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4

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Solution Technologies Related to Water Quality

FUJI ELECTRIC

Creating a Better Tomorrow with Trustworthy Technology

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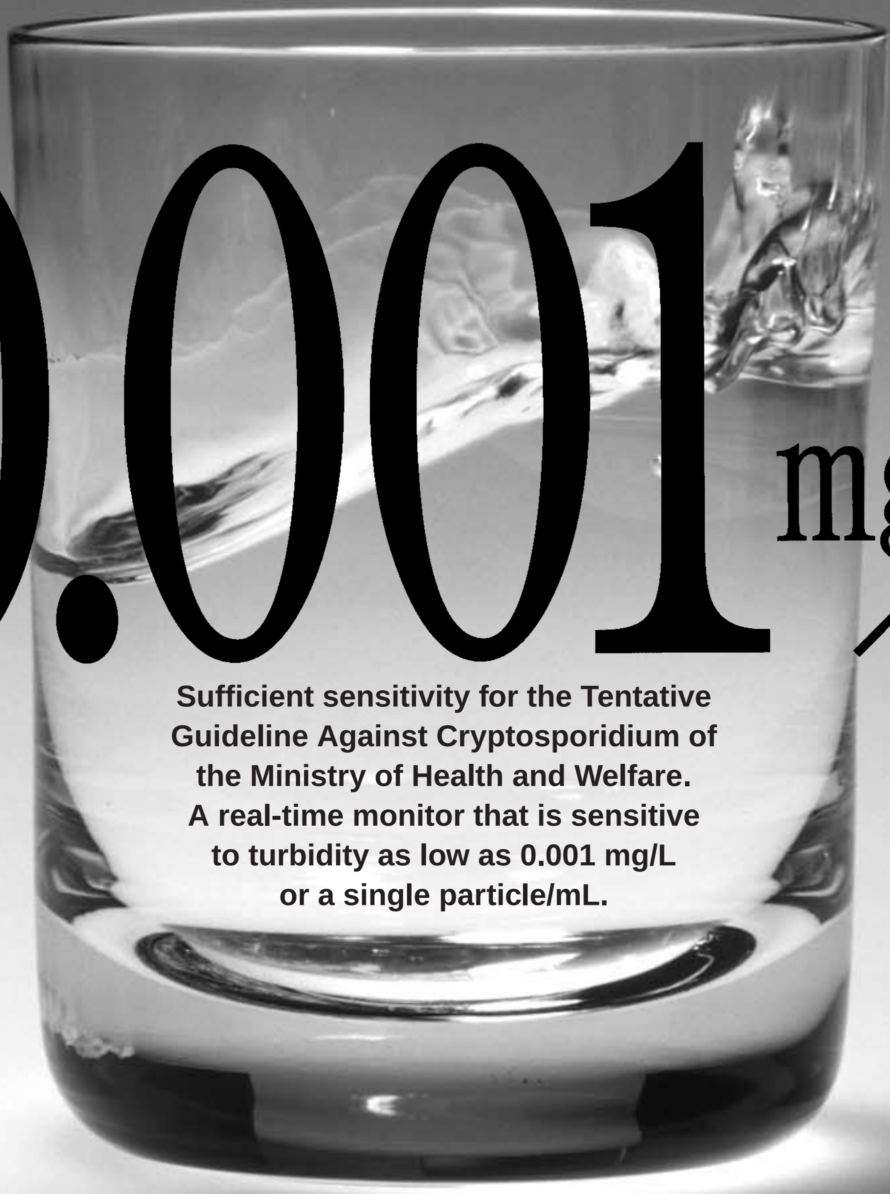

0.001 mg/ℓ

Sufficient sensitivity for the Tentative Guideline Against Cryptosporidium of the Ministry of Health and Welfare.
A real-time monitor that is sensitive to turbidity as low as 0.001 mg/L or a single particle/mL.

Purification plants are required to perform severe turbidity control to prevent cryptosporidium, a pathogenic microbe, from entering. Fuji Electric has developed a high-sensitive turbidimeter that detects each individual turbidity particle with laser beams.The turbidimeter realizes real-time monitoring of turbidity as low as 0.001mg/L, sufficiently satisfying the Tentative Guideline of the Ministry of Health and Welfare. Moreover, it can count a number concentration of particles of 0.5 µm or larger in diameter, and a thorough preventive measure can be taken against cryptosporidium considered as large as about 5 µm.

Fuji Electric High-Sensitive Turbidimeter

FUJI ELECTRIC
REVIEW

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Solution Technologies Related to Water Quality

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Cover Photo:

Creatures originated from water. The maternal water that drops out of the clouds and flows down rivers or underground into the sea is polluted by the working of people, but is purified into vapor and returns to the sky.

Purified water, a gift from heaven, has become insufficient and more polluted with an increase in population and an advance in civilization. It is indispensable for maintenance of life that people should purify water polluted by their working and continue to monitor pollution.

Fuji Electric, an all-around electrical manufacturer, has accumulated ample experiences and technologies for water treatment and has supplied many water quality maintenance systems for security of people's life.

The cover photo images safe and good tasting water supply, the goal of water quality technology, with a refreshing torrent for a background.

Fuji Electric Co.,Ltd. Head Office : No.12-1, 1-chome, Yurakucho, Chiyoda-ku, Tokyo, Japan

Trends of Solution Technologies Related to Water Quality

Haruo Ito
Kiyoshi Kazama
Masakatsu Fukuda

1. Introduction

In Japan, when viewing urban areas and their water sources such as lakes, marshes, or rivers from the sky, you will see lakes and marshes greened by a water bloom, rivers that are thin, yellowish, and turbid, and waterworks taking in water from the downstream of rivers. As a result, most people feel uneasy about their water supply. The eutrophication of rivers, lakes, and marshes, chronic water shortages, and frequent problems with river water quality are all menaces to urban living. Moreover, people fear contamination of sewage and city water treatment after traffic accidents. There exists the possibility of toxicant effluence from the oils and chemicals carried by motor vehicles. Thus, various problems remain in the water environment. Our administration is promoting measures including the establishment of two laws to preserve city water sources, a plan for returning sewage to the upstream of rivers through superhigh-grade treatment, and the amendment to the River Act incorporating measures for environmental preservation.

Current topics concerning the water environment

Fig.1 Current topics of the water environment

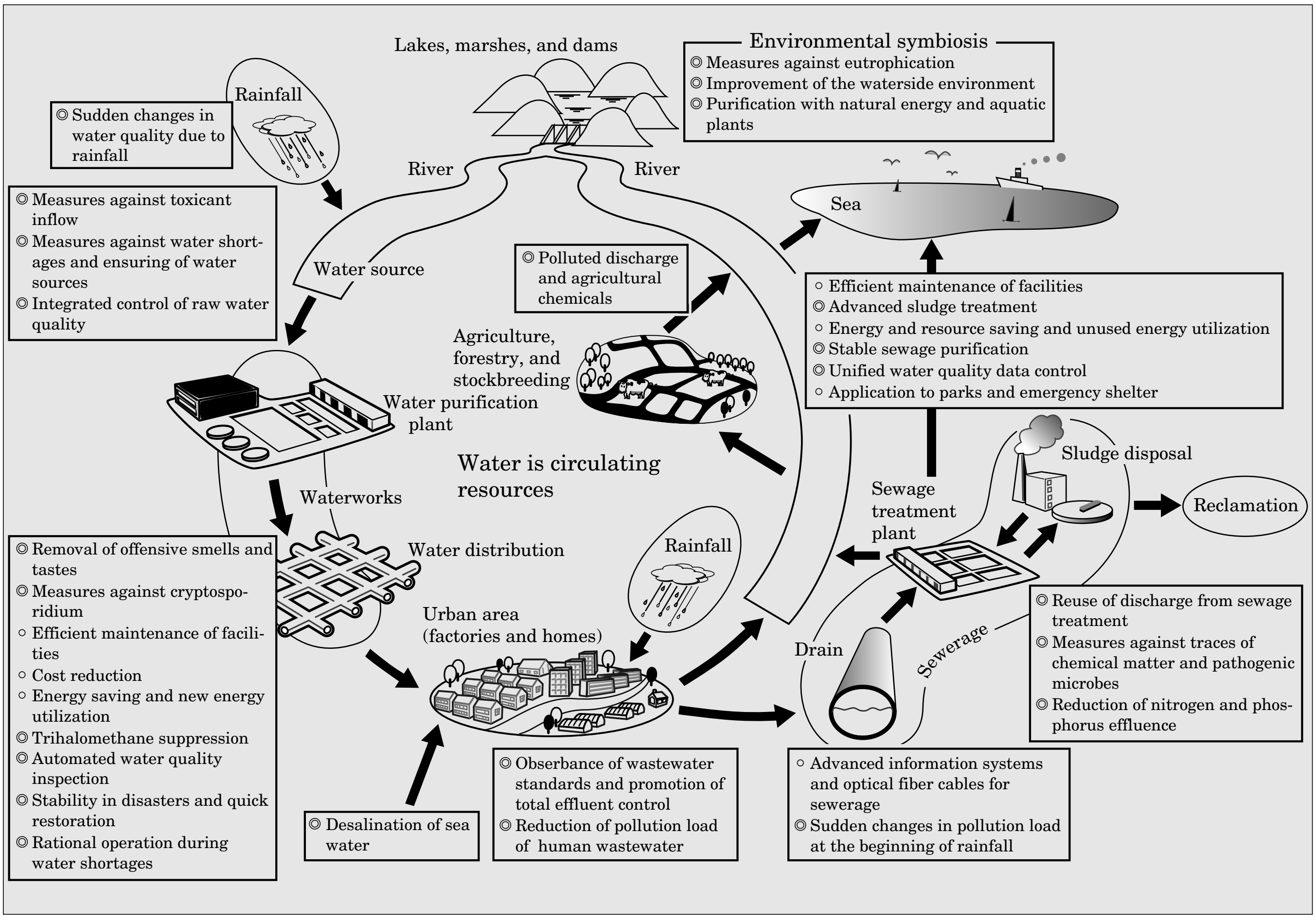
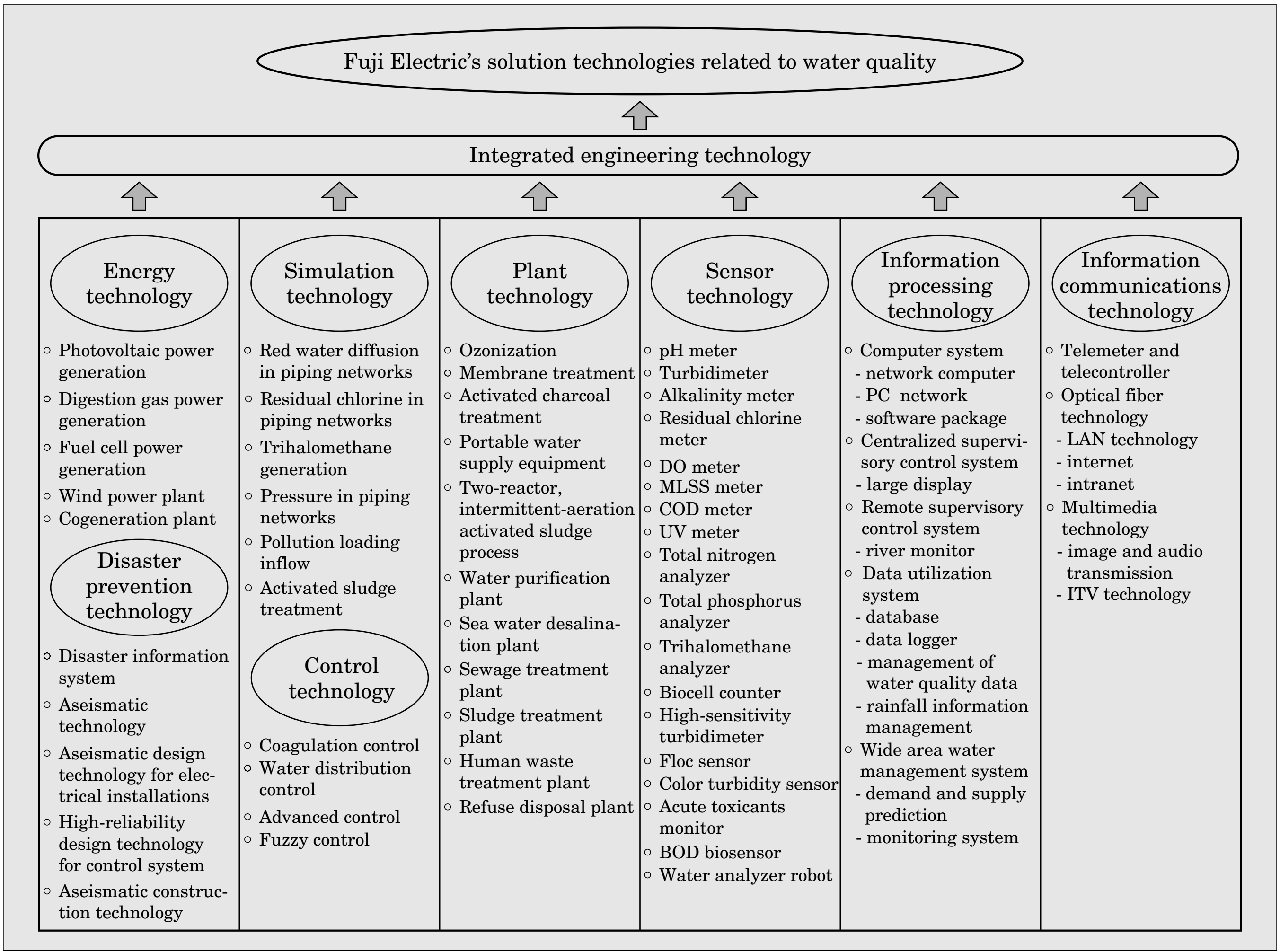


Fig.2 Scheme of Fuji Electric's solution technologies related to water quality



are shown in Fig. 1.

Amidst the growing trends toward the improvement and preservation of the water environment, Fuji Electric is tackling the problems of the water environment with various solution technologies used in energy, plant, process, and EIC (electric control, instrumentation, computer) system engineering.

We are researching clean energy (such as photovoltaic, digestion gas, and fuel cell power generation), new and advanced treatment and sewage disposal processes, an analysis and process simulation technique by using computers and a line of optimum EIC systems. In order to perform on-line water quality control to meet the increase in water quality problems, Fuji Electric has developed various sensors using the fundamental technologies of physics, chemistry, optics, and biology.

The scheme of Fuji Electric's solution technologies related to water quality is shown in Fig. 2.

This paper describes major problems in the water environment and the trends of Fuji Electric's solution technologies related to water quality.

2. Solution Technologies Related to Water Quality

Recently, the water quality of rivers, lakes and marshes for city water sources has been a problem. In 1996, there were no less than 300 cases of water quality problems which included toxicant effluence and unlawful waste abandonment in first-class rivers. Action was demanded on all fronts. In some urban districts in Japan, sewage treatment plants or factory drainage outlets are situated upstream of waterworks. Therefore, safety control of water quality sources is the most important priority of the water service.

Fuji Electric has developed an acute toxicants monitor that can continuously, sensitively, and automatically monitor the pollution of river, lake and marsh water used as raw water. We have also developed a river water management system that supports the river management staff when faced with water quality problems. The acute toxicants monitor, the key to the system, incorporates nitrifying bacteria sensitive to toxicants. They are immobilized in a microbial membrane and then fit to a dissolved oxygen electrode. It can sense the activity of nitrifying bacteria from the change in dissolved oxygen consumption, thus detecting toxicants that are mixed in with the river water.

Generally, the presence of toxicants is often measured by observing the behavior of fish. However, this type of measurement has a disadvantage-impreciseness due to differences between individual fish. Features of the acute toxicants monitor include a detection sensitivity of approximately 10 times that of the fish measurement, instantaneous reaction, and a function of sample water storage at the time of toxicant reaction. The monitor can quickly and positively detect toxicants. A wide area toxicant monitoring system can be established by positioning the acute toxicants monitor at multiple points, such as specified plants on the river, irrigation channels, and sewage treatment plant discharge outlets, and then linking them with information communications, computers, and problem management software. This system has been introduced into at least 10 domestic waterworks and rivers with deteriorated water quality in the metropolitan area. In March 1997, Fuji Electric and the Public Works Research Institute of the Ministry of Construction, a joint developer, received the Water Environment Institute prize for this technology.

This system conforms to the River Act, soon to be amended to include regulations for environmental preservation.

The symptoms of mass infection caused by cryptosporidium that broke out in the Kanto district in 1996 is believed to have been caused by city water. The Ministry of Welfare and Health issued guidelines for tentative measures against cryptosporidium, and discussions on improvement of the control method for the water purification process began.

Fuji Electric has marketed a high-sensitivity turbidimeter capable of on-line measurement of 0.1 degrees turbidity at the outlet of a filter basin as described in the guidelines for tentative measures. The turbidimeter adopts a forward scattering particle counter method and can measure very low turbidity of 0.001 degrees and particles that are 0.5 μm or larger, which a conventional transmission or surface scattering method cannot measure.

Fuji Electric has developed a floc sensor and controller which can realize low-turbidity operation of a water purification process and optimum chemical injection control to suppress the excessive injection of coagulant. This control system uses the size of the microflocs measured in the mixing tank as feedback signals and controls the amount of chemical injection to maintain the size of the flocs. This results in a floc formation with high sedimentation and minimized chemical injection. The optimum quantity of chemical injection is considered to be an effective measure against cryptosporidium and Alzheimer's disease, which is suspected to be caused by excessive injection of an aluminum coagulant. The control system is already operating in several waterworks and is effective in removing suspended solids at the stage preceeding intermediate chlorination to reduce side products by disinfection.

In the field of advanced treatment technology for water purification, Fuji Electric has developed a high efficiency, high performance ozonizer using glass lined pipes and a two-sided cooling system. The ozonizer powerfully decomposes offensive smells and tastes and trihalomethane precursors in raw water, contributing to a safe and good tasting water supply. In parallel with the development of this equipment, Fuji Electric is promoting studies on fundamental technology and simulation technology for advanced treatment processes such as physical and chemical theories and a high efficiency ozone reaction treatment technique (joint research with Tokai and Hiroshima Universities).

In the field of water supply, physical water distribution control technologies, such as terminal pressure uniformity, grouping service terminals, and measures against water leakage, have been studied and introduced. Recently, control technologies for water quality to supply safe and good tasting water have also been added. As a solution to the control of service water quality and through joint research with the Japan Waterworks Association, Fuji Electric has marketed a service water quality monitor which can detect the slight coloration of service water. Conventional water quality monitors measure only a yellow coloration. The new monitor can measure on-line several types of coloration including red (iron rust), yellow (humus), black (manganese) and white (air). It has a higher sensitivity than a visual inspection. With this monitor, the measurement of color, turbidity, and residual chlorine can be automated and greatly reduce the inspection load carried by the water service. For example, there was a case in which the monitor detected residual matter flowing through the pipe to the faucets as a slight coloration when the water supply was restored. Thus, the monitor's strength lies in the inspection of service water after pipe work and recognizing any damages in piping after a disaster.

In the field of sewerage, Fuji Electric has developed a BOD biosensor which can measure a BOD (biochemical oxygen demand) value within 20 minutes instead of five days by previous measurement. The principle of measurement of the BOD biosensor is that it has trichosporon, an omnivorous yeast, immobilized in a membrane. Its dissolved oxygen electrode detects the process in which the trichosporon digests organic matter from organism decomposition in sample water and simultaneously consumes oxygen dissolved in the water.

Recently, attempts have been made to quickly measure organic loading in water flowing into sewers with the BOD biosensor and utilize the data to control the volume of aeration and the extraction of sludge. A wide application of the BOD biosensors to sewage treatment plants is expected. The BOD value is an important organic pollution index for river water, and the BOD biosensor will increase in importance for monitoring water-environmental pollution and for continuous BOD monitors for wastewater discharge.

In the field of sewage treatment technology, Fuji Electric developed a two-reactor, intermittent-aeration activated sludge process (sold as a plant) that is effective in removing nitrogen and phosphorus found in sewage. The process has been successful in controlling the inflow of eutrophication matter into the water environment.

3. Future Prospects

To improve the water environment and water treatment, the administration has announced policies for a safe and good tasting water supply, construction of waterworks resistant to water shortages and earthquakes, preservation of the basin water environment, and prevention of closed water area pollution. In accordance with these policies, Fuji Electric's goal is the solution of the remaining problems of the water environment and offers broad solution technologies ranging from discrete to system products.

For effective measures against the eutrophication of closed water areas such as lakes and marshes, Fuji Electric is developing a system to improve lake and marsh water quality using flexible, film-shaped amorphous solar cells. In this system, a float with solar cells moored on the water supplies power to agitators, which circulate the river and marsh water and contributes to the maintenance of a sound ecosystem.

Even when an area's lifeline is toppled by a large earthquake or typhoon, the drinking water supply should have the highest priority. Quick restoration of the water supply facility is required. For this purpose, safety inspection of a substitute for the service water source with a portable acute toxicants monitor, ensuring satellite communications independent of ground systems, and command of dependable facilities with built-in battery systems are important.

Fuji Electric will concentrate an its sensor and information system technologies to obtain these goals.

When methods for improving the water environment and effective methods of water treatment are investigated, an accurate grasp of water quality conditions is fundamental. Fuji Electric possesses this fundamental understanding of the behavior of water quality constituents through its research and development of water quality sensors. We will further strive for the development of optimum water treatment equipment, control systems, and plant management techniques. On-line water quality sensors are indispensable to the automation of facilities to reduce operator burden and maintain reliable operation. We will also promote improvement of their performance and the development of new products.

Recently, public attention has been focused on the detection of toxicants and pathogenic substances mixed in raw water and inflow wastewater. One such topic was the detection of colon bacilli in raw water. In 1996, diseases caused by the O-157 colon bacilli and cryptosporidia, a pathogenic microbe, received national attention. In particular, direct detection of the cryptosporidium is difficult, and therefore, measurement of the number of colon bacillus groups as an index to infer pollution is necessary. The detection of colon bacillus requires two or more days using the official analytical method, and the shortening of measuring time is the goal of monitor development.

In sewerage, a reduction in the eutrophication of the water environment by denitrification and phosphorus removal in water treatment plans is promoted. Recently, however, in some treatment plans, denitrification was reduced by an obstruction to bionitrification. Harmful matter discharged by a chemical plant was suspected to be the cause. In the future, acute toxicants monitoring systems will be used in sewerage.

4. Conclusion

In this paper, some of the solution technologies relating to water quality which Fuji Electric is striving to develop were described. These include sensor, plant, control, and information processing technologies to solve the problems of the water environment. Solution technologies for the water environment will further develop and Fuji Electric will adopt the results to speed up the improvement of the water environment.

On the occasion of this special issue, we thank the parties involved with the water environment, waterworks, and sewerage. We would appreciate any further guidance and support.

Water Quality Analyzers for Water and Sewage Treatment

Takashi Aoki
Yasuhiro Shinohara
Yasuo Takahashi

1. Introduction

Water is supplied to greater than 95% of Japan, and emphasis is changing to from quantity to quality. As water pollution increases with the advancing industrial age and changes in life-styles, a safer and higher quality supply of city water is desired. In the Special Measures Act and the Work Promotion Act enacted in 1994, the Ministry of Health and Welfare and the Environment Agency stressed the prevention of water source pollution in addition to the previous Water Pollution Control Law and Lakes and Marshes Act. In 1993, the water quality standards for city water were amended. The number of standard items was increased to 46 items. 26 items to be monitored and 13 desirable items were added to supply safer and better tasting water. New treatment systems such as membrane treatment and ozonization have been introduced, and greater importance has been given to water quality control, increasing the demand for new techniques.

Only approximately 54% of households in Japan are connected to a sewage system. The promotion of equipment to raise this rate is a major issue. To restore the rapidly deteriorating water environment, improvements in effluent quality related to water pollution control in public water areas is also an important theme. The effluent quality has been strictly controlled by strengthening effluent standards, total emission controls, and enactment of more stringent prefectural effluent standards. Advanced treatment systems for denitrification and phosphorus removal have had positive results when used in sewage disposal plants, and it has become more important to reliably demonstrate the performance of water quality control treatments.

Because of the increasing expectation of users regarding water and sewage treatment of the changing environment and the advance of water quality measuring technologies, new on-line water quality sensors, in addition to conventional sensors, have been developed and introduced with positive results. This paper describes the process flows of water and sewage treatments, all types of water quality sensors (from basic models to those based on new principles), and water quality control in water and sewage treatment processes.

2. Water Quality Sensors for City Water Treatment

The relationship between the process flow of city water treatments, water quality control, and sensors is shown in Fig. 1.

2.1 Intake water

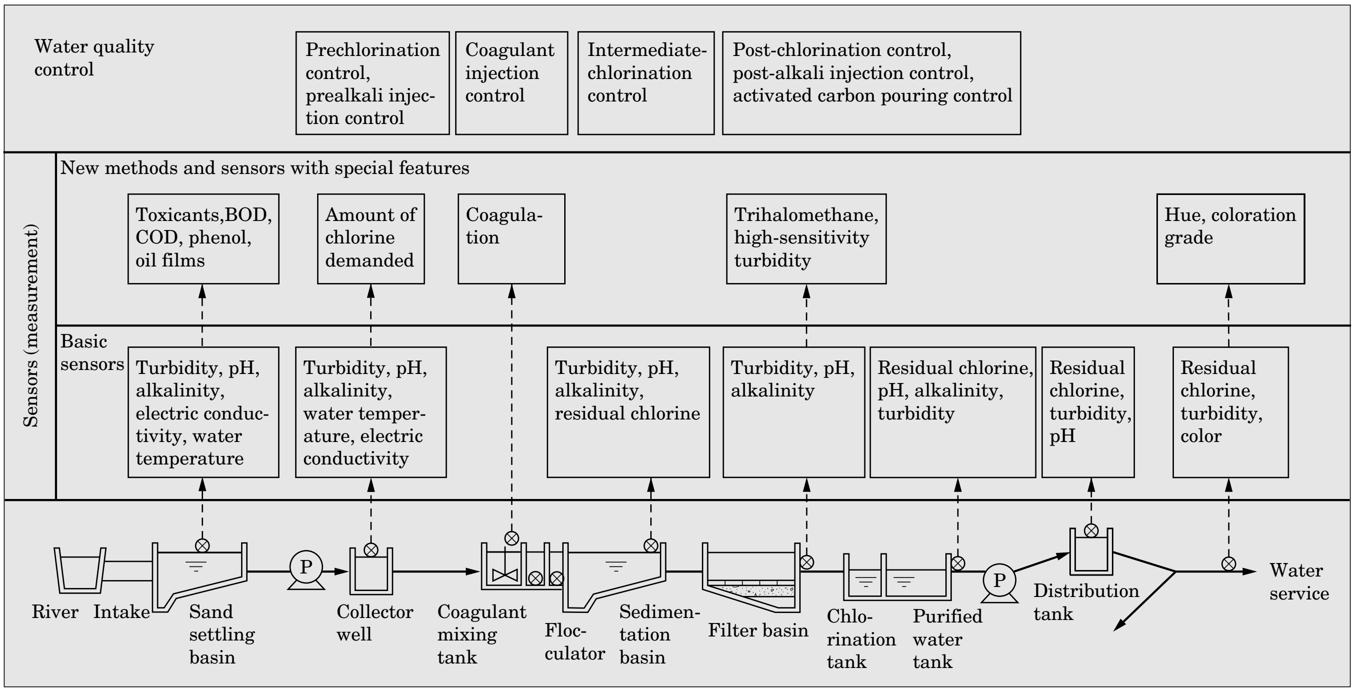
The safety and the general quality of source water are monitored for use as city water. Toxicants are the most important item to be monitored to verify the safety of source water quality. Until now, the general method used has been to visually monitor of fish behavior. As for sensors, cyanogen sensors are seldom used to monitor city water because their minimum detectable value is insufficient and reproducibility is poor. Recently, new technologies, a method of automatically judging abnormal fish behavior and a high-sensitivity toxicant sensor that utilizes a biosensor (Fuji Electric's product name: acute toxicant monitor), have been put to practical use. A remote monitoring application that includes both sensors and transmits video signal has also been implemented. Typical water quality items to be monitored include turbidity, pH, alkalinity, electric conductivity, and water temperature. Additional sensors for oil film, BOD (biochemical oxygen demand), COD (chemical oxygen demand), and phenol may be installed.

2.2 Raw water

To control the quality of raw water before the purification process, turbidity, pH, alkalinity, water temperature, and electric conductivity are measured as basic items. As a direct index for prechlorination, a chlorine demand sensor internally calculates values from the results of chlorination.

If a water source is a well, sometimes color is related to problems with the nature of the soil, and the water is monitored with a color sensor using a principle similar to that of the turbidity sensor.

Fig.1 Relationship between the process flow of city water treatment, water quality control, and sensors



2.3 Water mixed with coagulant

There are only a few examples of on-line water quality measurement in coagulant mixing tanks. Off-line jar tests are generally used to identify and confirm a coagulation state, a main water quality in coagulant mixing tanks. Other methods of testing for coagulation states are processing ITV pictures of flocculation states and an auto jar tester that automatically performs jar tests. Both of these methods judge results of floc coagulation and are incapable of real-time monitoring of the coagulation state. A new sensor which performs real-time measurement of floc diameters by analyzing the photodispersion of dual wavelength absorbance, and directly measures a flocculation state to give an index for coagulant injection control (Fuji Electric's product name: floc sensor) has been developed and implemented in practical applications.

2.4 Water under sedimentation

Turbidity, pH, alkalinity, and residual chlorine are measured to confirm results of coagulation, sedimentation, prechlorination and prealkali feeding, and to monitor water quality before intermediate-chlorination and filtration.

2.5 Filtered water

Filtered water undergoes turbidity control at the final stage of suspended solid removal and water quality control before post-chlorination and post-alkali pouring. In order to enact anti-cryptosporidium measures and to introduce membrane technologies into water purification, control that exceeds conventional measuring sensitivity is required, especially for the turbidity control. With regard to measuring technology, a sensor that utilizes particle counter and optical technology (Fuji Electric's product name: high sensitive turbidimeter) has been developed, and can measure up to levels of 0.001 mg/L. This sensor can also be used as a membrane rupture sensor for membrane treatment equipment. Trihalomethane, a carcinogen that has recently received a great deal of attention, is generated when a substance such as humic acid in raw water is disinfected by chlorine. Gas chromatography and mass spectrometry, official analytical methods for trihalomethane, are performed off-line with equipment that is difficult to use. A sensor, capable of on-line measurement of total trihalomethane concentration by measuring the fluorescent intensity of fluorescent substances produced by the Fujiwara reaction (Fuji Electric's product name: trihalomethane meter), has been developed. The measurement method of this sensor is highly correlated with the official analytical methods. The trihalomethane sensor is used as a sensor at water supply terminals to check for trihalomethane generation, in addition to verifying the condition of filtered water. Other water quality items for inspection are residual chlorine, pH, and alkalinity.

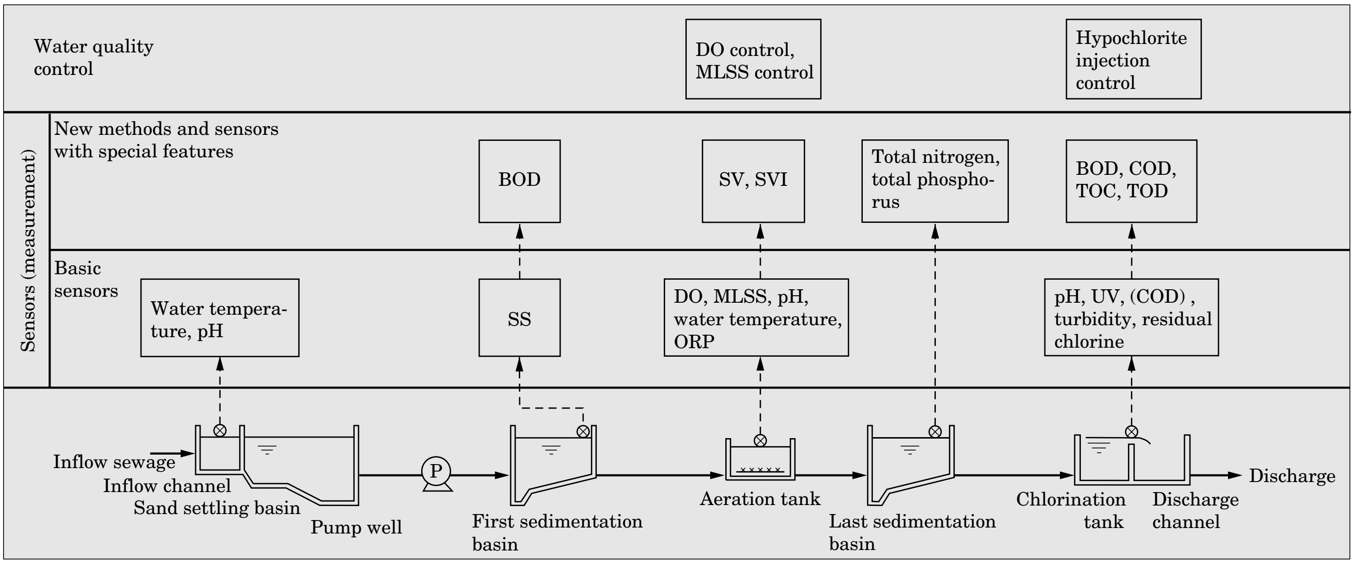
2.6 Water purification, conveyance, and distribution

Water quality is controlled after purification, after conveyance from purification plants, and before distribution. Major items for control are residual chlorine, turbidity, pH, and alkalinity.

2.7 Water service points

Water quality is controlled at the piping network

Fig.2 Relationship between the process flow of sewage treatment, water quality control, and sensors



ends positioned near consumers. Major water quality items measured on-line are turbidity, color, and residual chlorine. Color and turbidity, required to be inspected daily as stipulated in the Water Service Act, are evaluated by visual inspection. Colorimetry with conventional sensors was utilized as a substitute method, but has insufficient color sensitivity. Recently, a new optical sensor (Fuji Electric's product name: Service water quality monitor) to measure hues and coloration grades with the same sensitivity as visual inspection has been developed and put to practical use. This sensor can be used as a multisensor, with optional functions capable of measuring water pressure, water temperature, pH, and electric conductivity. With a built-in transmission unit, this sensor is designed for use as a centralized service water monitor over a wide area.

2.8 Advanced treatment

To remove offensive smells and tastes characteristic of degraded raw water quality and to reduce the potential of trihalomethane formation, advanced treatment facilities using ozone and ultraviolet rays have recently been introduced. It is important for ozone treatment equipment to have a dissolved ozone sensor to monitor the concentration of dissolved ozone in water.

3. Water Quality Sensors for Sewage Treatment

The relation between the process flow of sewage treatment, water quality control, and sensors is shown in Fig. 2.

3.1 Inflow sewage

To control inflow sewage conditions, water temperature and pH are generally measured. There are also instances of first flush pollution control employed at trunk inflow points.

3.2 First sedimentation tank outlet (after primary treatment)

Generally, there are no on-line measurements and SS (suspended solids) are rarely monitored. Recently, in some places, BOD loading measured with a BOD biosensor is utilized to automatically control the amounts of activated sludge and air.

3.3 Aeration tank

Aeration is the most important process in a treatment system that uses the standard activated sludge method. As a required water quality measurement, DO (dissolved oxygen), is used to control the amount of air blown into the tank.

Other general measurement items are MLSS (mixed liquor suspended solids), pH, and temperature. MLSS is especially used to control the amount of stored sludge and estimate the total volume of sludge in the system. In some cases, SVI (sludge volume index) is measured as an index for sludge in the tank. When an advanced biological treatment process using activated sludge for the purpose of denitrification and phosphorus removal is employed as a measure against eutrophication, it is necessary to control the nitrification or denitrification of activated sludge and the absorption or release of phosphorus. Anaerobic and aerobic control has been introduced using an ORP (oxidation reduction potential) sensor as an index to estimate activated sludge conditions.

3.4 Last sedimentation tank outlet (after secondary treatment)

To confirm results of advanced treatment processes for denitrification and phosphorus removal, the total

Table 1 Specifications of basic water quality sensors

Item \ Sensor	Turbidimeter	pH meter	Alkalinity meter	Residual chlorine meter with reagent	Free chlorine meter without reagent
Method of measurement	Surface scattering method	Glass electrode method	Neutralization titration with sulfuric acid	Polarography with a fixed rotating electrode	Polarography with a fixed rotating electrode
Measuring range, etc.	Range 1, 2 and 3, min. range 0 to 2mg/L, max. range 0 to 1,000mg/L	0 to 8, 0 to 14, 2 to 12, 4 to 10	0 to 50, 0 to 100 (mg/L)	0 to 1, 0 to 3, 0 to 5, 0 to 6 (mg/L)	0 to 1, 0 to 2, 0 to 3 (mg/L)
Accuracy of measurement	±2% FS (reproducibility)	±0.1 pH	±2% FS (reproducibility)	±2% FS (repeatability with checking fluid)	±2% FS (repeatability with checking fluid)
Response time, etc.	Continuous	Continuous	Approx. 10 to 99 min (setting)	Approx. 6 min (90% response)	Approx. 2 min (90% response)

Item \ Sensor	Electric conductivity meter	DO meter	ORP meter	MLSS meter	Other specifications
Method of measurement	Directly immersed 2-pole AC electrode method	Diaphragm galvanic electrode method	Glass electrode method	Scattering light comparator	Power supply: 100V ±10% AC Output signal: 4 to 20mA DC (isolated), partial optical signal output possible (optional) Ambient temperature: −5 to +45°C Ambient humidity: 90% RH or less
Measuring range, etc.	0 to 200, 0 to 500, 0 to 1,000 (μs/cm)	0 to 10, 0 to 15, 0 to 20 (mg/L)	0 to 600, 0 to 1,000, −700 to +700, 300 to 1,000, −200 to +500 (mV)	0 to 5,000, 0 to 10,000, 0 to 20,000 (mg/L)	
Accuracy of measurement	±1% FS (reproducibility)	±1.5% FS (reproducibility)	±1% FS (reproducibility)	±2% FS (reproducibility)	
Response time, etc.	Continuous	Approx. 1 min (90% response)	Continuous	Approx. 1 or 3 min (90% response)	

Table 2 Specifications of new water quality sensors

Item \ Sensor	Acute toxicant monitor	Floc sensor	High-sensitive turbidimeter	Trihalomethane meter	Service water quality monitor	BOD biosensor
Measuring method, range, accuracy, response time, etc.	◦ Biochemical sensor (detects acute toxicants, measures microbe respiration activity) ◦ Detection of abnormal water quality by measuring relative output values of respiration activity. ◦ Response time approx. 20 min	◦ NIR and UV absorbance dispersion analysis (measures floc diameters and absorbance) ◦ 2 to 500 (floc dia.) 0 to 2.5 (absorbance) (optional) ◦ Reproducibility C.V. value 10% or less ◦ Continuous measurement	◦ Forward scattering particle counter (converts density of particles into turbidity) ◦ 0 to 1mg/L (0.001mg/L measurable), density of 1 to 105 particles/mL, Turbidity or particle count can be selected. ◦ 0.5μm (countable particle dia.) ◦ Continuous measurement	◦ Measurement of fluorescence due to reaction of nicotinamide and trihalomethane ◦ 0 to 200μg/L (equivalent to chloroform) ◦ Reproducibility C.V. value 5% or less (at 50μg/L chloroform) ◦ Approx. 30 min per measurement	◦ Water quality measurement of multiple items. ◦ Color: transmission spectrophotometry, 0 to 10 deg. (range), ±5% FS (accuracy) ◦ Coloration grade: transmitted light RGB photometry analysis, 0 to 100% (range), ±5% FS (accuracy) ◦ Hue: transmitted light RGB photometry analysis, colorless, black, white, red, yellow, and other ◦ Turbidity: transmission spectrophotometry, 0 to 5 deg. (range), ±2% FS (accuracy) ◦ Residual chlorine: polarography, 0 to 2mg/L (range), ±5% FS (accuracy), ◦ 15 min interval between measurements ◦ Other: pH, water temperature, water pressure, electric conductivity (optional)	◦ Microbe sensor (in accordance with JIS K 3602-1990) ◦ 0 to 30, 0 to 60mg/L ◦ Reproducibility C.V. value 5% or less (11mg/L standard method), 3% or less (55mg/L standard method) ◦ Approx. 40min per measurement
Power supply	100V ±10% AC					
Output	4 to 20mA DC and alarm output	RS-232C, 4 to 20mA DC (optional)	4 to 20mA DC	RS-232C, 4 to 20mA DC	RS-232C, 4 to 20mA DC (optional)	4 to 20mA DC
Ambient temperature	5 to 35°C	−10 to +45°C	0 to 40°C	15 to 35°C	−10 to +45°C	5 to 30°C
Ambient humidity	85% RH or less	90% RH or less	95% RH or less	85% RH or less	90% RH or less	85% RH or less

nitrogen and total phosphorus in the water are measured.

3.5 Discharged water

Water discharged from a treatment plant into rivers, lakes, or the ocean is regulated under the effluent standards of the Water Pollution Control Law (which includes more stringent prefectural effluent standards) and the total emission regulations for water quality. Standard water quality items that can be measured on-line include pH, UV (ultraviolet), BOD, COD, TOC (total organic carbon), turbidity, and residual carbon. With the official analytical method, BOD requires five days for measurement. However, a sensor that utilizes a biosensor for quick, continuous measurement (Fuji Electric's product name: BOD biosensor) has been implemented in practical applications.

3.6 Rainwater

Measures against rainwater have recently become an important topic. When a storm water reservoir for flood control is installed to equalize loads and provide extra draining capacity, turbidity measurement is utilized to control quality of the rainwater inflow.

4. Basic Water Quality Sensors

Specifications of basic water quality sensors mainly based on physical and chemical technologies are shown in Table 1.

5. New Water Quality Sensors

Specifications of unique water quality sensors utilizing biotechnology, information processing technology, and new measuring principles are shown in Table 2.

6. Conclusion

To manage the operation and maintenance of waterworks and sewerage, water quality control will become increasingly important. Currently used on-line water quality sensors are still limited in type and also require more maintenance than conventional sensors. Fuji Electric will develop new water quality sensors to simplify maintenance, and will also improve conventional water quality sensors by prolonging maintenance intervals so they are easier to use.

River Water Management System and Supply Water Quality Monitor System

Hiroshi Tada
Tokio Ohto
Yoshiharu Tanaka

1. Introduction

Water supply systems are essential for the maintenance of health in our society. In Japan, two thirds of all water supply systems use lake and river water as their primary source. Therefore, the quality of source water significantly affects that of tap water. In recent years, public interest in the protection of the water environment has increased.

To cope with the above, Fuji Electric has lined up a variety of sensors and water quality monitor systems to examine the entire water environment. Among them, two systems introduced in this paper, river water management system and supply water quality monitor system.

2. Recent Change in Water Environment

Recently, the quality of river water in Japan has been substantially improved thanks to stricter effluent standards and such things as the widespread construction of sewerage. On the other hand, sudden water pollution has frequently been reported due to the effluence of oil and other harmful chemicals into rivers and the unlawful dumping of waste. These pollutants jeopardize the quality of urban life and the healthy functioning of the river ecosystem.

River water pollution is particularly a threat to cities whose water supply system intake point for water purification lies primarily in the lower reaches of a river.

Previous river water pollution reviews have stated that there has been a recent increase in the size of polluted areas and length of exposure of pollutants. It is difficult to say if adequate remediation measures have been taken in a timely fashion.

Because river water pollution may affect a larger area as time progresses, it is most important to detect the occurrence as early as possible.

By the end of fiscal 1996, 95.8% of all households were using waterworks. The doctrine of construction has changed from quantity to quality, or in other words, to the pursuit of “safe and good tasting water”. Most notably is the comprehensive inspection of water quality from water source to spigot by water quality managers.

In response to the recent changes and needs of the water environment, Fuji Electric has developed, in the field of river management, a river water (quality) management system. Monitoring river conditions 24 hours a day, this system detects water pollution promptly and supports various countermeasures against pollution. This system enables river water pollution to be minimized.

In the field of tap water quality control, Fuji Electric has developed a multi-color recognition system, based on the recognition algorithm for service water hue as specified in the Standard Methods for the Examination of Water. Fuji Electric has also completed a supply water monitor system, which automatically inspects daily items, whereby coloration of supply water can be measured. This equipment enables water supply utilities to monitor the colored water on-line after renewing the aged pipes.

3. River Water Management System

In Fuji Electric’s river water management system (Fig. 1) various management tasks (Fig. 2) are carried out to ensure the proper water quantity and quality. Maintenance of appropriate river water quality requires both sewerage construction and formation of a system responsive to sudden water pollution.

Figure 3 shows the tasks of the river water administrator in the event of water pollution and the support function of Fuji Electric’s river water quality monitor system.

Explanation is given below for each task phase.

3.1 Detection of water pollution

Water pollution, (effluence of harmful substances from specific enterprises, run off of agricultural chemicals from fields, unlawful dumping of toxic substances, spills from overturned industrial shipping trucks near rivers, etc.), can occur suddenly and spread rapidly. Therefore, rivers must be monitored 24 hours a day in order to detect pollution as early as possible.

Fig.1 Configuration of river water management system

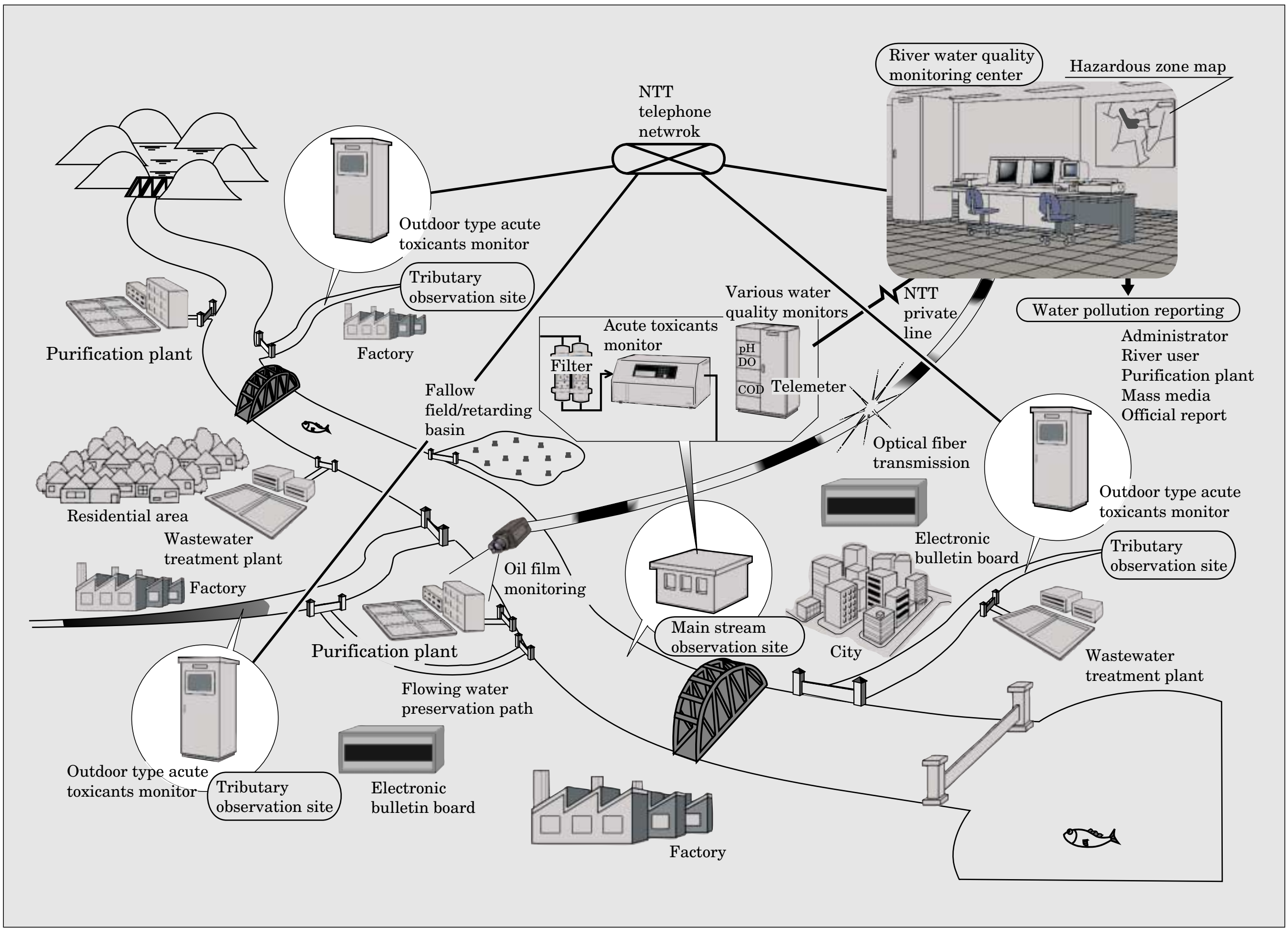
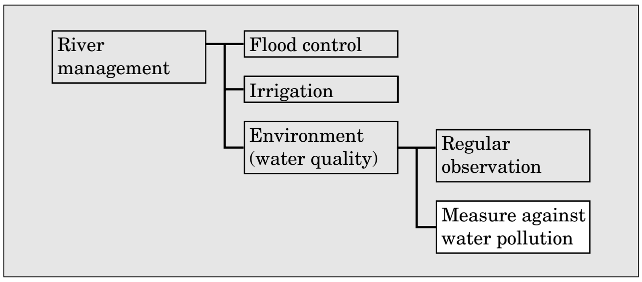


Fig.2 River management tasks



3.1.1 Oil detection

As oil flows down a river it disperses upon the surface of the water. Using an image analysis method, an infrared ray camera can observe slight changes in the refractive index of the water surface due to arrival of oil.

3.1.2 Acute toxicant monitor

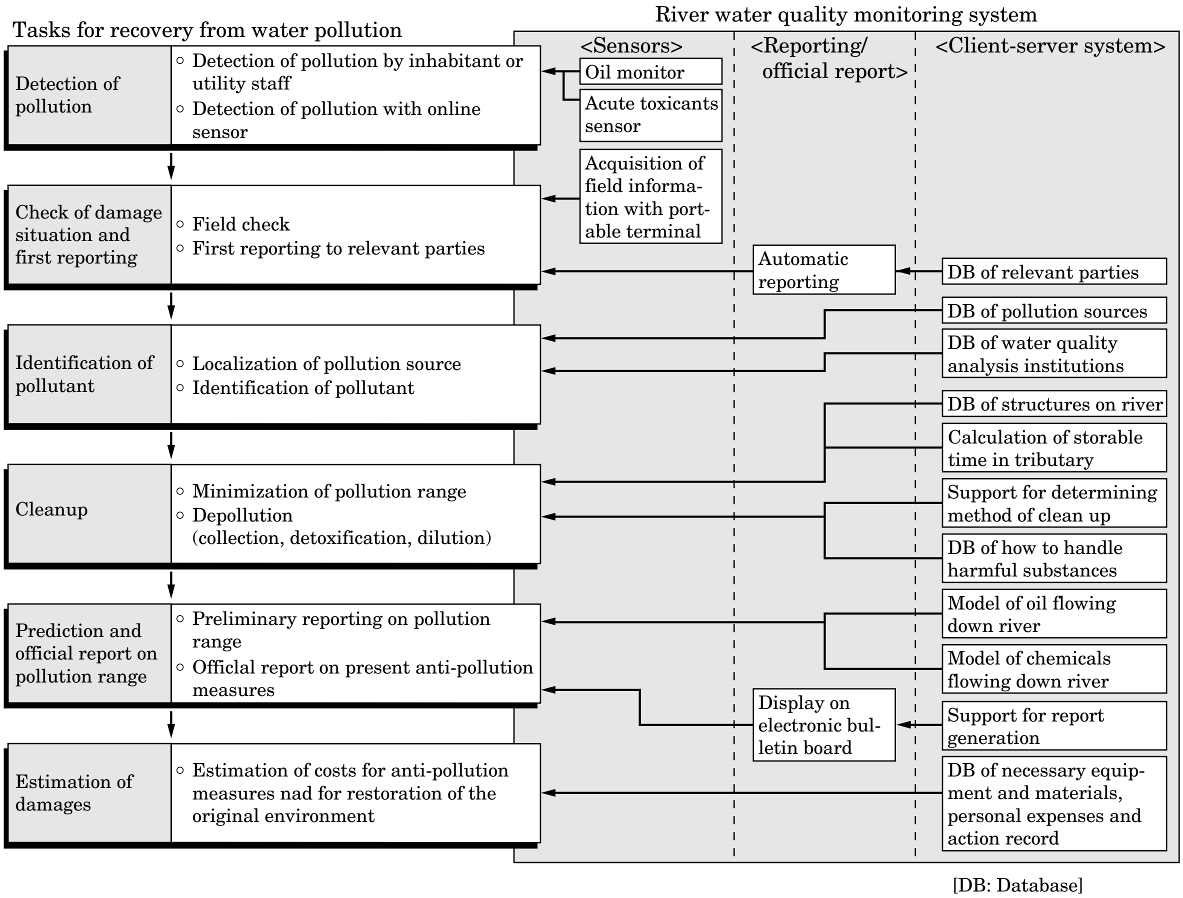
When the cause of water pollution is dissolved chemicals such as cyanide or phenol, it is difficult to defect the pollution early or before its effect appears. At present, the accepted method is to breed fish and continuously observe their behavior as they respond to the water environment. But this method has drawbacks such as lengthy breeding time, individual variation in resistance to toxicity and ambiguity in judgment of an abnormal state.

Fuji Electric has developed a biosensor, which detects toxicants using the activity of nitrifying bacteria. These microorganisms are a reliable index of pollutants because they are extremely sensitive to toxic substances. Acute toxicants such as cyanide, chlorinated organic compounds and agricultural chemicals are detectable with this type of sensor. Although toxicants cannot be identified, they can be screened. Detection sensitivity in terms of concentration is about 10 times as high as the fifty percent (median) lethal concentration for fish in 24 hours, and detection time is about 20 minutes. Details are listed in Table 1. Further, this sensor has a function for storing test water as soon as a harmful toxicant is detected. The stored water is usable for chemical identification of the toxicant by subsequent water quality analyses.

3.2 Check severity of damage and report to concerned parties

Once water pollution has occurred, it is important

Fig.3 Tasks for recovery from water pollution and methods of support by river water quality monitor system



to evaluate the severity of the damage closely at the site and report the results to an anti-pollution activity center. It is also necessary to share information with both the river water users and the party concerned with the cleanup. Because water pollution can occur at unknown locations, fixed-point observations alone are insufficient. A highly mobile information acquisition system is required.

3.2.1 Acquiring field damage information

Damage due to water pollution can have various effects, and there are cases where it is difficult to understand the situation exactly by the oral and written reports sent from the field. Due to the rapid growth of mobile computing technology in recent years, image information of pollution sites is now transferable to anti-pollution activity centers immediately by using a combination of digital cameras, portable information terminals and cellular phones. Moreover, when a portable map coordinate recognition unit, which utilizes a geo-stationary satellite, is added to the above combination, live image information and direct correspondence from the exact location can be established between multiple pollution sites and the anti-pollution activity center. This will facilitate all subsequent tasks for recovery from water pollution.

3.2.2 First reporting function

After checking the severity of damage at the site, it is necessary to arouse attention by issuing a preliminary report of pollution to all river users, including water supply utility companies, fishermen's cooperative associations, and river administration organizations such as the water pollution control liaison council. For this purpose, automatic reporting is made to all parties concerned by means of telephone, facsimile, electronic mail, etc.

3.3 Localization/identification of pollution source and pollutants

Because water pollution occurs suddenly, adequate preparations need to be made. Particularly at the early stage of water pollution, it is important to localize the pollution source and identify the pollutant, thereby preventing the pollution range from expanding.

3.3.1 Pollution source database (DB)

With regard to riverside enterprises dealing with harmful substances, this database contains the names of those substances, their possible destinations in the

Table 1 Chemicals detectable with acute toxicants monitor

No.	Item	Reference value	Detectable concentration	Toxicity to fish
1	General bacteria	100m/L or less		
2	Coliform group	Not detectable		
3	Cadmium	0.01mg/L or less		
4	Mercury	0.0005mg/L or less	——	0.1: “C”, 0.2: “R”
5	Selenium	0.01mg/L or less		
6	Lead	0.05mg/L or less		
7	Arsenic	0.01mg/L or less		
8	Hexavalent chromium	0.05mg/L or less		
9	Cyanide	0.01mg/L or less	0.05	0.48 to 0.78: “C”
10	Nitrogen in nitric acid/nitrous acid	10mg/L or less		
11	Fluorine	0.8mg/L or less		
12	Carbon tetrachloride	0.002mg/L or less	20	
13	1,2-dichloroethane	0.004mg/L or less	60	430: “B” (96h)
14	1,1-dichloroethylene	0.02mg/L or less	30	74: “B” (96h)
15	Dichloromethane	0.02mg/L or less	30	
16	cis-1,2-dichloroethylene	0.04mg/L or less	15	140: “B” (96h)
17	Tetrachloroethylene	0.01mg/L or less	6	13: “B” (96h)
18	1,1,2-trichloroethane	0.006mg/L or less	10	
19	Trichloroethylene	0.03mg/L or less	9	45: “B” (96h)
20	Benzene	0.01mg/L or less	60	46: “G” (24h)
21	Chloroform	0.06mg/L or less		
22	Dibromochloromethane	0.1mg/L or less		
23	Bromodichloromethane	0.03mg/L or less		
24	Bromoform	0.09mg/L or less		
25	Total trihalomethanes	0.1mg/L or less		
26	1,3-dichloropropane (D-D)	0.002mg/L or less	4	
27	Simazine (CAT)	0.003mg/L or less	0.6	
28	Thiuram (thiram)	0.006mg/L or less	0.06	0.10: “C”
29	Thiobencarb (Benthiocarb)	0.02mg/L or less	80	1.6: “C”
Items related to properties which tap water should have : 17 items				
30	Zinc	1.0mg/L or less		
31	Iron	0.3mg/L or less		
32	Copper	1.0mg/L or less		
33	Sodium	200mg/L or less		
34	Manganese	0.05mg/L or less		
35	Chlorine ion	200mg/L or less		
36	Calcium, magnesium, etc. (hardness)	300mg/L or less		
37	Residue on evaporation	500mg/L or less		
38	Anion surface active agent	0. 2mg/L or less		18.7: “C”, 3.7: “S”
39	1,1,1-trichloroethane	0.3mg/L or less	16	72: “B” (96h)
40	Phenols	0.005mg/L or less	0.7	24.7: “C” (24h)
41	Organic substance, etc. (potassium permanganate consumption)	10mg/L or less		
42	pH level	5.8 or more and 8.6 or less		
43	Taste	Not abnormal		
44	Odor	Not abnormal		
45	Chromaticity	Level 5 or less		
46	Turbidity	Level 2 or less		

(shaded) : Detectable item

< Note > Toxicity to fish is indicated in median lethal concentration (TLm). The alphabetic letter suffixed to each numeral abbreviates the name of the test sample fish shown below. The numeral in parentheses denotes an exposure time (h).
[Test sample fish] “C”: Carp, “S”: Sweetfish, “R”: Rainbow trout, “G”: Gold fish, “B”: Bluegill
TLm stands for median tolerance limit.

event of pollution, responsible persons, etc.

3.3.2 Localization of pollution source

The pollution source database is correlated with the aforementioned field information (pollution site, severity of damage, etc.) to locate the pollution source.

3.3.3 Database of water quality analysis institutions

This database contains information such as a list of analyzable substances, the availability of nighttime and holiday analysis, addresses and telephone numbers.

3.4 Cleanup

Cleanup methods can be roughly classified into collection, detoxification by neutralization, and dilution. The optimum method varies with pollution site (tributary or main stream), scale of pollution, pollutant, etc. However, the basis of any cleanup procedure is to confine the range of pollution. When pollutants invade a tributary, it is imperative to restrict the range of pollution within the tributary. This will prevent the harmful substance from flowing into the main stream. Once a harmful substance reaches the main stream, it will be swept up by the stronger current and disperse over a wide range, making cleanup work very difficult.

Once pollutants have entered the main stream, area confinement through collection or neutralization of the pollutant is generally impossible. In this scenario the pollutant becomes diluted by the influx of water reserved in a dam or from other rivers in the same river system. In both cases, it is essential to know the proper procedure for handling harmful chemicals and to know the current inventory of cleanup equipment/materials.

3.4.1 Database on river structures

Information is stored about the locations of weir/gate installation, remote controllability and amount of time necessary for closing. In addition, an on-river structure capable of blocking the flow of a pollutant is selected at a downstream point closest to the pollution site.

3.4.2 Calculation of storable time in tributary

The amount of time water can be stored in the tributary area is calculated through correlating the water level at the occurrence of pollution, Q-H characteristics and information about the flow blocking point.

3.4.3 Estimation of cleanup time

Cleanup time is estimated depending on the severity of pollution and the equipment/materials to be used.

3.4.4 Equipment and material storage database

This database stores information on the performance, application, storage location and storage quantity for all equipment and materials used during cleanup. This helps locate the necessary materials in the shortest time possible.

3.4.5 Support for decision making on cleanup method

Choices of possible cleanup methods are presented and given a preferential order through a combination of the aforementioned measures, thereby supporting determination of a cleanup plan.

3.4.6 Harmful substance database

Special knowledge required for cleanup is easily accessible. Using a desired keyword one can access information about various harmful substances. This system can automatically convert image data to text, and is able to retrieve data after reading sources such as technical literature and books with an image scanner. Therefore, a rich database can be configured with less time spent on data entry.

3.5 Prediction and official report on pollution range

In the instance of a large-scale water pollution event, it may be a necessary to stop water intake at a purification plant, in addition to immediately reporting to inhabitants, river water users, water supply utilities and the mass media. In such cases, it is necessary to not only enact all possible de-polluting measures and report the current damage situation, but also to predict an expansion of the polluted area. This may enable water users to prepare for an unexpected situation before the pollution reaches their territories. The river administrator must officially report the progress of countermeasures against the pollution to all parties concerned and obtain their consent.

3.5.1 Predictive calculation of damage range due to oil

Dispersion of oil is comparatively easy to estimate. Therefore, the down-flow of oil can be predicted by cumulatively adding the river flow velocity at each point on the river to the rate of oil dispersion. When we correct this predicted result by the actual measurement obtained by the oil sensors within the water quality observatory stations installed at each point on the river, the range of damage can be confidently predicted and the effects of disturbance factors such as wind and sea level are minimized. The predicted range of damage can be accessed simply by an online-display superimposed on the water system map at the anti-pollution activity center, thus enabling the center to take preliminary measures.

3.5.2 Predictive calculation of damage range due to chemicals

Dispersion of the dissolved chemicals can be estimated. The online display of the predicted damage due to the relevant chemical can be calculated by correcting the estimated dispersion according to the river flow velocity by the actual measured data as in the above calculation for oil.

3.5.3 Official report

The specific countermeasures undertaken must be officially reported to all parties concerned. The mass media is entitled to press conferences on the countermeasures currently taken against pollution using either CRTs or large-size television displays, which are located at the anti-pollution activity center. Municipalities and inhabitants are able to access information on electronic bulletin boards installed at city halls. The river administrator especially must urge inhabitants to recognize that he/she is responsible for implementing the countermeasures against water pollution. This is required for the following reason. Usually inhabitants report water pollution sightings to the police or a fire station. A report to the river administrator, the organizer of the cleanup, is a rare case. Hence, there are many cases when critical time is lost.

3.6 Estimation of damages

Article 67 of the River Act stipulates the principle that it is responsibility of the party, which caused the water pollution accident to bear the expenditure of the countermeasures taken.

In this regard, the river water management system offers the following support function.

In the pollution damage estimation database, the rate of each expenditure item, such as equipment/ materials used or personnel expense, is determined for each step in the cleanup procedure (i.e. countermeasure against pollution and restoration of water environment). Rates, which are specifically due to the occurrence of pollution, are then multiplied by the number of actions taken by the staff and entrusted party to estimate the total damage to be claimed.

4. Supply Water Quality Monitor System

In this new age of water quality, the role of the tap water supply has evolved from providing simple volumetric assurance to ensuring “safe and good tasting”. On the other hand, this new age is responsible for negative factors affecting water quality, such as the aforementioned degradation of the entire water environment and the sudden pollution of rivers, which serve as tap water sources. In light of these negative factors, more attention is being drawn towards management of water supply systems and their ability to ensure emergent water supply and prompt restoration of disasters.

To cope with this, it is imperative to establish a general automatic water quality monitoring system that can oversee a wide range of processes. This system must not only inspect the water purification process but must overlook every step from the outlet of purification plants to the water supply terminals. In response to these needs, a variety of automatic water quality monitoring systems with a wide range of applications has been developed. One example, required by the Waterworks Law, is the fully automated, daily inspection (of color, turbidity, residual chlorine concentration) at the water tap.

Fuji Electric has proposed “hue” and “coloration grade” as new indexes which quantitatively describe the appearance of water, and has developed a device, (the “color-turbidity sensor”) which can automatically measure both these new indexes and the preceding indexes, chromaticity and turbidity respectively. “Hue” indicates the color of the water and “coloration grade” represents the degree of water coloration. For instance, a yellowish hue suggests coloration due to an organic substance and a reddish hue may be attributable to inflow of iron rust. According to the coloration grade, the level of abnormality can be surmised.

4.1 Principle of coloration grade and hue measurement

Figure 4 shows the configuration of this sensor. The while light from the light source is dispersed with the above-mentioned optical color filters of three primary colors to obtained red, green and blue spectral-sensitivity lights. These lights are radiated to water samples to measure their respective transmittance values. The resulting hue of the water sample is judged to be any of five bands; colorless, white/black, yellow, red and other. This color judgment method, known as the CIE 1931 standard colorimetric system by the Commission Internationale de I’Eclairage, was introduced as an effective tristimulus filter method for measuring coloration of tap water in the Standard Methods for the Examination of Water (explanatory edition).

Next, the newly defined “coloration grade” is described. First, luminance is introduced as the z axis into an xy coordinate scheme that defines the hue and purity of color in a three-dimensional color space (Fig.

Fig.4 Configuration of color-turbidity sensor

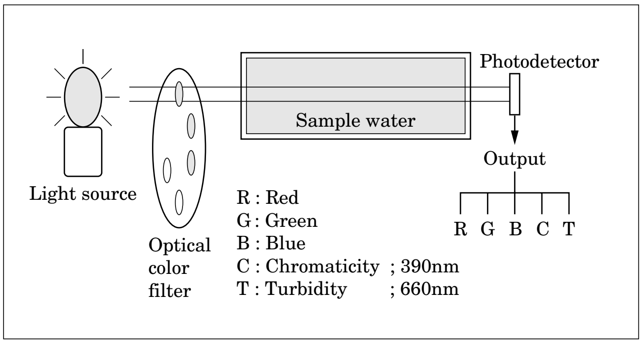


Fig.5 Principle of coloration grade and hue measurement

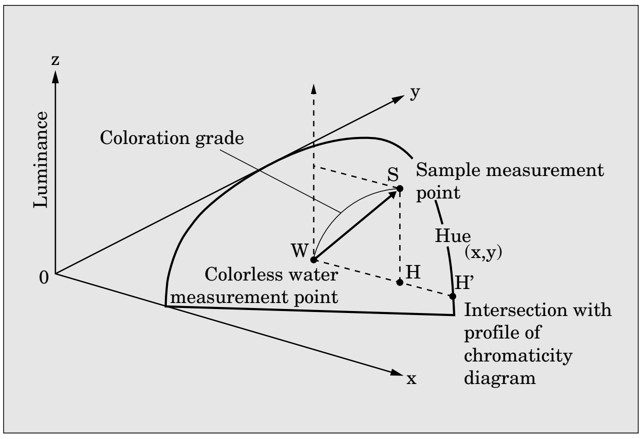


Fig.6 Configuration of the monitor system

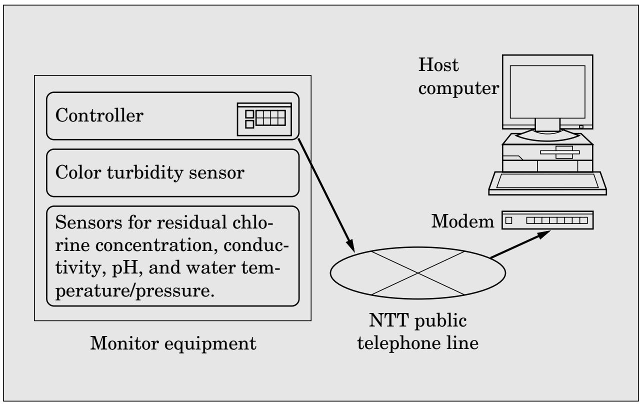
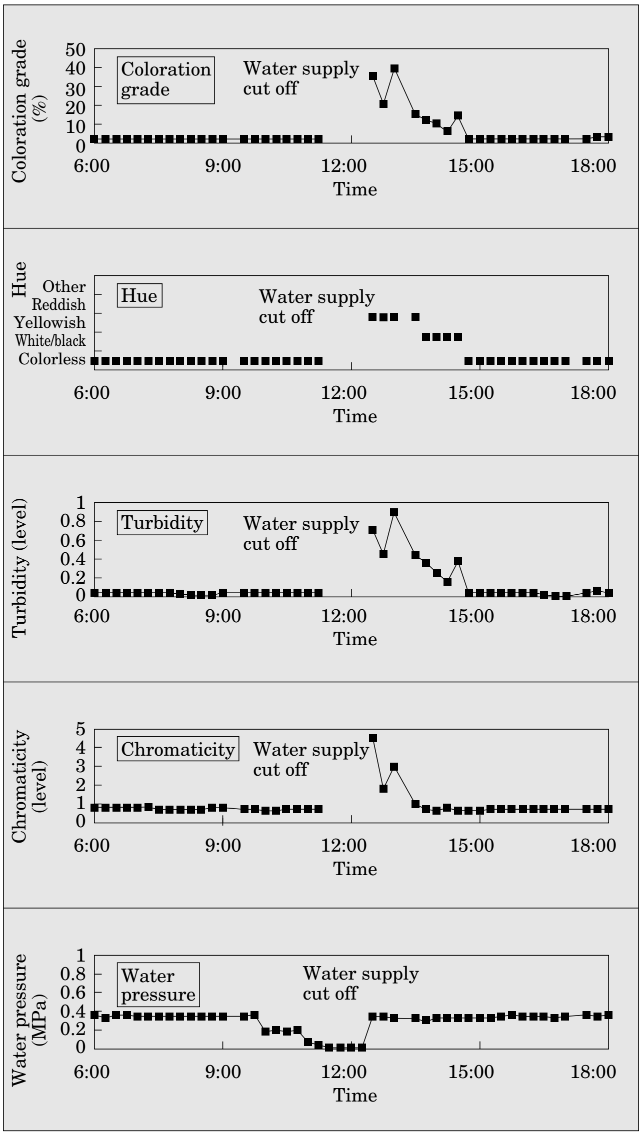


Fig.7 Situation of field test in city A



5). Next, a colorless water measurement point is replaced with W and a sample water measurement point is replaced with S. S's projection onto the xy plane is point H and the intersection of the line extended from W through H with the profile of chromaticity diagram is H'. The coloration grade can be expressed by the vector, which connects W and S. The range of coloration grade measurements is set 10 times higher than the visual threshold (roughly corresponding to chromaticity 5).

4.2 Configuration of monitor system

The configuration of this monitor system is illustrated in Fig. 6. The monitor equipment examines each sensor for residual chlorine concentration, electrical conductivity, pH, water temperature and water pressure in addition to the aforementioned color-turbidity sensor. The measured data is transmitted to the host computer via an NTT (Nippon Telegraph and Telephone Corp.) public telephone line.

4.3 Example of field test

Below is an example field test where the monitor equipment was set up at the water tap in city A and the host computer was installed at Fuji Electric Corporate Research and Development, Ltd. to measure coloration grade, hue, turbidity, chromaticity, etc (GL), 24 hours a day.

Figure 7 shows data of water quality through a water tap in city A, which was observed with the monitor equipment at the time of water interruption. The interruption lasted from 11:30 to 12:45. From 13:00, shortly after recovery from the interruption, levels of coloration grade, chromaticity and turbidity rose and the hue turned yellowish. Then at 14:30, chromaticity returned to normal levels. At the same time, hue turned white/black. Later, at 15:45, coloration grade and turbidity returned to normal levels, and hue turned colorless.

From the above data, the following assumptions can be made. Yellowish water containing suspended matter flowed in from 13:00 to 14:30. Then only suspended matter continued flowing in until 15:45. This assumption is reasonable, because the suspended matter, which repeatedly rises and settles, remains in pipes longer than dissolved substances, which determine chromaticity.

4.4 Usefulness of coloration grade and hue measurement in the supply water quality monitor system

The color-turbidity sensor allows for simultaneous multi-measurement of hue, such as the red color of iron rust (typical coloration of tap water), the black color due to manganese, the yellow color derived from dissolved organic substances, the white color due to bubbling or mixing of zinc, etc. This measurement is more useful for water quality control than the conventional chromaticity measurement, which detects only the presence of a yellowish brown color. Clearly, this measurement is extremely useful for both checking the deterioration of water pipes and tracing the behavior of water each minute after recovery from a water interruption event, such as an earthquake or water leakage correction, to name a few.

5. Conclusion

The river water management system and supply water quality monitor system have been introduced above. These systems contribute to the protection of the environment, which is one area drawing great attention in the field of river management. In addition, both systems provide fully automated, daily water supply inspection by water supply utilities. These systems respond to a wide range of changing water conditions, providing general maintenance of water quality from water source to tap water supply.

Finally, the authors would like to express their gratitude to the river management authorities and the Japan Water Works Association for their guidance and recent advancements in the field of water quality control.

Advanced Water Treatment and Process Control

Kazutaka Takahashi
Ryutaro Takahashi
Nobuyuki Motoyama

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.

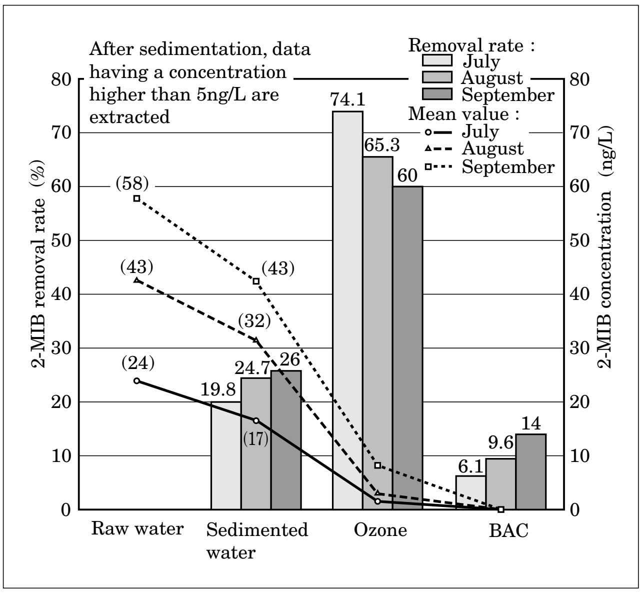
Conventional treatments, including removing algae by means of chemical cohesion and sedimentation together with pre-chlorination, are effective in eliminating odor caused by algae, grass odor and fish odor, as well as hydrogen sulfide odor and rotten odor from sunken material at the bottom of water sources.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

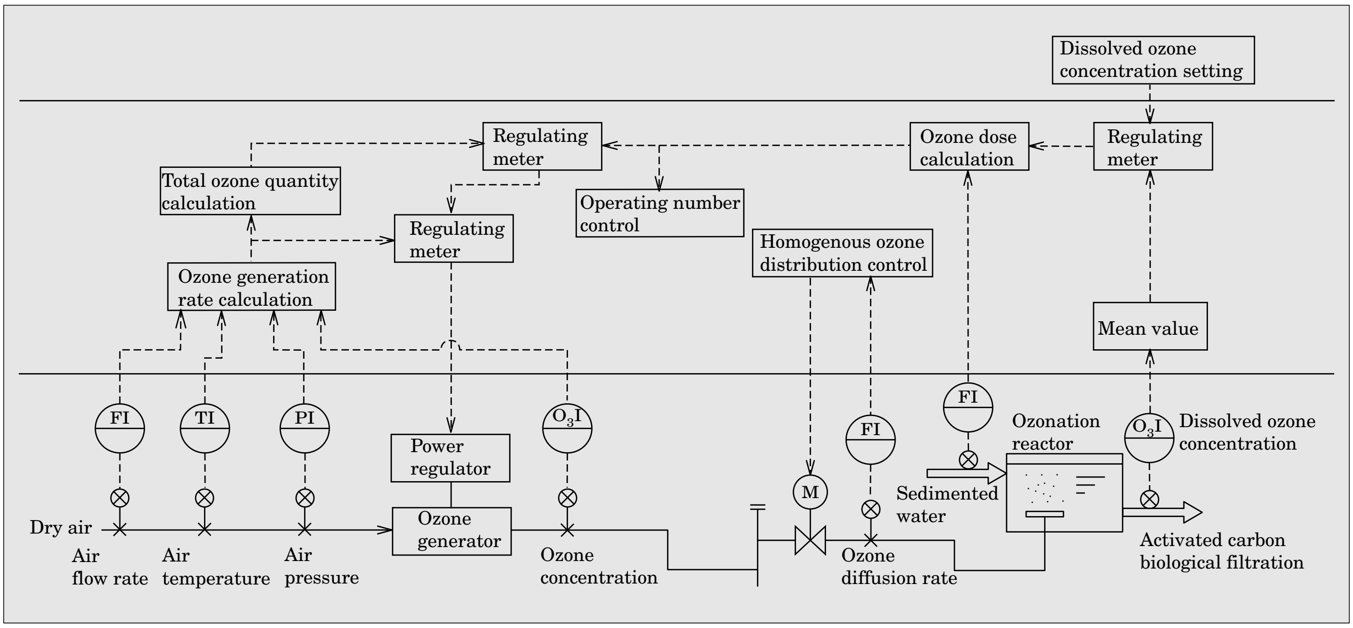
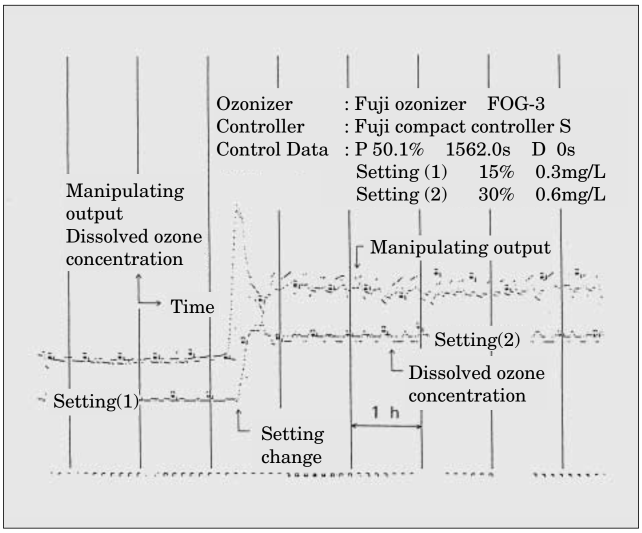


Fig.3 Constant-value control of residual ozone concentration (PI control)



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

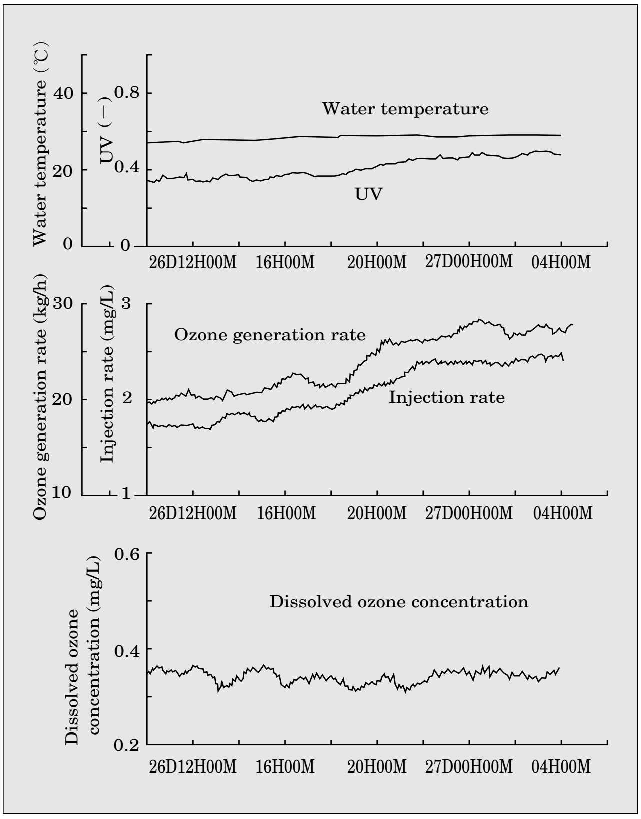
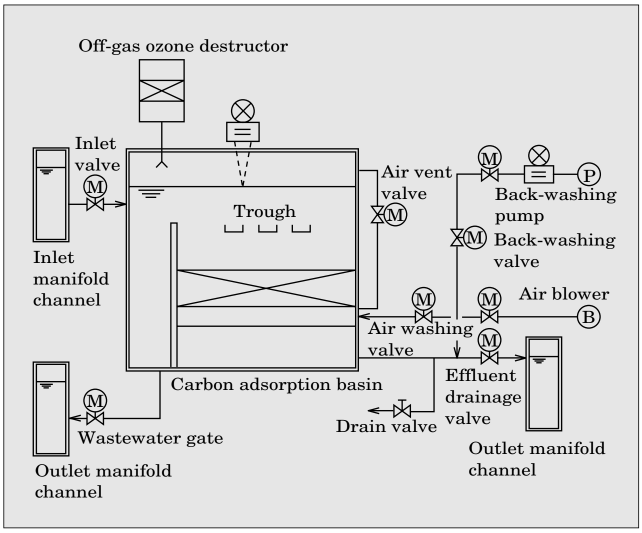


Fig.5 Flow diagram of the activated carbon treatment plant



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.

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

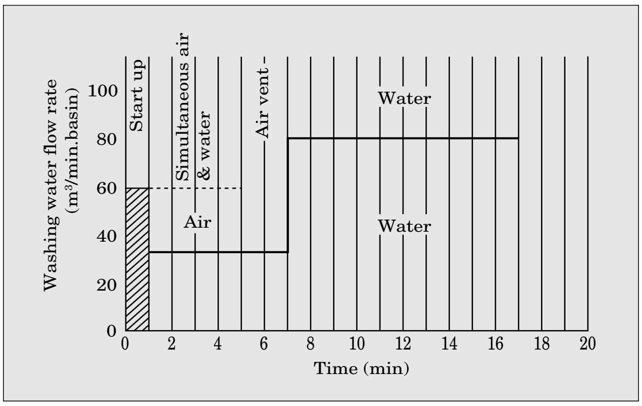


Table 2 Washing control process for the activated carbon treatment
"Rear ozonation + activated carbon" treatment

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.

Measurement and Control of Trihalomethane

Yasuo Nakahara
Souichirou Yamamoto
Kouji Kawakami

1. Introduction

The carcinogenic trihalomethane has been the target of regulation for the past 16 years since a notice was issued by the Ministry of Health and Welfare, and for 4 and a half years in an appended article to the water quality standard prescribed by the Waterworks Law.

However, a survey by the Ministry of Health and Welfare reports that water utilities in which the trihalomethane concentration in drinking water exceeds 70% of a standard value have not decreased but increased in number and that the concentration has already exceeded the standard value in some utilities. This threatens the safety of drinking water, its most important quality.

Concentration of the population in urban areas (near rivers) and large quantities of consumption (waste) in the present age have created an adverse environment for the raw water used in water supplies. This paper outlines the current status of the mechanism that produces trihalomethane and the measures for reduction. A new analyzer for trihalomethane and a monitoring and reduction system capable of automated and rapid instrumentation are described.

2. Environmental Changes and Water Quality Regulation

2.1 Mechanisms that produce trihalomethane and environmental changes

The expansion and concentration of population and industry has caused rapid increases in water demand and at the same time, a shortage of water has exerted an enormous adverse influence on the society.

A conventional waterworks and sewerage system usually has a water purification plant in a river upstream, and a wastewater treatment plant that processes drainage in the vicinity of the river mouth to discharge the processed water to the sea. This type of water purification system is known as “monocycled”. On the other hand, new systems have two or more water purification plants and wastewater treatment plants existing together in one river. This type of water purification system is known as “recycled”. Refer to Fig. 1. In many recent cases, the situation has forced the waterworks and sewerage system to switch from the monocycled type over to the recycled one.

Sufficient self-purification of the river water cannot be expected from Japan’s water environment, because the distance from the head to the mouth of a river is as short as several hundreds of km. To use the river water repeatedly, it is inevitably necessary to biodegrade the BOD (biochemical oxygen demand) components and decompose the ammonia of the industrial and domestic wastewater in the wastewater treatment plant. However, at present, the expansion of sewerage still lags behind that of waterworks.

The trihalomethane problem was first reported by Dr. Rook of the Rotterdam water service. The Rotterdam water service has an intake point downstream in the Rhine, where water has been used repeatedly for many years. Dr. Rook detected chloroform (a kind of trihalomethane) in the water of the Rhine in 1972 and pointed out that the cause was chlorination in the river water.

Fig.1 Monocycled type and recycled type waterworks and sewerage

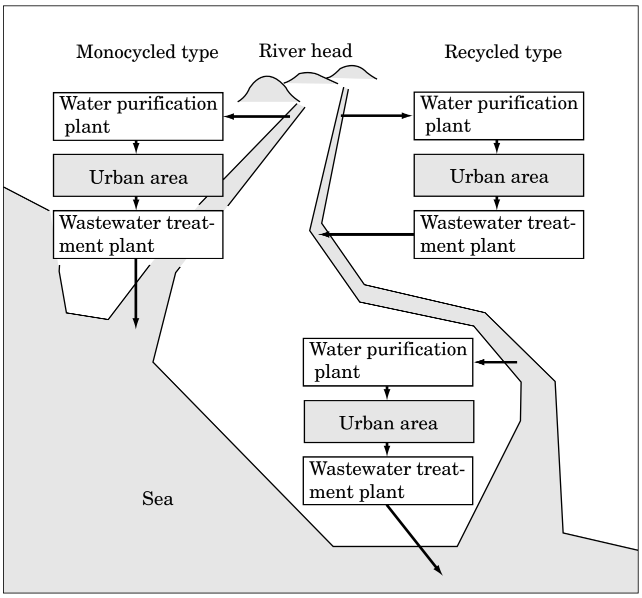
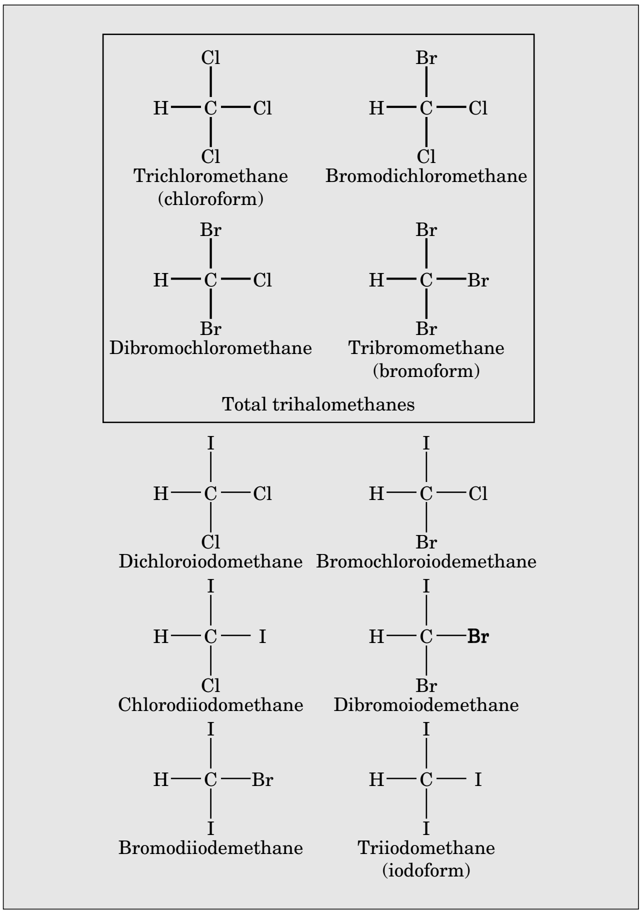


Fig.2 Family of trihalomethanes



At that time, another paper was published concerning the high cancer death rate of the citizens of New Orleans, downstream of the Mississippi in the United States. The reported cause was drinking water.

Simultaneously, trihalomethane (especially high concentrations of chloroform) was detected in drinking water in a survey by the Environmental Protection Agency in the United States. Further, an animal experiment has disclosed the carcinogenicity of trihalomethane. Since these events, the worldwide concern for trihalomethane has risen.

Figure 2 shows the family of trihalomethanes. Chloroform, bromodichloromethane, dibromochloromethane and bromoform are types of trihalomethane. Their content rate is high in drinking water and is generically defined as the total trihalomethane content. These trihalomethanes are produced in the following processes.

At first, the above-mentioned BOD formation potentials biometabolize by self-purification of the river and the sewerage process, and produce biodegradable persistent organic matter, for example, humic acid or fulvic acid, etc. Then, this matter is disinfected by chlorine in the water purification plant and in the wastewater treatment plant. This process forms the trihalomethane.

Table 1 Standard values of trihalomethanes

Item	Standard value (mg/L)
Total trihalomethanes	0.1 or less
Chloroform	0.06 or less
Dibromochloromethane	0.1 or less
Bromodichloromethane	0.03 or less
Bromoform	0.09 or less

Table 2 Number of water service utilities in excess of trihalomethane standard values

Term of survey	Number of utilities in excess of 70% of standard values	Number of utilities in excess of standard values	Number of utilities surveyed
1991 to 1993	94	——	——
1993	34	8	——
Jan. to Aug., 1994	79	4	1,469 (only including surface water utilities)

In general, changes in the following water environment cause an increase in trihalomethane concentration.

(1) Prechlorination

If the river is short in length, ammonia is insufficiently nitrified by self-purification. In this case, prechlorination is performed in the water purification plant to oxidize ammonia with chlorine completely. Therefore, biodegradable persistent organic matter reacts with highly concentrated chlorine before it is removed by coagulation-sedimentation and produces trihalomethane.

(2) Concentrated biodegradable persistent organic matter

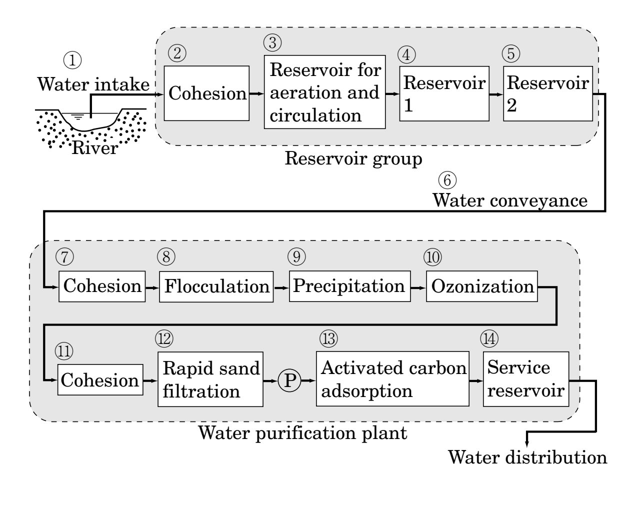
To use river water repeatedly to prevent shortages, the waterworks and sewerage systems of the recycled type have been expanding. Therefore, large amounts of biodegradable persistent organic matter that have leaked from wastewater treatment plants have become more concentrated in the downstream areas.

As mentioned above, the trihalomethane problem in our country is significant due to the fact that river distance is short in Japan.

2.2 Water quality regulations

The first regulation concerning trihalomethane in Japan assumed a control target value of the total trihalomethanes concentration to be “0.1 mg/L or less”, based on the maximum permissible concentration level (0.1 mg/L) that the Environmental Protection Agency established in 1979. The maximum permissible concentration level is prescribed in the notice “Measures

Fig.3 Example of repetitive processes



against trihalomethane in water service" issued by the manager of the Water Supply and Environmental Sanitation Department of the Ministry of Health and Welfare on March 25, 1981.

Thereafter, standard values for each trihalomethane were added as shown in Table 1, and enforced as of December, 1993, as the drinking water quality standard was revised by the Public Welfare Ministerial Ordinance No. 69 on December 21, 1992.

The number of the water utilities in excess of 70% of the standard value reached 79 utilities, and four utilities exceed the standard value, according to a survey by the Ministry of Health and Welfare concerning the quality of drinking water examined from January to August, 1994. These numbers greatly exceed previous values, even though various measures for reduction have been implemented since 1993. Refer to Table 2.

Those utilities in excess of 70% of the standard value might exceed the standard value if the water environment changes. Therefore, measures against trihalomethane are urgently required.

3. The Current Status of the Measures for Reducing Trihalomethane

3.1 Basic idea for reducing trihalomethane

A basic policy for reducing trihalomethane is presented as follows.

(1) Reduction of biodegradable persistent organic matter in the field water at intake
(2) Reduction of ammonia concentration before coming in contact with chlorine in the water purification plant
(3) Reduction of chlorine feeding volume in the water purification plant
(4) Removal of trihalomethane that is produced
(5) Monitoring and control of trihalomethane in the water distribution network

The typical examples of the measures for reducing trihalomethane are described as follows.

3.2 Removal of organic matter by process repetition

In Amsterdam and Rotterdam, downstream areas of the Rhine, the repetition of the maximum possible treatment including the processes (1) to (3) mentioned above has been applied for long time to stabilize the water quality.

Fig. 3 shows the process flow of the Maas Bisbosch Klaringen systems in the Rotterdam water service.

The organic matter is sufficiently removed by a physicochemical process and biodegraded by cohesion at the water intake point and water storage for long time ((3) to (5)). Suspended matter in the field water, ammonia, biodegraded organic matter and trace toxicants are removed as shown in this figure. These treatments aim to effectively use processes (1) to (3) mentioned above.

The next stage of the treatments in the water purification plant follows as the coagulation-sedimentation processing ((7) to (8)), the decomposition of biodegradable persistent organic matter by ozonization, and the third cohesion. The final stage is the sand filtration and the feeding of the activated carbon.

A thorough removal of the organic matter is achieved in this way.

3.3 Reduction of chlorine feeding quantity

The chlorine is usually fed for the purpose of disinfection only filtration is completed. However, as a step to purify heavily-polluted field water, prechlorination is conducted before the coagulation-sedimentation and intermediate chlorination is performed during processing of the precipitation reservoir and the filtration reservoir. These treatments are performed for the following purposes. Refer to Fig. 8.

(1) To process germs
(2) To exterminate living organisms such as algae and bacteria
(3) To remove iron and manganese by oxidation
(4) To process ammonium nitrogen and organic matter
(5) To process offensive tastes and odors

Recently, the deterioration of the river water quality has forced many water purification plants to preprocess the field water with chlorine. Thus, the trihalomethane problem is more serious at present.

In recent years, there has been a change from prechlorination to intermediate chlorination. However, there is a limit to the removal of organic matter by coagulation-sedimentation. At high ambient temperatures or during a summer drought, when biodegradable persistent organic matter is heavily concentrated in the field water (the permanganic acid demand rises), the powdered activated carbon has to be fed before cohesion.

3.4 Advanced treatment using ozone and biological activated carbon

Currently, one of the most effective treatments as the measures for reducing trihalomethane is to use ozone and biological activated carbon.

Settled water is led to the ozone contact basin as shown in Fig. 8, and ozone oxidizes and decomposes the organic matter not removed by coagulation-sedimentation.

At the same time, the biodegradable persistent organic matter becomes biodegrading and is biodegraded by the latter treatment using biological activated carbon.

Moreover, ammonia that has not been nitrified is nitrified by the nitrifying bacteria being adsorbed on the surface of the activated carbon. This is also another effect of treatments using biological activated carbon.

Thus, this highly advanced treatment using ozone and biological activated carbon favorably reduces trihalomethane in the following respects.

(1) Reduces concentration of biodegradable persistent organic matter, the forerunner of trihalomethane formation

(2) Nitrification of the ammonia causes increased chlorine consumption

This treatment has begun to be introduced in water purification plants in large cities, for instance, in the Kanamachi Purification Plant of the Tokyo Waterworks Bureau and the Shibajima Water Purification Plant in Osaka city

4. Method of Measuring Trihalomethane

Gas chromatography, a simpler process, is able to analyze trihalomethane and other chlorinated organic compounds, that is, low-boiling-point compounds. This is one of the reasons why the trihalomethane problem has been widely recognized.

The official analytical method that is prescribed in the water quality standard and its principle is described as follows.

(1) The purge-and-trip gas-chromatography mass-spectrometry (PT-GC-MS)

Volatile organic compounds are purged from the sample water in their gas phase, driven into the trap tube and concentrated. Next, after they are heated in the trap tube, and if needed, cooled and concentrated again, they are led into a gas-chromatography mass-spectrometer to separate each component. The concentration of volatile organic compounds is obtained as the intensity of the respective mass spectrum and the value of the selective fragment ions.

(2) The head-space gas-chromatography mass-spectrometry (HS-GC-MS)

This method uses a constant amount of the gas in a gas-liquid equilibrium at fixed temperature. The concentration of volatile organic compounds is obtained by the selective ion detection method or the gas chromatography.

(3) The purge-and-trap gas-chromatography (PT-GC)

This method utilizes gas chromatography by using an electron capture detector (ECD) or a flame ionization detector (FID) after pretreatment which is the same as in the PT-GC-MS method.

These methods using gas chromatography excel in respects of generality and sensitivity and are widely utilized in water quality test labs at water purification plants.

However, these methods require complex operations and skill. Pretreatment and measurement takes several hours. These methods are difficult for frequent measurements and unsuitable for continuous monitoring.

Fuji Electric Co., Ltd. developed a trihalomethane analyzer capable of performing continuous and automated measurement. Described below, this product achieved continuous monitoring of the total trihalomethanes.

5. Measures for Reducing Trihalomethane Using the Trihalomethane Analyzer

5.1 The trihalomethane analyzer

(1) Measuring principle

The trihalomethane analyzer, a Fuji Electric product, uses a principle quite different from that of gas chromatography but equals the gas chromatography in sensitivity.

That chlorinated organic compounds and the pyridine derivatives react in strong alkali and emit red light has been known for many years as the Fujiwara Reaction.[1]

Some successful research was conducted to apply this reaction to sensors and the analysis of chlorinated organic compounds.[2][3][4] However, those results were not put to practical use due to the toxicity of pyridine, the instability of the fluorescent substance, and the failure in achieving the same sensitivity as that of the gas chromatography.

Later, Mr. Okumura et al. discovered that by using nicotinamide instead of pyridine and measuring the fluorescence, only the trihalomethane could be detected with sensitivity at the ppb level.[5]

Based upon this research of Mr. Okumura, Fuji Electric developed the trihalomethane analyzer, achieving high sensitivity and automated measurement.

Figure 4 shows the external view of the device and Fig. 5 shows its measuring principle.

Sample water that includes the trihalomethane is led to the separation unit, where only the trihalomethane is extracted into the gas phase section through a gas permeable membrane. The carrier solution, in which nicotinamide is mixed with alkali liquid, is also

Fig.4 External view of trihalomethane analyzer

Fig.5 Measuring principles of the trihalomethane analyzer

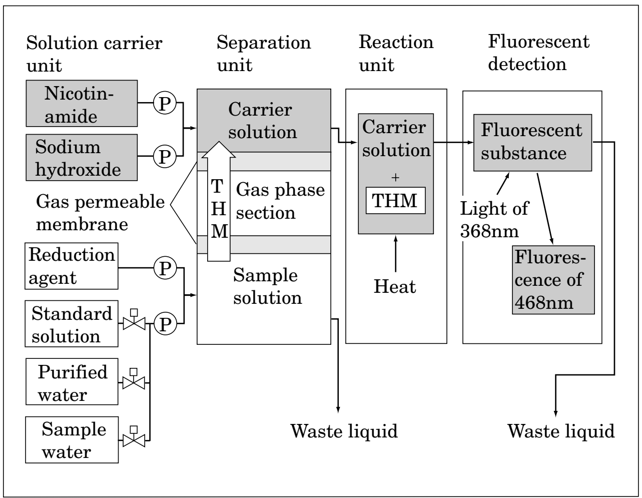


Fig.6 Correlation of measurements by trihalomethane analyzer and gas chromatography

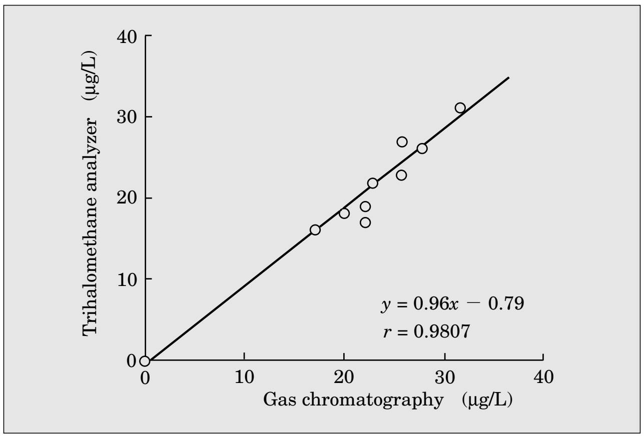
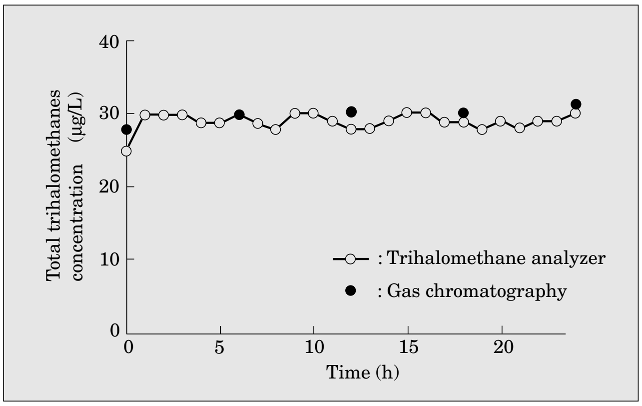


Fig.7 Example of automated operation of trihalomethane analyzer



led to the separation unit and dissolves the trihalomethane concentrated in the gas phase section through another gas permeable membrane.

Then, the carrier solution that dissolved the trihalomethane is led to the reaction unit. The trihalomethane and the nicotinamide produce a fluorescent substance by the Fujiwara Reaction. In the fluorescence detection unit, an exciting ray of 368 nm is applied to the fluorescent substance, which radiates fluorescence of 468 nm, representing the trihalomethane concentration.

The most significant characteristic of this device is that the Fujiwara Reaction occurs without being influenced by substances coexisting in the sample water because only gaseous trihalomethane is extracted from the sample water into the separation unit.

Samples of drinking water from various locations were measured by this trihalomethane analyzer and gas chromatography. The correlation was examined as shown in Fig. 6.

Figure 7 shows a comparison of measurements of trihalomethane concentration over the course of one day. These results verified that the sensitivity of this device is equal to that of the gas chromatography and is suitable for continuos measurement.

(2) Specification

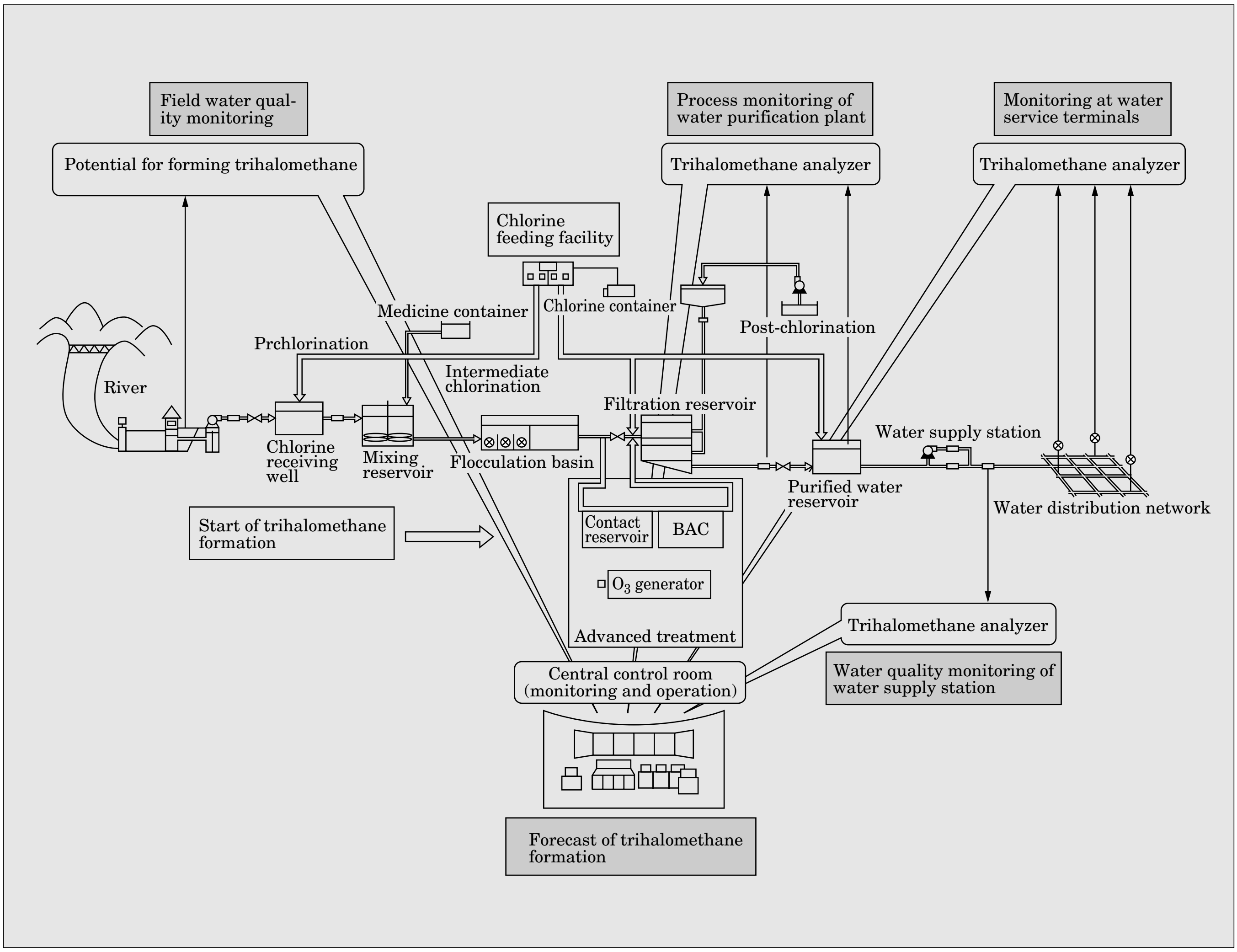
A summary of the trihalomethane analyzer specifications is listed below.

(a) Measuring object: Total trihalomethanes
(b) Measuring system: Measurement of the fluorescence in the reaction of alkaline nicotinamide and trihalomethane
(c) Measuring time: Within 40 minutes approx.
(d) Sample water: Drinking water from the water supply, etc.
(e) Range of measurement: 0 to 200 μg/L (equivalent amount of chloroform)
(f) Ambient temperature: 5 to 40°C
(g) Dimensions: W500 × H440 × D470 (mm)
(h) Power source: 100V ±10V AC at 50/60 Hz
(i) Power consumption: 500VA or less
(j) Mass: 50 kg approx.

5.2 Continuous monitoring system using the trihalomethane analyzer

Using trihalomethane analyzers, continuous monitoring of the total trihalomethanes can be centralized for the processes after feeding chlorine in the water purification plant and in the water distribution network. Figure 8 shows this trihalomethane monitoring

Fig. 8 Flow of water treatment and the trihalomethane monitoring system



system.

(1) Trihalomethane monitoring in the water purification plant

The system measures the biodegradable persistent organic material in the river water as the trihalomethane formation potentials, determines the initial concentration after feeding chlorine, and monitors the concentration in the purified water reservoir, that is, the final outlet for the water purification plant.

In addition, these functions usually help monitor the initial trihalomethane concentration in the water distribution network.

(2) Trihalomethane monitoring in the water distribution network

This system measures the trihalomethane concentration at the observation site of each water supply station and the main water distribution network to centralize real-time monitoring. Simulation (to be described later) is used to forecast the trihalomethane increase at the water service terminals. The trihalomethane concentration can be monitored and forecast at all locations of the water distribution network.

5.3 Forecast of trihalomethane increase in the water distribution network

One of the troublesome points of the trihalomethane problem is that the trihalomethane produced by feeding chlorine into the water purification plant increases in a water distribution network.

Tambo et al. conducted research to quantify the increase of trihalomethane in a water distribution network. The following equation of increase can be applied.

$$\mathrm{THM} = k\,[\mathrm{Cl_2}]^a\,[\mathrm{TOC}]^b\,[\mathrm{pH}]^c\,[t]^d \quad \cdots\cdots (1)$$

Here,

k, a, b, c, d : Constants
$[Cl_2]$: Available chlorine concentration
[TOC] : Total organic carbon
[pH] : pH value
$[t]$: Chlorine contact time

The dependency of trihalomethane formation on the chlorine feeding volume and the organic matter concentration has been previously described. The above expression also shows that trihalomethane increases as the pH is higher and the chlorine contacting time is longer.

Each utility which takes necessary precautions against trihalomethane, has experimentally obtained a similar equation so field water will be easier to treat.

Fuji Electric's trihalomethane monitoring system uses the data continuously measured by the trihalomethane analyzers together with data from the above-mentioned equation of increase, the water distribution network, and the water supply operation to forecast the trihalomethane concentration at outlets of the water purification plant, the water supply station and the water service terminals.

5.4 Measures for reducing trihalomethane with continuous monitoring

The following measures for reducing trihalomethane can be implemented by using the trihalomethane continuous monitoring system of Fuji Electric.

(1) Measures for reduction in the water purification plant

(a) By continuously monitoring the potential for forming trihalomethane in field water and the water after coagulation-sedimentation, it is possible to feed the activated carbon to the field water, optimize the coagulant dosage and change the point of chlorine feeding.

(b) At the time of chlorine feeding, by determining the amount of initial trihalomethane, it is possible to forecast the trihalomethane concentration at the outlet of the water purification plant, and adjust the chlorine dosage depending upon the chlorine contacting time.

(c) By monitoring trihalomethane or the potential for forming trihalomethane in the latter stages of advanced treatments (ozonization and feeding the activated carbon), it is possible to evaluate the capability of this treatment to eliminate the potential for forming trihalomethane.

(d) Based on the trihalomethane concentration in the purified water reservoir, it is possible to forecast trihalomethane increases in the water distribution network, and to promptly feed this information back to earlier stages of the purification treatment.

(2) Measures in the water distribution network

Forecasted increases of trihalomethane in purification plant utilities are verified based on continuous data from each water supply station and typical water service terminals. The following measures can be implemented in case of a rapid concentration rise.

(a) At points where increases in the trihalomethane concentration are observed, the following water operation measures are possible; it is possible to selectively increase the amount of water supplied from the water purification plant, where the trihalomethane concentration is lower at the outlet, or to feed purified water from an advanced treatment.

(b) Based on data of the forecast water demand and the flow time, it is possible to plan water operations for reducing trihalomethane.

6. Conclusion

The paper summarized trihalomethane in the water supply, the mechanism that forms trihalomethane and measures for reducing it. Moreover, this paper presented a new trihalomethane analyzer that uses fluorometry and an accompanying monitoring system.

The authors wish to continue their efforts to prevent deterioration of the water environment, and to pursue safety by proposing useful measures for reducing trihalomethane, contributing to research on trihalomethane measurement and improving the trihalomethane monitoring system.

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Sensor for Cryptosporidium

Yoshio Tanaka
Yoshio Saito
Dabide Yamaguchi

1. Introduction

Since ancient times, Japan has been blessed with pure, fresh water. For this reason, Japanese people believe that city water is clean and safe and do not hesitate to drink it without boiling. Drinking fresh, unboiled water has been a part of the Japanese way of life.

However, in recent years, pollution of river water and groundwater has increased in this country, making that water neither clean nor safe. At present, alarms are being sounded regarding the safety of the water supply. Water supply safety is threatened by the dumping of poisonous substances such as cyanide into river water (unintentional pollution due to unexpected water accidents), the generation of carcinogenic substances such as trihalomethanes caused by the chemical reaction of river water eutrophicated in marshes and lakes, and chlorine (pre-chlorine) used to purify water in water purification plants.

There are many examples in foreign countries of rain water, polluted by the feces of both domestic and wild animals, that flowed into rivers which passed through purification treatments in water purification plants and was supplied as city water, resulting in cases of infection by cryptosporidium. To utilize river water effectively, intake gates for city water are often located downstream in rivers. This is believed to increase the risk of contaminating the city water with cryptosporidium.

This paper introduces cryptosporidium and countermeasures to prevent it, based on tentative guidelines by the Japanese Ministry of Health and Welfare, and describes sensors and coagulation control techniques required for implementing those countermeasures.

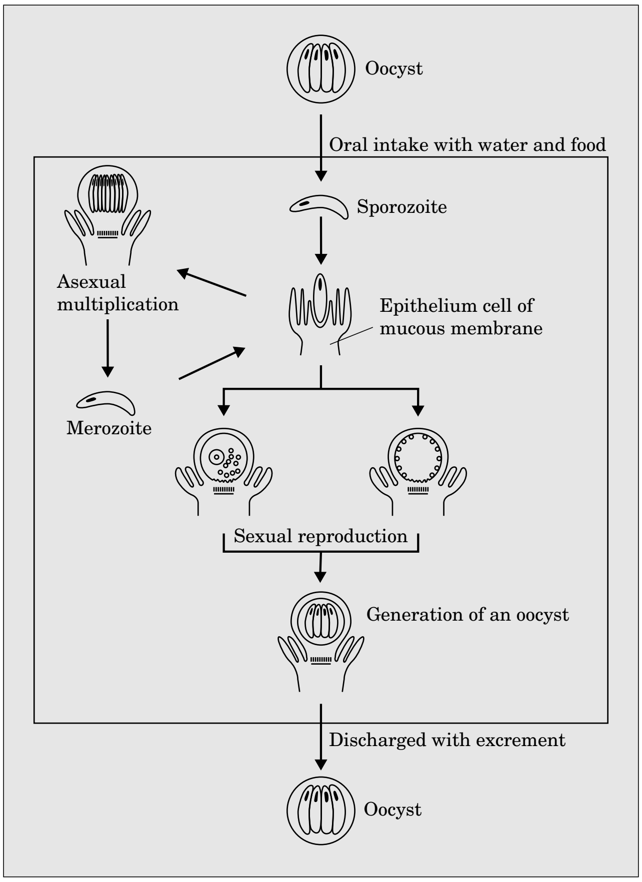
2. Cryptosporidium

Cryptosporidium is a parasitic protozoa belonging to the coccidium of sporozoa, approximately 5 µm in size and oval shaped. Cryptosporidium is a parasite that infects many mammals such as human beings and domestic animals such as dogs, cats, cows, pigs, horses and goats. The infection of wild animals such as deer, monkeys, hares and rats has also been reported.

The life cycle of cryptosporidium is shown in Fig. 1.

In water and food, cryptosporidium exists in form of an oocyst covered by a hard shell and does not multiply. If it enters the human body through the mouth, sporozoites separate in the small intestine, enter the epithelium cells of mucous membranes and form parasitic cells there. In parasitic cells, sporozoitea generate banana-shaped merozoites by asexual multiplication. The merozoites enter other epithelium cells in mucous membranes and repeatedly multiply. One part of a merozoite generates oocysts again by

Fig.1 Life cycle of cryptosporidium



sexual reproduction and each oocyst forms four sporozoites. Matured oocysts are discharged together with excrement, and become a new source of infection.

If a person contracts cryptosporidium, water-like diarrhea and a stomachache will continue for about three days to one week, sometimes accompanied by vomiting and a fever. If the patient's immune mechanism functions normally, multiplication of the protozoa will be halted and the individual will heal naturally. However, in some cases, immune deficient patients have died. Oocysts will continue to be discharged in the patient's stools for several weeks.

At present, an effective cure for this disease has not been discovered and prevention is only existing countermeasure.

Oocysts discharged in natural wet environments such as water or wet soil continue to have an infecting ability for two to six months. Oocysts cannot withstand cold and dryness, and loose the ability to infect if exposed to a temperature below – 20°C for 30 minutes or under dry conditions at a normal temperature for one to four days.

The infecting ability can also be eliminated by boiling for about one minute. Even a small number of cryptosporidium have the ability to infect or to show symptoms.

Oocysts have a very hard shell. It is reported that their resistance is 690,000 times stronger than colon bacillus, and that 80 mg/L of chlorine for 90 minutes or 1 mg/L of ozone for 5 minutes is required to eliminate infecting abilities from 90% of oocysts. Therefore, it is believed that the infecting ability of cryptosporidium cannot be eliminated by chlorine disinfection, as is commonly applied in water purification plants.

Most cases of cryptosporidium infection from city water have happened in the USA and UK. For example, in 1984 in Texas, groundwater polluted by sewage was supplied to 5,900 people and about 2,000 of them were infected. In 1987 in Carolton, Georgia, about 1,300 out of 32,400 people became infected. In 1993 in Milwaukee, about 1,600 thousand people were supplied with polluted water, about 400 thousand were infected and about 400 of them died. This was the largest case of infection in the world.

3. Countermeasures against Cryptosporidium

3.1 Tentative guidelines by the Japanese Ministry of Health and Welfare

On October 4, 1996, the Japanese Ministry of Health and Welfare issued "Tentative Guidelines for Countermeasures against Cryptosporidium in the Water Supply", providing necessary information and guidance to all the relevant authorities in prefectures, ordinance-designated cities and special wards. The guidelines included the following contents.

(1) Background and purpose
(2) Possibility of cryptosporidium pollution in the water supply
(3) Preventive countermeasures
(4) Emergency measures to deal with outbreaks of cryptosporidium infection

Preventive countermeasures specified in the guidelines are discussed below.

3.2 Extensive treatment in existing water purification plants

3.2.1 Common requirements

In the guidelines, water purification plants assumed to be polluted by cryptosporidium intake surface water at points downstream of facilities that treat and discharge human or other mammalian excrement. At such a water purification plant, one of the following purification treatments to remove cryptosporidium is required: rapid sand filtration, slow sand filtration, or membrane filtration.

Moreover, the guidelines require water turbidity to be less than 0.1 degree at the outlet of the filtration basin. This is used as a fundamental standard to prove the thoroughness of the above treatment. Requirements common to all three methods of filtration are listed below.

(1) Water turbidity at the filtration basin outlet must be maintained at less than 0.1 degree.
(2) For this reason, changes in the raw water quality should be promptly reflected in the operation of water purification treatment.
(3) At that time, a well-adjusted turbidimeter should be used.
(4) Water turbidity at the filtration basin outlet should be measured for each filtration basin. If that is impossible, water turbidity should be measured at least for each treatment system.

3.2.2 Requirements for the rapid sand filtration method

(1) Coagulant dosage
  (a) A coagulant should be used.
  (b) Equipment must be prepared and maintained to adjust an appropriate coagulant dosage and pH in response to raw water test results of turbidity, pH, temperature, alkalinity, etc.
  (c) The dosage of coagulant is to be determined according to jar test results of the raw water to be treated. Jar tests are to be performed periodically and test results fedback to adjust the dosage and pH.
  (d) As the jar test has a large time lag, in order to prepare for sudden changes of raw water quality, dosages for high turbidity are to be determined in advance, based on test results using artificial high turbidity water or past actual results.
  (e) The expiration dates of chemicals used for coagulation such as the coagulant and alkalis shall be adhered to.
(2) Coagulating operation
  (a) Stir immediately after applying dosage to

diffuse coagulant throughout the raw water uniformly.

(b) When a dosage has been changed, verify results in the flocculation basin and sedimentation basin.

(3) Sedimentation operation

(a) Pay attention to the detention time and flow rate in the sedimentation basin to achieve sufficient sedimentation.

(b) If it is required to improve the sedimentation effect, arrange some equipment such as an inclined plate.

(4) Rapid filtration operation

(a) The filtration rate in the sedimentation basin should not be changed suddenly.

(b) The sedimentation basin should be washed periodically, even if only slightly clogged.

(c) Washing of the sedimentation basin should be performed at a suitable expansion ratio.

(d) The sedimentation basin is usually washed so that the final turbidity of the washing drain becomes less than two degree (less than one degree if possible).

(e) Immediately after washing, the filtration function of a sedimentation basin is not effective. Therefore, water should not be discarded until turbidity at the basin outlet becomes less than 0.1 degree.

3.2.3 Requirements for the membrane filtration method

Membranes are to be inspected for abnormalities to prevent problems caused by ruptured membranes. If any abnormality is detected, the operation of equipment and systems belonging to the membrane concerned is to be stopped.

3.3 Problems and prospects concerning enforcement of the tentative guidelines

3.3.1 Measurement and control of a turbidity of 0.1 degree

The essence of the countermeasures against cryptosporidium in this guideline is to maintain the turbidity of filtrated water at less than 0.1 degree. However, it is difficult to measure turbidities less than 0.1 degree reliably and accurately with existing turbidimeters that utilize transmitted light or scattered light methods. Measurement for the purpose of controlling turbidity below 0.1 degree requires precision of greater than 0.01 degree. The accuracy of measurement of existing surface scattering type turbidimeters is generally ±2% FS for a measuring range from 0 to 2, and the practical measuring limit is about 0.04.

After the cryptosporidium outbreak in Milwaukee received a great deal of attention, in addition to the conventional turbidity measuring method, a particle count method has increasingly been used in water purification plants in Europe and USA. In the conventional method, the quantity of light attenuated or scattered by more than one turbid particle within a light beam field is measured. In the particle count method, a contracted narrow light beam is used and the light scattered from individual particles is counted as pulses. Accordingly, the former method is suited for relatively high concentration turbidity, while the latter method is suited for measurement of low range turbidity, where only one or fewer particles exist in the field of a contracted light beam.

Until now, as seen in cases of foreign countries, the particle count method has been used to manage the number particles of each individual size. The conventional method of turbidity measurement has been used reluctantly in most cases. Fuji Electric believes that turbidity control below 0.1 degree, as required by the aforementioned guidelines, and particle count control, expected to become more important in the future, should be performed on identical equipment simultaneously. Based upon light scattering theory, Fuji Electric has developed this type of equipment that can count individual size particles as well as measure turbidity.

Membrane processing is a significant method to remove cryptosporidium. As described in the guidelines, it is necessary to detect membrane abnormalities in order to prevent accidents due to ruptured membranes. The following are methods to detect membrane abnormalities: ① a sonar method using ultrasound, ② a pressure fluctuation method, and ③ a method of monitoring turbidity. However, ① and ② are not continuous monitoring methods but periodical inspection methods. As mentioned above, method ③ does not have sufficient sensitivity when used with existing devices. Therefore, for this purpose also, particle counting is a significant method for measuring the turbidity of particle flow.

3.3.2 Countermeasures against rapid changes in raw water quality

The universal task of water purification is to provide treated water with a high level of safety and consistent quality, irrespective of changes in the raw water quality. The tentative guidelines request that more manpower be assigned to the important task of maintaining the turbidity of filtrated water below 0.1 degree. Moreover, the guidelines require that the desired water quality level be maintained. This level has stricter requirements than the standard water quality value (up to 2 degrees).

The guidelines require that the turbidity removing capacity of the coagulation-sedimentation process should be maximized in order to maintain good turbidity of filtrated water.

As described below, Fuji Electric has succeeded in developing a system that realizes the optimum dosage rate of a coagulant in real-time by measuring the mean floc diameter in a flush mixing tank and then performing feedback control to obtain the most suitable floc diameter in accordance with raw water turbidity.

4. Coagulation Sensor and Coagulation Controller

Among water purification treatments, coagulation and sedimentation are the most important processes. Until now, coagulant dosages have been determined by indirect measurement using traditional jar tests. Fuji Electric developed and systemized a “coagulation sensor” (Fig. 2) which measures the mean diameter and concentration of flocs in real-time in a rapid mixing tank or a flocculation basin, and a “coagulation controller” which performs feedback control of coagulant dosing, based on measured values of coagulation. It is relatively easily to incorporate this sensor and controller into existing systems.

4.1 Special features

(1) Special features of the coagulation sensor

The sensor that has been developed can measure the mean diameter of flocs from micro-flocs to grown flocs (2 to 500 μm). A combined measurement of the coagulation state can be performed by simultaneously measuring the floc concentration and the ultra-violet absorbance of dissolved organic matter. In-line measurement is possible by utilizing a direct immersion type sensor.

(2) Special features of the coagulation controller

Realizing that floc diameters in a flush mixing tank define the quality of sedimentation-treated water, a new method of controlling coagulant dosage has been employed. In order to respond properly to rapid changes in raw water quality, the latest control algorithms of model predictive control and adaptive control have been introduced to achieve stable and highly reliable control.

4.2 Principles

The coagulation sensor irradiates the treated water containing flocs with light consisting of two kinds of wavelengths, ultraviolet and near-infrared rays. The fluctuation of transmitted light is analyzed by means of “dual wavelength absorbance photodispersion analysis”. Figure 3 shows the principle of the measurement and Fig. 4 shows changes in absorbance due to flocs passing through.

Ultraviolet absorbance (which includes the effect of dissolved organic matter and suspended solids, and is affected by the coagulant and dissolved color components in addition to suspended particles that are detectable by near-infrared rays) is classified by component with infrared absorbance (which is not affected by coagulant and only fluctuates due to suspended particles in the flocs such as clay and other particles). Three values, E_{m1}, E_{RMS1} and E_{RMS2} (see Fig. 4 for an explanation of the symbols) are measured directly, and are used to calculate the floc diameter and floc concentration.

Fig.2 Coagulation sensor

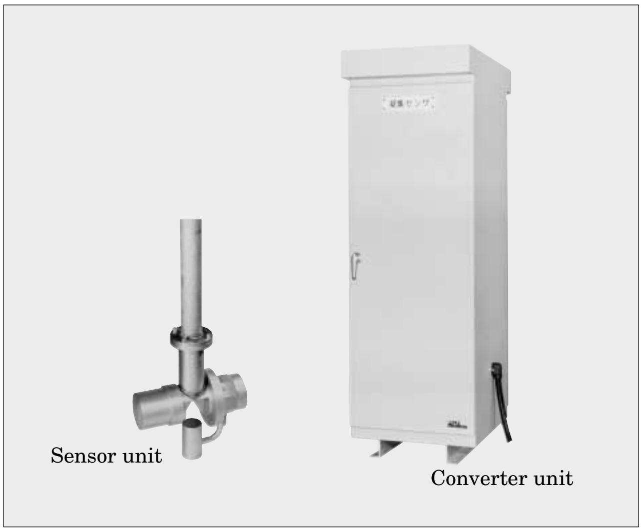


Fig.3 Principles of coagulation sensor operation

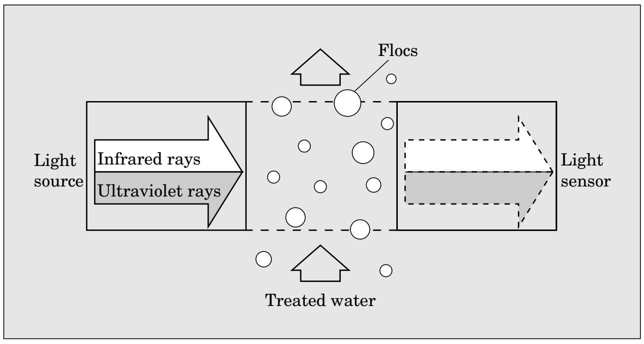
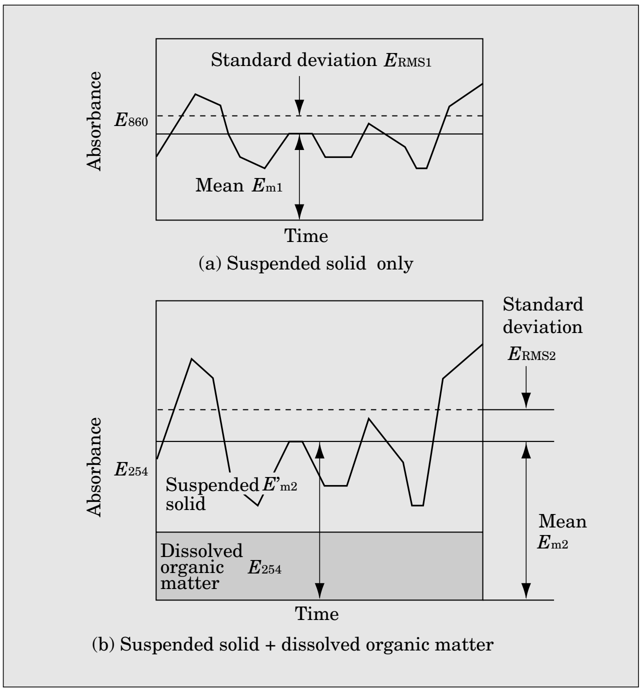


Fig.4 Changes in absorbance occurring with the passing of flocs



Floc diameter

$$D = \sqrt{\frac{4AE_{\mathrm{RMS1}} \bullet E_{\mathrm{RMS2}}}{\pi Q E_{\mathrm{m1}}}} \cdots\cdots (1)$$

Floc concentration

$$N = V\,(E_{\mathrm{m1}} / E_{\mathrm{RMS1}})^2 \cdots\cdots (2)$$

Where, A, Q and V are constants.

4.3 Validity

Through implementing this system it is possible to realize the minimum required dose of coagulant, resulting in reduced plant operating costs and a reinforced purification treatment against cryptospordium. Benefits of this system are listed below.

(1) Reliable response is possible even in cases of sudden changes in the raw water turbidity.
(2) The bothersome task of adjustment the dosage rate in response to seasonal changes of the raw water quality is not required.
(3) The dosage rate of coagulant can be reduced.
(4) The load of the sedimentation basin and filtration basin can be reduced.
(5) Sludge discharge is reduced.
(6) The dehydration efficiency of discharged sludge is improved.
(7) Labor saving is possible.

4.3.1 Floc diameter and turbidity removal rate

Figure 5 shows the relationship between floc diameter in the mixing tank and turbidity removal rate after the sedimentation treatment. The targeted control value is different for each purification plant.

4.3.2 Raw water turbidity and treated water turbidity

Figure 6 shows the changes in turbidity for raw water and for treated water. In spite of the sudden change in raw water turbidity, the turbidity of treated water was held below 1 mg/L.

5. High-Sensitive Turbidimeter

In the field of waterworks, the necessity for control and measurement of turbidities below 0.1 mg/L is increasing in accordance with the desirable water quality items prescribed in the “City Water Quality Standards” and the “Tentative Guidelines for Countermeasures against Cryptosporidium in the Water Supply”. Because the “high-sensitive turbidimeter” (shown in Fig. 7) utilizes a forward scattering type particle counter method, measurement of the low turbidity range (0.001 mg/L), which has been immeasurable with the existing transmitted light method or surface scattering method, is now possible.

5.1 Special features

(1) The forward scattering type particle counter method is employed.
(2) Measurement of the low turbidity range (0.001 mg/L) is possible.
(3) Both turbidity and particle concentration can be

Fig.5 Relationship between floc diameter in the flush mixing tank and turbidity removal rate after sedimentation treatment

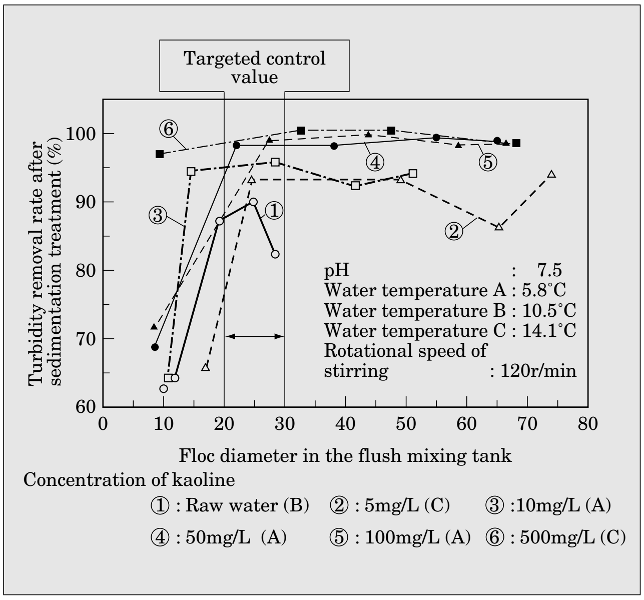


Fig.6 Change in raw water turbidity and treated water turbidity

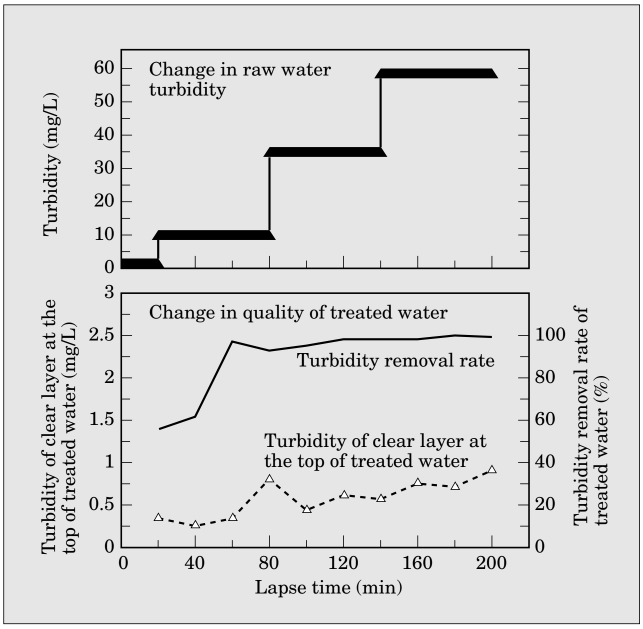


Fig.7 Appearance of high-sensitive turbidimeter

displayed and output selectively.

(4) Since the pulse counting method is utilized, reliable continuous measurement is possible.

(5) Maintenance is easy and does not require much effort. The flow cell is easily detachable.

5.2 Application

5.2.1 Turbidity control of outlet water of sedimentation basin in a water purification plant

By passing the sedimentation basin outlet water through a deforming basin and into a high-sensitive turbidimeter, low turbidity control (0.1 mg/L) can be achieved in accordance with the "Tentative Guidelines for Countermeasures against Cryptosporidium in the Water Supply".

5.2.2 Sensor to detect membrane abnormalities

Abnormalities in membrane modules at membrane processing facilities or at membrane regeneration facilities are sensed by detecting the number of leaked particles (due to a membrane rupture). If an abnormality is detected, a particle concentration alarm is issued. When high-sensitive turbidimeters are to be used as sensors to detect membrane abnormalities, it is desirable to install one unit for each membrane module. In a membrane processing system consisting of several or dozens of membranes, if an abnormality is detected only in some membranes, the process can continue to operate using other normal modules by closing valves connected to abnormal modules only. In a large-scale system consisting of nearly one hundred modules, because it is expensive to install high-sensitive turbidimeters at all membranes, it is desirable to install one turbidimeter for every unit of several membranes. Further, it is possible to reduce the load to the remaining normal membranes if the motor is controlled according to the number of abnormal modules via an "abnormal signal", transmit from the high-sensitive turbidimeter and received by the water quality monitoring and control system.

5.3 Principles

The principle of measurement is shown in Fig. 8. A laser beam from a laser diode irradiates sample water that flows continuously through a flow cell. The laser beam is scattered by particles in the sample water and creates scattered light, which is transformed to electric pulses by a photodiode. The number of pulses corresponding to the number of particles passing through the beam-irradiated zone is observed. The relationship between particle concentration and turbidity is linear and is highly correlated. Turbidity and particle count can be displayed and output selectively by keyed operation. For control of low turbidity below 0.1 mg/L, the particle counter method is most suitable.

5.4 Specifications

Specifications for the high-sensitive turbidimeter are given in Table 1.

Fig.8 Measuring principles of high-sensitive turbidimeter

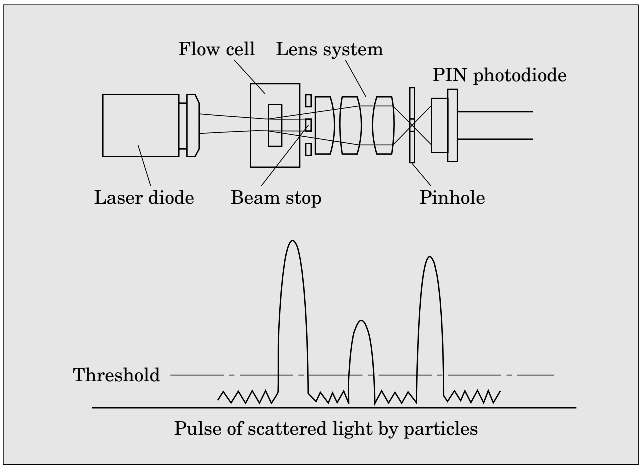


Table 1 Specifications of high-sensitive turbidimeters

Item	Specification
Measuring method	Forward scattering type particle counter (turbidity converted from particle concentration)
Measuring range	Turbidity: 0 to 1 mg/L (0.001 mg/L turbidity can be measured) Particle concentration: 1 to 10^5 particles/mL Turbidity/particle concentration can be selected (in both the display and output).
Measurable particle size	Larger than 0.5 μm
Output signal	4 to 20 mA DC (allowable load resistance: less than 550Ω)
Method of display	Digital display
Ambient temperature	0 to 40°C
Ambient humidity	Less than 95% RH
Place of installation	Indoors

6. Conclusion

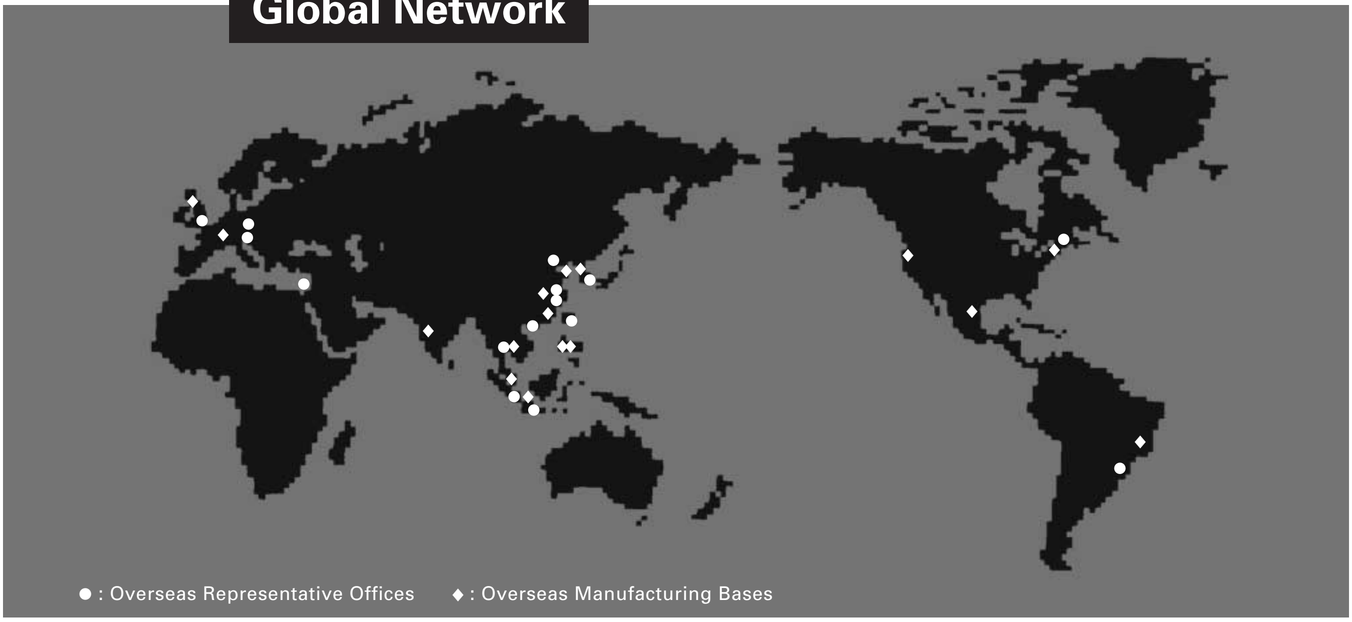
This paper introduced cryptosporidium and countermeasures to prevent it as specified in the "Tentative Guidelines for Countermeasures against Cryptosporidium in the Water Supply" by the Japanese Ministry of Health and Welfare. In addition, the coagulation sensor/controller and high-sensitive turbidimeter which aid the countermeasures have also described.

Cryptosporidium is considered a safety problem for city water, and present a more fundamental task than the making of good tasting water. With its sensor and control technologies, Fuji Electric will endeavor to maintain a safe water supply in spite of a deteriorating water environment.

Reference

(1) J.B. Rose: Occurrence and Significance of Cryptosporidium in water, Journal AWWA, Research & Technology, Feb. 1988

Global Network



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■**FUJI ELECTRIC CORP. OF AMERICA**
●Head Office
Park 80 West Plaza Ⅱ, Saddle Brook, NJ07663, U.S.A.
TEL : (201) 712-0555 FAX : (201) 368-8258

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■**FUJI ELECTRIC GmbH**
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TEL : (02)780-5011 FAX : (02)783-1707

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Bangkok Representative Office, Room No.1202, 12th Fl.
Two Pacific Place
142 Sukhumvit Rd. Bangkok 10110, THAILAND
TEL : (02) 653-2020, 2021 FAX : (02) 653-2022

■**P. T. BUKAKA FUJI ELECTRIC**
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TEL : (021) 5266716～7 FAX : (021) 5266718

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#04-05 Hawpar Technocentre, Singapore 749598, SINGAPORE
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