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Research Article

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Study on the chlorine decay model in the water distribution system

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ABSTRACT

Maintaining some chlorine residual concentration in the water distribution system is the key step to the safety of water quality. In this text, it puts forward a new chlorine decay model after studying the chlorine spatial and temporal decay. Each decay coefficient to the model adopts the dynamic simulation of the computer to estimate. Also a modeling case is presented, it shows that the new model is more practicality and adaptability. On the basic of the water quality model, it builds the early-warning and prediction system, which will have great realistic meanings for improving the water quality and ensuring the safety of the water supply system.

Keywords: Comprehensive model, The early-warning and prediction system, The safety of water quality.

INTRODUCTION

The importance of keeping chlorine residual in water distribution system

Chlorine is the most widely used in water treatment of disinfectant, in maintaining a certain water distribution system of surplus chlorine density, it can be not only harnessed the water reproduce the bacteria, and when the water in the transmission process are pollution again, still can have certain protective effect, at the same time, it also helps to maintain the quality of the water aesthetics (such as reducing chromaticity, etc) [1]. However, the United States and some European countries in water distribution system whether to keep a certain amount of residual chlorine concentration have different views. The European Union in the water quality standards of disinfectant concentration no regulations; while the United States requirements of pipeline network to the entry of the surplus chlorine density not less than 0.2 mg/L [2].

Because of our country's water pollution is more serious, many experts and water treatment workers think that our country's water distribution system maintaining a certain amount of residual chlorine is very necessary at present. The reason why system keep the residual chlorine are the following points,(1) reducing the probability of resurrection of Escherichia coli;(2) protecting system from pollution;(3) controlling the formation of biofilms;(4) being the water quality of the early warning system;(5) restraining the vigor of the pathogen which is invaded the system [3]. City water supply water quality standards which is promulgated by Ministry of Construction rules that the density of residual chlorine(free chlorine)that is in contact with the water after 30 min must be not less than 0.3 mg/L or density of total chlorine that is in contact with water after 120 min water must be not less than 0.5 mg/L; the density of chlorine must be not less than 0.05 mg/L in the end of the pipeline. So keeping residual chlorine in the pipeline is an important measures to guarantee of the water quality.

Analyzing the residual chlorine attenuation model

Disinfecting by the chlorine can produce at the same time. If chlorine is too much, the water from the pipeline smells a strong chlorine taste [4]. So we must control quantity of chlorine which is added to the water. Wanting to control it, we must know the distribution of chlorine’s concentration in the each place of pipeline [5]. Only with the predicting from the water quality model, we can know how it distributes. And if we want to set the water quality, we must make it clear that the situation of decaying of chlorine in the water.

The attenuation of residual chlorine in water distribution system mainly comes from two aspects, consumption by the water and consumption by the shell of pipeline. The specific performance on the following four aspects: (1) the organic and inorganic chemicals in water can react with residual chlorine; (2) residual chlorine reacts with biofilms adhere to the pipeline and some other components of the pipeline; (3) depleting in the process of corroding of the shell of pipeline; (4) quality transfer between water and shell of pipeline.

There are many research about the residual chlorine attenuation in the water now, and many scholars from home and abroad have put forward a variety of chlorine attenuation dynamic model of experience and half experience. The models and their advantages and disadvantages were summarized in the Table 1:

Table 1 Summary of the model of residual chlorine attenuation in water

Serial number	Reaction Order	Expression	Parameter	Advantage	Defect
1	Level 1 reaction	$C = C_0 \exp(-k_b t)$	k_b	Briefness because only a parameter; most widely used	Can't reflect the situation of rapid response that just input chlorine.
2	Level 2 reaction	$C_X = \frac{C_{X0}(1-K)}{1-Ke^{-M(1-K)t}}$	K M	Can reflect the situation of rapid response, especially input chlorine twice.	Cannot adapt to the whole process well.
3	Parallel level 1 reaction	$C = C_0 z \exp(-k_{bf} t) + C_0(1-z)\exp(-k_{bs} t)$	k_{bf} k_{bs}、z	Good adaptability, and there are three parameters.	Three parameters are difficult to determine.

In totally, the more the parameters for the model, and the more accurate simulation result is, and it is more difficult. So only must through the trials to determine the most suitable for a dynamic model of a network.

Comprehensive model analysis

In fact, reaction of chloride and the material in the water belongs to the complex reactions. Initially total reaction rate is fast, substances that easy to react with chlorine is dominant in the reaction, and substances that easy to react with chlorine is negligible because its physical reaction rate is relatively small at this time , but the situation is opposite later. At present, it is still not a precise residual chlorine attenuation model that can describe the attenuation process. Domestic research basically all use the level 1 attenuation model, but the study found that it is not accurate to simulate chlorine attenuation. Because of the attenuation coefficient is changing at different time(For the same initial chlorine density, chlorine attenuation coefficient is diminishing), therefore it has the scholar that proposed the method of using segmented simulation, but it has no specific model. Putting forward the following total model of chlorine attenuation at the conclusion of the predecessors the basis of research achievements:

$$\frac{dC}{dt} = -(k_b C + k_3 C^n) - W - \frac{k_f}{r_h}(C - C_w) = -(k_b C + k_3 C^n) - \frac{10^{k_c T}}{r_h} - \frac{k_w k_f C}{r_h (k_w + k_f)} \quad \text{-------- (1)}$$

The first item on the right side of the type means consumption of chlorine in the pipeline water(react with the organic and inorganic chemicals in water); the second item means chlorine consumption that be caused by pipeline wall corrosion; the third item means chloride consumption on the pipeline wall(including that reacts with biofilms adhere to the pipeline and some other components of the pipeline and quality transfer between water and shell of pipeline).

With ignoring the item of corrosion, the type can be simplified as:

$$\frac{dC}{dt} = -(k_b C + k_3 C^n) - k_c C = -(k_b + k_c)C - k_3 C^n = -kC - k_3 C^n \quad \text{-------- (2)}$$

Type: k_3 means attenuation coefficient that relate to water quality; k means attenuation coefficient of comprehensive item; n means each reaction series($1< n \leq 2$); C is residual chlorine density at t moment; T is water quality step length.

That its index of n is variable is the biggest characteristics of this model, so the whole model becomes flexible up.

Using different n in the different stages of residual chlorine attenuation, and with dynamic simulation real-time fixed confirm n.

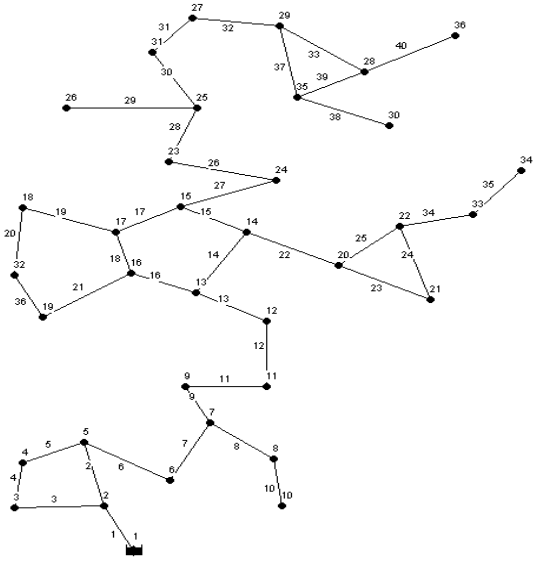
Parameters estimation dynamic simulation

The determination of the attenuation coefficient is the key point in the residual chlorine water quality model calculation. Due to the many factors that influent the coefficient , and it is changing, that increase the difficulty of determining the coefficient. Usually, a specific attenuation model of the attenuation coefficient is determined by using artificial determination method such as field testing and laboratory testing. Artificial determination method is not only time-consuming, but also will be affected by the many subjective uncertainty interference. In addition, a lot of objective factors on the determination also can have very big effect, such as the accuracy and status of measuring instruments, the use of sampling equipment and sample treatment and so on. So artificial determination coefficient has its many unavoidable defects, and put forward the method of dynamic simulation computer for attenuation coefficient. Now some of the water company installs the on-line water quality detection instrument in the pipeline network node place(Can detect water quality parameters such as chlorine density, turbidity, PH value and so on), using the genetic algorithm to estimate value of attenuation coefficient by using real-time transfer of water quality data. Relating numerical about the scope according to consult to each of the literature at first(Can be the scene determined to speed up the convergence rate of the calculation procedure and precision when it is necessary),and revising on the basis of deviation between measured value and calculated value until total variance of the simulation results and the measured node values is minimum. At this time the corresponding coefficient value is the best attenuation coefficient value in this condition. Of course, the choice of the points of water quality inspection must be representative, and we can use random stratified sampling method .

Example

Background

The graph is a small city simplified network of water diagram:



Graph 1 Topology graph that has been simplified

Parameter estimation

By using the genetic algorithm and sensitive analysis to work out program, assume that water point chlorine density remain in 1.1 mg/L, estimate the different periods of time according to the measured attenuation coefficient. The results are as follows Table 2.

Table 2 The corresponding results of the model of the parameters

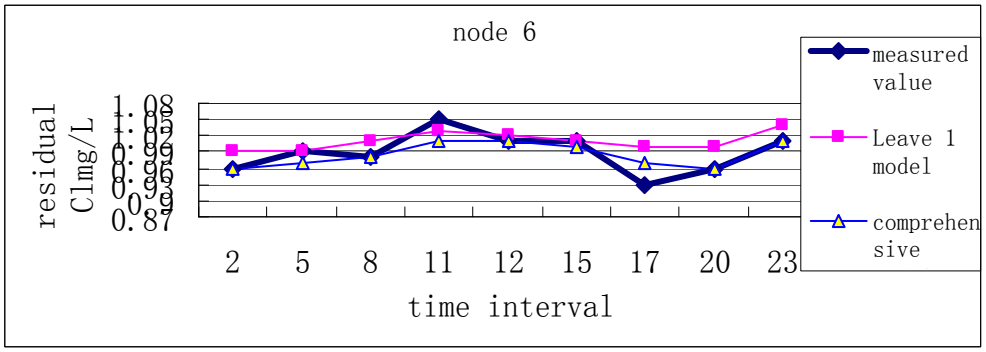
period of time	Choose the attenuation model				note
	Level 1 reaction model	Comprehensive reaction model			
	k1	k7	k8	n	
2	3.2	0.1	4	1.8	3, 11, 10, 25 are the checkpoint
5	2.5	0.1	3	1.8	
8	1.6	0.1	2	1.8	
11	4.3	0.1	5.5	1.7	
12	1.9	0.1	2	1.6	
15	3.4	0.1	4	1.6	
17	0.8	0.1	1	1.8	
20	1.7	0.1	2.5	1.8	

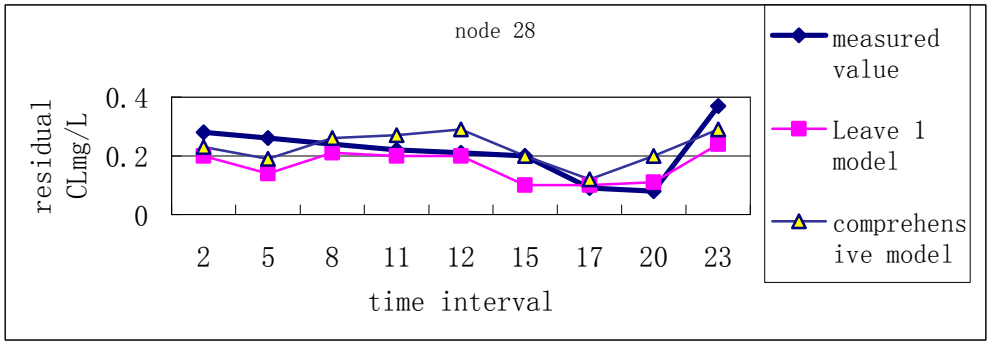
Calculation of residual chlorine density calculation in the node

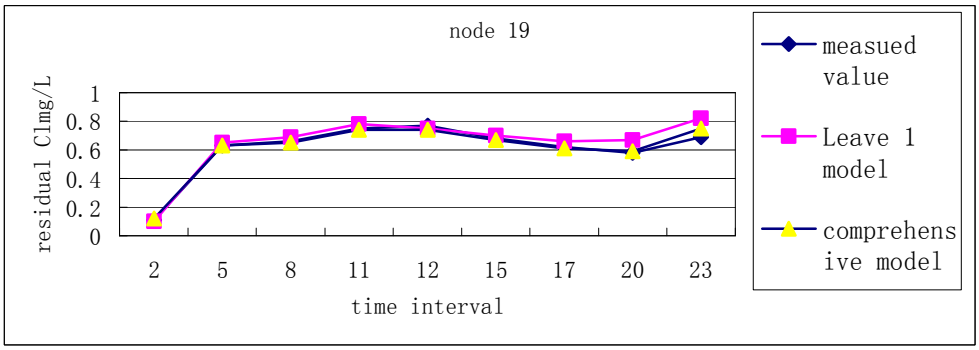
Using coefficient formula estimated by Table 2 to correspond respectively into the formula, it can be obtained in each time each node of the residual chlorine density. Such as Table 3 and Graph 2 reflect the situation of the comparison of calculated value and the actual value of the node 6, 28, 19. From the right of Table 3 (correlation coefficient column) can also be seen that level 1 attenuation model and comprehensive attenuation model all has good correlation. The correlation of comprehensive model is higher than the level 1 point, comprehensive model that can be better reflected of the residual chlorine attenuation in the water.

Table 3 Comparison between measured and simulation value

Node	Attenuation mode	Time	Correlation coefficient									
		2	5	8	11	12	15	17	20	23		
6	measured		0.96	0.99	0.98	1.05	1.01	1.01	0.93	0.96	1.01	
	simulation	Leave 1	0.99	0.99	1.01	1.03	1.02	1.01	1	1	1.04	0.98
		comprehensive	0.96	0.97	0.98	1.01	1.01	1	0.97	0.96	1.01	0.99
28	measured		0.28	0.26	0.24	0.22	0.21	0.2	0.09	0.08	0.37	
	simulation	Leave 1	0.2	0.14	0.21	0.2	0.2	0.1	0.1	0.11	0.24	0.78
		comprehensive	0.23	0.19	0.26	0.27	0.29	0.2	0.12	0.2	0.29	0.65
19	measured		0.11	0.63	0.66	0.75	0.77	0.68	0.62	0.58	0.69	
	measured	Leave 1	0.1	0.65	0.69	0.78	0.75	0.7	0.66	0.67	0.82	0.97
		comprehensive	0.12	0.63	0.65	0.74	0.74	0.67	0.61	0.59	0.75	0.99







Graph 2 Comparison between measured and simulation value

Water quality model warning forecast system

It can set up the early warning forecast system of water quality based on the water quality model. System is mainly composed of hardware and software (Monitoring system + simulation software) two parts. Hardware include RTU(Remote Terminal Unit) construction of water quality monitoring, such as water quality parameters online detector, communication equipment and so on; software's main part is the simulation program and its corresponding document.

It can display the whole dynamic network residual chlorine density change each node by use of residual chlorine water quality model. With different colors in different range of surplus chlorine density of nodes or pipeline section being colored, just as drawing equal water quality. When you find that the network node surplus chlorine density close to standard, the system is issued a warning signal; when the node surplus chlorine density lower than the national standard, the system issued a warning signal.

Early water quality warning was a target system, includes not only warning of certain time, it should also include a period of time warning of changing trend. It has the foresight advanced function, and it has the alert function to change trend of water quality and influence, also can provide scientific reference for the processing of water quality deterioration, and so as to provide a powerful basis to add chlorine.

CONCLUSION

From the above analysis of the gods, Residual chlorine attenuation level 1 reaction model and comprehensive model of the experimental data and the data has better agreement, comprehensive model reflects the pipe to the actual situation of residual chlorine attenuation relatively.

Establishing water quality prediction system in the early warning residual chlorine based on the water quality model to adjust the system design and operation scheme, reducing the risk of deterioration of water pipe network, establishing accident rapid response mechanism for water quality, it all has the important practical significance to improve water quality, ensure the safety of water supply.

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