Full-scale survey on carbonatation-related degradation of concrete structures in WWTPs

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Introduction

■ JS' past approach

WWTP requires countermeasures against corrosion of concrete structures due to sulfuric acid derived from hydrogen sulfide. JS has studied corrosion prevention technology and develped technology standards (*JS Mannual**) based on the study results.

*In 1987, JS established " Concrete Anti-Corrosion Coating Guidelines (Draft)". Since then, several technical evaluations and revisions of the guideline were conducted.

**JS Manual*: Technical Manual on Corrosion Control Measures for Sewerage Concrete Structure

■ What happens in reactors?

Concrete structures deteriorate due to carbon dioxide, which is generated by oxidation of organic matter by microorganisms. But we do not have enough knowledge about its occurrence and degradation mechanisms which is not covered by the *JS Manual*.

Gas phase → Neutralization by carbon dioxide gas
Liquid phase → Chemical erosion by erosive free carbon dioxide

⇒ Conducted field surveys at two WWTPs to understand the occurrence and progression of deterioration and their ambient environment at their aeration tanks.

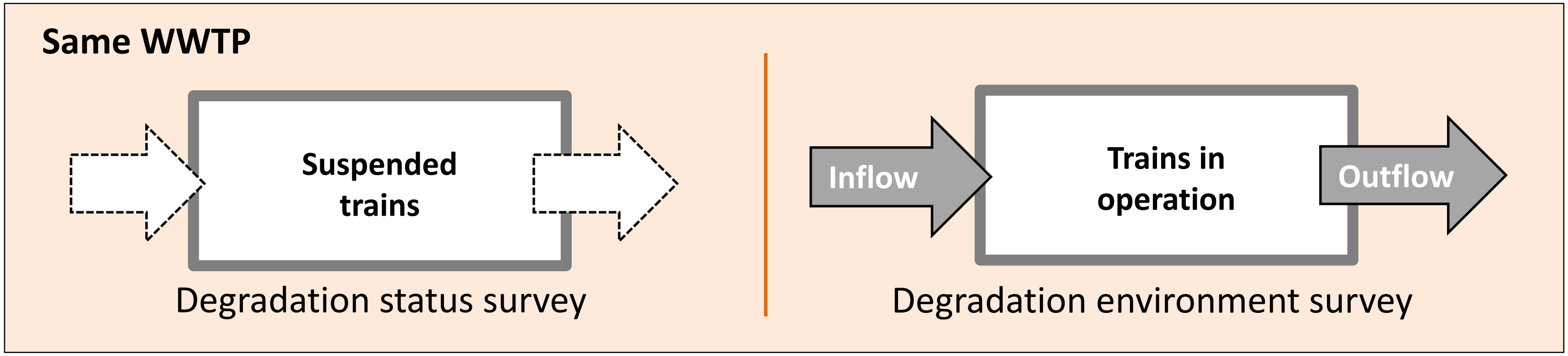
Investigation Procedures (1/2)

Investigation items

Contents		Items	Note
Degradation in Gas phase	Environment	Carbon dioxide concentration	One week continuous measurement by portable densitometer
	Conditions	Neutralization depth	JIS A 1152(chipping) Average of 3 measuring points per location
		Appearance and surface abnormality	Visual inspection, finger touch, test hammer inspection
Liquid phase	Environment	Erosive free carbon dioxide concentration,Total carbonate concentration, pH and alkalinity	Wastewater test procedure
	Conditions	Neutralization depth	JIS A 1152(chipping) Average of 3 measuring points per location
		Appearance and surface abnormality	Visual inspection, finger touch, test hammer inspection
Other commen survey		Temperature and humidity, water temperature, ORP	—
		Operation status	Interview with facility manager

Investigation Procedures (2/2)

Approach



- Perform deterioration investigations when facilities are deactivated for equipment replacement and facility inspections.
- Conduct a deterioration environment survey at the adjacent train in operation with comparable operating conditions (inflow water, existing facilities, etc.).

Survey conditions

Neutralization depth

Measurement of carbon dioxide gas

Visual inspection

Target Facilities (½)

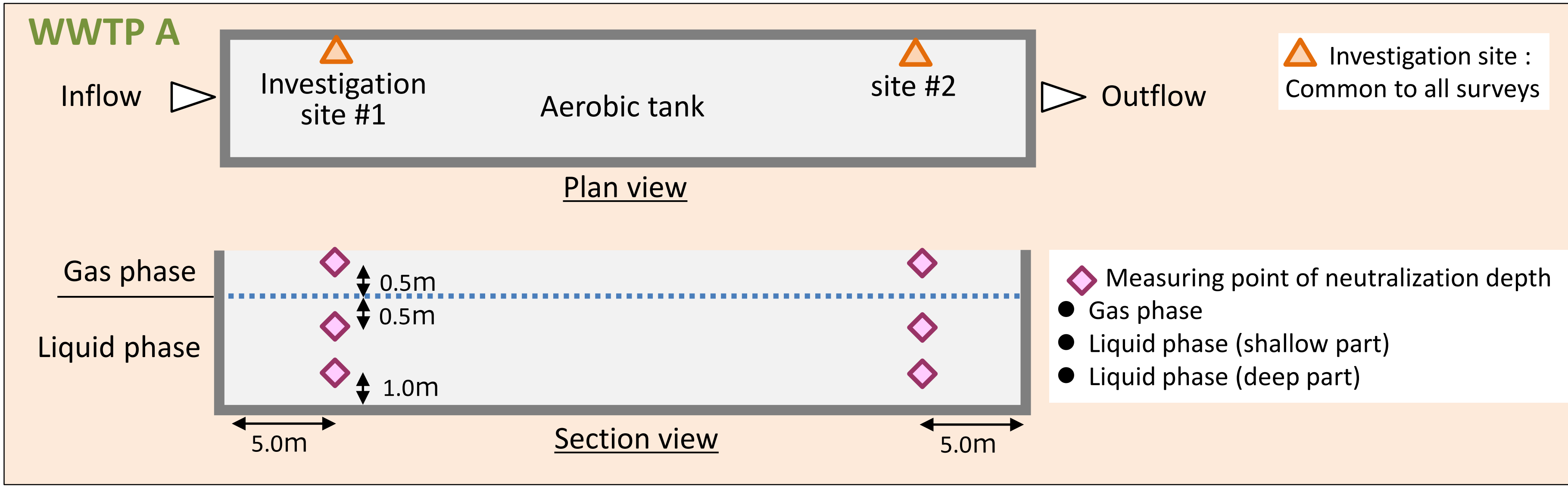
■ Target facilities of this time's investigation

Items	WWTP A	WWTP B
Design performance	114,200m^3/day (maximum daily capacity)	49,000m^3/day (maximum daily capacity)
Treatment process	CAS	A/O process
Aeration	Rotational flow	Full scale aeration
Cover	Overall	Overall
Service life (investigated train)	25 years	42 years
Size of a reactor (width × length × depth)	6.5m×64.0m×5.5m	Anaerobic：8.0m×22.1m×4.5m Aerobic：8.0m×36.9m×4.5m
Date of Investigation	February 2020	January 2020

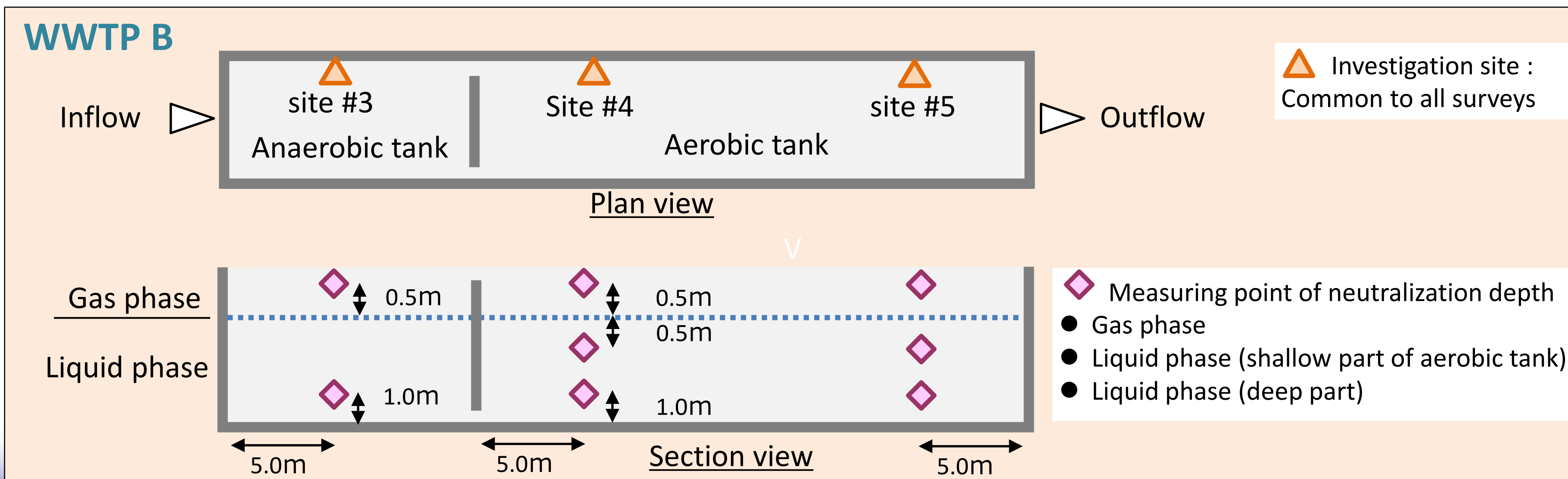
Target Facilities (2/2)

■ Investigation site

WWTP A

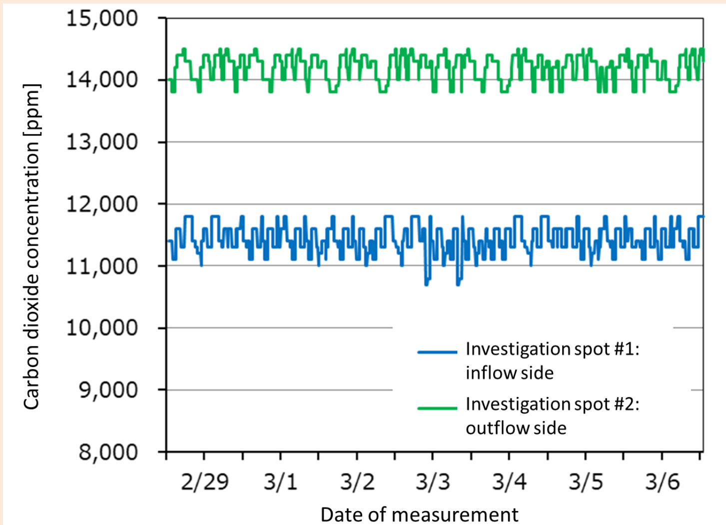
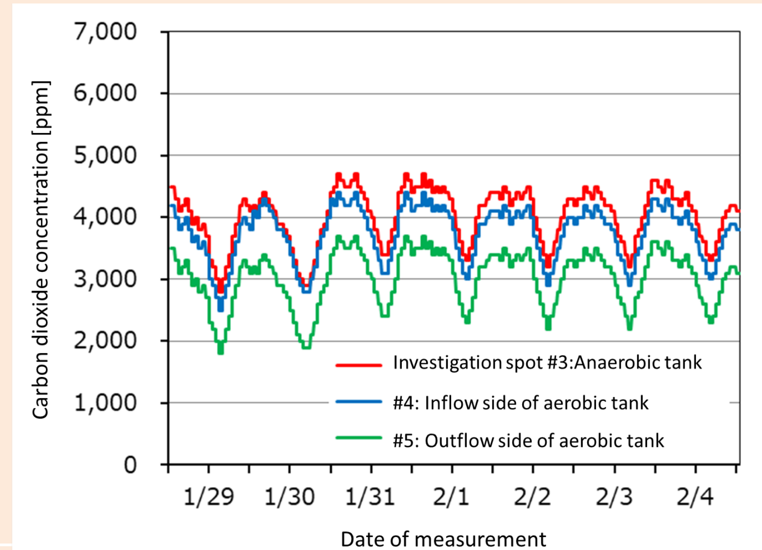


WWTP B



Results of Gas Phase Investigation （１）

■ Degradation environment/Carbon dioxide concentration

	WWTP A	WWTP B
Measured value		
	Inflow side: 11,000～12,000ppm Outflow side: 13,800～14,500ppm	Inflow side of aerobic tank: 2,500～4,500ppm Outflow side of aerobic tank: 1,800～3,700ppm
Event	There is a clear difference in concentration between the inflow and outflow sections.	Regular daily fluctuations can be seen, which is high in the daytime and low at night
Hearing results	Among the four sections in the reaction tank, one on the inflow side is operated with a reduced aeration rate.	The system is operated with a reduced aeration volume at night when the inflow load is down.

Note: The concentration of carbon dioxide in the atmosphere is about 300 to 500 ppm

→ Depending on facility operation procedures, the concentration of generated carbon dioxide varies widely.

Results of Gas Phase Investigation（2）

Degradation status: Neutralization depth

Unit (mm)

Investigation site			Measuring point #1	Measuring point #2	Measuring point #3	Average
WWTP A	#1	Inflow side of aerobic tank	4.3	6.8	7.3	**6.1**
	#2	Outflow side of aerobic tank	5.3	5.5	5.3	**5.3**
WWTP B	#3	Anaerobic tank	6.5	20.0	1.0	**9.2**
	#4	Inflow side of aerobic tank	5.3	20.5	5.3	**10.3**
	#5	Outflow side of aerobic tank	16.8	16.1	15.5	**16.1**

- All investigation sites showed a progression of neutralization.
- There was no regularity in the differences between the different study sites and the depth of neutralization, **nor was there any relationship with carbon dioxide concentration.**
- In the WWTP B, the gas phase showed greater neutralization depth than the liquid phase at the average of the aerobic tank.

Results of Gas Phase Investigation（３）

Consideration of Neutralization Rate Formula

The progression of concrete neutralization is widely recognized to be proportional to the square root of its number of years in use. It can be predicted using the following equation.

$$X=A\sqrt{t} \Rightarrow \underline{A=X/\sqrt{t}}$$

X ：Depth of neutralization (mm)
A ：Neutralization rate coefficient (mm/year)
t ：Years in use

	Years in use (t)	Investigation site	Neutralization depth (X)	Speed factor of neutralization (A)	Carbon dioxide concentration
WWTP A	25	#1	6.1	1.22	#1：11,000～12,000ppm #2：13,800～14,500ppm
		#2	5.3	1.07	
WWTP B	42	#3	9.2	1.41	#3：2,800～4,700ppm #4：2,500～4,500ppm #5：1,800～3,700ppm
		#4	10.3	1.59	
		#5	16.1	2.49	

WWTP B, which has a lower carbon dioxide concentration, had a larger neutralization rate coefficient.→ **In addition to CO2 concentration, other factors, including concrete material/quality and mixing condition in the tank, could affect the neutralization rate.**

Results of Gas Phase Investigation （ 4 ）

■ Degradation status, Visual inspection

There were no cracks, floats, exposed reinforcing steel, etc., and the sound of hammering by inspection was solid.

No abnormality was found on the surface of the gas phase by visual inspection in both WWTPs.

Results of Liquid Phase Investigation (1)

Degradation environment: Water quality investigation

Investigation site			Erosive free carbonate (mg/L)	pH	Alkalinity (mg/L)
WWTP A	#1	Aerobic: inflow side	**7**	6.9	120
	#2	Aerobic: outflow side	**8**	6.5	64
WWTP B	#3	Anaerobic	**6**	6.7	170
	#4	Aerobic: inflow side	**5**	6.6	150
	#5	Aerobic: outflow side	**5**	6.6	130

- No high concentrated erosive free carbonate were found.
- The concentration was lower than facilities where degradation has occurred (18-40 mg/L)*.

* Reference: the Japan Sewage Works Association: Sewerage Facility Planning and Design Guidelines and Commentary, Part II - 2019 Edition

Results of Liquid Phase Investigation（2）

■ Degradation status：Neutralization depth

Unit (mm)

Investigation site				Measuring point #1	Measuring point #2	Measuring point #3	Average
WWTP A	#1	Aerobic: inflow side	Shallow	11.0	10.3	8.3	**9.8**
			Deep	7.0	6.5	5.5	**6.3**
	#2	Aerobic: outflow side	Shallow	11.0	6.0	10.0	**9.0**
			Deep	9.0	7.3	9.0	**8.4**
WWTP B	#3	Anaerobic	Deep	1.0	1.0	1.0	**1.0**
	#4	Aerobic: inflow side	Shallow	10.8	11.0	10.5	**10.8**
			Deep	9.8	6.3	8.8	**8.3**
	#5	Aerobic: outflow side	Shallow	9.5	11.3	9.3	**10.0**
			Deep	9.0	9.3	10.8	**9.7**

- The anaerobic tank was hardly neutralized (investigation #3).
- For both the plants, no significant differences were observed among the measuring points along the flow.
- In both facilities, the neutralization progressed more in the shallow area than in the deep area (average).
- In aerobic tanks, neutralization depth was larger in liquid phase for WWTP A and gas phase for WWTP B (both averaged over the aerobic tanks), showing different neutralization characteristics between the plants.

Results of Liquid Phase Investigation（3）

■ **Degradation status：Visual inspection**

The surface can be easily shaved off with a scraper (softening of the surface)

The aggregate of the concrete frame is exposed.

● Both WWTPs showed surface anomalies, although only partially.

→ While no high concentrated erosive free carbon dioxide was observed, it is assumed that the surface degradation has progressed.

Conclusion

Summary

Results of field surveys on reactors at two WWTPs

- Highly concentrated carbon dioxide exists in the gas phase of the reactors. The concentration of carbon dioxide varies greatly depending on the operation procedure of the facilities.
- The liquid phase of the reactors showed partial dissolution of the concrete surface and aggregate exposure. Therefore, the degradation due to the erosive free carbonate is considered to have progressed.
- No progress of neutralization was observed in the anaerobic tank. In the aerobic tank, neutralization in the liquid phase progressed faster in the shallow area than in the deep area, while there was no significant differences were observed among the measuring points along the flow.

Future issues

- Continue the investigations on the degradation caused by carbonic acid in concrete structures of WWTPs to accumulate further knowledge.
- Establish comprehensive measures against corrosion and degradation including technical standards to control concrete degradation by carbonic acid.