NOVEL METHOD OF TRIHALOMETHANEM CONTROL

Gareth Patchett - Principle Engineer, AECOM NZ LTD, Hadi Tai – Process Specialist – AECOM UK Ltd

ABSTRACT

Trihalomethanes (THM) are a bi product of the water treatment process and are formed when chlorine is used as the disinfectant. They are produced whenever chlorine reacts with natural organic matter in the water. If the levels are not controlled then they may become a hazard to health. The level of THM in NZ supplies is restricted by the DWNZ regulations. The maximum allowable value is relatively high (0.2mg/l chloroform compared to 0.1mg/l Total THM in the EU and 0.08mg/l Total THM in the US). In step with international trends this MAV is likely to be reduced in the future and will present an increased challenge to water suppliers and distributors.

The conventional methods of reducing THM levels are to either take measures to reduce the levels of organic matter before chlorination, limit the levels of chlorination as much as possible or to use alternate disinfection methods. All these methods can be effective but also can be complex and costly. Biologically active carbon filters combined with ozone dosing is now an established method used to reduce organic matter. This is effective but has both high capital and operating cost implications. Replacing chlorine with alternate disinfectants (e.g. ozone or UV treatment) is also an option but all other technologies incur an increase in cost and complexity.

In this presentation, an alternate approach that has been used to supplement these is discussed. This is where the contact time with the chlorine is reduced to a minimum and constantly monitored and controlled. The amount of decay of the chlorine is directly proportional to the amount of THM formed and therefore can be predicted and controlled automatically. Work in the UK has shown that the correlation is very reliable and systems have been implemented whereby THM is controlled automatically and a maximum of 0.05mg/l (Total THM) has been achieved with no additional dosing or asset replacement.

The basis of the control is to compare historical contact time (the length of time the water has been subjected to a given chlorine concentration) with the historical inlet and outlet chlorine levels. By working out the decay, the THM level can be calculated. The chlorine levels can then be set to achieve the minimum Ct required and the storage time can be adjusted in a dynamically rather than utilising a fixed set point. For example when flows are low, lower chlorine doses would be applied and less storage might be held.

An operator interface at the SCADA presents the control data clearly and provides both historical information as well as the live THM prediction

KEYWORDS

Disinfection bi products, Contact Time, Organic matter, Chlorine decay

1 INTRODUCTION

Trihalomethanes (THM) are a bi product of the water treatment process and are formed when chlorine is used as the disinfectant. They are produced whenever chlorine reacts with natural organic matter in the water. If the levels are not controlled then they may become a hazard to health.

The challenge was to successfully design and commission a project for five water treatment plants that were to supply over half of the total daily water demand of Northern Ireland and to meet a stringent level for THM in the treated water. Whilst it is normal and expected to design to meet standards for disinfection bi products, in this case the required standard was lower than that experienced by us to date and moreover was an even greater challenge given the nature of the raw water. For all five treatment plants, the raw water consisted of part or all water derived from Lough Neagh or the River Bann. Lough Neagh is the largest lake in the British Isles and has a catchment area that includes large areas of intense agricultural activity as well as waste water plant outfalls along the route of the River Bann. The Lough is shallow with an average depth of less than 10metres. It is known for its high nutrient content and also for experiencing algal blooms during the summer.

Figure 1 – Location of the raw water supply

The maximum allowable level of THM in the treated water was limited to 0.05mg/l (50ug/l) total THM. The design that had been developed for the treatment plants was robust and consisted of pre ozonation, coagulant dosing, dissolved air flotation, rapid filtration, post ozonation, granular activated carbon filters, chlorine dosing and then manganese removal contactors. Despite the sophistication and multi stage treatment process, predicted THM levels were occasionally above the required limit especially during the late summer months when water temperatures are typically around 19^{o}C.

It was clear that a supplementary method was going to be required in order to achieve the challenging standard. In order to tackle this we went back to basics and looked at the factors that affect THM formation and assessed which of the factors were within our control. We broke these down according to the following table;

Table 1 – Assessment of factors affecting THM formation

Factor	**Influence**	**Constraints**	**Action possible Y/N**
Chlorine concentration	Significant	Contract specifies outlet chlorine level. Contact Time must be achieved	Y Potential for flexibility on dosing levels at differing dosing points within the constraint of achieving contact time
Reaction Time available	Significant	Existing storage reservoirs. Contact Time must be achieved	Y Operating levels can be varied within the constraints of achieving contact time and minimum levels of storage
Bromide concentration in raw water	Medium	Raw water quality	N Bromide cannot be removed and brominated species cannot be influenced.
Temperature	High	Weather	N Temperature cannot be modified without substantial cost.
Control of pre cursors; Coagulation dose Coagulation pH, Ozone dose, GAC regeneration frequency	Medium/High	Process operation, Cost and water quality	Y but optimum condition prevail.
pH of outlet water	Medium	Contract	N

By analyzing the parameters in the table we concluded that we could reduce THM levels in the long term by optimizing coagulation control, regenerating GAC at the appropriate frequency and maximizing ozone dosing. This became part of the operating plan for the treatment works. GAC media condition was monitored by the installation of UV 254 absorbance monitors on the post GAC sampling point. Pre and post ozone dosing was installed with a variable dose rate for both dosing points. Coagulation control using raw water turbidity and DOC was also installed and commissioned.

Once these operating practices were in place, in real time, the only parameter that we could directly control was the chlorine retention time in the form of;

- The chlorine level applied before and after the clear water tanks
- The retention time in the clear water tanks

This parameter was identified as critical and complimentary to the longer terms practices.

We therefore had the challenge to be able to relate these two factors to the level of THM formation so as to be able to automatically control the water treatment plants in order to meet the THM level challenge.

2 METHOD OF DEVELOPMENT

In order to control the chlorine retention time it was important to be able to understand the criticality of the measures under different conditions. A method was developed that used utilized models and calculations that have been developed in the industry. The key parameters that needed to be calculated were identified as;

1) Being able to predict the level of chlorine decay given;

    a. The flow rate in and out of the tank

    b. The level of input chlorine

    c. The change in level

    d. The Temperature

2) Being able to predict the amount of THM formation given a level of chlorine decay.

Both of these parameters are influenced by the properties of a given tank (its flow characteristics) and a given decay rate. Therefore experimental data had to be gathered in order to customize the equations that had been previously derived by others.

The method therefore consisted of the following steps

- Modeling the contact tanks to understand and predict the chlorine decay
- Establish the site specific relationship between chlorine decay and THM formation
- Calibrate the model for changes in season and variations in the treatment process

By carrying out testing at laboratory scale, chlorine decay rates could be understood. This was combined with a series of tracer tests for each clear water tank. The tracer tests were carried out at selected different levels and the model of flow and contact time through each tank at different flows was developed.

Then, again at laboratory scale, chlorine retention tests were carried out using water obtained from the new processes. Retention in the clear water tanks was simulated at laboratory scale and a relationship between chlorine decay and THM formation was made. In effect, the constants for the chlorine decay rate equations that had previously been developed by others were established.

$$TTHM = k \,.\, t^a \,.\, Co^b \,.\, TOC^c . Temp^d . pH^e . UV_{254}{}^f . Br^g$$

(Amy et al., 1987; Townsend and Trip, 1995; Clark., 1998; Clarke and Sivaganesan 1998).

$$THM = K_{tc\,.} \,.\, dC$$

(Moore et al 1979, Hua 2001)

Finally the laboratory scale tests were repeated at 2 different seasons so that constants could be established for all conditions.

3 RESULTS

3.1 UNDERSTANDING AND PREDICTING CHLORINE DECAY

The results of the first stage showed clearly that the model that was developed could reasonably accurately predict the chlorine decay for each contact tank.

Figure 2: Comparison of predicted Cl2 level with actual for site 1

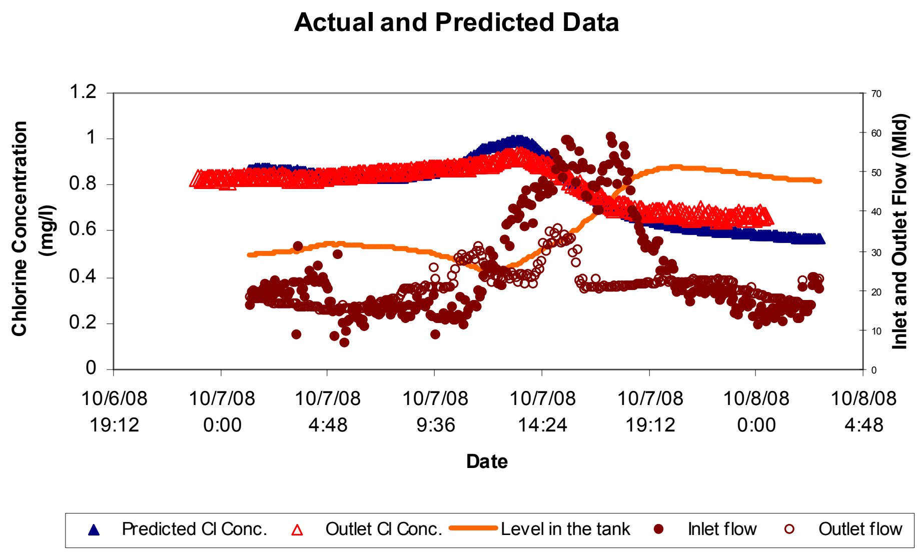
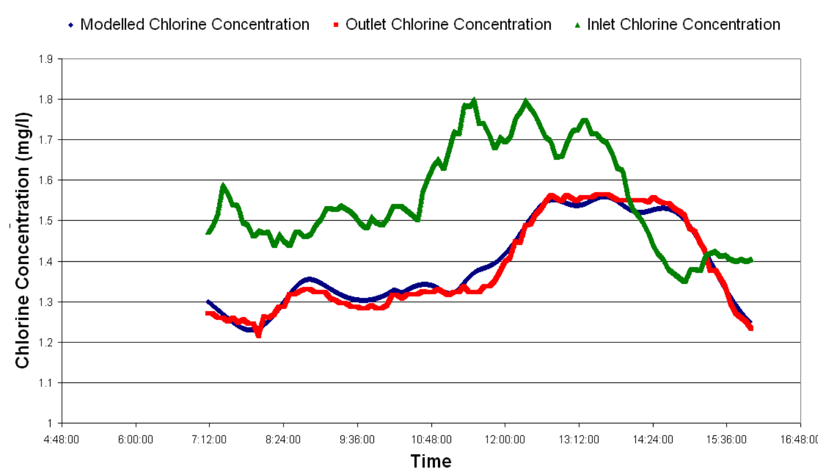


Figure 3 - Comparison of predicted Cl2 level with actual for site 2



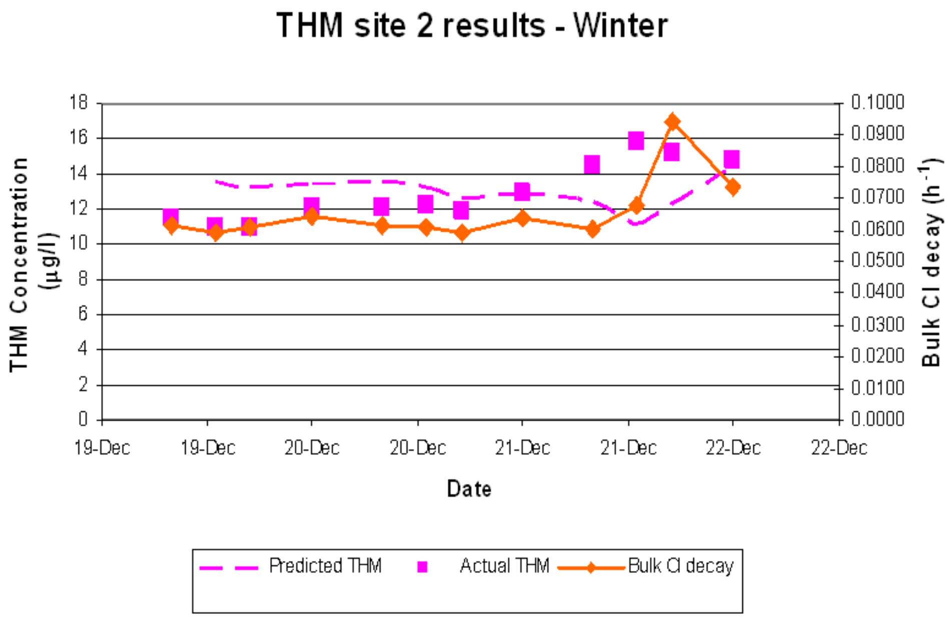
Examination of figures 2 demonstrates that, as would be expected, the chlorine level leaving the tank falls as the retention time increases. This is because the amount of chlorine decay is greater. The blue line clearly follows the red line. The significance of being able to develop this model was that it enabled us to predict chlorine decay given future flow data. This is an important point to consider as the results are described.

3.2 ESTABLISH THE SITE SPECIFIC RELATIONSHIP BETWEEN DECAY AND THM

Once the chlorine decay had been effectively modeled we could start to relate the decay to the actual THM formation. If this could be validated then we knew it would then be possible to relate contact tank operation to THM formation. The results of this work showed that this relationship could be made. Because actual THM values were populated by spot sampling, the immediate relationship is not as clearly shown as with the chlorine decay prediction; however it was clear that the relationship was strong enough to offer a clear guide to approximate THM output values. Given adequate safety margins in operation this would allow predicted THM data to be used to influence operational process settings at the plants.

The results of this can be seen in the example below;

Figure 4 – Predicted THM versus actual THM



4 IMPLEMENTING THE CONTROL SYSTEM AT THE WATER TREATMENT PLANTS

Once the relationship between the retention time and the chlorine decay had been accurately related to THM formation the next step was to implement control system changes at the plants in order to automate the process.

The first step in this was to simulate the controls using a spreadsheet version of the calculation and using real time site data, run the simulations to establish the implications of the proposed changes. Then a functional description was written to describe how the system would function and finally the control was written in PLC code. The basis of the control system was

1) Gather data in real time for the previous 24 hours of plant operation (flows, tanks levels and chlorine levels in and out of the tank)

2) Calculate the theoretical THM value.

3) Compare the calculated THM value with the target.

4) Assess the future 24 hour flow values and then calculate a new Clear water tank level to achieve the required retention time

Figure 5 – Spreadsheet simulation of THM calculation

AECOM

Ballinrees WTW
THM Control Calculations

Historical Data		
Historical Tank Level	%	45.00%
Historical average flow	l/s	230.0
Summated Mn outlet (SMO) flov	l/s	250.0
New Works Outlet Cl Conc.	mg/l	1.2
Coco-DAF Outlet Flow	l/s	150
Coco-DAF Outlet Cl Conc.	mg/l	1.2
Outlet Cl conc.	mg/l	0.8
No. compartment in service	no.	2.0

Calculated Historical Data		
Historical retention time	h	7.33
Inlet Cl Conc.	mg/l	1.20
Bulk chlorine decay	h^{-1}	0.055

Calculated Next 24h Data		
Nominal Retention Time	h	5.89
Predicted outlet Cl Conc.	mg/l	0.87
Predicted THM Conc.	µg/l	46.7

Next 24h Data		
Tank level Set point	%	40.00%
Predicted Future Flow	Mld	22
Pre CWT inlet Cl Conc. Set pt	mg/l	1.20
No. compartment in service	no.	2.0

Recommended Control Parameters		
Predicted outlet Cl Conc.	mg/l	0.90
Target Retention time	h	5.2
Tank target level	%	35.5%

WARNING RISK OF THM FAILURE

CONSIDER
1) Increasing the Ozone dose
2) Decreasing the clear water tank level set point
3) Decreasing the pre clear water tank Cl set point

Process Data		
Max Tank Level	m	4.5
Tank Surface area	m²	1498.5
Mn Contactors THM Conc.	µg/l	30
KTC	µg/l/mg/l	50
Target THM Conc.	µg/l	45

Key	
	Input Data
	Control Parameter
	Calculated Parameters

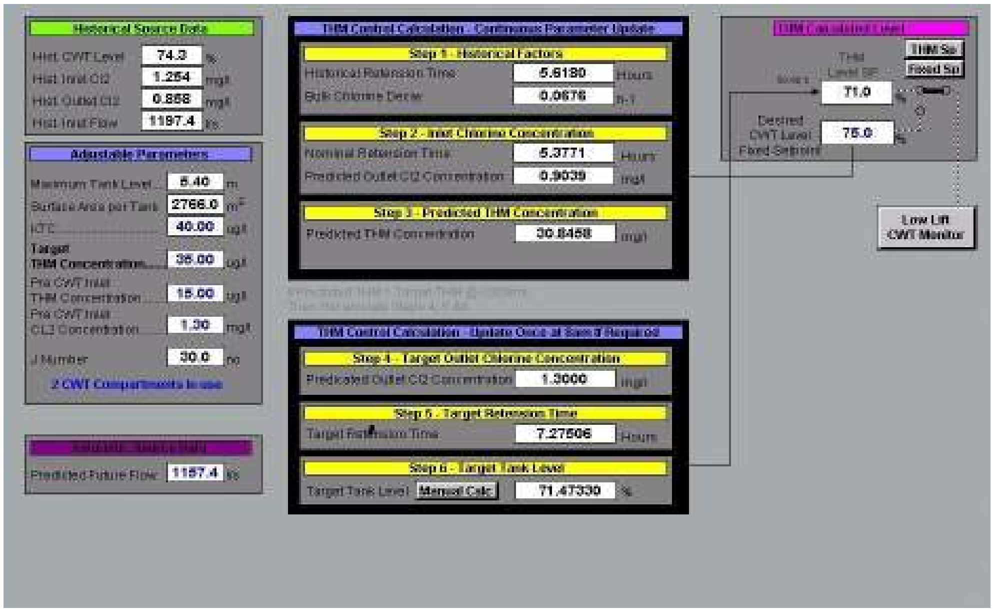
This spreadsheet is the property of AECOM Design Build. It should not be copied or used without permission.

For real time implementation certain protection and limits had to be put on the magnitude of the control systems actions. Examples of this were;

- Maximum and minimum tank levels
- Maximum and minimum input values (e.g. flows/ chlorine decay levels)
- A manual over-ride system.

The software was then loaded into the works PLC systems and SCADAs and commissioning was undertaken. The outputs from the works PLC was compared and checked against the spreadsheet versions for each site. Initially tank level control was set by manually inputting the calculated value. As confidence grew the systems were tested in full automatic operation.

Figure 6 – An example SCADA screen for one water treatment plant



5 CONCLUSIONS

- The calibrated algorithm that was developed was able to be used to predict THM values at the outlet of the water treatment plants. The on line data that is required for this was identified as;
    - The measured chlorine level being delivered into the contact tank – last 24 hours
    - The measured chlorine level detected on the outlet of the contact tank – last 24 hours
    - The average level in the contact tank
    - The predicted outflow from the contact tank in the next 24 hours
- The algorithm and its output can be used to generate optimum works process settings in order to reduce THM levels
- It is a useful tool that has helped to meet a very challenging target of 0.05**m**g/l.
- The model needs to be regularly calibrated to allow for.
    - Seasonal changes in THM formed in the upstream processes
    - The age of an condition of the GAC media
    - Any biological effects in the GAC media (BAC)
- The method is only applicable to systems that are dominated by the chlorinated species of tri halo methanes. The accuracy of the calculation of THM based on chlorine decay would be substantially lower in waters containing brominated species.

Use of this method of THM control has great potential in Australia and New Zealand. Whilst the current limits are not as stringent as those experienced in this project, there are challenges to Water Undertakers especially in tanks where chlorine decay is significant.

ACKNOWLEDGEMENTS

The following persons are acknowledged for their work on this project;

- Brenda Franklin (AECOM UK) – Technical direction and project management
- Ben Courtis (now GE Water Ltd) – Research, concept, laboratory and site work and model calibration
- Hadi Tai (AECOM UK) – Development of algorithm calculation, Functional description
- Paul Searby (AECOM UK) – Software development and integration

REFERENCES

1) Temporal and Spatial Variations in Bulk Chlorine Decay within a Water Supply System. Benjamin J Courtis, John R West and John Bridgeman J Environ Eng (New York) 135(3):147-152 (2009).
2) Chlorine demand-based predictive modeling of THM formation in water distribution networks, Benjamin J Courtis, John R West and John Bridgeman NURW 6(6):407 - 415 (2009)
3) Modeling THMs in water treatment and distribution systems, D. Brown 1 ; J. R. West 1 ; B. J. Courtis 2 ; J. Bridgeman 1 Proceedings of the ICE - Water Management, Volume 163, Issue 4, pages 165 –174 , ISSN: 1741-7589, E-ISSN: 1751-7729
4) Water Quality Chlorine Management - B.J. Courtis, PhD Thesis, University of Birmingham, 2003
5) Developing models for predicting Trihalomethanes formation potential and kinetics, Amy, G.L., Chakik, P.A., Chowdhury, Z.K., 1987, J. American Water Works Association, 79(7), 89-97.
6) Modeling of THM in Water Distribution Systems, Townsend, Jacqueline A., Tripp, Sandra L. - Charlotte Mecklenburg Utility Department". American Water Works Association 01-Jan-1995
7) Chlorine demand and TTHM formation kinetics- a second order model, Clark R.M 1998.– JOEE 124(1) 16-24
8) Predicting chlorine residuals and TTHM formation in drinking water. Clark R.M and Sivagansan M (1998) J Environ Eng 124 (12), 1203-1210
9) The kinetics of Chlorine-Ammonia reactions in sea water. Johnson JD and J G W Inman (1978). Department of Env, Sci and Eng, UNC school of Public health.
10) Kinetics of Chlorine decay. Vasconcelos JJ et al. JAWWA 89(7):54-65, 1997
11) Modeling Chlorine Concentrations in a Network and Applications to Paris Distribution Network. Proceedings of AWWARF and USEPA conference on water quality modeling in distribution systems. Cincinatti, Ohio. Warble O, Dumoutier N., Duguet J.P., Jarrige P.A., Gelas G. and Depierre J/F., (1991) 4-5 Febuary 1991. USA AWWA pp 77-87;
12) A model for chlorine concentration decay in pipes. Water research. Biswas[, P., Lu C. and Clark R.M. (1993) Vol. 27, No. 12, pp 1715-1724
13) Analysis of factors influencing chlorine decay in piped distribution systems Beatty, R., Bliss P.J., Vintage D.C., Clayton P. and Kelley J.P.(1996[Courtis, Benjamin (GE Power & Water)]). Proceedings of Australian Water and Wastewater 16th Federal Convention . Australian Water and WasteWater Association, Sydney, pp 159-165
14) Relative importance of the phenomena responsible for chlorine decay in drinking water distribution systems. Kiene L., Lu, W., and Levi, Y, (1998). Water Science and Technology, Volume 38, No. 6 pp 29-227Levi, 1998;
15) Hua, F., 2000; PhD Thesis THM formation in water treatment works. University of Birmingham, UK.
16) Hallam, N.B., 2001 PhD Thesis Water quality in distribution systems, The University of Birmingham, UK.