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ADVANCED WATER PURIFICATION AND OZONATION

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1. INTRODUCTION

One-hundred years have passed since the birth of modern water supplies in Japan. The pervasion of municipal water supplies throughout the nation exceeds 93% and has entered the "wide pervasion age". However, the growth of industrial activity and the increased flow to public water basins of different wastewater have given rise to the problem of undersirable taste and odor of municipal supplied water. Recently the existence of trace organic chemical substances and trace organic halides in river water, etc. and of trace organic chemical substances (trihalomethanes (THM)) in municipal supplied water has been detected. Therefore, effective action from a new standpoint at water supplies has become necessary.

Because of such situation, research and development of new water purification processes aimed at the supply of "safe and fine drinking water" centered about urban districts where undersirable taste and odor occur frequently has advanced. Long-term experiments by pilot plant have proved that ozonation, activated carbon treatment, biological treatment are effective. These processes are called "advanced water purification processes" as opposed to conventional purification processes.

In 1988, the Ministry of Walfare of Japan established a subsidy system for the first time for activated carbon treatment, ozonation, and biological treatment processes for the introduction of advanced water purification plants, and advanced purification of potable water entered into the implementation stage from the research stage. From the standpoint of the history of potable water in Japan, such aspects were big transition "from quantity to quality", and were called the opening of the second century of waterworks. Advanced purification of potable water greeting such new aspects is outlined and its technology introduced.

2. ADVANCED PURIFICATION OF POTABLE WATER

2.1 Need for advanced treatment

In Japan, resources of most potable water are rivers, dams and other so-called surface water. Besides direct pollution of water resources by municipal sewage and domestic waste-water due to an increase in population of their basins, occurrence of undesirable taste and odor and other problems has arisen at dams, etc. with the growth of algae due to eutrophication.

The water purification processes used widely in the past were those to coagulate and to precipitate insoluble substances by adding a coagulating agent to the raw water, then to filtrate supernatant rapidly. However, even though those processes can remove the insoluble components, the removal of the substances which cause undesirable taste and odor and soluble precursor which become the source of trihalomethanes (THM) is difficult.

To deal with such problems, the introduction of ozonation, A.C. adsorption, and other advanced purification processes is necessary.

2.2 Advanced purification process

Fig. 1 classifies the advanced water purification processes. Ozonation, activated carbon treatment, and biological treatment correspond to those.

Besides independent application of each of such purification processes, they are also combined, as required. Especially, the combination of ozonation with activated carbon treatment is effective. The deodorization effect of each treatment process when ozonation and activated carbon treatment are used together is shown in *Fig. 2.* It can be seen that the deodorization effect of ozonation differs with the ozone dosage and that undersirable odors can be almost completely removed by using it with acti-

Fig. 1 Advanced Water Purification Systems

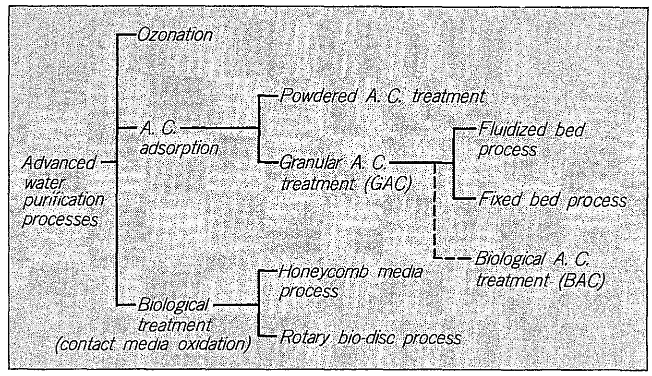


Fig. 2 Deodorization effect of each treatment process

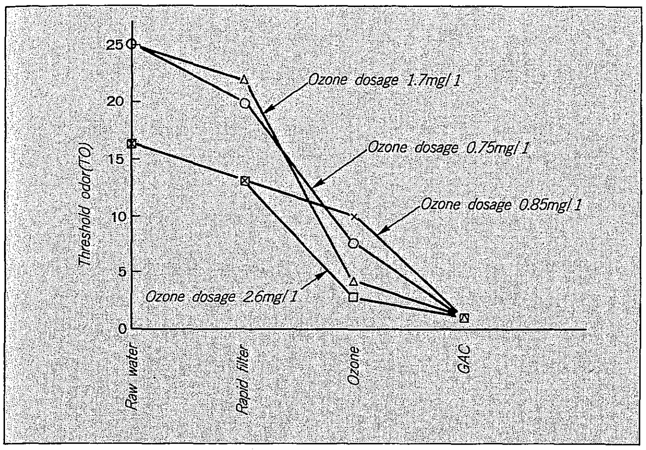
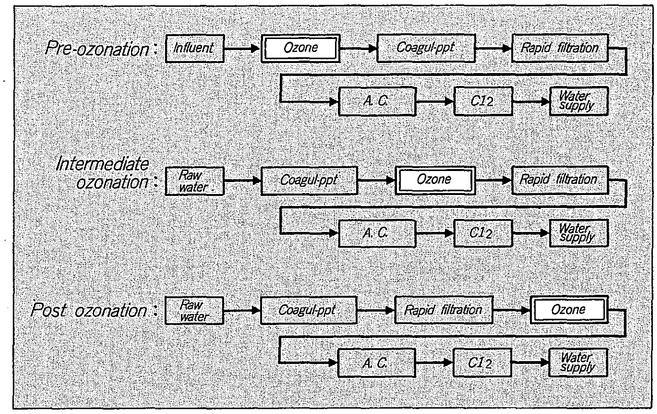


Fig. 3 Ozone injection points at advanced water purification



vated carbon treatment. Besides, sharing of the load to be removed by ozonation and activated carbon treatment also extends the life of the adtivated carbon.

Of the activated carbon treatments, that called biological A.C. treatment is a treatment system that forms a biological phase on the surface of granulated activated carbon and performs both physical adsorption on activated carbon and biochemical treatment by biological phase at the same time. It is a treatment process from which much is expected in the future. In addition to an ammonia removal effect, this processing system is also said to extend more than triple the life of the activated carbon. When ozonation is performed before biological A.C. treatment, biological treatment is improved, etc. Generally biological A.C. treatment and ozonation are combined.

2.3 Ozonation and injection point

The functions and main effects of ozonation in water purification are:

(1) Breakdown of original ordrant substances . . . Elimination of undesirable taste and odor
(2) Degradation of organic pollutants . . . Improvement of adsorpability of activated carbon
(3) Breakdown of trihalomethanes precursors . . . Reduction of trihalomethanes
(4) Activation of biological treatment . . . Improvement of processability of biological A.C. treatment
(5) Oxidation of Fe and Mn . . . Removal of iron and manganese
(6) Improvement of flocculability . . . Reduction of the amount of coagulant used
(7) Disinfection and inactivation of virus . . . Disinfection

The only use of ozone in disinfection is not recognized in Japan.

The injection point of ozone in the water purification process is decided according to the effect expected of ozonation. Typical ozone injection points are shown in *Fig. 3*. For instance, when the purpose is improvement of flocculability, preozonation is used. Therefore, when a large multiple effect of the ozone is expected, ozonation is performed at two or more injection points. In France, there are also examples of injection of ozone at three points.

3. OZONATION TECHNOLOGY

3.1 Composition of ozonation facility

An ozonation facility consists of (1) ozone generator that generates the ozone, (2) ozone contactor in which ozone and raw water contact and react, (3) ozone destructor that breaks down the unreacted ozone exhausted from the ozone contactor, and (4) electric and instrumental equipments for all ozonation facility. (See *Fig. 4*.)

3.2 Ozone generator

High reliability, as well as power and space saving, are demanded of the ozone generator used in potable water ozonation.

The ozone generator that uses a glass-lined ozone generation pipe developed by Fuji Electric meets such demands and has the following features:

(1) Since the inside of the outer grounding electrode (stainless steel pipe) is a structure lined with glass, the glass is cooled directly and the cooling effect is very high. (See *Fig. 5*.)
(2) Since the cooling effective is high, efficiency is high (generation yield of ozone 76g/kW).
(3) The amount of ozone generated per ozone generating pipe is high and since shape of the generator is square,

Fig. 4 Composition of ozonation facility

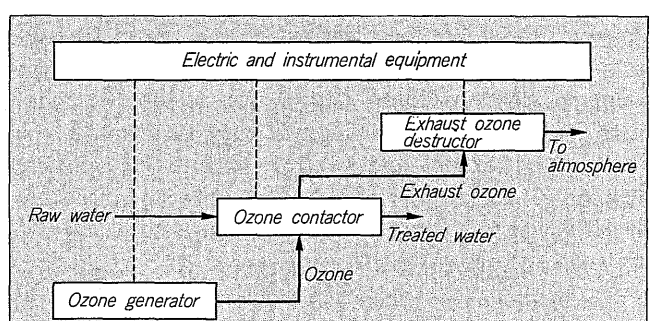


Fig. 5 Structure of glass-lined ozone generating pipe

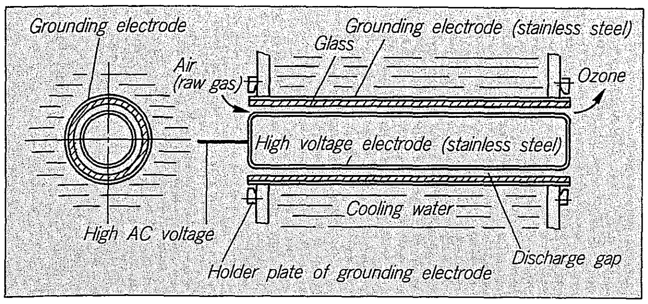
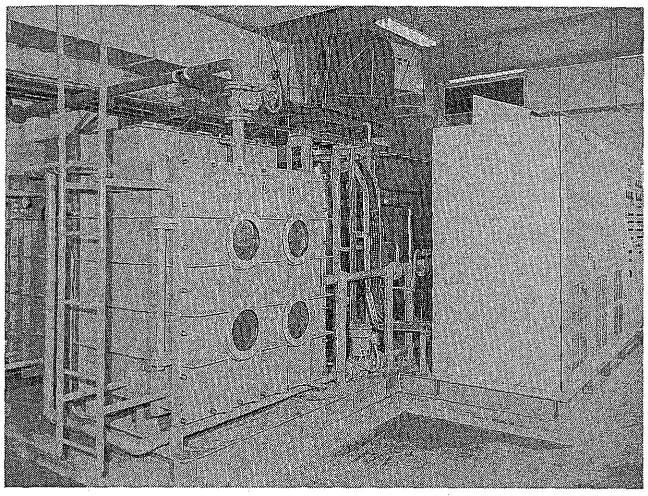


Fig. 6 Exterior view of ozone generator (4.5kg/O_3 h)



installation space is small.

(4) The inside of the stainless steel pipe is lined with glass and the breakage rate is low.

(5) Because the grounding electrode can be dismantled from the body, maintenance and inspection of cooling water side are possible.

An exterior view of the ozone generator with glass-lined ozone generating pipe is shown in *Fig. 6*.

3.3 Ozone contactor

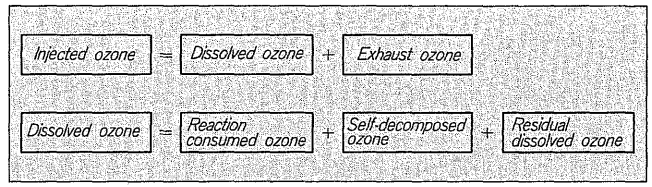
(1) Mass balance of ozone at ozone contactor

At the ozone contactor, the ozone sent from the ozone generator is mixed into the raw water in the form of fine bubbles. The ozone in the bubbles is dissolved in the water from the bubble surface. The bubbles rise and the ozone that cannot be dissolved before the bubbles enter the air through the surface of the water is exhausted to the air as exhaust ozone. On the other hand, the ozone dissolved in the water is consumed by reaction and also by self-decomposition. Contactor design must satisfy the conditions (1) high ozone dissolving efficiency, (2) ample mixing of dissolved ozone, and (3) maintenance of detention time only long enough for reaction between ozone and the substance to be treated to progress sufficiently.

(2) Ozone dissolution

A method by which a porous ceramic diffuser is placed at the bottom of the water and ozone is passed

Fig. 7 Ozone mass balance in ozone contactor



through the diffuser and is diffused in the water as fine air bubbles is widely used to dissolve ozone in water.

The amount of ozone dissolved into water from inside of air bubble per unit time is expressed by following equation:

$$O_z = K_L a\,(KC_G - C_L) \quad \cdots\cdots (1)$$

where, O_z: Amount of ozone dissolved into water in a unit time (g/h)

K_L: Overall mass transfer coefficient (m/h)

a: Surface area of total air bubbles in water (m^2)

K: Distribution coefficient of ozone gas to water (–)

C_G: Ozone concentration in air bubbles (g/m^3)

C_L: Ozone concentration in water (g/m^3)

Of above parameters, the value of a is an important parameter which is determined by the plant design conditions. That is, a is determined by the bubble diameter, bubble upward velocity, liquid depth, etc. To increase the ozone dissolution efficiency, the bubble diameter must be small and the liquid depth must be deep. However, when the liquid depth is made deep, the pressure of the ozone gas must be made high and since the power consumption becomes high for that reason, a liquid depth of 4 to 6m is generally suitable.

(3) Ozone reaction

When deciding the retention time of ozone contactor the reaction time between substance to be treated and ozone becomes an important parameter. However, there are many kinds of substances in the actual raw water, and these coexising substances may affect the reaction rate. The effect of carboxylic acid on ozone decomposition of geosmin, a substance which causes potable water to have a musty odor, is shown in *Fig. 8*. It can be seen that geosmin alone is about 90% decomposed in 10 minutes and that when it coexists with carboxylic acid, the reaction time increases as its molecular weight rises. Such effect is an important problem in contactor design and further research is progressing.

(4) Contactor hydraulic properties

Regarding ozonation of potable water, the amount of water treated is generally large and the horizontal area of the ozone contactor is large relatively to the liquid depth. With a contactor of such a shape, the water flow is not simple counter current or simple cocurrent and a large mixing effect appears. Therefore, the shape of the contactor must be decided so that a shortcut flow is not produced and the necessary reaction time is obtained.

Fig. 8 Effect of carboxylic acid on geosmin decomposision

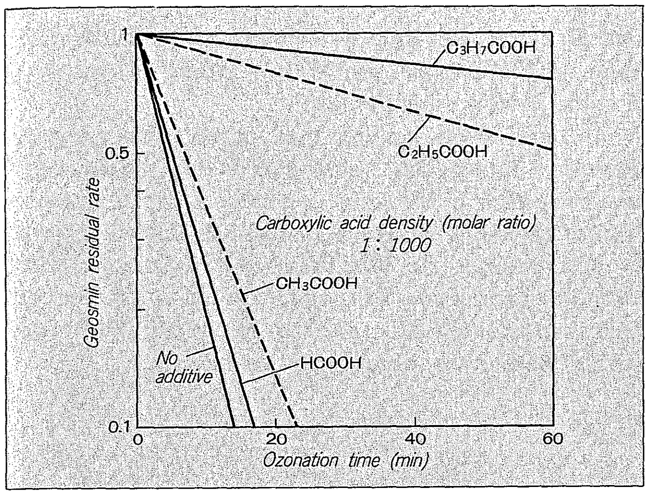


Fig. 9 Mixing characteristic experiment by ozone contactor model

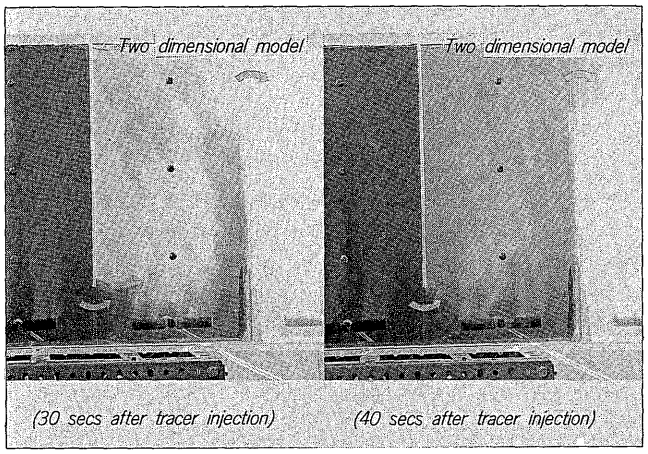


Fig. 10 Delta responsiveness of ozone contactor outlet in model experiment (4th of 4 compartments)

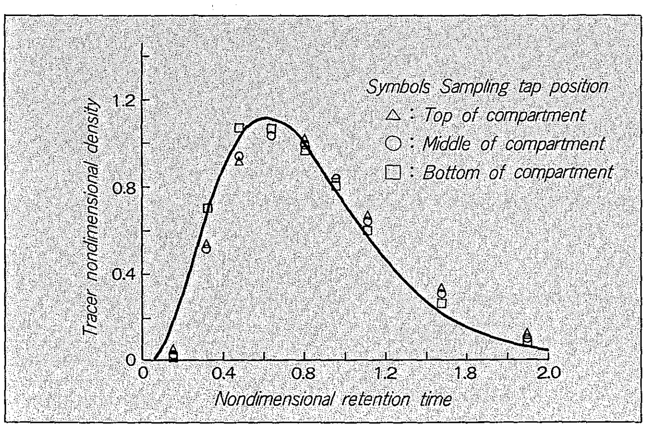
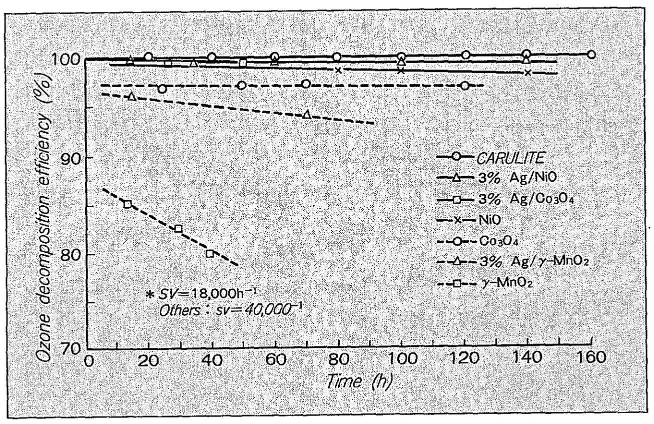


Fig. 9 is an example of a model experiment of the mixing property of an ozone contactor. Dye is injected in the form of a pulse as the tracer and the mixing property is studied by menas of its responsiveness. *Fig. 10* shows an example of variation of tracer concentration at the outlet when the contactor was divided into four compartments. This result agrees with the results of simulation by

Fig. 11 Ozone decomposition property of various catalytic destructors



vessel train model. The effect of the number of compartment of the contactor can be evaluated and the shape of the contactor can be optimized from the results of these experiments.

3.4 Exhaust ozone processing

Since the concentration of the exhaust ozone discharged into the air as the undecomposes component from the contactor is considerably high, it must be discharged into the atmosphere after decomposed. The conventional activated carbon system was widely used to decompose the exhaust ozone. However, for ozonation of potable water, the large scale activated carbon system consumes a large amount of carbon and it is undesirable from the standpoints of running cost high and replacement work troublesome. The catalytic method is available as an exhaust ozone processing method which alternates the activated carbon method. There are various kinds of catalysts for ozone decomposition. Their decomposition properties are shown in *Fig. 11*. The evaluation items of catalysts are usage temperature and processing air flow per hour per catalyst volume (SV). The lower the usage temperature, the less the heating energy and the large SV, the smaller the amount of catalyst needed. Compared from these view points, the manganese dioxide catalyst, CARULITE is an excellent catalyst.

3.5 Dosage control of ozone

Since the amount of ozone required varies with variation of the water quality and variation of the influent flow rate, the amount of ozone generated must be controlled accordingly. The ozone dosage is controlled automatically by constant concentration control of exhaust ozone or constant concentration control of dissolved ozone. Constant concentration control of exhaust ozone measures the concentration of the exhaust ozone from water surface the contactor with an ozone-meter and automatically controls the ozone generation amount so that this value is constant. This method uses the correlation with the ozone requirement for the pollutants in the water to be treated. Constant concentration control of dissolved ozone uses also the same principle. However, besides the slight difference between the control characteristics of both, from the standpoints of measurement ease and stability, because the measurement of ozone is more reliable, exhaust ozone control is widely used. However, when ozonation is followed by biological A.C. treatment, dissolved ozone control is necessary so that the high dissolved ozone does not have an negative effect on the organisms in activated carbon layer.

4. CONCLUSION

The application of ozone to water treatment began in Europe and has a history of about 100 years. At first, it was used in disinfection of potable water and was adopted to various processes after that. Ozonation is now being used at more than 1000 water purification plants in the world. In Europe, the mainstream of ozone use was application to potable water purification.

In Japan, ozone has been used for more than ten years. However, during this time, remarkable developments have been made in the ozone generator in Japan, improvement of generating efficiency, dimensional reduction by the use of an inverter, etc. have been achieved. Hereafter when advanced purification of potable water enters the full scale implementation stage, the trend will be toward further improvement of ozonation technology.