Advanced Water Treatment and Process Control

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1. Introduction

In recent years in Japan, public attention has been focused on odor source material and organic compounds such as trihalomethane in tap water. While public demand for safe and good tasting water has been increasing, many of the advanced water purification systems including ozonation and activated carbon treatment, have been introduced into the bureau of waterworks in many districts, especially in city areas. The quality of water from various sources such as rivers and lakes is very diverse due to differences in pollution including eutrophication. As a result, various methods or a combination thereof are considered in the application of advanced water purification. Hence, in constructing an advanced water purification system, it has become more important to design an optimal system from the viewpoint of water quality and stable control of the treatment process.

In this paper, advanced water purification as a combination of ozonation and activated carbon treatment, as well as its effective operation and process control, shall be discussed.

2. Production of Safe and Good Tasting Water

2.1 Requirement for good tasting water

In general, good tasting water satisfies the ingredients and quality items shown in Table 1. Ingredients such as hardness (calcium and magnesium ion densities) and free carbon dioxide (carbonic acid gas) are important in good tasting water. Underground water and spring water are therefore tasty because carbonic acid gas and minerals are imparted to them through the soil during their purification.

Table 1 Requirement for good tasting water in Japan

Water quality item	Value
Temperature	Lower than 20°C
Hardness	10 to 100mg/L
Free carbon dioxide	3 to 30mg/L
Evaporation residuals	30 to 200mg/L
Odor intensity (TON)	Less than 3 degrees
Potassium permanganate consumption	Less than 3mg/L
Residual chlorine	Less than 0.4 mg/L

On the other hand, the largest factor contributing to bad tasting water is odor source material. Water tastes and smells bad when algae propagate at a high rate and generate a musty odor in the water sources, due to human pollution. Furthermore, increased chlorine injection from water filtering plants due to the increased pollution of water sources results in a higher chlorine residual. This also contributes to bad tasting water.

The requirement for advanced water treatment is further increasing. With the pursuit of “better taste” and “increased safety”.

2.2 Odor removal performance of advanced water purification

2.2.1 Odor source material

The problematic odor in tap water is primarily caused by either algae which propagate in eutrophicated lakes or in water discharged from there or by microorganism such as ray fungi. Most of the problems are musty odors and two kinds of material have been confirmed as sources: geosmin and 2-Methylisoborneol (2-MIB), which are generated by blue-green algae and ray fungi.

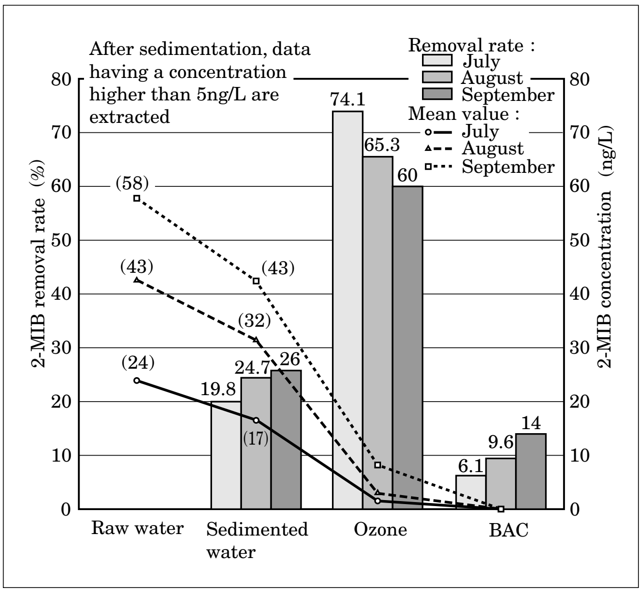
Conventional treatments, including removing algae by means of chemical cohesion and sedimentation together with pre-chlorination, are effective in eliminating odor caused by algae, grass odor and fish odor, as well as hydrogen sulfide odor and rotten odor from sunken material at the bottom of water sources. But they are hardly effective in eliminating musty odor source material dissolved in the water.

Actual data showing the results of eliminating odor source material with the advanced treatment using ozonation and activated carbon treatment are shown in Fig. 1. As shown, advanced water treatment removes almost all of the odor source material.

2.2.2 Trihalomethane

At present, the control target of trihalomethane contained in the water supply is set at an annual mean value of less than 0.1 mg/L.

Fig.1 Monthly operation data showing 2-MIB removal



The technology for reducing the trihalomethane in tap water includes water purification systems that "suppress the generation of trihalomethane" and "eliminate generated trihalomethane": Techniques that have been actually applied for reducing trihalomethane include the following:

(1) Application of intermediate chlorination instead of pre-chlorination

This is the least expensive method but requires fine control of the chlorine injection rate. Therefore, careful study must be made before introduction into purification plants where water quality fluctuates widely.

(2) Elimination of pilot material by means of the activated carbon powder or granule treatment.

This is effective in eliminating trihalomethane but not effective enough for iron, manganese and ammonified nitrogen.

(3) Elimination of pilot material by a combination of ozonation and activated carbon treatment.

This method provides the greatest reduction in trihalomethane, and further reduction of odor source material is expected.

2.2.3 Disinfection of cryptospordium parvum

One of the results of ozonation is disinfection. Recently, problems related to such pathogenic microorganisms as cryptospordium have arisen.

Cryptospordium is a type of the protozoa which propagate in the intestines of mammals and is discharged with their excrement, resulting in pollution of the water environment. As the size of the cryptospordium oocyst is 4.5 to 5.4 μm when mixed into water supply sources, turbid particles of this size must be removed very carefully during water filtration.

A mass infection broke out in the United States in 1993, caused by cryptospordium in tap water. Among the 1.6 million people supplied with the water, 400,000 people suffered from diarrhea, and more than 400 of those people died.

Cryptospordium is surrounded by a thick oocyst. Chlorine disinfection, which is generally applied to the water supply, is almost ineffective for inactivation of the oocyst. As permanent measures against pollution by cryptospordium, the following three measures were adopted by the city of Milwaukee:

(1) Changing the water intake of the water filtration plant to a position where it is not affected by pollution.
(2) Removing more particles and turbidity by the combination of a cohesive agent supply system with a filtration system.
(3) Introduction of ozonation as the preceding disinfection process (an expected removal of at least 2 log = 99%)

The planned ozonation facility utilizing ozone disinfection has a maximum injection rate of 2.5 mg/L, a treated water flow rate of 1.04 million m^3/d and a resident period of 20 minutes.

3. Advanced Water Purification Processes

Advanced water purification is a treatment for removing chemical material and odor source material which cannot be removed by conventional treatment. In particular, ozonation is an excellent treatment technology for disinfection, decolorization and deodorization. It can be more effective when combined with the activated carbon treatment. For effective operation of the advanced water treatment system, construction of the optimal treatment processes and effective and stable operation control of the plant are important.

3.1 Ozonation process

Of the advanced water treatment processes, the ozonation facility consists of an ozone generating system, an ozone contactor, an off-gas ozone destructor and instrumentation. Figure 2 shows a flow diagram of the ozonation process.

3.1.1 Ozone dose control

The types of ozone dose control actually in use today are ① total ozone generation control, ② ratio control, and ③ concentration control.

For facilities which have only slight fluctuations in the quality and temperature of the water to be treated, a minimal injection rate control is sufficient. But for facilities with higher water quality fluctuations, off-gas ozone concentration control or dissolved ozone concentration control is applied. However, a slowly reacting PI control is used here in accordance with the several minutes of idle time between the generation of ozone in the ozone generating system and its detection by means of off-gas ozone or dissolved ozone generating system and its detection by means of off-gas ozone or dissolved ozone concentration detectors via the piping and reactor. Furthermore, there is a delay of several

Fig.2 Ozonation control flow diagram

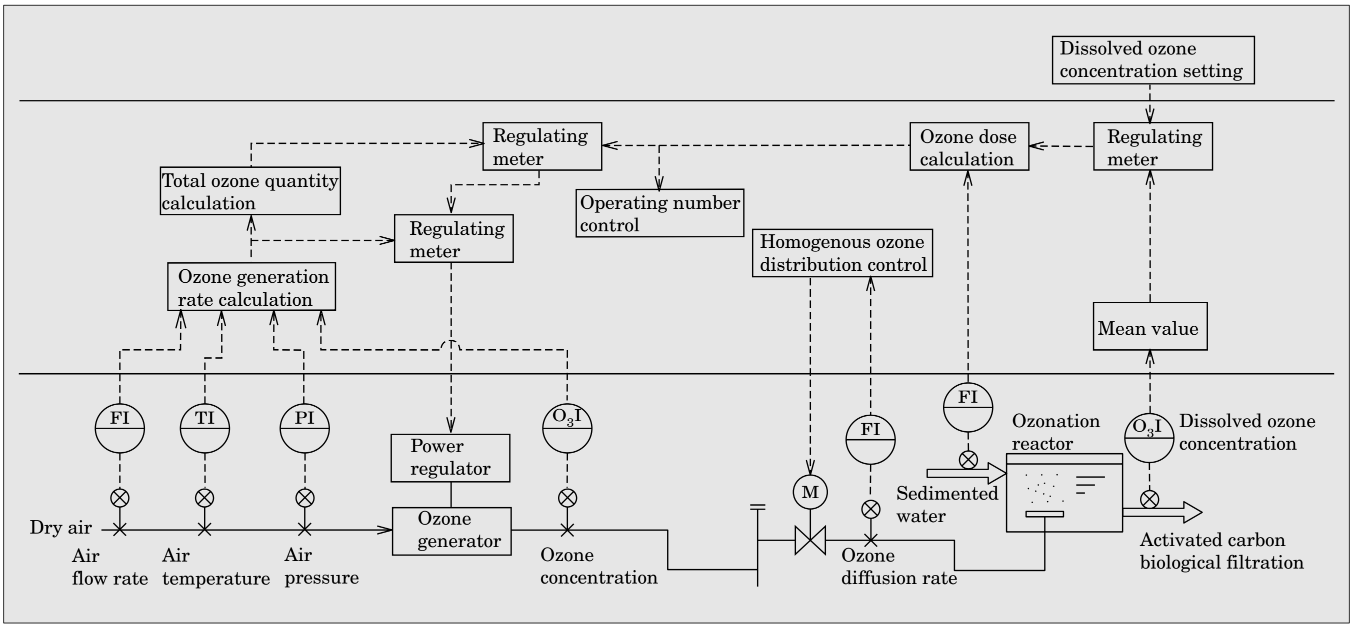
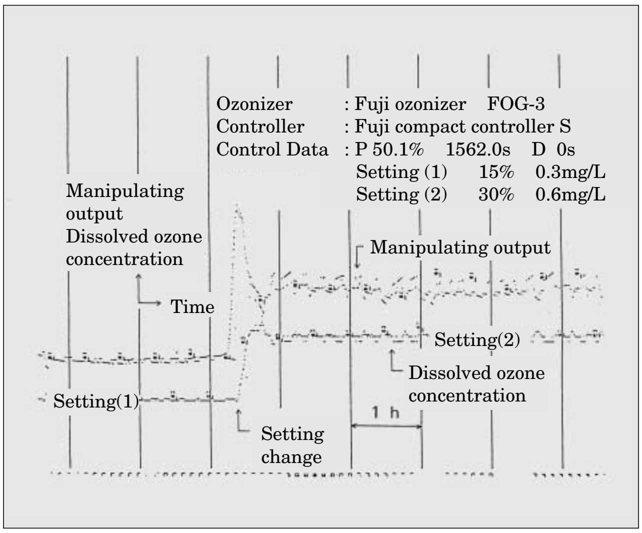


Fig.3 Constant-value control of residual ozone concentration (PI control)



minutes until the ozone concentration reaches equilibrium. An example of the dissolved ozone constant-value control using PI control is shown in Fig. 3. As shown, the overshoot of dissolved ozone concentration after changing its setting is about 12%, and its settling time is about 30 minutes. The change in water quality can usually be followed up, but if there is a drastic change in the water flow rate, it cannot be followed up alone by controlling the concentration of the off-gas ozone or dissolved ozone. Even in such cases, stable control is realized by controlling the ozone generation rate, calculated by the product of the injection rate multiplied by the raw water flow rate, where the optimal injection rate is determined from the off-gas or dissolved ozone concentration. The principle of this ozone concentration control and its process control characteristics are discussed below.

(1) Principle of ozone concentration control

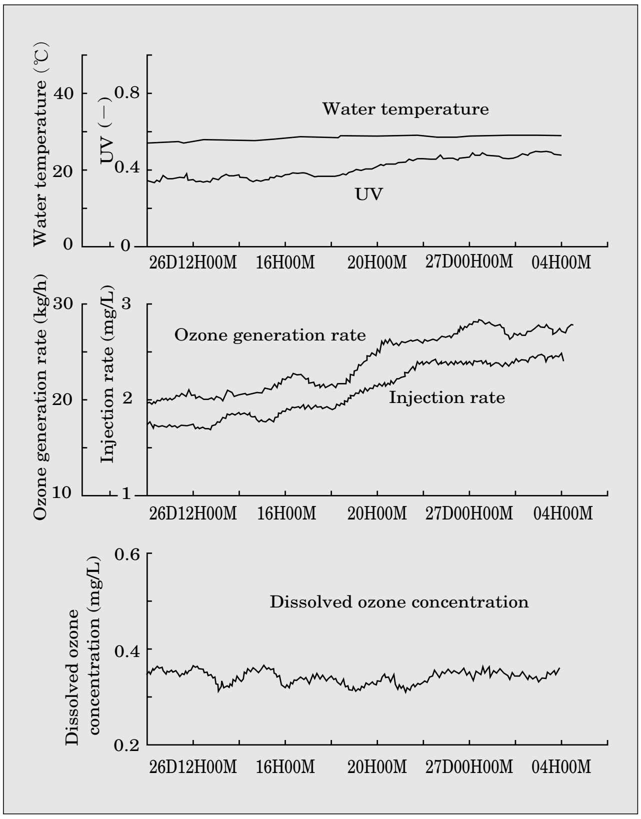
If raw water and ozone come in contact in the ozone contactor, most of the injected ozone is exhausted by the reaction as well as by self-disintegration, but some is carried out with the treated water as dissolved ozone. The remainder is discharged into the atmosphere as off-gas ozone. Ideally, the quantity of ozone to be injected is just enough for the intended reaction, without any remaining off-gas ozone or dissolved ozone. In actuality, however, some excessive ozone must be injected to achieve the desired reaction. The off-gas ozone and dissolved ozone increase if excessive ozone is injected but decrease if too little ozone is injected. Hence, the ozone concentration is the substitute index that shows an excess or lack of ozone in the contactor. The constant-value control for off-gas ozone or dissolved ozone concentration utilizes this correlation for ozone dose control.

(2) Process control characteristics

There are two kinds of dissolved ozone control: one loop control and cascade control. One loop control compares the setting of the controlled value of dissolved ozone concentration with its actual measurement and outputs. According to its deviation, control signals are sent to the power regulation inverter of the ozone generator. The inverter, after receiving this signal, changes its output power frequency, resulting in a change of the ozone generation rate so that the dissolved ozone concentration coincides with the setting.

Cascade control uses the dissolved ozone as the primary control target value. By constantly controlling the power for the ozonizer, a quick ozone generation rate that follows up the water quality is possible. The power required by the ozonizer highly related to the

Fig.4 Application example of dissolved ozone concentration control



ozone generation rate and is hardly affected by other factors. The ozone generation rate can be controlled more stably by controlling the ozonizer's power supply.

(3) Locating and selecting sensors

Stable measurement of the dissolved ozone concentration control is generally difficult due to the lack of sensibility of the sensors or dirt in the sampling system. In giving stable control characteristics to the dissolved ozone control, attention should be paid to the following points:

(a) Sampling should be made at places such as the residence basin outlet where water flow is stable.

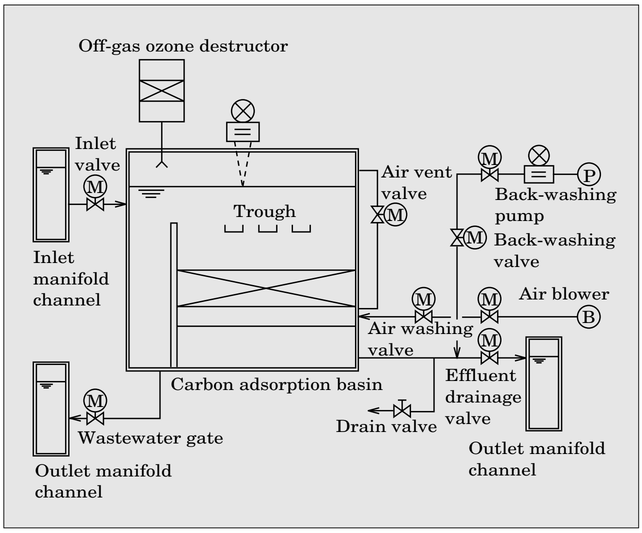
(b) placing a filter in front of the sensor should be avoided at all costs, and sensors with high sensibility should be selected.

3.1.2 Actual example of optimal application of dissolved ozone concentration control

As opposed to off-gas ozone concentration control, the dissolved ozone concentration control monitors residual ozone in the treated water. The control index is closer to the actual water quality, enabling improved ozone dose control for fluctuations in water quality. Figure 4 shows an example of a dissolved ozone concentration control, which has been in operation for about 5 years for a water supply.

With the increase of the UV ray absorption rate (UV260) as an index of water pollution, the ozone injection rate increases simultaneously at the inlet of the ozone contact basin by constant-value control of the dissolved ozone concentration. This indicates that the ozone dose satisfactorily follows up the water quality fluctuations.

Fig.5 Flow diagram of the activated carbon treatment plant



Ozone dose control should reduce operating costs of the facility as well as achieve stable water quality.

Dissolved ozone concentration necessary for achieving the intended reaction is determined by factors including the speed of ozone reaction with material to be treated and dissolvable ozone injection rate. Fuji Electric provides a variety of control systems that can handle variations in water quality.

Essentially, it is desirable for the control to select, in addition to water flow rate, such water quality indices as concentration of odor source material and organic material. Fuji Electric is pursuing the realization of the original method of determining the optimal injection rate from water quality data that includes trihalomethane and odor source material. But we are still in the testing stages due to the complexity of the correlation between various parameters, ozone injection rate and treated water quality.

3.2 Activated carbon treatment process

The activated carbon absorption facility can be either fixed or fluid. A typical flow diagram of the treatment is shown in Fig. 5. The following should be considered in designing an activated carbon absorption facility in order to utilize its absorption performance effectively: contact time, spatial velocity (SV), linear velocity (LV), carbon layer thickness, granule diameter and the water collection facility.

In the water collection facility, a suitable washing control is important for operation. These include a washing method for the activated carbon layer, washing time and washing water.

Although, "intermediate ozonation + activated carbon" and "rear ozonation activated carbon" are applied in conjunction with ozonation, the treatment processes

Fig.6 An example of washing control for the activated carbon treatment

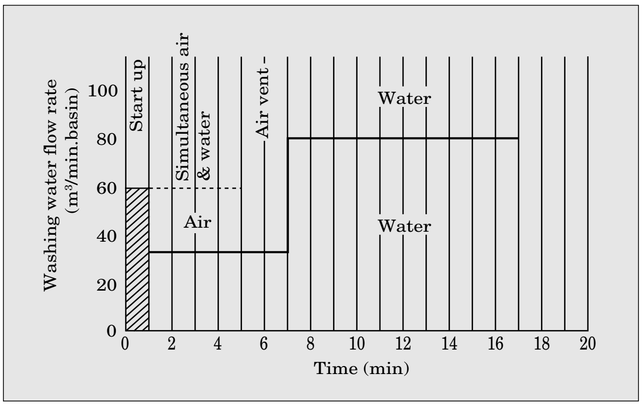


Table 2 Washing control process for the activated carbon treatment
"Rear ozonation + activated carbon" treatment

Process	Inlet valve	Effluent valve	Air valve	Back wash valve	Waste water gate	Drain valve
① Treatment process	○	○				
② Simultaneous air & water washing process			○	○		
③ Water washing process				○	○	
④ Waste water process	○					○

differ largely according to the purpose of the washing, the intended water quality after the washing and the washing control process.

3.2.1 Objective of washing the activated carbon absorption basin

"Intermediate ozonation + activated carbon" treats water by transforming organic material difficult to decompose to easily decomposing ones through ozonation and by improving biological effects with the activated carbon treatment. Furthermore, because the activated carbon absorption process is placed after the chemical congestion and sedimentation process, the former process also performs filtering. Therefore, in this case, the objective of cleaning the activated carbon treatment facility is to remove suspended material accumulated in the activated granular carbon treatment basin. It removes the lost head of water and recovers its homogenous linear velocity, resulting in stable operation and extended life of the facility. Mere "back-washing" does not have enough of an effect in removing suspended material accumulated around the carbon granules so the carbon layer must be washed vigorously by an expansion rate of 20 to 30%. This is the reason a combination of "back-washing + air washing" is adopted. Figure 6 shows an example of the washing control for the activated carbon treatment.

Washing is started about once every 3 days when:
(1) the filtration operation time has reached 96 hours.
(2) the lost head has reached 2.0 mm, or
(3) the treated water turbidity exceeds 0.2 degrees.

"Rear ozonation + activated carbon" has a filtration process that precedes the activated carbon treatment, resulting in the removal of suspended material and suppression of the increase in the lost head. Although washing once a month is therefore possible, it is executed once every 3 days for the purpose of suppressing microorganism leakage.

3.2.2 Process control for the activated carbon absorption basin

The washing control process of "rear ozonation + activated carbon" is shown in Table 2. As "intermediate ozonation + activated carbon" has filtration as the following step, the washing is performed in this sequence: treatment → simultaneous washing → water washing. The turbidity of the water is controlled less than 0.2 degrees.

With "rear ozonation + activated carbon", washing is performed in the following sequence: treatment → simultaneous washing → water washing. But, because this system is directly followed by the distribution basin, a "waste water process" is added after performing carbon washing for draining the increased turbidity of the treated water. The process control corresponding to each of the various treatment systems is required for controlling the treated water within the specified quality limit.

4. Conclusion

In the city of Osaka whose water source is the Yodo River and Tokyo whose water source is the Tone River, construction of advanced water purification facilities in the bureau of waterworks is now in the peak. In the future, construction of advanced water purification facilities will improve along with the increasing demand for "safe and good tasting water" in the provinces. Furthermore, a new system for small waterworks has been developed a combination of the ozonation + activated carbon treatment with a membrane filtration process. All of these items contribute to the increasing importance of the advanced water treatment process control. With the goals of simplified operation of the process control and stable water quality, we will continue our research and development for a more effective and advanced water treatment process that includes monitoring, control and instrumentation.

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