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Application of Membrane in Municipal Wastewater Treatment and Reuse

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도시 생활폐수 처리 및 재활용에 관한 막의 응용

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1. Introduction

Water is an essential resource for life. In today's development-oriented world it has become more essential in various fields. Among various field of studies the industrialization and the urbanization are two most important disciplines where water is a vital resource. Though water covers more than 70% of the earth's surface it is not always available in adequate quantity. So long, most of the major urban areas have been able to cope with increasing demands by providing water from available sources, but as population continues to grow (which is a normal tendency in developing world), this solution will no longer be feasible and the region where water is scarce will have to rely on other water-transfer means.

On the other hand, the daily wastewater produced creates a lot of disposal problems. It has therefore become acceptable in many parts of the world that wastewater also can be considered as a good and reliable source of water supply. In this regard various methods have been developed for the recovery and reuse of water from such origins.

A conventional wastewater treatment system is a set of unit processes put together in a manner to achieve a desired end product. There are many combinations of unit processes that could be used to achieve the same degree of purification. The designer's problem is to determine the best combination form the engineering point of view. Numerous processes and methods are employed in the treatment of wastewater.

Membrane separation technique, which is also a new technique has been applied to municipal and industrial wastewater treatment. Researchers have used various types of membranes for solid-liquid separation in combination with conventional treatment methods. Higher degree of wastewater treatment can be obtained by using this system. The advantages of this technique include the minimum sludge waste by maintaining low F/M ratio, and the reduced plant size by maintaining higher bio-mass concentration in the reactor[1-2].

In conventional biological wastewater treatment, membranes can be inserted at three locations viz : after the primary sedimentation, in the activated sludge tank and after the secondary sedimentation, in the tertiary treatment with or without pretreatment. Many investigations to see the feasibility of using membranes after primary sedimentation were found uneconomical. The membranes were clogged rapidly by the organic contaminants in the wastewater.

Various types of membrane treatment techniques are reverse osmosis, electrodialysis, ultrafiltration and microfiltration. The electrodialysis is widely used on the brackish water treatment or in industries where removal of ionic salts is involved. On the other hand, the reverse osmosis method is generally employed for the production of water for artificial dialysis.

Ultrafiltration and microfiltration membranes are used in both water and wastewater treatment. The ultrafiltration and the microfiltration membranes can operate at low pressure compared to the reverse osmosis and the electrodialysis. Therefore these methods of membrane filtration can be used with less cost in the field of water and wastewater treatment.

2. Current Process for Sewage Treatment

Conventional biological treatment processes have been originally designed for sewage treatment mainly for converting dissolved biodegradable substances into more stable inorganics or into bio-mass. Improvements on these processes have been made it possible to remove nitrogen and phosphorous from sewage. Various biological processes used for sewage treatment are activated sludge process, biofilm process and stabilization ponds[3-4]. Classification of principal biological processes are shown in Fig. 1.

Although the effluent quality from these different treatment processes can be maintained within the standard specifications, it can not directly be reused without further advanced treatment.

3. Application of Membranes Coupled with Conventional Treatment Processes

The followings are several typical applications of Ultrafiltration(UF) and Microfiltration(MF) membranes coupled with conventional treatment processes.

3. 1. Biological Treatment by Using UF and MF

3. 1. 1. Membrane in Aerobic System

YAMAMOTO and his coworkers(1988) applied hollow fiber membrane directly in the aeration tank for activated sludge process, and the treated water was filtered through the membrane by suction. Two reactors were operated separately with 0.1μm membranes(Fig. 2). The stable treatment of synthetic

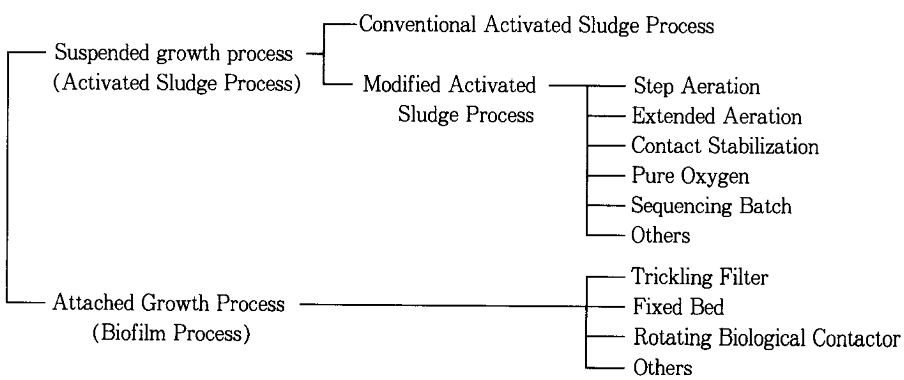


Fig. 1. Classification of principal biological processes.

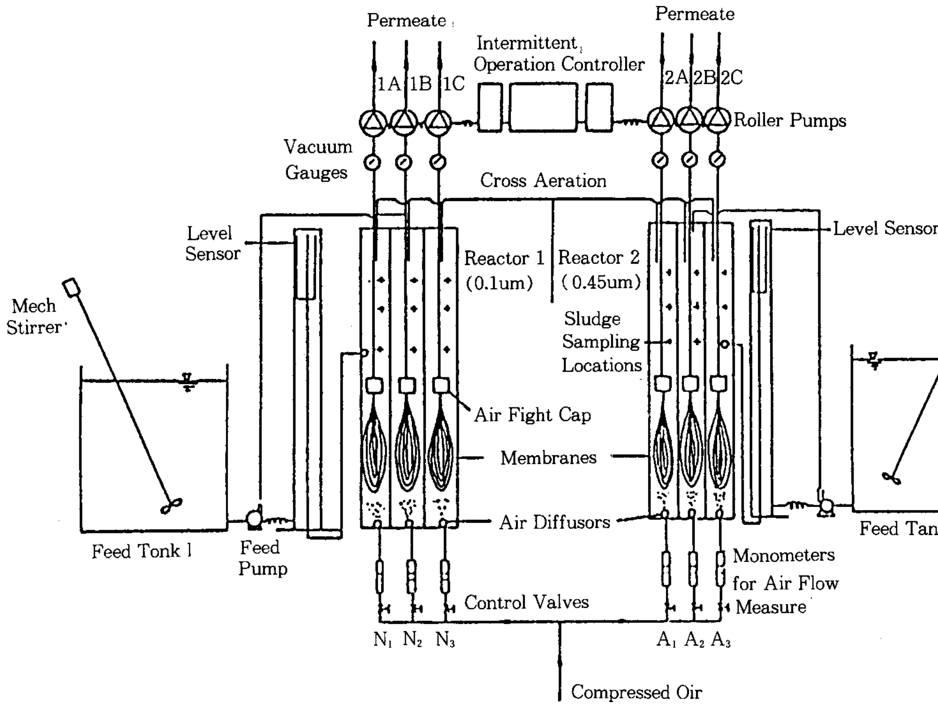


Fig. 2. Laboratory scale experimental set-up(activated sludge-EHF microfiltration configuration (YAMAMOTO et al., 1988).

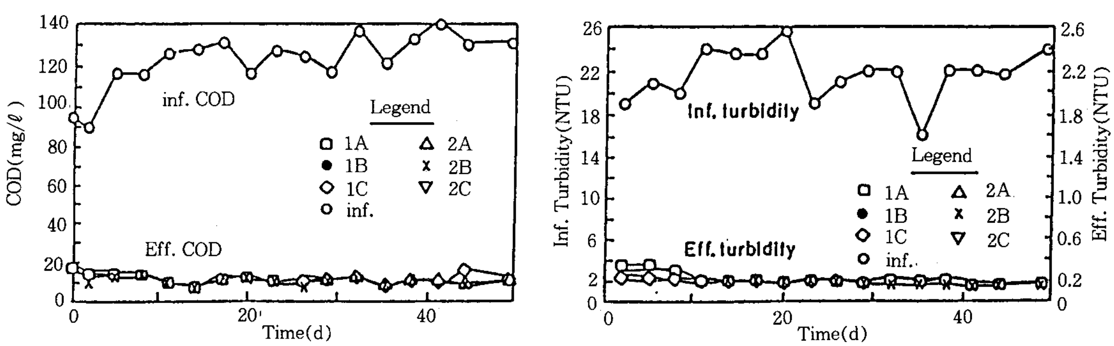


Fig. 3. Influent/effluent COD and turbidity at a volumetric organic loading of 1kg COD/m^3 · d(YAMAMOTO et al., 1988).

wastewater was observed for about 50 days at a volumetric COD loading of 1kg COD/m^3 · d by using intermittent suction with a low pressure of less than 10kPa. The effluent COD was always about 10mg/ℓ. After reaching a steady state, COD supplied was almost oxidized to keep MLSS constant in the reactor without sludge waste, which suggests that total oxidation can be achieved in this system. Fig. 3 shows the influent/effluent COD and turbidity at a volumetric organic loading of 1kg COD/m^3 · d[5].

The result showed the mean flux was slightly decreased but was kept above 0.1m^3/m^2 · d. Effluent turbidity was within 0.5 NTU(Nephelometric turbidity unit) and was almost constant during the experiment. COD concentration of the effluent was main

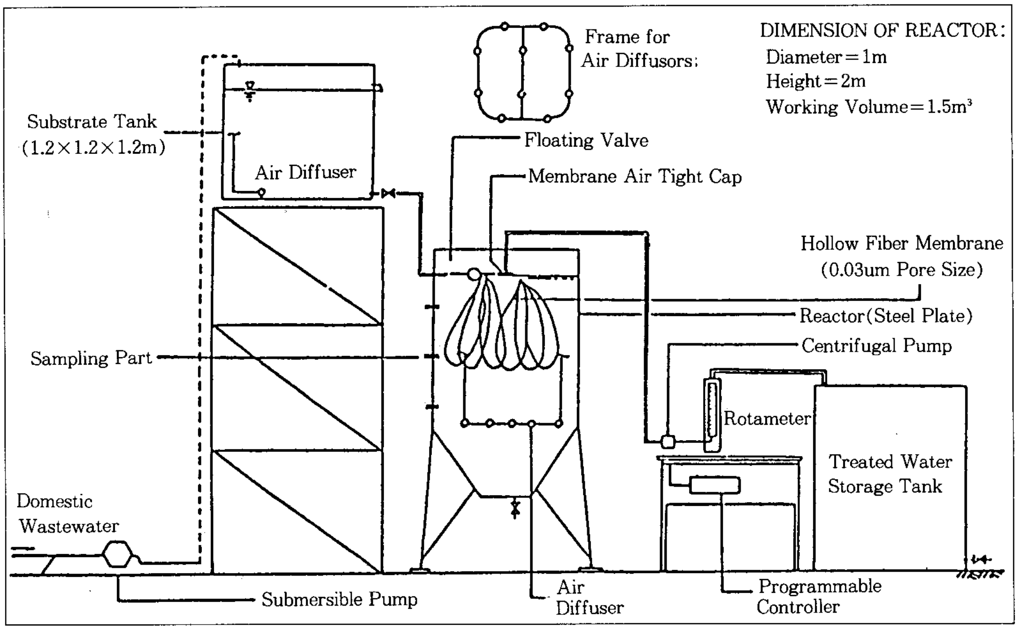


Fig. 4. Schematic of pilot scale membrane bioreactor(CHIEMCHAISRI, 1990).

Table 1. Comparison of Performance under Aerated and Non-Aerated Conditions

	Parameters	N1	N2 & N3	A1	A2 & A3
Stability	HRT	Rapidly increased from 1 to 8.33 hrs.	Can be maintained at 3 and 6 hrs.	Can be maintained at initial value of 1 hr.	Can be maintained at 3 and 6 hrs.
	Transmembrane pressure	Rapidly increase from 8 to 24cm. Hg.	Maintained at low value	Slightly increased	Maintained at low value
Effluent quality	COD removal	No different between both conditions was observed. Effluent COD concentration was below 20mg/ℓ and stable throughout the run.			
	Nitrogen	70-90% TKN removal		>95% TKN removal	
		No difference in nitrogen removal between both conditions. Nitrogen removal was about 70%.			
	Orthophosphate	No orthophosphorous removl was observed under both conditions.			

N1, N2 & N3 and A1, A2 & A3 are non aerated and aerated reactors respectively

tained less than 20mg/ℓ and was independent of influent COD value which ranged from 90 to 140mg/ℓ.

CHIEMCHAISRI(1990) studied membrane bioreactor with different operating conditions such as aerated and nonaerated with different HRT. The performance of hollow fiber membrane module in activated sludge process aerobic reactor supplied with diurnally varying feed was also investigated at the pilot-scale unit(Fig. 4)[6]. Two hollow fiber membrane modules were immersed in an aeration tank of the activated sludge system[6]. Microporous hollow fiber membrane of 0.03㎛ pore size with 9m² surface area(MITSUBISHI RAYON Co., Japan) was used in this study. A centrifugal suction pump

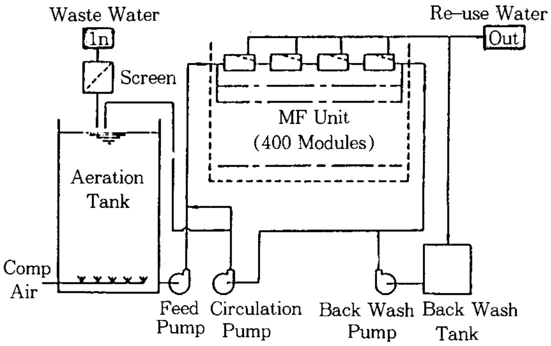


Fig. 5. Block diagram(water reuse promotion center, Japan).

was used at 10 : 10 minute intermittent operation (10 minutes pump "on" and 10 minutes pump "off") to extract the permeate through the membrane. From Table 1 it can be seen that non-aerated bioreactor has an advantage over the aerated condition at an initial HRT of 3 and 6 hrs, since lower energy consumption was required while giving similar effluent quality and process stability. However, the aeration is required in order to prevent clogging of membrane at lower HRT.

CHIEMCHAISRI(1990) reported that the cost of membrane bioreactor is higher than that of conventional sewerage aeration treatment system. However, this system produces a higher quality water and is appropriate in those places where the cost of the land and water supply are very high, since the recovery of permeate and the reduced plant size are possible in this system.

MAHMOOD and KHAJORNSAK conducted laboratory-scale experiments and reported the feasibility of hollow fiber microfiltration for solid-liquid separation from the aeration tank of an activated sludge process with Asian Institute of Technology wastewater[7-9].

Fig. 5 shows a typical block diagram of aerobic-membrane wastewater treatment system.

3. 1. 2. Membrane in Anaerobic System

In early 1970's anaerobic biological treatment system consisting of a suspended growth biological reactor and a membrane ultrafiltration process was developed. Recently this system has been used for wastewater treatment reuse in large buildings in Japan. Fig. 6 shows the schematic diagram of pilot scale experimental set up for anaerobic membrane process called Membrane Anaerobic Reactor System(MARS) process. The demerits of anaerobic treatment may be overcome by using this process.

Though several basic researches have been made on the MARS process to date, there are no studies on the potential reliability and operational cost of the MARS process. Department of Sewage Works (Tokyo Metropolitan Government) conducted research on MARS with pilot plant. Based on this research OKUNO and his coworkers(1986) reported some conclusions on the performance of this process. They reported that the removal rates of suspended solids, COD and BOD of ultrafiltration unit were about 95%, 50% and 70% respectively. Nearly all the methane generated from the anaerobic reactor was discharged within the ultrafiltration filtrate as dissolved gas. They also found the removal rates of coliform bacteria and coliphage were 99.85 % and 99.89% respectively.

BEN AIM(1984) discussed the operating and maintenance costs of ultrafiltration process[10] as follows :

- Fixed power consumption

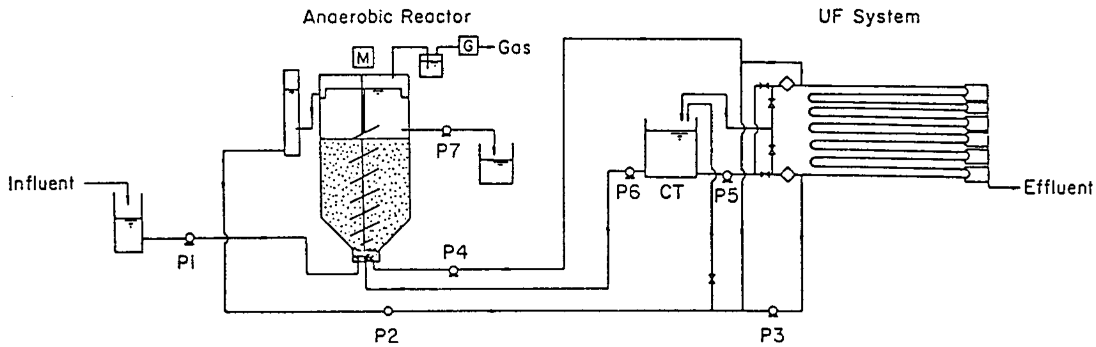
Since ultrafiltration plants are usually automated, they require little operating labor.

- Maintenance materials

The ultrafiltration process relied heavily on pumps. The repair or replacement of pump components constitutes a good percentage of maintenance material costs. A second large cost item is cleaning chemicals. Some feeds permit prolonged plant operation without membrane cleaning. However, under severe conditions, cleaning may be required frequently.

- Membrane replacement

The ultrafiltration membranes are subjected to a flux decay, commonly attributed to compaction. For severe applications, the membrane replacement cost



P1 : Feed Pump P4 : Return Pump P7 : Sludge Discharging Pump
P2 : Pressure Pump P5 : Cleaning Pump CT : Cleaning Tank
P3 : Circulating Pump P6 : Cleaning Water Return Pump M : Stirring Motor

Fig. 6. Schematic diagram of membrane anaerobic reactor system(OKUNO et al., 1986).

can be determined on the basis of the service warranty resulting from the pilot plant tests.

An estimation of the total cost of the MARS process, including anaerobic treatment, ultrafiltration and sludge treatment and disposal is the subject of a further study[11].

The present practice of disposal of septic tank effluent which consists of pathogens, organic wastes, toxic matters etc. is to drain into soil and it can not be reused. But this method of wastewater disposal is creating problems in semiurban areas whers sewer system is not available. To solve this problem the effluent of septic tank would be treated by membrane units. Feasibility studies are in progress to observe the performance of this kind of units to use septic tank waste to treat the domestic wastewater.

3. 2. Direct Removal of Contaminants

When contaminants are dissolved, high molecular

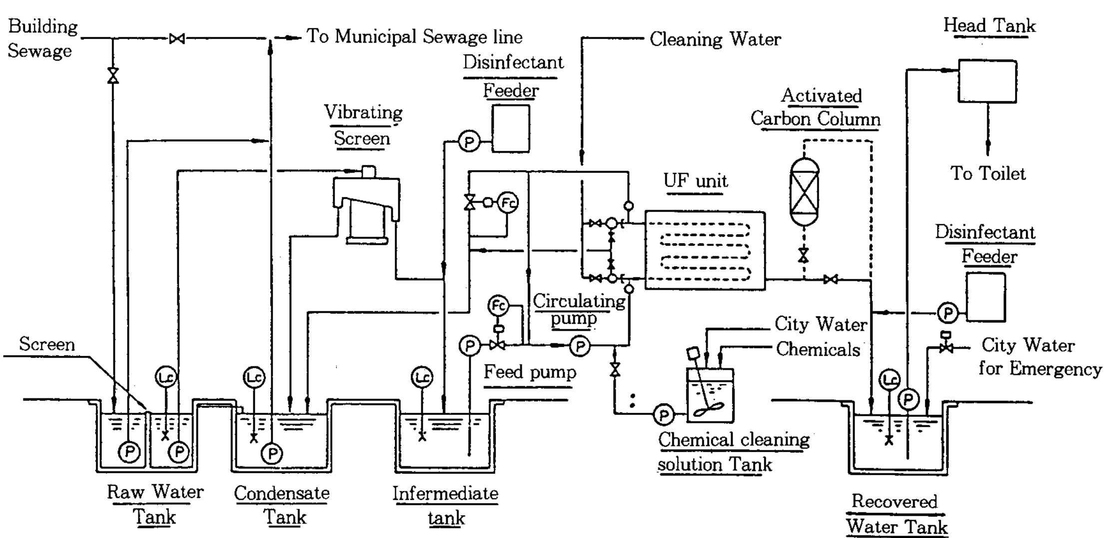


Fig. 7. Process flow sheet.

Table 2. Experimental Data from Direct Removal of Contaminants Using Ultrafiltration

	Experimental value				Tentative Standard
	Influent	Pretreated	Ultrafiltration	Activated Carbon	Toilet Flush
Suspended solids (Range)	74 (46–110)	52 (52–88)	0		30
Color	Yes	Yes	Very Slight	None	No disagreeable color
Color	Yes	Yes	Very Slight	None	No disagreeable color
pH(range) pH	(7.3–7.8) 7.4		(6.9–7.8) 7.4		6.5–9.0
BOD(range) BOD	(132–233) 153	(65–158) 89	(5–27) 17	(5–8) 6	20
COD(range) COD	(55–67) 55	(36–44) 41	(8–18) 13	(4–8) 5	40
Soluble matter (range) Soluble matter	(327–410) 360	(350–367) 352	(300–350) 325		5000
Ammonia(range) Ammonia	(2–20) 15	(2.20) 15	(5–10) 8		20
Hardness			137		400
Chlorine Ion			44		400
Iron			0.11		1

Table 3. Comparison of Wastewater Treatment Systems and Their Performances

Researchers	System used	Results
1. CHIEMCHAISRI, C.	Activated Sludge Process, Membrane Bioreactors in Domestic Wastewater Treatment. 0.03 ㎛ pore size hollow fiber membranes were used in the pilot scale experiments.	Steady state flux, Effluent turbidity<0.5 NTU, COD removal efficiency 80–98% and> 90% Nitrogen converted to Nitrate nitrogen.
2. KHAJORNSAK S.	Activated Sludge Process, Domestic Wastewater Treatment Using Membrane Bioreactor. Both Laboratory and Pilot scale experiments were conducted using 0.45㎛ pore size hollow fiber membrane.	50–70% removal efficiency of dissolved matter, 100% removal of fecal coliform, 84–94% of COD removal & constant permeate quality.
3. HAHMOOD T.	Activated Sludge Process, Application of Membrane Separation to Activated Sludge Process. Laboratory Scale experiments were conducted using 0.45 & 0.1㎛ pore size hollow fiber membranes were used.	COD removal > 95%, Nitrification 100%, Denitrification 30–40%, 100% removal of faecal coliform & stable against shock loading.
4. OKUNO N., et al.	Anaerobic Process, Application of Anaerobic Fixed Bed Process to Domestic Wastewater Treatment Followed by Membrane Separation. Ultrafilter membranes with molecular cut off size of 13000 were used in the experiment.	Coliform bacteria removal 99.85% Effluent COD & BOD 25 & 29㎎/ℓ but these values were found significantly dropped after aerobic polishing of ultrafiltration permeate.

materials or suspended materials can be removed directly from wastewater using membranes. There are many examples of water reuse using ultrafiltration in individual buildings in Tokyo, Japan.

RAYON ENGINEERING Co., Japan has developed a special water reuse system using ultrafiltration. This system extracts reusable water through ultrafiltration from wastewater and the residual concentrated wastewater is disposed to a municipal sewage piping. The company has reported about 20 examples of such plants applied in Tokyo, Fukuoka and other overpopulated cities of Japan. Typical process flow sheet of the system is illustrated in Fig. 7 and data taken in the experiments are illustrated in Table 2[12–13].

4. Comparison of Applications of Membrane in DIfferent Treatment Processes

From the foregoing discussion we came to know about the application of membrane coupled with conventional processes for the municipal wastewater treatment. Results of wastewater treatment studies performed by several research groups using laboratory and pilot scale reactors are presented in Table 3.

5. Conclusions

Membrane application in municipal wastewater treatment and reuse is a new technique and is under research. However this system of treatment has not been fully developed, it has shown a very good performance in treating municipal wastewater. Up to now, the application of membrane in large scale municipal wastewater treatment and reuse has not been reported. Feasibility studies are in progress in this regard. But there are many examples of its application in small scale. It has already been proved economical in small scale application and is becoming popular day by day with improved performance.

List of Symbols

Symbol	Description
EHF	Polyethylene Hollow Fiber.
F/M	Food/Microorganism Ratio.
MARS	Membrane Anaerobic Reactor System.
MLSS	Mixed Liquor Suspended Solids.
TKN	Total Kjeldahl Nitrogen.
10 : 10	10 minutes pump "ON" and 10 minutes pump "OFF".
NTU	Nephelometric Turbidity Unit.

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