Presentation

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Chairperson (Mr. Hiroto Oda)

We would like to call upon the representative from the City of Shanghai, Ms. Zhou Ya Zhen, for the next presentation.

Ms. Zhou Ya Zhen (SHANGHAI)

Good afternoon, Mr. Chairman and various city representatives. It is a great pleasure to attend the 3rd Working Level Conference of the Asian-Pacific City Summit. I am Zhou Ya Zhen from Shanghai Nanshi Water Treatment Co., Ltd. Today, I would like to talk to you about the "Application of Fuzzy Control in the Automatic Dosing of Coagulants." I will mainly introduce you to the principles of fuzzy control and its application in the automatic dosing of coagulants. It is used as a means to overcome the problems of the large interval between coagulant dosing and feedback, in addition to many other influencing factors, to ensure the quality of processed tap water.

First of all, I would like to outline briefly the tap water system in Shanghai. The circles on the slide denote water treatment and pumping stations. There are more than ten water treatment plants in Shanghai, the largest of which has a treatment capacity of 1.4 million ㎥ per day. At present, the total treatment capacity of Shanghai City amounts to 6.8 million ㎥ of water per day. We have built aqueducts from the upper reaches of the Huang pu River and also from the Changjiang River in the last two years to ensure a water supply of internationally acceptable standards in response to the demand created by the development of Shanghai. Please look at the screen. The red line indicates the first phase aqueducts, and the orange line the second phase aqueducts, from the Huang pu River. The water treatment plants were originally located in the middle and the lower reaches of the Huang pu River. We have built aqueducts from the upper reaches of the Huang pu River and the Changjiang River to improve the water quality. This was achieved with an investment from Shanghai City and a loan from the World Bank (the International Bank for Reconstruction and Development). At present, raw water is taken from the upper reaches of the Huang pu River and the Changjiang River, and water quality has improved with little change in water treatment technology itself. Due to large variations in raw water quality, and the lack of timely adjustments in the manual control of the dosing of agents, more burden was created for workers. This caused larger amounts of coagulant to be used and led to a large variation in the quality of water after treatment.

Recently, water treatment in Shanghai has become more and more automated. Waterworks experts and technicians have been striving for some time to clarify the relationship between the amount of coagulant used and the turbidity index in raw water. It has, however, been very difficult to ascertain how much of the agents should be used due to many important factors in the condition of the raw water, such as turbidity level, water temperature, volume, pH value and the operating conditions in each treatment process, such as coagulation, sedimentation, filtration and the standard the water should have reached by the end of the treatment.

Previously the optimal amount of coagulant to be used was determined according to the vacuum jar test. Because raw water quality changes constantly, it is difficult to use the vacuum jar test, which depends on water from one instant, to maintain an optimum quantity of coagulant constantly.

In the past few years, the introduction of automated agent dosing systems for water treatment has seen the development of new methods such as the post-treatment water quality feedback method. In this method, water is led from small-scale water treatment systems into large-scale systems, in accelerating amounts. Other systems include the raw water quality feedback method and the PLC method. In theory, these methods are reliable, yet the following problems have been observed:

- A time delay is caused when measuring water quality variables, such as the turbidity level;
- It is difficult to draw up a mathematical model for the variables of large volumes of raw water and the amount of coagulant to be used;
- There are impurities in the water which cannot be measured using electrophoresis;
- There is great non-linearity in the coagulating process.

For these reasons, it is difficult to say that the aforementioned methods are reliable for use in operations. Hence, fuzzy control was introduced into the existing methods.

At present, fuzzy control is beginning to be introduced into the field of automated control as one of the most advanced techniques available. It is especially suitable for control areas where the input and output cannot be formulated, and where it is difficult to establish a precise mathematical model. We have constructed an automatic coagulant dosing system in one water treatment process. This process has three main sections: feedforward, PID control and feedback modifier. The fuzzy control was introduced to the feedback section; with the simultaneous addition of adaptive calculus, the stream current (SC) setting of the PID control was modified, thus controlling the amount of alum used. The introduction of this method into water treatment has had a marked effect. The problems of the important factors and the time delay have been overcome; furthermore, its application has reduced the amount of alum used, and moreover water quality has improved.

Second, I would like to give a brief account of the concept of fuzzy control. Fuzzy control is a type of automation which exactly mirrors the reasoning of the human thought process. To enable fuzzy reasoning, the fuzzy controller is composed of three sections. The first section is the fuzzy converter. First physical quantities, which have been measured using sensors and AD converters, are converted into precise numeric volumes; these precise numeric volumes are then converted into the fuzzy assemble subordinate degree. In other words, the volumes are turned into a language, which the learning database can understand and operate on. The second section is the fuzzy reasoner. This involves combining reasoning based on the fuzzy control rules set by experienced operators and experts and those fuzzy control rules and the fuzzy subordinate degree established in the first section. Then with the calculated weighted average, language conversion and the subordinate degree are obtained. The third section is the non-fuzzy converter. Based on a parameter of language conversion and the subordinate degree from the fuzzy reasoning, a typically accurate value is found according to the suitable non-fuzzy method. This becomes the output volume.

There are two methods to enable fuzzy control in actual application: as shown in the table or following mathematical formulae. Of these, the mathematical method requires more sophisticated hardware and greater memory space; the calculations are bigger, so the speed is slower. However, it is highly applicable and its all-purpose use is most outstanding, thus making it the mainstream of fuzzy control development. In contrast, the method shown in the table requires little memory space and the calculation is fast and very practical, making it a comparatively easy system that can be applied widely.

Fuzzy control is often combined with adaptive calculus in actual application. The system itself can furthermore be adapted using adjustments, that can be made according to the rules of fuzzy reasoning, and the accumulation of data from running the control system over a long period.

Third, I would like to explain, concisely, the design of an automatic control production system.

Development of the control system has been completed and the system is in use at a water treatment plant owned by our company. Every day the plant purifies about 100,000㎥ of water which are taken from the Huang pu River. Alum is added to the water through four diaphragmatic measuring pumps. A servomotor controls the amount of alum the pumps use. The water then passes through the horizontal sedimentation reservoir and the normal speed filtration reservoir before finally going into the purified water reservoir.

Consider first the quality of the raw water. This raw water used at the treatment plant is taken from the Huang pu River. The turbidity level of the water varies greatly and the water is influenced by climate. The water level of the Huang pu River also changes according to the season, as does the turbidity level. Since the turbidity level of the raw water varies greatly, it has been found impossible to regulate the amount of agents added by manual control at the optimal time, so the quality of the water produced was inconsistent. Therefore the amount of agents used was large, which created more work. In addition, due to a big variation in the raw water variables, it had been difficult to reach a desirable result with the conventional control method. Due to this, variations also occurred in the properties of the purified water. To be precise, water temperature fluctuates between 10℃and 34.5℃; ammonium nitrogen fluctuates between 0.05㎎ per liter and 0.8㎎ per liter; turbidity level fluctuates between 6 NTU and 94 NTU; conduction fluctuates between 36㎲/cm and 53㎲/cm; pH value fluctuates between 7 and 7.5;oxygen consumption volume fluctuates between 2.5㎎ per liter and 9.0㎎ per liter; dissolved oxygen fluctuates between 1.2㎎ per liter and 5.6㎎ per liter.

We designed fuzzy control in the automatic coagulant dosing fuzzy control system under these variable conditions. The fuzzy control in the automatic dosing system is based on Program Logic Control (PLC) and is a multiple input/single output fuzzy center control system. Once the center has been input into the system, fuzzy reasoning takes place according to the Mamdani Method using information from the learning database. Non-fuzzy calculations are made according to the centroid method of the single output, thus producing an accurate output value.

According to the theory of water purification, there are two influential factors in determining the amount of coagulant to be used: one is raw water variables such as turbidity levels, pH value, flow rate and water temperature; the other is the water quality variable that should be attained after purification has taken place. Therefore, to be able to use fuzzy control we have been collecting the physical quantity data of the raw water turbidity levels, the raw water flow rate, the turbidity level after sedimentation, electrophoresis, etc. The physical quantity data is input into the PLC, which then appropriately calculates the volume changes in the turbidity level after sedimentation, following which the PLC determines whether there have been any sudden changes in the flow rate of the raw water. After that, the collected physical quantity data and the intermediate volume gained from calculations are input into the fuzzy controller.

In the actual design, fuzzy reasoning is carried out in two groups.

The first group is a reasoning system comprised of input variable 2 and output variablel. Of those, the fuzzy input is the following: the deviation of the turbidity level after sedimentation and the deviation between the set point and the average filtration value for the turbidity level after sedimentation at any given time. These are then defined according to the five levels of the fuzzy subordinate degree functions (large positive, small positive, zero, small negative, large negative). The tendency in variation of the turbidity level after sedimentation is acquired by integrating the deviation of the variation of the turbidity level of the same period, and this is defined by three levels of fuzzy subordinate degree functions (large positive, zero, large negative). The input of the subordinate degree functions is based on the adoption of a triangular subordinate degree function and fuzzy reasoning from the two input values. The output is then also defined by the five levels of the output subordinate degree functions (large positive, small positive, zero, small negative, large negative). Finally, this results in a modified value for the amount of agents to be added per unit of raw water.

The second group is also a reasoning system comprised of input variable 2 and output variablel. The electrophoresis value and flow rate of the raw water are input. Based on detection and the fuzzy reasoning of the PLC learning database, the electrophoresis value from the present raw water flow rate can be obtained. This is then compared with the actual electrophoresis value, and another modified value for the amount of agents to be added per unit of raw water, which is determined according to the PID operation method.

The two values obtained from these processes are averaged by weight in order to obtain a final value for the amount of agents to be used per unit of raw water. Then, the modified amount of agents to be used per unit of raw water is added, which is then multiplied by the water rate to obtain the amount of coagulant that has to be used.

Adjustments and trial operations of the fuzzy control system were conducted. Experts in the field of water purification drew up the fuzzy reasoning rules, yet there were discrepancies with the actual conditions; thus, these rules did not agree completely with the conditions. Therefore, in our trial operations we adjusted the reasoning rules that had originally been set. The learning database is based on empirical data that has been accumulated over time, so at the beginning of operations it was not perfected. The other goal of our adjustments was to make the learning database complete in the trial operations.

Once the adjustments had been finished, the system was ready to be introduced. To maintain and safeguard itself, the system will use its self-learning ability to adjust to any slow moving changes that are caused during operation.

Finally, I would like to talk about application results. We have recorded a lot of data since the fuzzy control system was introduced. In comparison with the previous manual agent dosing controls, analyses show that since the system was introduced not only has the quality of the treated water improved, but there has also been a big increase in company profits.

Compared to the previous control system, the acceptance rate has increased on a wide scale and the variation in the turbidity level of treated water has clearly been reduced Although the variation in the turbidity level of treated water dosed by manual control fluctuated between 0.3 NTU and 0.75 NTU, the variation in turbidity level of water treated using the fuzzy control system is about 0.5 NTU, which shows little fluctuation.

That concludes the application of fuzzy control in the automatic dosing system.

The automatic coagulant dosing system we designed is a part of the fuzzy control system in the water treatment process. Since its introduction, the fuzzy control system has proved to be both accurate and promising. This system can be introduced into other water treatment plants. We are employing great efforts into water treatment and its control in order to supply better quality tap water to our users.

I would like to end my address by expressing my deep gratitude to the secretariat of the 3rd Working Level Conference of the Asian Pacific City Summit for the invitation.

Thank you. (Applause)

Discussion

Chairperson (Mr. Hiroto Oda)

Thank you very much, Ms. Zhou Ya Zhen, for your presentation. We just heard a case report about the application of fuzzy control technology in the automatic dosing of coagulants in water treatment plants using cutting-edge technology. I listened to it with great interest and believe that many of the participants here have an interest in the system and its further practical application.

Are there any questions about her presentation? It would be appreciated if you would introduce the method of water quality control at your own water treatment plants. Ir. Hj. Asari from Kuala Lumpur, go ahead, please.

Ir. Hj. Mohmad Asari Daud (KUALA LUMPUR)

Thanks, Mr. Chairman. I'm Asari from Kuala Lumpur. Two factors have been taken to derive the amount of alum to be used. In this case alone, number one is the quantity of water, and number two is the quality of water. So I saw the graph there. Does it show any real mathematical relationship between the effect of quantity to the dosing and the effect of quality? So in terms of the effect of the dosing, which one has more effect? Is it the quantity of water, or is it the quality of water, and what percentage is it?

Chairperson (Mr. Hiroto Oda)

Thank you very much, Ir. Hj. Asari. This is a question of a mathematical relation-does quantity or quality have more influence? Could you please answer him, Ms. Zhou Ya Zhen?

Ms. Zhou Ya Zhen (SHANGHAI)

I should say that both the turbidity and the volume of water have large effects on the amount of alum used. Various quality conditions in the raw water affect the dosing amount. Because of the unstable quality conditions of the raw water from the upper reaches of the Huang pu River in Shanghai, we considered various factors for the design of the system. A proportional relation should be seen, especially between the volume of the water and the amount of alum used. In this system, we considered the control of the dosing amount mainly depending on the variation of the turbidity. We also considered, indirectly, water temperature and the variables of electrical conductivity. From the outset, the water supply system of Shanghai City was huge and used to be manually controlled. Previously, raw water was taken from the middle and the lower reaches of the Huang pu River and the turbidity level varied with the source location. The building of aqueducts from the upper reaches of the Huang pu River made it possible to collect raw water with a comparatively stabilized turbidity level. The turbidity level of raw water, however, varies greatly depending on the season and the change of water volume at the upper reaches of the Huang pu River. In the system, the turbidity level is presumed to have quite an effect on dosage.

Chairperson (Mr. Hiroto Oda)

Thank you very much. Ms. Yamamoto, JICA's Development Specialist, please.

Ms. Keiko Yamamoto (JICA)

I understand that you have adopted this fuzzy control system due to a large variation in the quality of raw water. How much variation is seen, annually and daily?

Chairperson (Mr. Hiroto Oda)

Would you please answer this question, Ms. Zhou Ya Zhen?

Ms. Zhou Ya Zhen (SHANGHAI)

Shanghai collects raw water from two bodies of water; one is the Huang pu River, the other is the Changjiang River. Water quality variables of these rivers are different. For instance, the turbidity level of the raw water of the Huang pu River indicates a maximum of 250 NTU or more and a minimum of 4～5 NTU in winter when water treatment is particularly difficult due to low temperatures and low turbidity levels. The turbidity level fluctuates annually between these figures. Another factor that is difficult to control is ammonium nitrogen. The ammonium nitrogen level is comparatively high in January and February with 1.3～1.5mg per liter in the Huang pu River and, at the lowest point, in October with 0.0001mg per liter or less. The average is about 0.0002mg per liter. Because the treatment of the entire system is rather difficult, it is controlled manually in most of the treatment plants in Shanghai. The center laboratory in Shanghai usually conducts the treatment. Furthermore, the raw water monitor and measuring station in the division for environmental protection surveillance measurement collects data and informs the water treatment plants in the city. Further treatments are required according to the condition of the raw water. Therefore, we are researching how to realize the automation of treatment under rather variable conditions. The two terms mentioned above are the main variables.

Chairperson (Mr. Oda Hiroto)

Thank you very much. Are there any other questions?

Mr. Tan Nam Seng (SINGAPORE)

I have two questions. Look at the water quality you have, with the two parameter indicators, ammonium nitrogen, you have a variation of 0.5 to 0.8mg per liter. Then the other variation is the turbidity from 6 NTU to as high as 94 NTU. My question is when you have this high level of ammonium nitrogen, what measures are you taking for the removal of ammonium nitrogen?

My second question is about the change of turbidity from as low as six to as high as 94. I believe in the removal of this turbidity, basically you use aluminum sulfate. What is the lowest dosage you have used and what is the highest dosage you have used?

Chairperson (Mr. Hiroto Oda)

Thank you very much. Would you explain the methods of eliminating ammonium nitrogen and the amount of aluminum sulfate used to eliminate turbidity, Ms. Zhou Ya Zhen?

Ms. Zhou Ya Zhen (SHANGHAI)

Firstly, I'll talk about the elimination of ammonium nitrogen when at a high level. Although water control isn't in my specialty, I understand that it is controlled by treatment with chlorine, that is, a treatment method using large quantities of chlorine. At present, we use this treatment method to control ammonium nitrogen, though we are aware the method is a controversial one.

Secondly, regarding the amount used to eliminate turbidity, it chiefly depends on variations of the turbidity level of the raw water. It is not always true that the amount used is high when the turbidity level is high and that the dosing amount is decreased when the turbidity level is low. Even in cases of low temperatures and low turbidity levels, a reasonable amount of alum is sometimes required. Usually, 20～40kg of alum per 1,000m³ of water are used. Recently, the conditions have improved as the water source locations have changed. Now we take water with low turbidity levels from the upper reaches using long-distance aqueducts. The sedimentation process is used as a treatment process following long-distance water conducting. Therefore, the turbidity level of raw water should, on the whole, be lower than before.

Chairperson (Mr. Hiroto Oda)

Thank you very much. According to Ms. Zhou, treatment with chlorine is conducted to eliminate ammonium nitrogen and a dosage of 20～40kg of alum per 1,000m³ of water are used. Mr. Tan, does that answer your question?

Mr. Tan Nam Seng (SINGAPORE)

Yes. I understand the answer. I'd just like to share something with the delegates here. We have a waterworks facility in Johore, the Johore River Waterworks, from where we abstract, and we are facing a similar problem with turbidity variations as in your case. It can be as normal as 20-30 NTU and can be as high as 230 NTU, so our aluminum sulfate dosage has varied from 20mg per liter to as high as 60mg per liter, which is about three times the dosage. Thank you.

Chairperson (Mr. Hiroto Oda)

Thank you very much, Mr. Tan. Now, we will turn to the representative from Oita City.

Mr. Kimiyoshi Hiramatsu (OITA)

I'm also engaged in water treatment, so I speak from experience. Ms. Zhou from Shanghai talked about coagulants in her presentation. We also tried various controls; in general, we feedforward the turbidity level of raw water, then feedback the turbidity level of water after treatment. Practically, however, it varies depending on the raw water quality, especially, the turbidity level, pH value, alkali level and electrical conductivity. Twice the amount of coagulant is generally required for twice the volume of water. The raw water turbidity level varies from 3 NTU up to 500 NTU in our case. pH values also vary from 7.0 up to 9.5 in cases of heavy rain. pH values and alkali levels vary widely, but the amount of coagulant used doubles at most. Ten times the water volume naturally requires ten times the amount of coagulant. For our control system, to begin with, we used an arithmetic figure control; that is, the amount of injection escalates in stages as the turbidity level rises to a certain degree. Once exceeding the level, we manually adjust the dosing; we control the dose using a modified numerical value conversion by multiplying by 1/2 or 1/3. We also think, as you mentioned in your report, that the dosing amount of coagulant is effected by the quality of raw water. But we believe from our experience that pH, alkali levels etc. influence it rather than the turbidity level.

Chairperson (Mr. Hiroto Oda)

Thank you very much. That was a response from Oita City about their own experience; pH and alkali levels have a greater effect than the turbidity level. That concludes the presentation from Ms. Zhou Ya Zhen of Shanghai City. Thank you very much.

That's all for this morning. Before the afternoon schedule starts, we will show you a video produced by Fukuoka City Waterworks Bureau.

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