ADVANCED TREATMENT IN WATER AND SEWAGE WORKS

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1. INTRODUCTION

Recently, the global warming due to carbon dioxide, the depletion of the ozone layer and global scale environmental problems have begun to be paid wide attention. The air and waters are the most important constituents of environments (to mankind) and their gradual contamination is regaining attention. The water environment, in particular, is closely associated with our daily life and water pollution is focused as topics especially widely. There is the global water circulation system and rivers and lakes are involved in the system. Water purification plants intake water from rivers and lakes and used waters are recharged into rivers as sewage treatment plant effluent. This is also a part of the circulation, therefore, advanced treatment of water is required for human life and natural environment.

Fuji electric has been working on ozone generation and ozonation technology for a long time. From the viewpoint of ozonation, advanced treatment in water and sewage works is discussed below.

2. ADVANCED TREATMENT IN WATER WORKS

The pollution of rivers, lakes and other water resources has increased with the development of industry and population explosion. Problems such as the increase of ammoniac nitrogen in river waters and unpleasant taste and odor of water supplies have arisen. It is said that in 1990, more than 20 million people in Japan suffered from taste and odor in drinking water. The effect of chlorinated trace organic compounds such as trihalomethanes on health has been discussed and advanced water purification has been introduced to cope with these problems.

Advanced water purification treatment is defined as the treatment using activated carbon adsorption, ozonation or biological treatment, or the treatment using 2 or 3 processes mentioned in combination. Ozonation + activated carbon adsorption process is mainly used when the objective of treatment is to remove taste and odors and to reduce trihalomethanes. In the case to remove ammoniac nitrogen, biological treatment is useful. Ozonation is very effective to remove taste and odors and as the pretreatment of biological activated carbon adsorption, ozonation improves the biological decomposition properties and extends the life of activated carbon.

3. ADVANCED TREATMENT IN SEWAGE WORKS

3.1 Water environment and advanced treatment

Waters polluted by industrial activity and domestic activity are treated by sewage works and the effluent into natural environment would be involved in global water circulation or the effluent would be reused by human activity. Therefore, sewage works play a role to protect the water environment. Advanced water treatment in sewage works is defined as the treatments used to satisfy these requirements, such as (1) to meet water quality level, (2) to prevent eutrophication and (3) to reuse water.

The advanced water treatments that ozonation is effective would be described here.

(1) Reuse

The development of water resources is increasingly difficult so that treated water has begun to be used as a important water resource. Treated water has been already used as rinsing water in sewage treatment plant. Recently, the cases that treated water is distributed to consumers have been increased. The distributed water would be used as rinsing water, miscellaneous water and used for landscape function and water intimate parks, etc.

It is necessary that color and odors of reused water are removed satisfactorily for user not to feel discomfortable any more. For this purpose, ozonation is very effective and several ozonation facilities have been operated at a number of sewage plants. For example there is a facility to distribute ozonated water to the Makuhari zone in Chiba Prefecture.

(2) Disinfection

So far, chlorine is generally used to disinfect the final effluent. With chlorine disinfection, the residual chlorine retains its disinfectability, but there is a case that residual chlorine may have adverse effect on the biosystem of the river and other final effluent destination. Ozone, on the other hand, has a greater disinfectability than chlorine and since it decomposes rapidly, it has almost no secondary effect on the final effluent destination. Therefore, ozone disinfection is effective in protecting the microorganisms and the fish and other biosystems which feed on them, in the effluent destination.

Chlorine disinfection may produce trace chlorinated organic compounds such as trihalomethanes by the reaction between the residual organics and chlorine in treated water. Ozone disinfection is also effective against this problem. Therefore, it is expected that ozone will be used in the future as a disinfectant that is "No Harm To The World".

4. SYSTEM COMPONENTS AND PROBLEMS OF ADVANCED TREATMENT

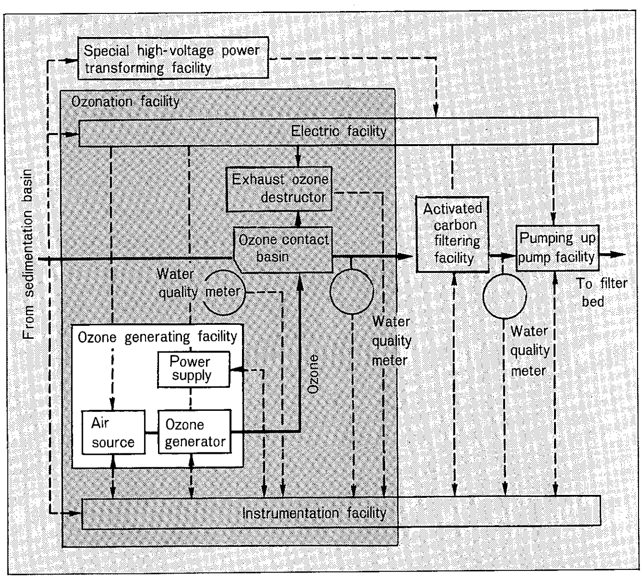
4.1 System composition

The composition of an advanced treatment system varies with applied field, purpose, plant scale and so on. From the view of ozonation, system components and technical problems are described here.

Advanced treatment system is a combination of a number of unit processes (ozonation, activated carbon adsorption, etc). These unit processes are further incorporated in the conventional treatment process. Each unit process consists of various equipments. Ozonation process consists of ozone generator which generates ozone gas, contactor in which reaction between substances in water to be treated and dissolved ozone occurs, exhaust ozone destructor which decomposes the unabsorbed ozone gas from the contactor, etc.

The electric facility supplies power to the equipments of the advanced treatment facility. The supervisory control system enables to control equipments of unit process and whole system of advanced treatment. It also performs data processing to harmonize or interlock the advanced treatment processes with the conventional processes. (see **Fig. 1**)

Fig. 1 Composition of advanced treatment plant for drinking water



4.2 Ozone generating facility plan and problems

The following items must be considered when planning the ozonation facility in advanced treatment:

(1) Ozone contactor
- Improvement of removal rate and dissolving effect
- Space-saving by optimum design

(2) Ozone generator
- Power saving and high reliability
- Reduction of harmonics

(3) Supervisory control facility
- Effective hierarchical and horizontal dispersion

4.3 Ozone contactor

The purpose of the ozone contactor is (1) to dissolve ozone and (2) to react dissolved ozone with sustances to be removed. It must be designed so that the removal efficiency of the substances may be satisfactory as the results of high absorption efficiency and effective reaction. For large scale advanced treatment plant, it is necessary that the volume of contactor should be optimum because relatively large space is needed for contactor.

In the past, since it was difficult to evaluate quantitatively parameters that determine the performance of the contactor, so that the contactor design sometimes depended on engineer's experience. Some papers were reported about the design of ozone contactor with numerical simulation but many of these assumed simply that the water flow were plug flow. Therefore, these investigations could not be applied to a large scale of complete mixing flow contactor.

Fuji Electric developed a comprehensive simulation model for a comparatively large contactor so that ozone absorption efficiency, removal efficiency of target substance, etc. in the contactor could be evaluated. A highly effective contactor can be designed by the noval simulation. If the parameters about hydraulic characteristics and ozone absorption characteristics, raw water quality and other design conditions are input, a computer output the concentration of substance to be removed and ozone concentration of treated water by the simulation. As a result, the removal efficiency and ozone absorption efficiency can be found (see **Fig. 2**).

The factors important from the standpoint of contactor design are described below.

(1) Hydraulic retention time and retention time distribution

Retention time is one of the most fundamental specifications of a contactor. The volume of a contactor is determined by the retention time and flow rate of treated water. The retention time means the necessary reaction time until the substrate to be removed reacts with ozone and decrease to the expected value. However, unless the contactor shape is cylindrical and the flow is plug flow, short cut flow and circulation flow occur and water flows out faster or slower than the hydraulics retention time. Therefore, real retention time has a distribution and this phenomenon is called as "retention time distribution". The

Fig. 2 Input and output of ozone contactor simulation model

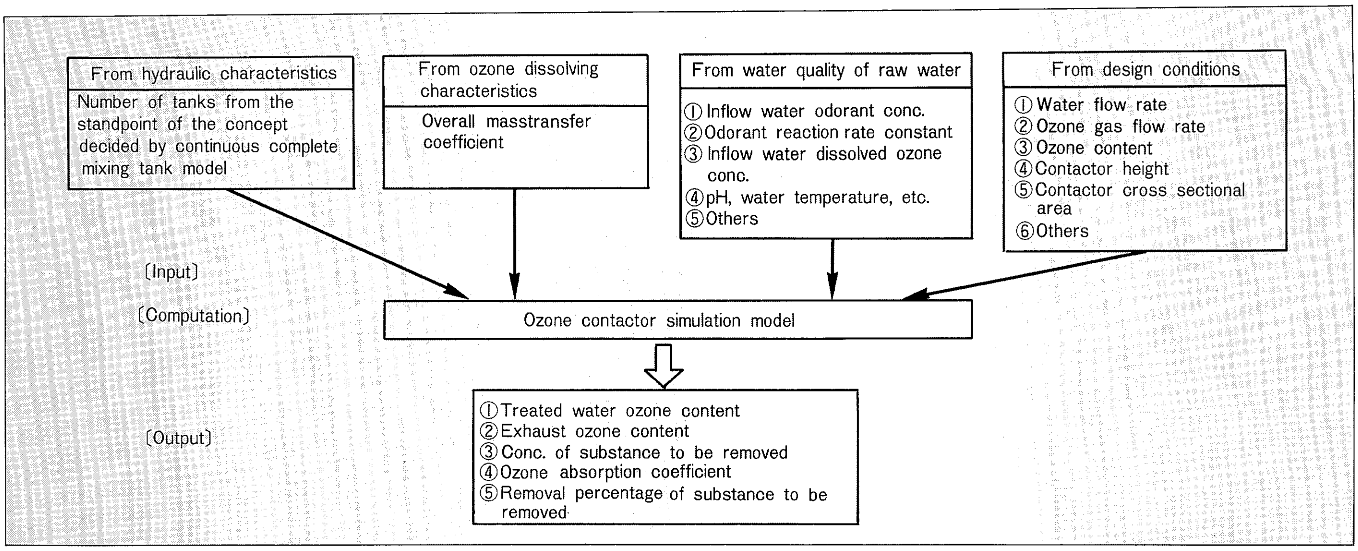


Fig. 3 Example of separation of ozone contactor

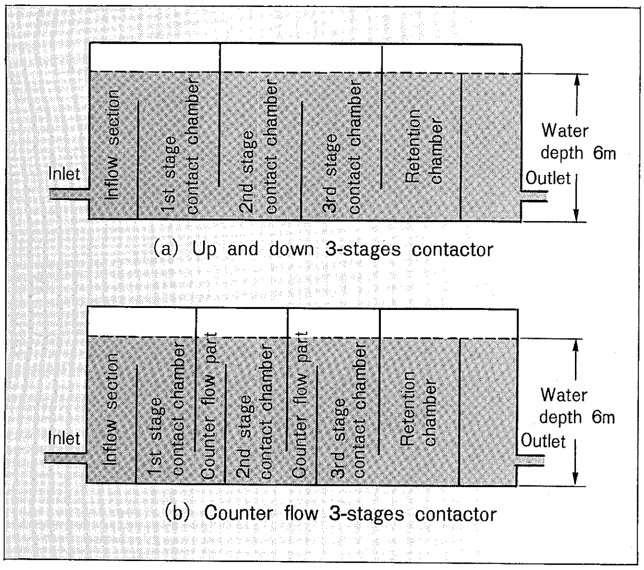
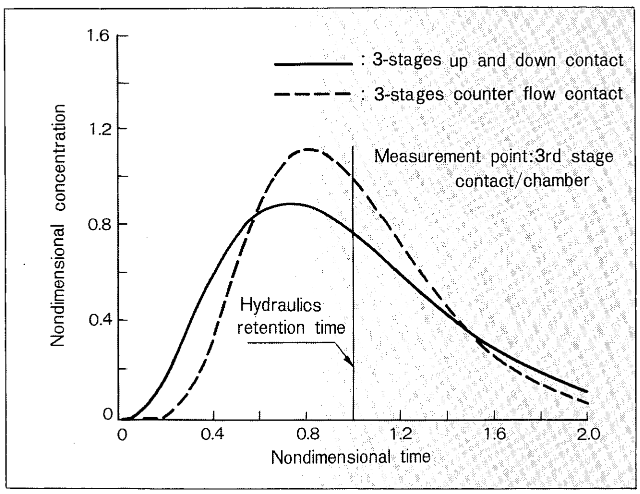


Fig. 4 Distribution of retention time of 3-stages up and down flow and counter flow contact



retention time distribution depends on flow conditions in the contactor and is affected a large degree by the shape of the contactor.

For contactor design, in consideration of the retention time distribution, the hydraulics retention time should be determined so that the necessary reaction time is reserved as a whole. Therefore, the estimation of retention time distribution should be of significant importance. Practically, retention time distribution would be estimated by the experiment using small scale "model contactor".

(2) Contactor shape and retention time distribution

When the contactor is divided into a number of stages as shown in **Fig. 3** (each stage is called as contact chamber), the fraction of short cut flow would become drastically small. It was proved by the result that the peak points of the curves in nondimentional time shown in **Fig. 4** could be close to the hydraulic retention time. Theoretically, the larger the number of divisions, the greater the effect that reduce the fraction of short cut flow. But large number of division means structural complexity and higher construction cost, wherefor comprehensive judgement is important.

There are two ways that water flows into the contact chambers. The one is a method that water and ozone gas flow in counter direction each other at each chamber (**Fig. 3 (b)**). The other is a method of division so that water flows up and down (**Fig. 3 (a)**). The former method that flow mode of each chamber is counter flow has superior characteristics in retention time distribution (see **Fig. 4**).

(3) Ozone absorption efficiency

To use the dosed ozone effectively, the ozone absorption efficiency is required to be high. Many important factors are involved in ozone absorption efficiency such as the contactor's water depth, air bubble diameter, liquid/gas ratio (L/G), ozone gas concentration, ozone consumption substances concentrations, reaction rates. The effect of

Fig. 5 Relation between water depth of ozone contactor and ozone dissolving efficiency

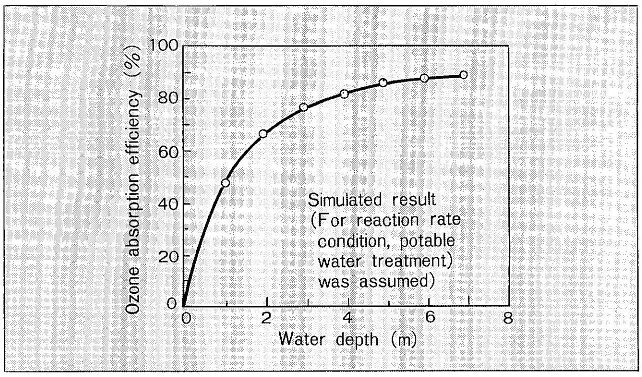


Fig. 6 Relation between number of stages of contactor and odorant removal rate

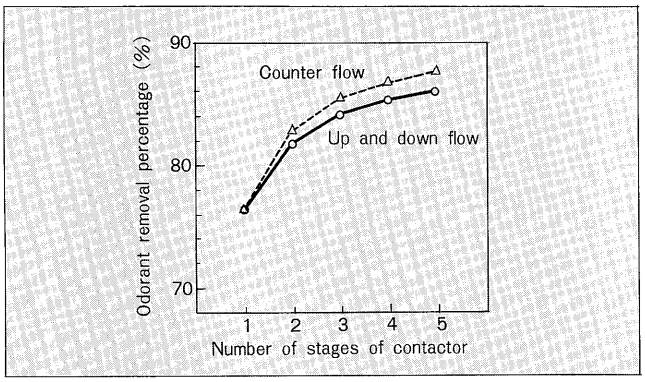


Fig. 7 Structure of glass-lined ozone generating tube

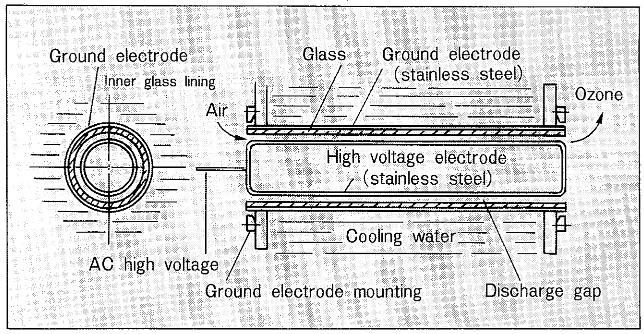
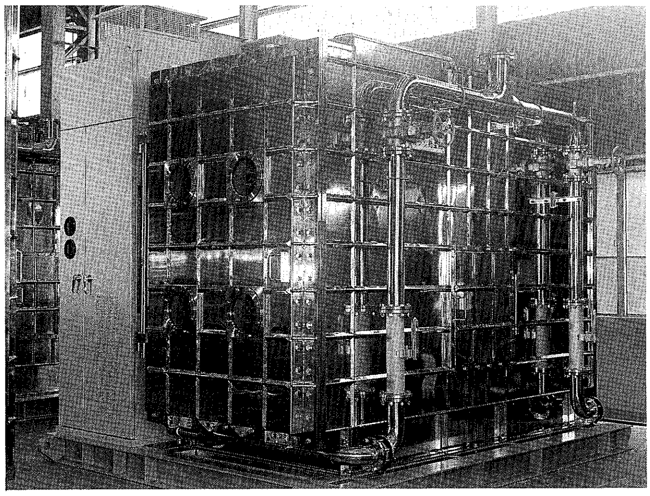


Fig. 8 Exterior view of large ozone generator (18 kgO_3/h)



water depth on the ozone absorption efficiency estimated by the simulation is shown in **Fig. 5**. In this case, for the reaction rate conditions of the ozone consumption substances in raw water, potable water was assumed to be used. As it is shown in **Fig. 5**, the ozone absorption efficiency tends to saturate at depth of about 6m and this result corresponds with the generally accepted optimum value of 4 to 6m. Since ozone absorption efficiency partly depends on the substances concentration in raw water, it tends to be better for secondary treated water of sewage and other wastewater.

(4) Comprehensive evaluation by simulation

The performance required for contactor is of course to satisfy the water quality level given by the requirement of the treated water. Since the process to remove the substances in the contact chamber involves mass transfer phenomena, retention time distribution and chemical reactions, it is very complicated to evaluate the performance of a contactor. In contactor design, the optimum conditions is often determined using experimental data. But from the result obtained by labo-scale experiment, it is not able to estimate conditions related to actual contactor shape and dimension in practical accuracy, so scale-up experiment is needed. Although the results of pilot plant experiment is expected to close to the planning actual contactor, the total run of the experiments would be limited because it takes much time and much cost to run in the cases of many conditions required to design. As a results, simulation is effective means in such case. For example, the relationship between odorous compounds removal percentage and number of chambers under the condition of the same hydraulics retention time is shown in **Fig. 6**. It is clear that as the numbers of stages is increased, removal ratio increases and the counter flow system is superior if the number of stages is the same.

4.4 Ozone generator

(1) Energy saving, high reliability

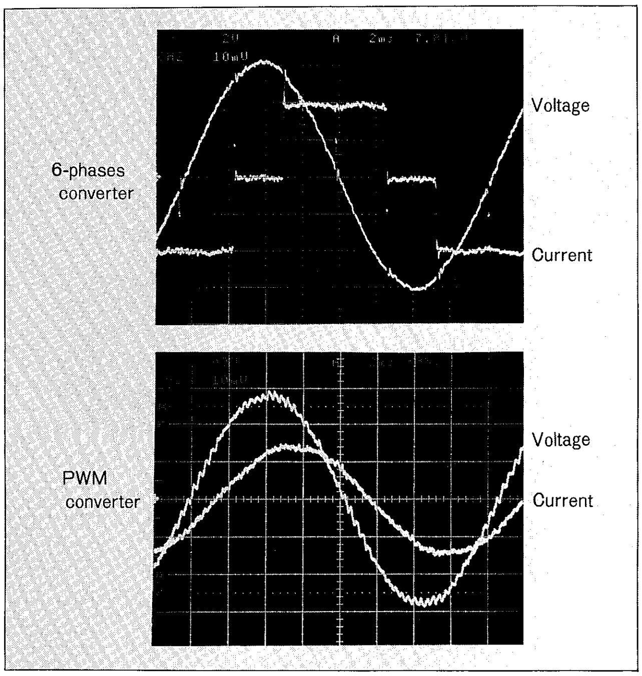
Power saving and high reliability are demanded of ozone generators used in advanced treatment. Both coping by ozone generator alone and by entire facility are considered for these problems.

For an ozone generator alone, this problem is dealt with by using a Fuji Electric original glass-lined ozone generating tube. The glass-lined ozone generating tube consists of a stainless steel tube, which is the outside ground electrode lined inner with glass and has the following features (**Fig. 7**):

(a) The glass dielectric is cooled directly by outside cooling water and the cooling effect is very high.

(b) Since the cooling effect is high, the ozone generating efficiency is high (ozone generation 76 g/kWh).

Fig. 9 Shape of current and voltage wave of 6-phases converter and PWM converter



(c) The inside of a stainless steel tube is lined with glass and the failure rate is extremely small and reliability is high.

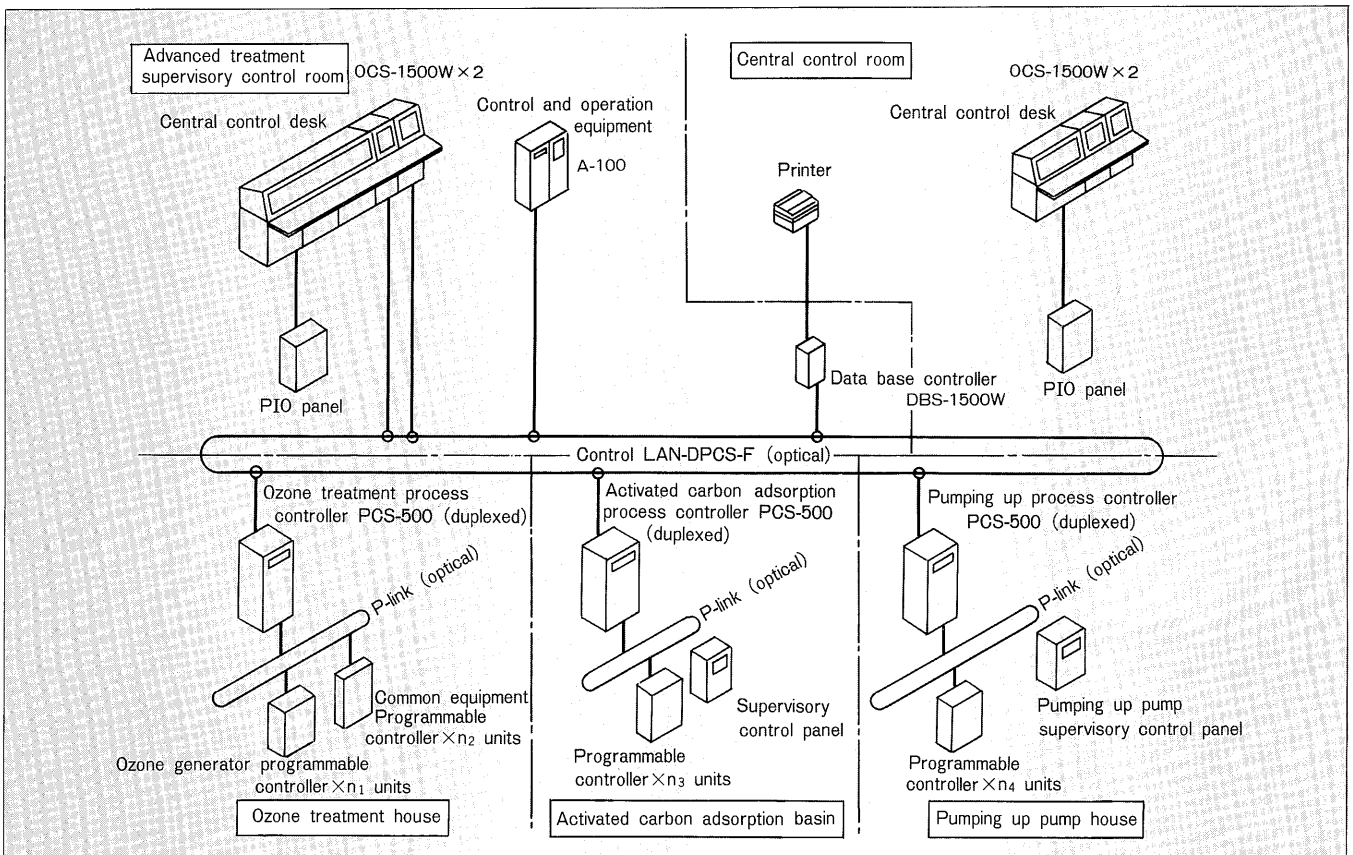
(d) The ground electrode is constructed so that it may be removed from the equipment body and maintenance and inspection of cooling water side are possible.

A large ozone generator used in advanced drinking water treatment is shown in **Fig. 8**.

The number of units must be studied for an energy saving and high reliability measures through an overall ozone generating facility. In water and sewage works, the variation of the treatment flow rate is large and the variation of the necessary ozone generation is also large. The generation of ozone can be continuously adjustable in the range of 100 to about 5% of rated capacity. The discharge power is also reduced in proportion to this. However, since the air source blower, desiccant dryer, and other auxiliary equipments operate continuously at the normal rating, the auxiliary equipment power consumption is constant regardless of the capacity of ozone generation. Therefore, assembling multiple ozone generators and starting and stopping each unit, including the auxiliary equipment, by controlling the number of operating units corresponding to required ozone generation saves overall power. The reliability of the entire facility can also be improved by using a multiple unit composition.

(2) Power supply harmonic countermeasure

Fig. 10 Example of supervisory control system of advanced treatment of drinking water



The ozone generator is driven by a 1,000 Hz power supply. Therefore, a high frequency converter is provided as the power supply. This DC converter usually generates large harmonics to the power supply. If the capacity of the ozone generator is not very large relative to the facility capacity, these harmonics are not a problem. However, when the capacity is large, the other facilities are affected by capacitor overheating, etc. Recently, this problem has been dealt with by using an active filter, etc. Fuji Electric, however, has advanced one step further and can incorporate a converter that does not generate harmonics into the ozone generator power supply, as required. This unit performs control such that the converter input current approaches a sine wave by PWM control (pulse width control). (see **Fig. 9.**) This PWM converter has the following features:

(a) Harmonic suppression effect is large.

(b) The power factor can also be controlled at almost 1 simultaneously with harmonic suppression and the capacity of the power transformer can be reduced.

(c) Space is saved by combining the ordinary converter and active filter functions into one function.

4.5 Advanced treatment system supervisory control

An advanced treatment system is functionally divided into hierarchical levels from component unit level to entire system. At the same time, an entire system is assembled by horizontally dispersing the pump facilities, etc. in response to function. Therefore, the supervisory control system is also divided into hierarchical levels and horizontally dispersed to match these functions. An example of a supervisory control system of an advanced treatment plant for drinking water is shown in **Fig. 10**. In this system, for the ozone treatment facility in particular, one ozone generator and one set of auxiliary equipment directly associated to it are handled as one ozone generating installation and are controlled by allocating one programmable controller to this installation. The equipment around the ozone contactor (including the exhaust ozone destructor) are controlled by a separate programmable controller as ozone treatment facility common equipment and are divided into hierarchical levels so that the programmable controllers are controlled by a process controller that controls the entire ozone treatment facility. Here, the process controller controls the following:

(a) Number of operating unit of ozone generators

(b) Automatic starting of standby unit

(c) Linking of ozone generator and exhaust ozone destructor

(d) Ozone dosage (selection of total ozone generation rate according to the situation and allocation of ozone generation rate to each ozone generator)

When multiple ozone generators are controlled in group units like this, a hierarchically high level process controller, besides parallel installation of ozone generators with equipment side control panel, is necessary.

5. CONCLUSION

Focusing on ozone treatment, advanced treatment in water and sewage works was described. It is expected in Japan that advanced treatment of drinking water, about which there have been many studies and researches for more than 10 years, will finally enter the implementation stage. And construction of advanced treatment plant will be continuing in the future. On the other hand, advanced treatment of sewage is considered in the beginning stage and will be also popular in the future. In either case, the construction of actual facilities and their operation has just begun. With the evaluation of the running data, further advanced technology will be developed.