Disinfectant dosing of blended drinking waters

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Abstract:

In order to secure drinking water supply in South Australia, a seawater desalination RO plant (SWRO) is to be constructed for commencement of operation in 2010. The plant will be located Port Stanvac and will produce desalinated water supplied directly to customers or following blending with conventionally treated (coagulation, flocculation, settling, filtration and disinfection; Happy Valley WTP) water sourced from local catchments and the River Murray. Disinfection will be performed on the treated surface water and following blending with RO water at various mix ratios.

Supplementation of treated drinking water from the Happy Valley WTP with variable proportions of desalinated water will present new challenges to water treatment plant operators in determining the correct chemical disinfectant dose needed to ensure compliance with drinking water quality guidelines and community expectations. Chlorine is used as the primary disinfectant in drinking water supply at all Adelaide metropolitan water treatment plants, and is planned for the Adelaide Desalination Plant at Port Stanvac. This disinfectant is effective for a range of microbial pathogens that can potentially be found in drinking water but can decay rapidly in oxidation reactions with organic compounds present in surface and ground waters. The rate of chlorine decay is also influenced by factors such as pH and temperature of the water.

In planning and development of the SWRO plant, procedures for disinfectant dosing that result in compliance with Australian Drinking Water Guidelines for water quality need to be established. In order to develop a practical disinfectant dosing procedure for blended waters, a range of laboratory based chlorine-decay experiments were conducted of simulated blended waters to generate data from which chlorine decay models might be developed. Chlorine decay data was generated of treated water from the Happy Valley WTP (post filtration), following blending with a synthetic RO water (SW) and of the SW alone.. A range of chlorine doses and temperatures were trialled in the chlorine decay experiments. From this data, a chlorine decay model was established that describes decay through reactions of chlorine with 'fast' and 'slow' reacting compounds. The model is an exponential decay function comprising two components that describe the fast and slow decay reactions. This proposed model requires minimal input data, comprising the initial chlorine dose and the chlorine residual at 72 hours of the unblended Happy Valley treated water, to estimate decay curves for blended waters. It is anticipated that from this modelling approach, suitable disinfectant doses may be rapidly determined.

Keywords: Chlorine decay, desalination, blend, fresh surface water.

1. INTRODUCTION

Extended drought and impacts from climate change in the southern regions of Australia have reduced the security of drinking water supplies sourced from local catchments and from the Murray-Darling Basin. To address the reduced water security, state governments in Australia have embarked on the development of seawater desalination plants. In South Australia, the state government has approved the construction of a seawater reverse-osmosis desalination plant (SWRO) at Port Stanvac, scheduled to commence production in December 2010. When completed, the desalinated water will be pumped to the Happy Valley Water Treatment Plant and there blended with conventionally treated (coagulation, flocculation, sedimentation and disinfection) surface water before distribution to customers. The blended water ratio will vary from 0-100%, depending on surface water availability, operational cost efficiency, water quality targets and customer demands. It is anticipated that the blending proportions of treated fresh water with desalinated seawater will change frequently and rapidly.

The blending of waters will present new challenges to water treatment plant (WTP) operators in determining the chemical disinfectant doses needed to ensure compliance with drinking water quality guidelines and community expectations. Chlorine is used as the primary disinfectant in drinking water supply at all Adelaide metropolitan water treatment plants, and is planned for the new SWRO plant at Port Stanvac. This disinfectant is generally very effective but can decay rapidly in oxidation reactions with organic compounds present in surface and ground waters. In contrast to conventionally treated water, desalinated water by reverse-osmosis (RO) is predominantly free of natural organic matter. As a consequence, chlorine decay rates are very low compared with natural fresh waters. In planning and development of the SWRO plant, procedures for disinfectant dosing that maintain compliance to the Australian Drinking Water Guidelines, for waters blended at frequently changing ratios, need to be established.

The application of models and predictive tools in the supply of drinking water has been widely reported, including Adgar et al. 2000 (process control); Baxter et al. 2002, Stanley et al. 2000, van Leeuwen et al. 2003 and 2005, Daly et al 2007(coagulation control), Kastl et al. 2004 (removal of dissolved organic matter), and Sohn et al 2004 (disinfectant by-product formation). A range of mathematical approaches and prediction techniques have been used including multivariate analysis, polynomials, exponential functions, artificial neural networks, linguistic equations and Langmuir isotherms (Daly et al. 2007).

Here, we report the development of a model designed to enable prediction of disinfectant (chlorine) decay in fresh surface water blended with desalinated seawater, at different percentage ratios. The model was developed from data acquired of Happy Valley Reservoir (South Australia) water and synthetic RO water.
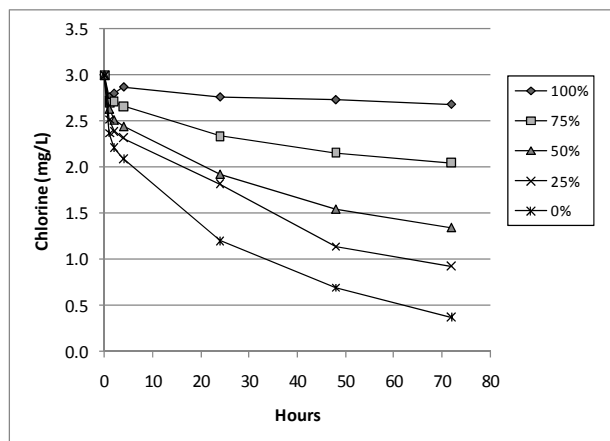
.2. MATERIALS AND METHODS

In order to generate data from which mathematical models could be developed, chlorine decay experiments were conducted on water samples collected from the Happy Valley Water Treatment Plant (post coagulation and filtration) and following blending of this water with a synthetic water (SW) sample that simulated reverse osmosis water. The SW was prepared with high purity Milli-Q water with the following chemical composition: total dissolved solids, 300 mg/L; pH 8.0; alkalinity (as $CaCO_3$) 60 mg/L; calcium, 20mg/L; bromide, 0.65 mg/L and boron, 1.1 mg/L. Chemicals added to Milli-Q water were NaCl, NaOH, HCl, $NaHCO_3$, $CaCl_2$, NaBr and sodium tetraborate, of analytical grade.

Chlorine decay tests were performed as described by Eaton et al. (1998) and Daly et al. (2007). These were conducted on Happy Valley conventionally treated water post filtration (HVCTW) and water samples blended (at 25%, 50% and 75%) with the simulated RO water. Chlorine doses used ranged from 2 to 4mg/L at 15°C and 25°C.

Data generated from one series of chlorine decay experiments conducted at 25°C, where the initial chlorine (Cl_2) dose (C_0) was 3 mg/L are shown in Figure 1. From this data set, a decay function was determined that relates the residual chlorine in HVCTW and blended waters with the initial chlorine dose and time since dosing, over

72 hours. The decay function has two components that describe rapid and slow disinfectant decay, as previously detailed by Fisher et al. (2004).

From these equations, a model was further developed that allows chlorine residual estimation from the initial chlorine dose and the residual in HVCTW water only at 72 hours. Further data series of chlorine decays were obtained by experimentation to compare these with model data.

Figure 1. Chlorine residuals in Happy Valley treated water and blended water samples dosed with chlorine at 3 mg/L at $25^{o}C$

3. RESULTS AND DISCUSSION

From the chlorine decay curves of HVCTW (0%), SW (100%) and blended waters (25 to 75%) shown in Figure 1, the variable coefficients (A, B, C and D) of Equation 1 that describes each curve were determined (Table 1). The initial chlorine dose applied to the water is the sum of A and C, and from this data the ratio of A to chlorine dose (R1) for each curve was determined. For that data set, the relationship between R1 and the blended percentage was determined (Equation 3). It was assumed that from this relationship, the A and C coefficients could be determined for different chlorine doses applied to Happy Valley water.

Chlorine Residual$_{total}$ (mg/L) = $Ae^{(-Bt)} + Ce^{(-Dt)}$ (1)

Where t=time (hr) and the algorithm coefficients of data shown in Figure 1 are detailed in Table 1.

The D variables of Equation 1 (Table 1) describe the decay rates of the slow reacting organics. A relationship between this variable and blend percentage is given by Equation 6. The B variables describe the decay rates of fast reacting organic compounds and from the data set used, no apparent trend was evident, with values mostly above 1. Various B values within the range 1.4 to 6 were trialled for fitting against actual chlorine residual values of Table 1, and the B value of 2.4 was selected. With these B variables at t>2hr, the Equation 1 component, $Ae^{(-Bt)}$ approaches zero. Hence, the chlorine residual is described by $Ce^{(-Dt)}$, at t>2 hr.

Table 1. Co-efficient values of chlorine decay curves (Equation 1) of HVCTW, SW and blends dosed with Cl_2 at 3 mg/L at $25^{o}C$.

Blend	A	B	C	D	A/(A+C)[*]	C/(A+C)[‡]
0%	0.6687	2.6147	2.3274	0.02588	0.2229	0.7771
25%	0.5131	3.2278	2.4851	0.01449	0.1710	0.8290
50%	0.4863	1.3682	2.5001	0.00945	0.1621	0.8379
75%	0.3074	6.0480	2.6925	0.00422	0.1025	0.8975
100%	0.18799	-	2.8120	0.00065	0.0627	0.9373

[*]Ratio1, R1, and Ratio 2, [‡]R2;

Chlorine dose (mg/L), $Cl_0 = A + C$ (2)

A= Cl_0 x A/(A+C) (3)

Where A/(A+C) = 0.2221-0.001556 x % and % is the blend percentage.

B = 2.4, (value between 1.4 and 6.1). (4)

$C = Cl_0 - A$ (5)

$D = -0.005238 + 0.03085e^{(-0.016\ 0024\ x\ \%)}$ (6)

In order to develop a practical tool for water treatment operators to determine chlorine dosing requirements for HVCTW, SW and blended waters, the aim of the model development is for minimal input data requirement. Laboratory experimentation and water sample analyses to generate chlorine decay curves are both expensive and time consuming, and this would be demanding where two sources of water are mixed at ratios that vary frequently. Therefore the model development aims to allow prediction of chlorine decay curves for a selected blend mix, based on data only of the initial dose applied and of the residual chlorine concentration in HVCTW at 72 hour.

At 72 hours from chlorine dosing, $Ae^{(-Bt)} = \sim 0$; where B variable is 2.4   (7)

and Chlorine Residual$_{72hr,}$ $(Cl_{72}) = \sim Ce^{(-Dt)}$ (8)

From HVCTW data of the chlorine residual at 72 hour and of the chlorine dose (Cl_0) used, the D coefficient variable can be determined,

$D_0 = -Ln(Cl_{72}/C)/72$, where D_0 is of the 0% mix or HVCTW.   (9)

At 0% mix, $C = Cl_0$ x 0.7771 (refer to Table 1).   (10)

With the calculated D coefficient variable at 72 hr, a % (blend) value (0_N%) of a new data set (Chlorine dose$_N$, and 72 hour residual dose$_N$, Data$_N$)) that equates to 0% of the original data (3mg/L chlorine at 25°C, Data$_0$). is calculated.

0_N% (equivalent value to 0_0% Data$_{o\ at\ 72\ hr}$) $=$ $[Ln((D_0 + 0.005238/\ 0.03085)]/0.01600241$ (11)

Reassigning 100% blend range of Data$_N$ between 0_N% and 100% by the following: 100% - 0_N%, the % unit (%$_{NU}$) for Data$_N$ is determined from the following: %$_{NU}$ = (100% - 0_N%) /100,   (12)

which is equivalent to one % (blend) unit of Data$_0$ for Data $_N$.

For a selected % blend (S%) to be modelled for Data$_N$,

N% = S% x %$_{NU}$,   (13)

where N% is the calculated equivalent % blend value to the actual selected % blend (S%.).

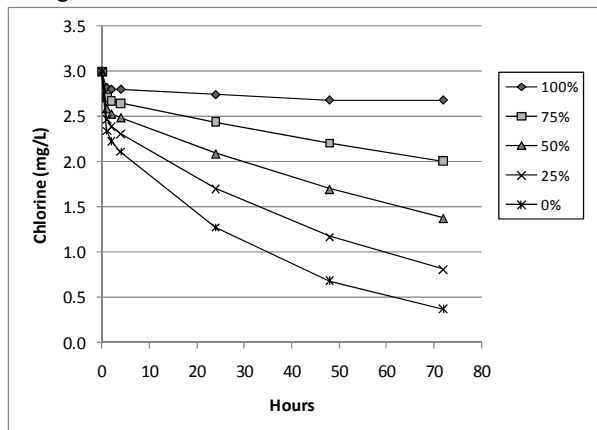Using $D = -0.005238 + 0.03085e^{(-0.016\ 0024\ x\ \%)}$ and N%, new data D values (nD) for each S% are calculated. Using data of R1 or R2, C_0, decay time (t) and D_N, the following can be calculated:

Chlorine Residual$_{t>2hr}$ (mg/L) $= \sim Ce^{(-nDt)}$ and   (14)

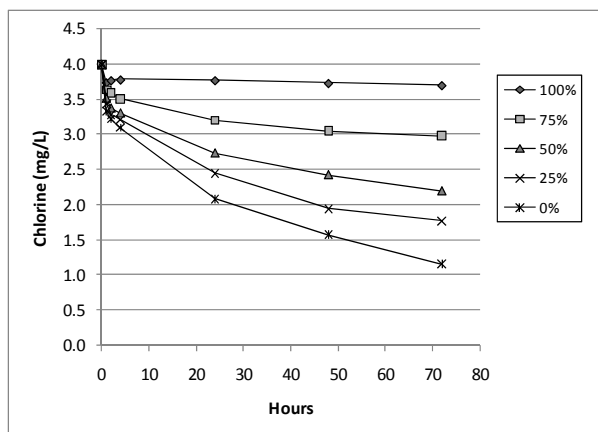Chlorine Residual$_{\leq 2hr} = Ae^{(-Bt)} + Ce^{(-nDt)}$ (15)

where B is taken to be 2.4.

By the above, model fitted data of chlorine decays obtained by laboratory experimentation (Figure 1) are shown in Figure 2.
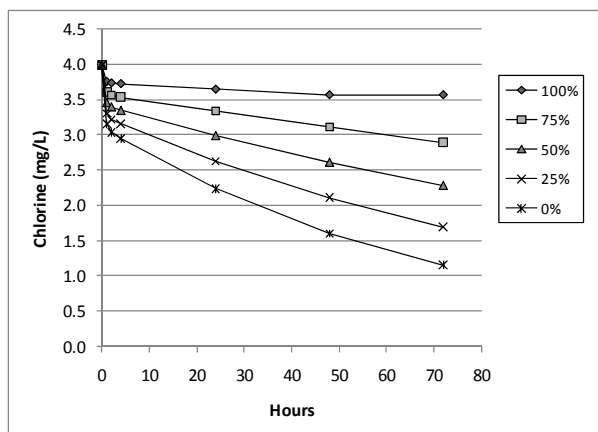

Figure 2. Model chlorine residuals of water samples for a chlorine dose of 3 mg/L at 25°C.

A new data set of chlorine decays with an initial dose of 4 mg/L was generated by laboratory experimentation at 25°C, and is shown in Figure 3.

Figure 3. Chlorine residuals in water samples dosed with chlorine at 4 mg/L at 25°C.

Using the model and input data of the chlorine dose (4 mg/L) and chlorine residual at 72 hours (1.15 mg/L) of Happy Valley water only, chlorine residual data were generated for waters blended between 25 and 75% with SW and SW alone (Figure 4). Predicted chlorine residuals are within 0.2 mg/L of actual residuals.

Figure 4: Model data of chlorine residuals of Happy Valley water, where C$_0$= 4 mg/L; T=25°C.

The model was further evaluated by comparing output data with actual chlorine decay curve data where water samples were tested at 15°C. In these decay experiments, the initial chlorine doses applied ranged between 2.0 and 3.3 mg/L. Model predictions of chlorine residuals between 0 and 72 hr were within 0.3 mg/L of the measured values and predominantly within 0.2 mg/L. It is well recognized that temperature has a significant effect on chlorine decay kinetics, and so modification of the above model will be pursued to specifically account for temperature. Other factors impacting on chlorine decay rates, such as dissolved organic carbon and pH will be investigated to assess the potential for prediction of chlorine decay curves from data of water quality parameters of fresh surface waters. If chlorine decay is able to be predicted by these or similar water quality parameters that can be readily obtained e.g. UV 254 nm absorbance of the HVCTW (a surrogate measure of dissolved organic carbon), then reliance on actual chlorine decay data, such as the 72 hr chlorine residual, may be minimized.

CONCLUSION

A preliminary model of chlorine decay in HVCTW and waters blended with synthetic RO water has been developed from laboratory acquired data. Following further adjustment to the actual quality of Port Stanvac RO water, the model has potential for application at a WTP for chlorine dose prediction for blended waters. The current model is based on input data of 72 hr chlorine residual of HVCTW and chlorine dose to predict the chlorine decay curves for selected percentage blends. Preliminary model evaluation trials have shown predicted chlorine residuals to be within 0.3 mg/L of actual chlorine measurements. Further development of the model will be done with the aim to predict chlorine decay curves from Happy Valley Reservoir source water quality.

ACKNOWLEDGEMENTS

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