Disinfection

➢ What is disinfection? Why to disinfect?

✓ *Disinfection is a process which inactivate or remove the pathogenic microorganisms in system.*

✓ *Treated (including disinfection) water should ensure the microbiological safety.*

✓ *Treatment should free from the secondary problem*

Microbial inactivation standard

USA Regulation

➢ Required treatment level

C. parvum conc. (Oocysts/100 L)	Required inactivation/removal level
0.01	1 log (90 %)
0.1	2 log (99 %)
1	3 log (99.9 %)
10	4 log (99.99 %)
100	5 log (99.999 %)
1000	6 log (99.9999 %)

Microbial inactivation standard

USA Regulation

- New stricter disinfection regulation (USA)

Disinfection law	Microorganism (level)	Turbidity[1]	Characteristics
SWTR (1989)	*Giardia* (3 log) Virus (4 log)	< 0.5 NTU	최초의 개량적 소독 기준 도입 원수 및 처리법에 따른 제거율 설정
IESWTR (1998)	*Cryptosporidium* (2 log)	< 0.3 NTU	*Cryptosporidium*에 대한 위험 대비. 시설 용량 10,000명 이상
LT1ESWTR (2002)	*Cryptosporidium* (3 log)	< 0.2 NTU	시설 용량 10,000명 이하에도 적용
LT2ESWTR (2003)	*Cryptosporidium* (3 log)	< 0.2 NTU	실증적인 실험 결과를 토대로 소독 기준을 반영

1) 4 시간 1회 측정, 월 측정 시료의 95 % 이상 만족

Microbial inactivation standard

- New stricter disinfection regulation (Korea)

2002, **Korean version of SWTR**
99.9% *Giardia* removal

(2001, Virus was detected in drinking water)

Disinfectants

- Chlorine → $HOCl, OCl^-$
- Chloramines → NH_2Cl
- Ozone → O_3
- Chlorine Dioxide → ClO_2
- Permangnate → $KMnO_4$
- Ozone/Peroxide → $O_3 + H_2O_2$
- Ultraviolet → UV 자외선
- AOP → $\cdot OH$

Oxidant/Disinfectant Overview

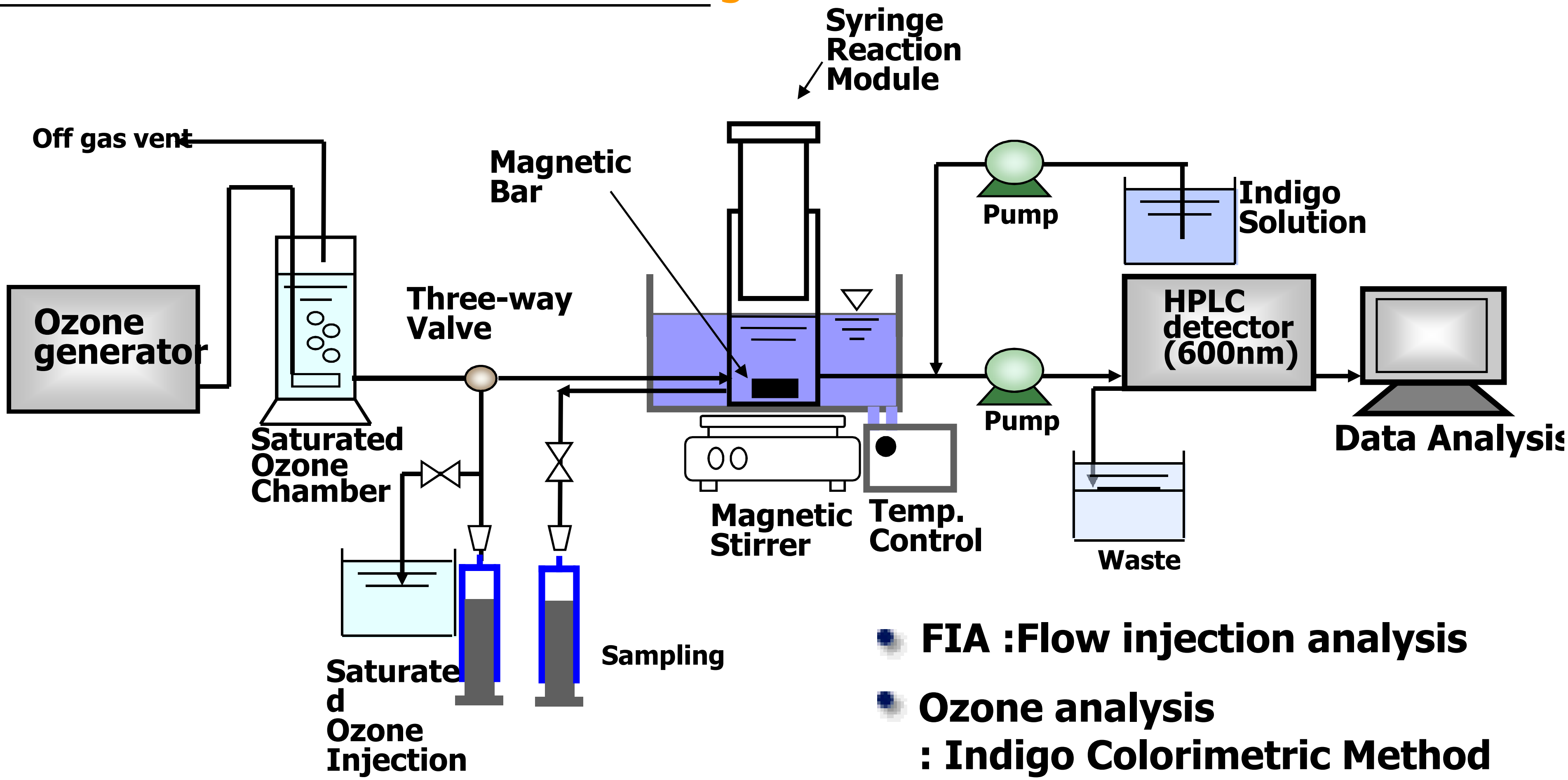
Technology	Oxidation	Praimary Disinfection	Residaul Maintenance
Chlorine	Fair	Fair	Good/Fair
Chloramines	Unacceptable	Poor/Fair	Good
Ozone	Good	Good	Unacceptable
Chlorine Dioxide	Poor	Poor	Unacceptable
Permanganate	Fair	Unknown	Unacceptable
Ozone/Peroxide	Good	Good	Unacceptable
Ultraviolet	Poor	Fair	Unacceptable

Oxidation Potentials of Common Chemical Oxidants Used in Water Treatment

	Oxidation Potentials (V vs NHE)
•OH	2.70
O_3	2.07
H_2O_2	1.78
HO_2•	1.70
ClO_2	1.57
HOCl	1.49
Cl_2	1.36

Schematics of disinfection treatment

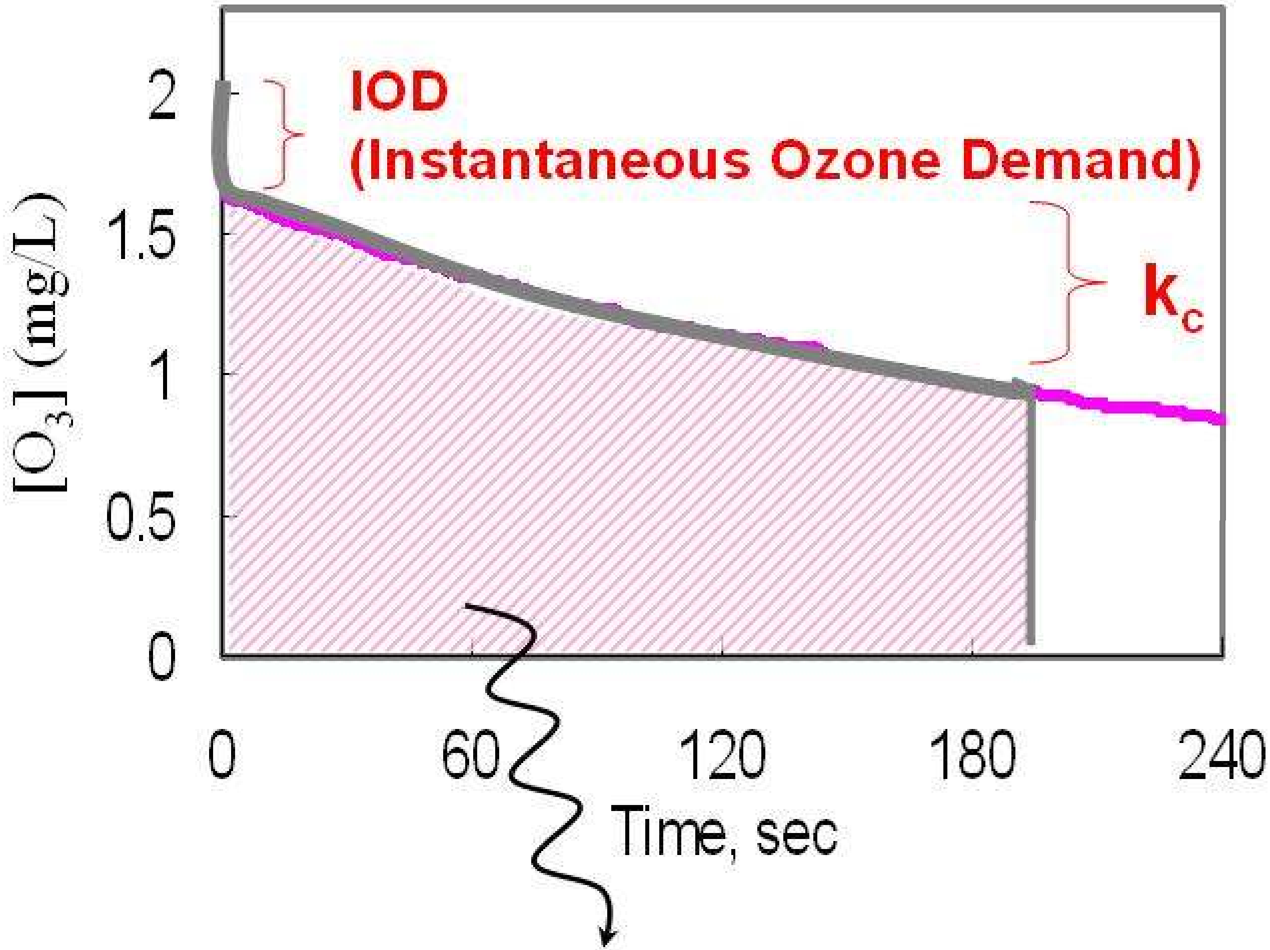
Chemical disinfection : O_3



- **FIA :Flow injection analysis**
- **Ozone analysis**
  : Indigo Colorimetric Method

Cho et al., 2001 (a); 2002 (a, c, d); 2003 (a - e), 2004 (e, g, h), 2005 (a)

Ozone Decay : Scheme



O_3 exposure = $[O_3]dt$

Ozone disinfection

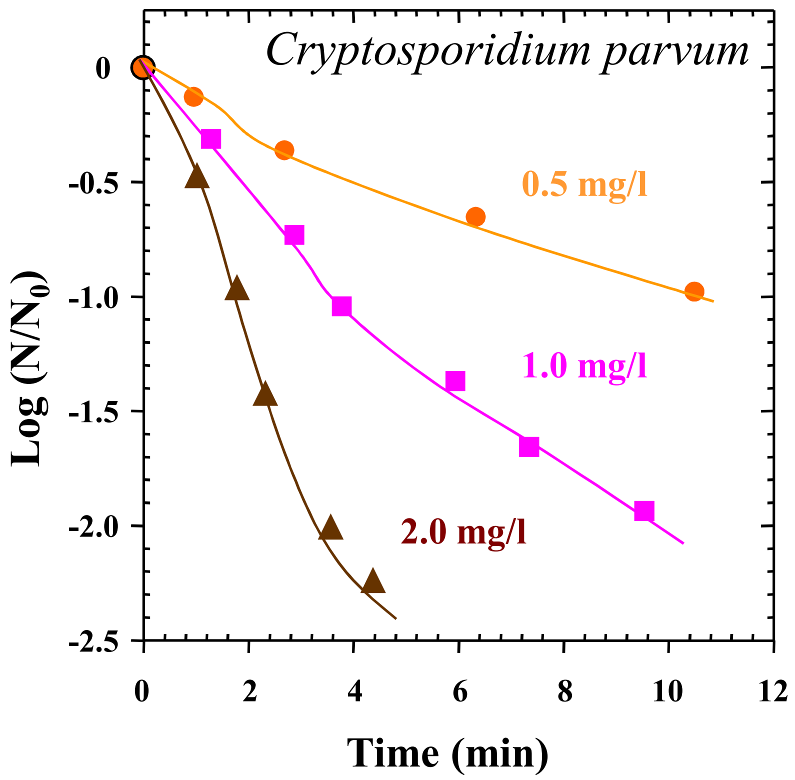
- **CT values**

	Disinfectants			
	Ozone (pH 6~7)	Free chlorine (pH 6~7)	Chlorine dioxide (pH 6~7)	Chloramine (pH 8~9)
E. coli	0.02	0.03 ~ 0.05	0.4 ~ 0.8	95 ~ 180
Polio virus	0.1 ~ 0.2	1.1 ~ 2.5	0.2 ~ 6.7	768 ~ 3740
Rotavirus	0.006 ~ 0.06	0.01 ~ 0.05	0.2 ~ 2.1	3800 ~ 6500
Giardia lamblia	0.5 ~ 0.6	47 ~ 150	26	2200
Cryptosporidium parvum	5 ~ 10	7200	78	7200

CT values : disinfectant concentration (mg/l) × contact time (min)

Ozone disinfection

- **Inactivation kinetics**



Ozone

Ozone is a powerful oxidant able to achieve disinfection with less contact time and concentration than all weaker disinfectants, such as chlorine, chlorine dioxide, and monochloramine

Limitation

Ozone can be used as a primary disinfectant since it cannot maintain a residual in distribution system. Thus, ozone
Disinfection should be coupled with a secondary disinfectants.

Ozone disinfection

- **Inactivation modeling**

Representative Models

Chick Model (1908)

$$Log\frac{N}{N_0} = -kT$$

Disinfectant : Phenol
Target : *Anthracnose* spore

Chick-Watson Model (1908)

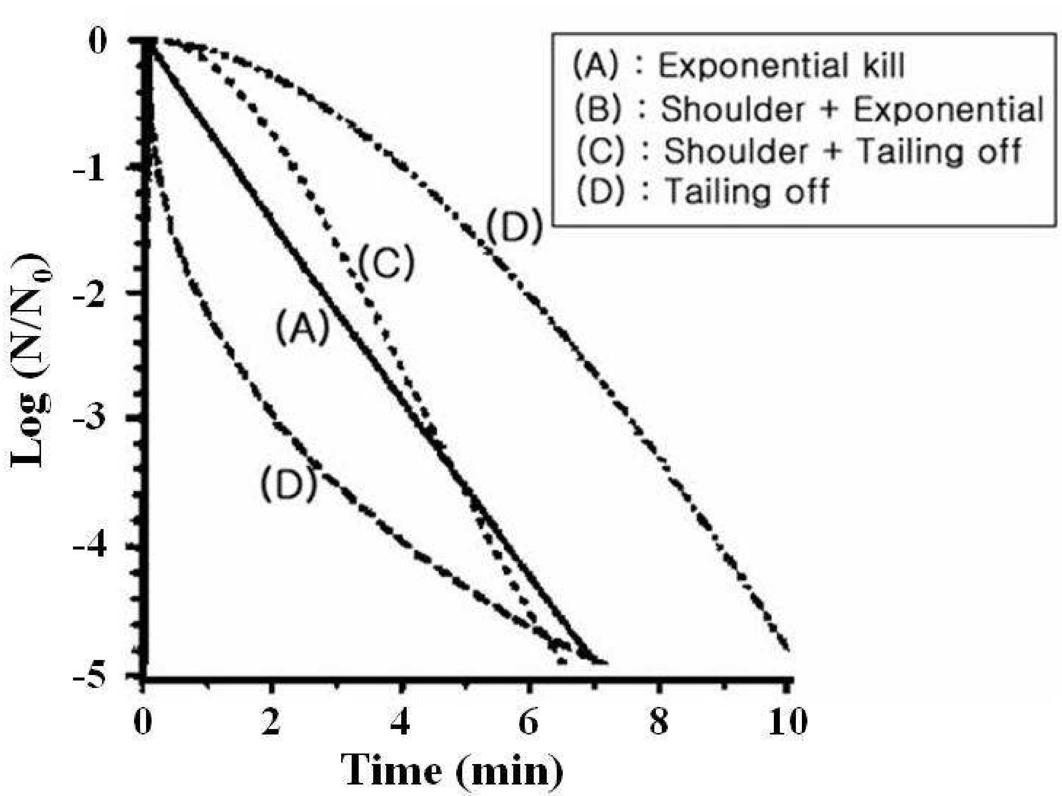
$$Log\frac{N}{N_0} = -kCT$$

Disinfectant : Ozone
Target : *E. coli*

CT concept

Ozone disinfection

- **Inactivation kinetics**



Ozone disinfection

- **Decay of ozone**

IOD (instance ozone demand)

k' : First order decay

$$C = C_0 e^{-k't}$$

Ozone disinfection

- **Inactivation modeling**

Representative Models with ozone decay

Modified Chick-Watson Model

$$Log\frac{N}{N_0} = -k\int_0^t Cdt \xrightarrow{\text{Integration}} \log\frac{N}{N_0} = -\frac{k}{k'n}C_0^n[1-\exp(-nk't)]$$

Delayed Chick-Watson Model

$$\log(\frac{N}{N_0}) = \begin{pmatrix} 1 & if\ \overline{C}T \le \overline{C}_{lag}T = \frac{1}{k}\log(\frac{N}{N_0}) \\ -k(\overline{C}T - \overline{C}_{lag}T) & if\ \overline{C}T \ge \overline{C}_{lag}T = \frac{1}{k}\log(\frac{N}{N_0}) \end{pmatrix}$$

$$where\ \overline{C} = \int_0^t Cdt \Big/ t$$

Ozone disinfection

- **Inactivation modeling**

  Model determination

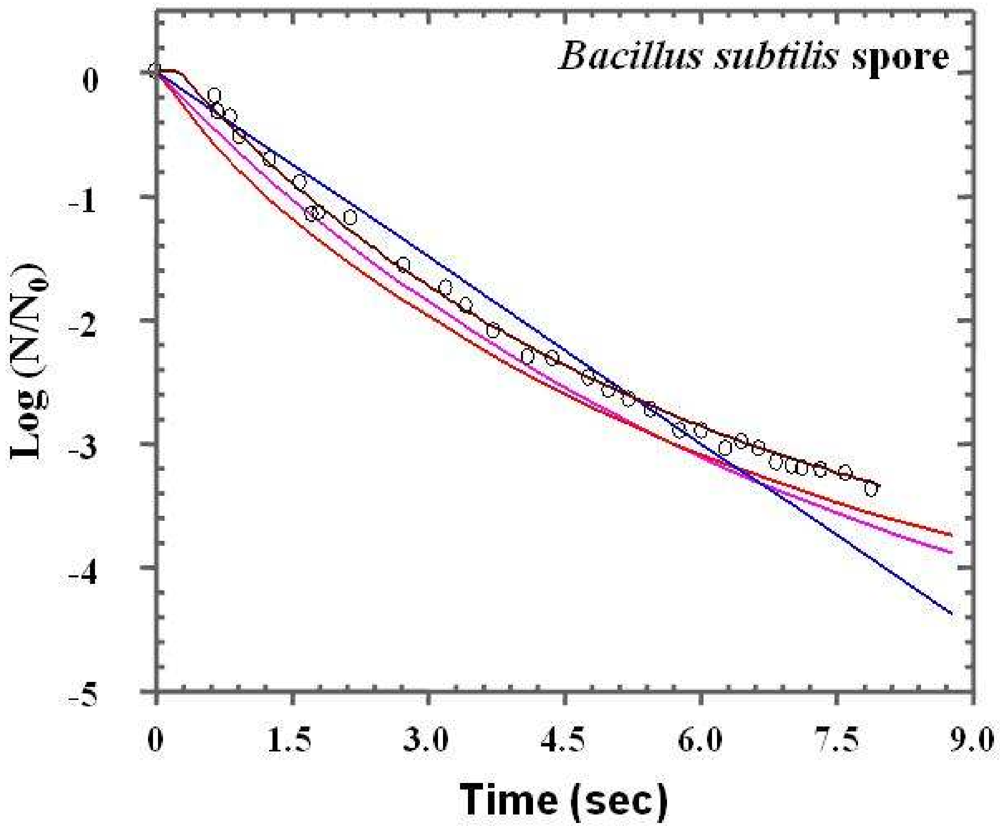
Minimum ESS (Error sum of squares)

$$ESS = \sum [\log(\frac{N}{N_0})_{observed} - \log(\frac{N}{N_0})_{fitted}]^2$$

Ozone disinfection

- **Inactivation modeling**

Model Fitness : Ozone disinfection



○ **Observed results**

Chick-Watson Model

Modified Chick-Watson Model

Modified Hom Model

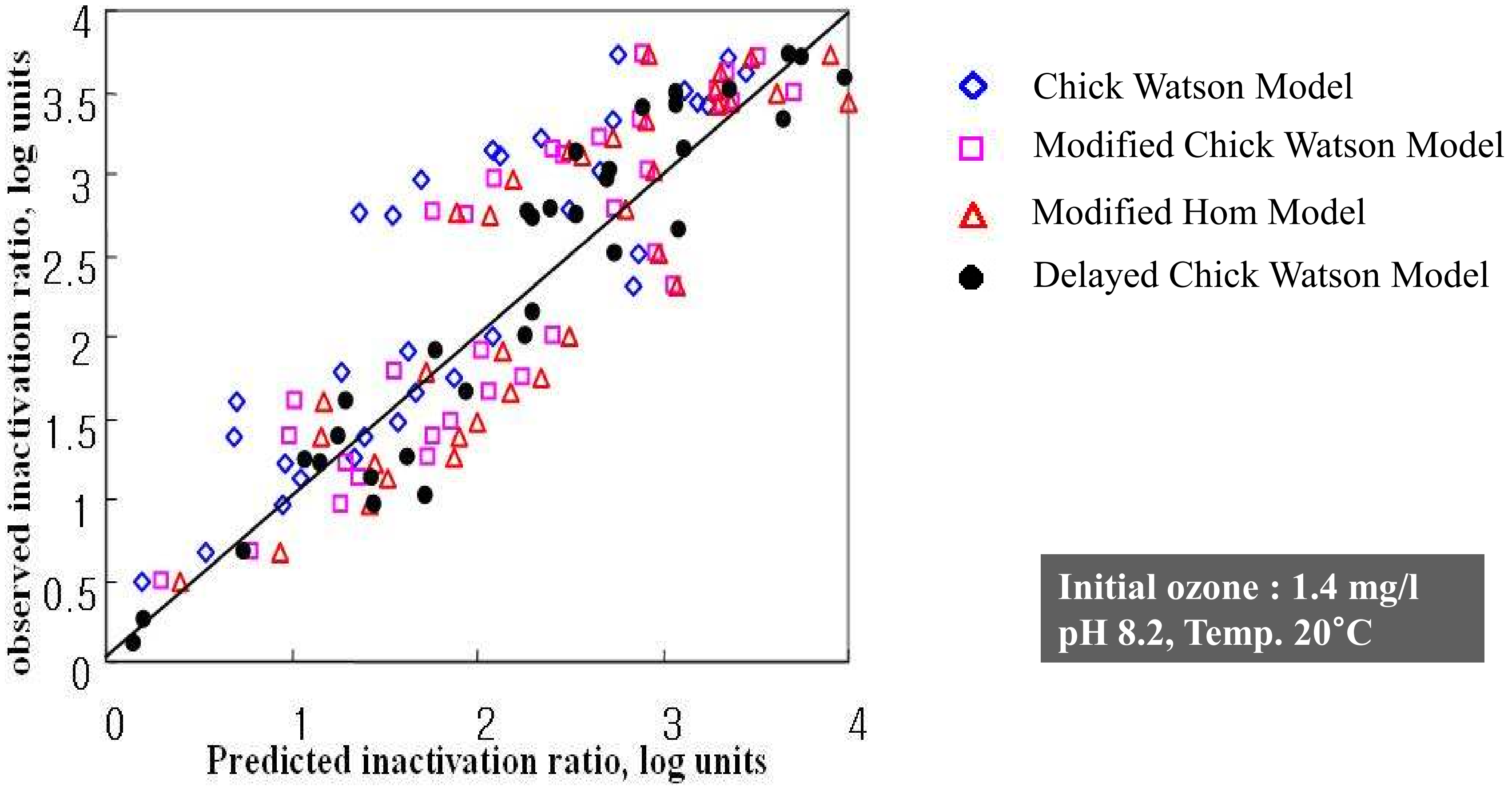
Delayed Chick-Watson Model

Initial ozone : 1.4 mg/l
pH 8.2, Temp. 20°C

Ozone disinfection

- **Inactivation modeling**

Model Fitness : Ozone disinfection



Initial ozone : 1.4 mg/l
pH 8.2, Temp. 20°C

Ozone disinfection

■ Inactivation modeling

Model Determination : Ozone disinfection

Water Type	pH	ESS (Error sum of squares)			
		CWM	MCWM	MHM	DCWM
Buffer Condition	5.6	3.56	2.74	2.58	2.36
	7.1	4.49	3.90	2.24	2.11
	8.2	9.92	4.87	7.17	3.48
Humic Acid	7.1	0.45	0.97	0.09	0.09
	8.2	2.40	1.36	0.26	0.23
Han River	5.6	4.10	0.97	0.21	0.13
	7.1	2.45	1.12	0.32	0.31
	8.2	2.44	1.44	0.34	0.17

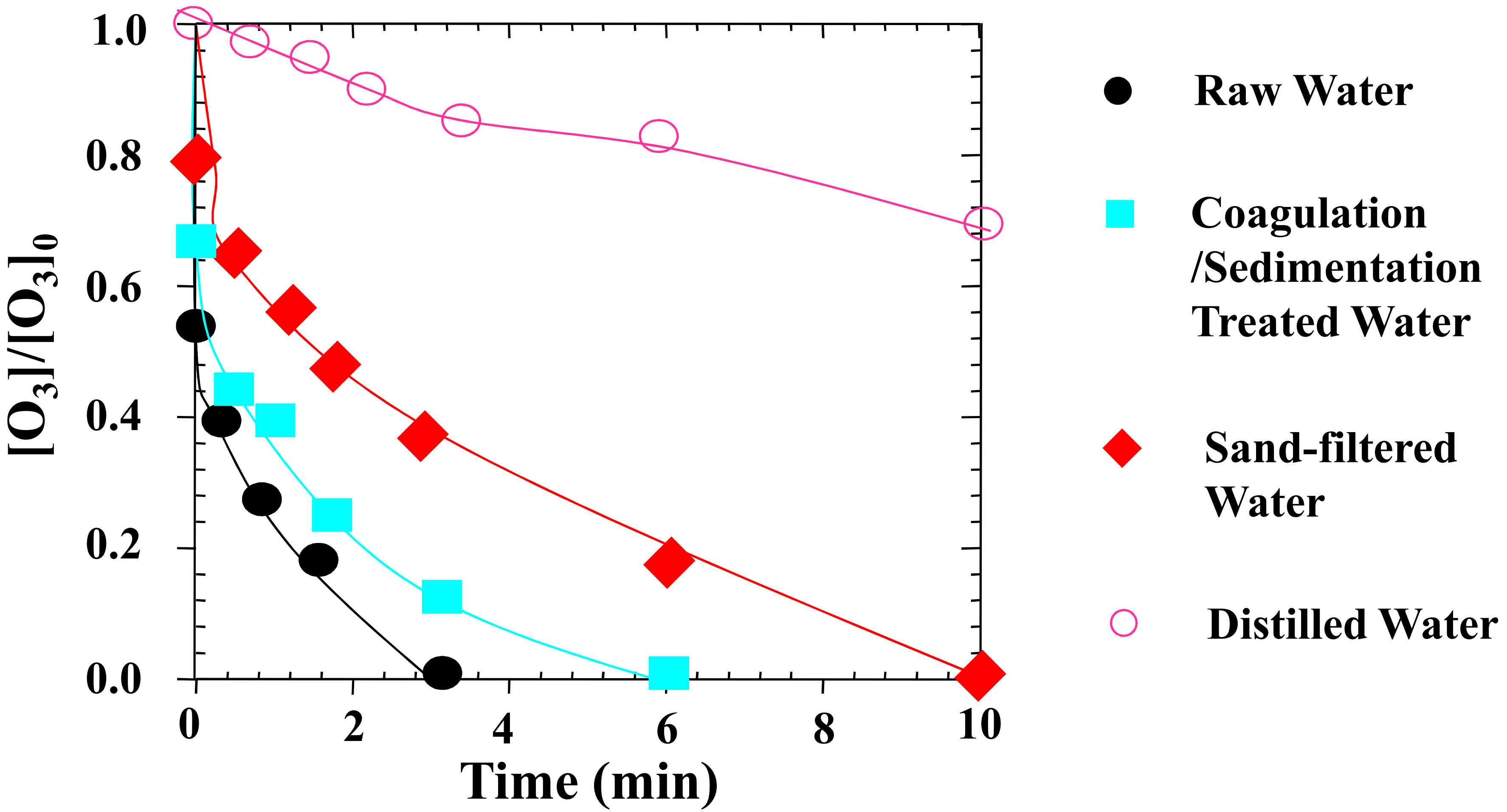
CWM: Chick-Watson Model **MCWM: Modified Chick-Watson Model**
MHM: Modified Hom Model **DCWM: Delayed Chick-Watson Model**

IV. Investigating disinfection kinetics

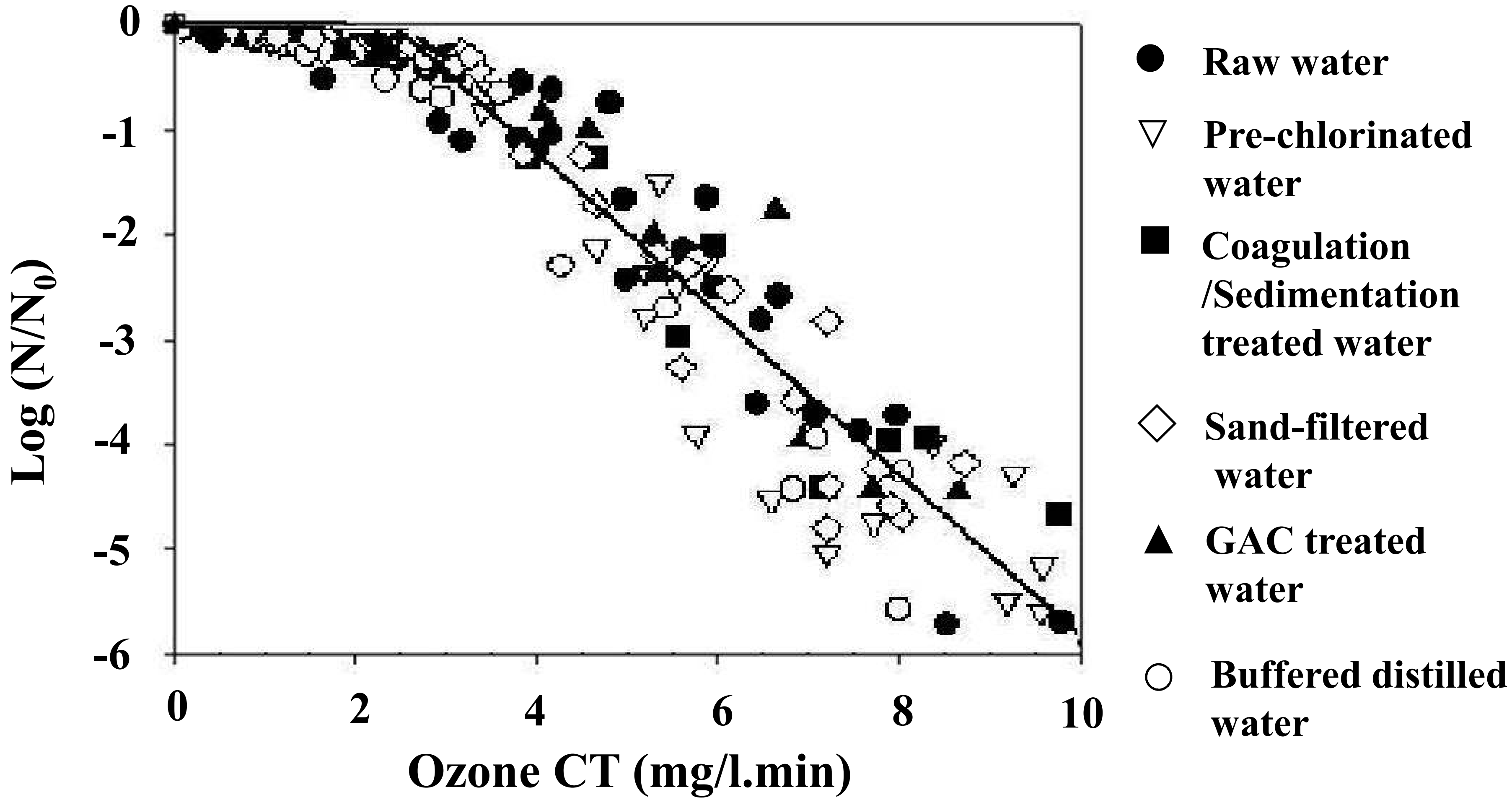
Question?: Does the specific inactivation constant exist in the world of microorganism inactivation ? (such as the specific rate constants observed in chemical reactions)

disinfectant (A) + microorganism (B) $\xrightarrow[\text{biomolecular reaction}]{\text{k, specific rate constant}}$

Pattern of ozone decay depending upon the level of treatment



The specific inactivation constant exists?



➔ **The specific inactivation constant exists.**

Summary (1), The specific inactivation constant exists ?

E. coli

	Slope (mg/l.min)$^{-1}$	**Lag constant** (mg/l.min)	Data N
O_3	$-(62 \pm 3)$	$(1.8 \pm 0.7) \times 10^{-3}$	
Cl_2	$-(32 \pm 3)$	$(1.5 \pm 0.1) \times 10^{-3}$	
ClO_2	$-(35 \pm 1)$	$(7.8 \pm 0.6) \times 10^{-4}$	

B. subtilis spore

	Slope (mg/l.min)$^{-1}$	**Lag constant** (mg/l.min)	Data N
O_3	$-(0.6 \pm 0.2) \times 10^{-2}$	$(0.50 \pm 0.03) \times 10^{-2}$	
Cl_2	$-(1.6 \pm 0.5) \times 10^{-4}$	(35 ± 5)	
ClO_2	$-(3.7 \pm 0.1) \times 10^{-2}$	(11.0 ± 0.6)	

Summary (2)

MS-2 phage

	Slope (mg/l.min)$^{-1}$	**Lag constant** (mg/l.min)	Data N
Cl_2	$-(14.0 \pm 0.4)$	$(2.0 \pm 1.7) \times 10^{-2}$	
ClO_2	$-(16.0 \pm 0.3)$	$(1.5 \pm 0.1) \times 10^{-2}$	

UV

	Slope (mW/cm^2)$^{-1}$	**Lag constant** (mW/cm^2)	Data N
E. coli	$-(0.32 \pm 0.01)$	(4.10 ± 0.16)	
***B. subtilis* spore**	$-(0.14 \pm 0.02)$	(6.20 ± 0.13)	
MS-2 phage	$-(4.2 \pm 0.01) \times 10^{-2}$	0	

Conclusions (Disinfection kinetics)

➔ **There are the specific constants of lag and slope in the world of microorganim inactivation similar to chemical reaction between two species (specific rate constant & observed rate constant):**

➔ **Why ?**