0397 \times (1.09757)^{T_{\text{temp}}}) \times \text{CT}$.

TABLE IV.D-4.—CT VALUES FOR CRYPTOSPORIDIUM INACTIVATION BY CHLORINE DIOXIDE¹ (MG/L × MIN)

Log credit	Water temperature, °C										
	≤0.5	1	2	3	5	7	10	15	20	25	30
0.25	159	153	140	128	107	90	69	45	29	19	12
0.5	319	305	279	256	214	180	138	89	58	38	24
1.0	637	610	558	511	429	360	277	179	116	75	49
1.5	956	915	838	767	643	539	415	268	174	113	73
2.0	1275	1220	1117	1023	858	719	553	357	232	150	98
2.5	1594	1525	1396	1278	1072	899	691	447	289	188	122
3.0	1912	1830	1675	1534	1286	1079	830	536	347	226	147

¹PWSs may use this equation to determine log credit between the indicated values: $\text{Log credit} = (0.001506 \times (1.09116)^{T_{\text{temp}}}) \times \text{CT}$.

UV dose requirements

TABLE IV.D-5.—UV DOSE REQUIREMENTS FOR CRYPTOSPORIDIUM, GIARDIA LAMBLIA, AND VIRUS INACTIVATION CREDIT

Log credit	Cryptosporidium UV dose (mJ/cm ²)	Giardia lamblia UV dose (mJ/cm ²)	Virus UV dose (mJ/cm ²)
0.5	1.6	1.5	99
1.0	2.5	2.1	58
1.5	3.9	3.0	79
2.0	5.8	5.2	100
2.5	8.5	7.7	121
3.0	12	11	143
3.5	15	15	163
4.0	22	22	186

Additional UV requirements

- All UV disinfection systems installed in drinking water or unrestricted reuse application must undergo validation testing prior to their installation
- Validation testing consists of quantifying the inactivation of a virus surrogate as a function of flow rate through the system and involves:
 - Full scale testing of a reactor that conforms uniformly to the UV reactors used by PWS and
 - Inactivation of a test micro-organism whose dose response characteristics have been quantified with low pressure mercury lamps

Conclusion on disinfection

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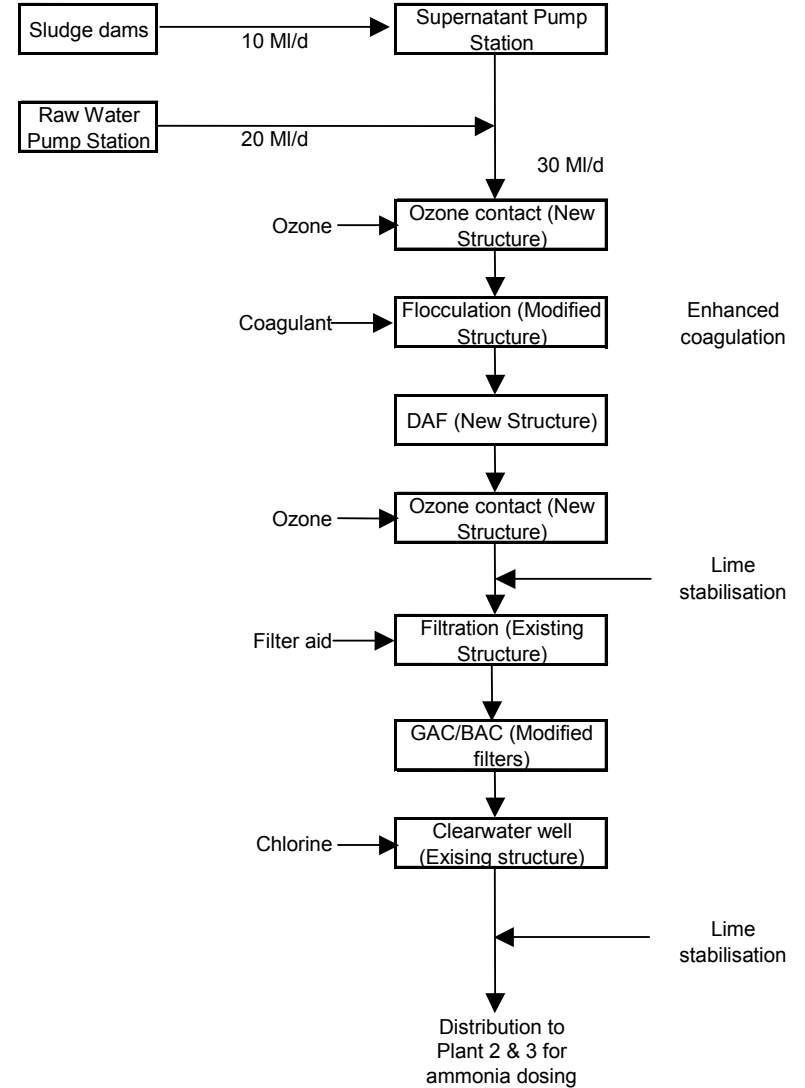
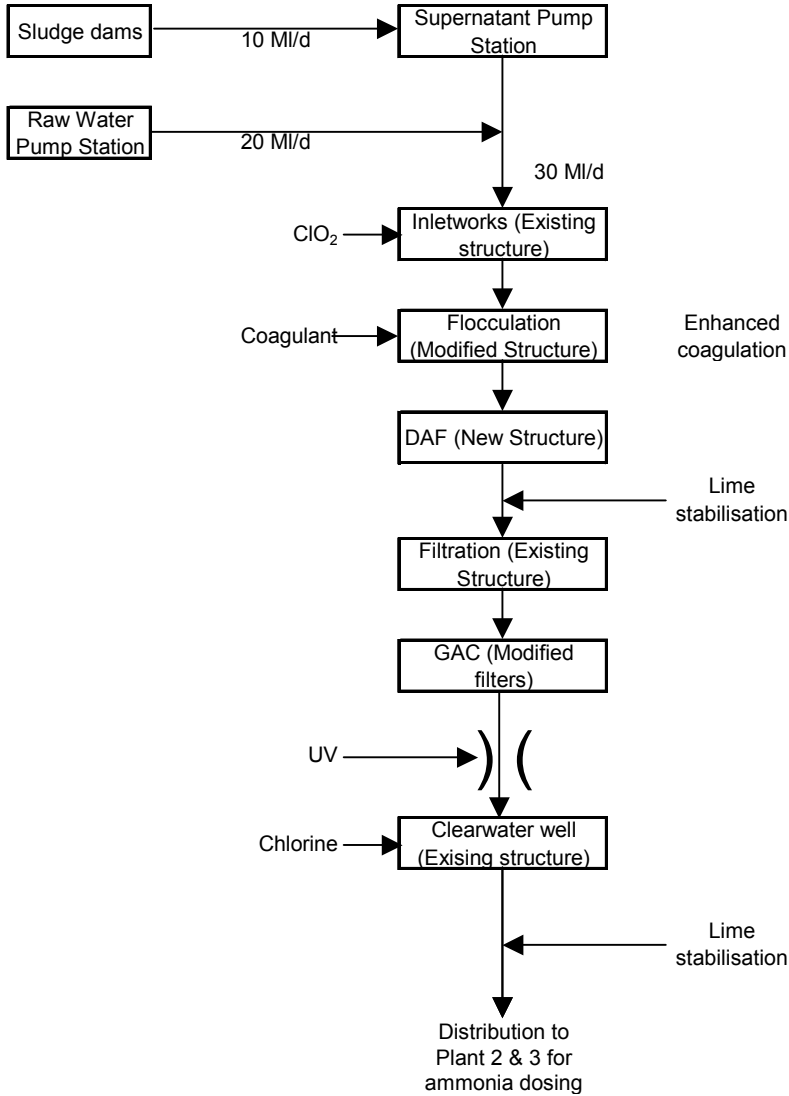
- Plant classifies under “Bin 4”
- Plant requires an additional 2,5 log removal credits ***IF*** filter water quality is acceptable (< 0,15 NTU)
- At least 1 log removal must be via ozone, chlorine dioxide, UV membranes or additional filtration.
- The microbial toolbox does not offer much in terms of feasible alternatives
- Disinfection options:
 - Ozone @ 10C: Ct = 25 (1mg/l after 25 min)
 - ClO₂ @ 10C: Ct = 690 (not feasible)
 - ClO₂ + UV

Engineering approach

PDNA

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Treatment alternatives



Life cycle costing

Item	Detail				Option 1		Option 2	
					R/annum	c/m ³	R/annum	c/m ³
Capital payment					<u>R 3,544,033</u>	<u>32.4</u>	<u>R 4,776,403</u>	<u>43.6</u>
Civil	over	20 years	@	11%	R 664,275	6.1	R 781,697	7.1
Mech/Elec/fees	over	10 years	@	11%	R 2,879,758	26.3	R 3,994,706	36.5
Maintenance					<u>R 567,480</u>	<u>5.2</u>	<u>R 449,733</u>	<u>4.1</u>
Civil		1% per annum			R 42,904	0.4	R 50,488	0.5
Mech / Elec		4% per annum			R 524,576	4.8	R 399,245	3.6
Operational					<u>R 3,974,578</u>	<u>36.3</u>	<u>R 1,377,482</u>	<u>12.6</u>
ClO ₂ - oxidation	0.25 mg/l @	105 R/kg			R 287,438	2.6		
ClO ₂ - disinfection	2.5 mg/l @	105 R/kg			R 2,874,375	26.3		
Ozone - electricity	345 kW @	0.2 R/kWh					R 604,440	5.5
Ozone - kVA	518 kVA @	R 40 /kVA/ month					R 248,400	2.3
Ozone maintenance	Allow	4% per annum					R 243,392	2.2
GAC regeneration	93750 kg @	4.5 R/kg every	18 mths				R 281,250	2.6
GAC regeneration	93750 kg @	4.5 R/kg every	9 mths		R 562,500	5.1		
UV - electricity	40 kW @	0.2 R/kWh			R 70,080	0.6		
UV - kVA	80 kVA @	R 40 /kVA/ month			R 38,400	0.4		
UV - maintenance	10% of cost/a for lamp replacement +4%				R 141,785	1.3		
Present value of future operational/maint. cost over 15 years @ 10%					R 68,130,867		R 27,408,222	
Estimated capital value					R 23,314,400		R 31,307,400	
TOTAL NET PRESENT VALUE					R 91,445,267		R 58,715,622	

Recommendations from the design

- Select alternative 2 based on:
 - Cost over the project life
 - One oxidant/disinfectant vs. 2
 - Operational issues are of similar complexity



General conclusions

- The purpose of the oxidant/disinfectant has to be defined
- There is no general process and each case has to be reviewed on its merits
- Pilot plant testing and design verification must receive more attention
- Disinfection design must be accountable to generally accepted guidelines
- Life cycle costing must be considered

Questions and discussion

- *Australian Drinking Water Guidelines (2004)*

Cryptosporidium oocysts are extremely resistant to chlorine and will not be killed by concentrations that can be practically used in drinking water. Other disinfectants such as ozone are more effective (Bouchier 1998). Recent developments have suggested that particular types of ultraviolet light disinfection may be effective against *Cryptosporidium* when assessed using animal models of infectivity. However, the scientific evidence is incomplete and further investigations are required before clear guidance can be provided on the applicability of the identified technologies to water supplies.