

Sensor for Cryptosporidium

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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

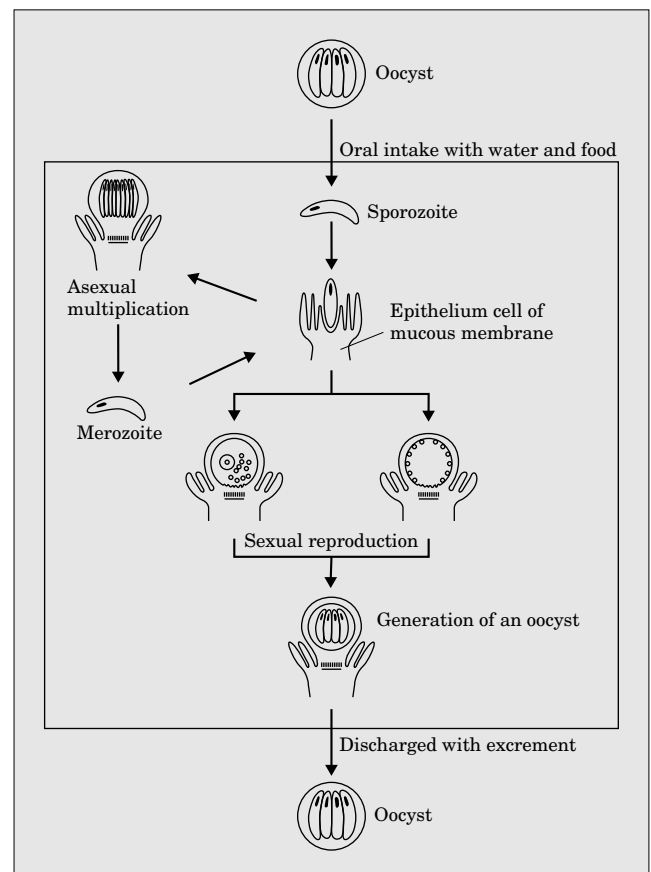
Cryptosporidium is a parasitic protozoa belonging to the coccidium of sporozoa, approximately 5 μm in size and oval shaped. Cryptosporidium is a parasite that infects many mammals such as human beings and domestic animals such as dogs, cats, cows, pigs, horses

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, sporozoites 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 lose 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 feedback 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 $\pm 2\%$ 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.

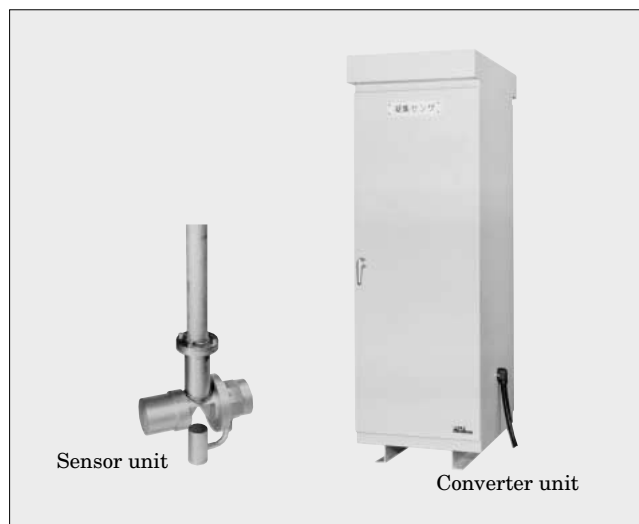
(2) Special features of the coagulation controller

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 wa-

Fig.2 Coagulation sensor



ter 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.3 Principles of coagulation sensor operation

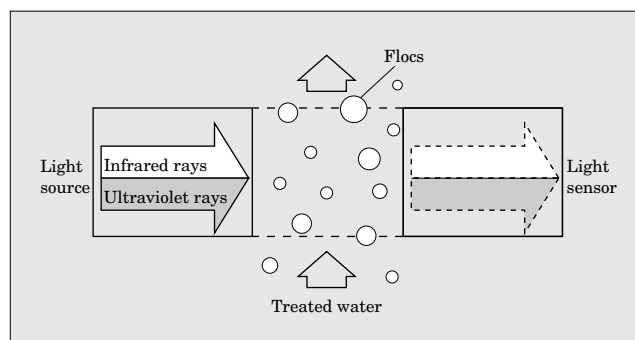
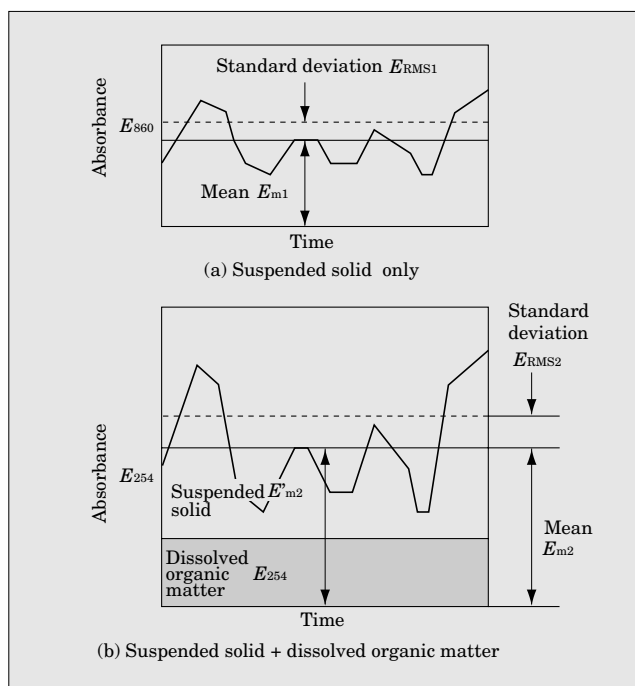


Fig.4 Changes in absorbance occurring with the passing of flocs



Floc diameter

$$D = \sqrt{\frac{4AE_{RMS1} \cdot E_{RMS2}}{\pi Q E_{m1}}} \dots\dots\dots (1)$$

Floc concentration

$$N = V (E_{m1} / E_{RMS1})^2 \dots\dots\dots (2)$$

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 cryptosporidium. 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 Counter-measures 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

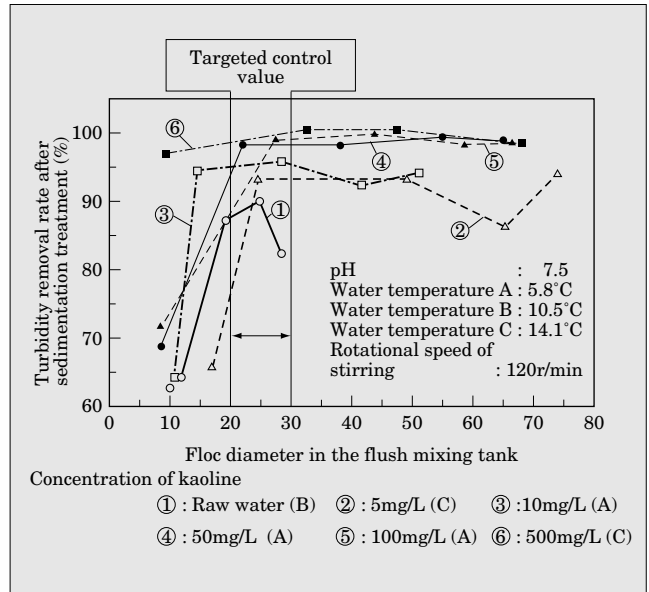


Fig.6 Change in raw water turbidity and treated water turbidity

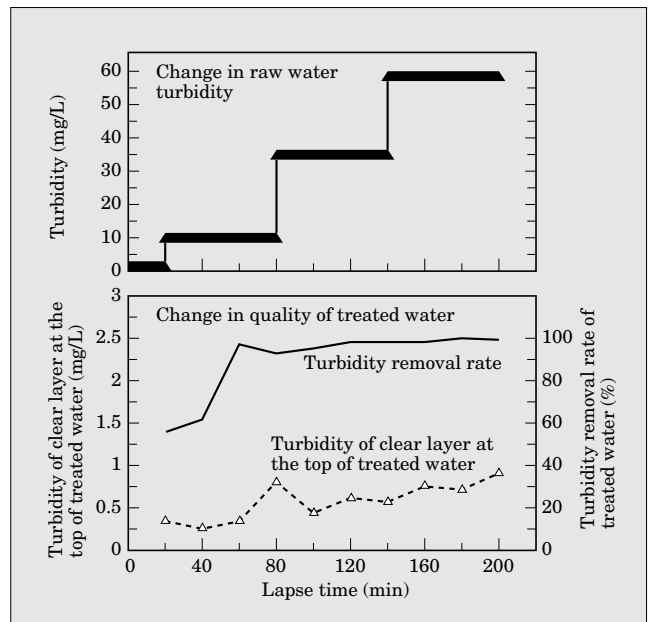


Fig.7 Appearance of high-sensitive turbidimeter



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

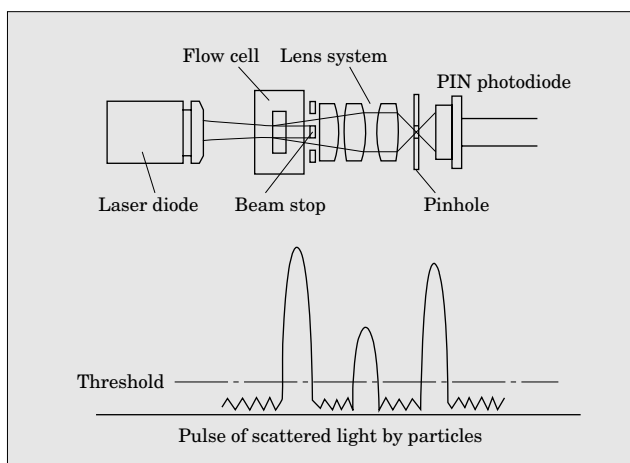


Table 1 Specifications of high-sensitive turbidimeters

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



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