APPENDIX F.4

Test Results of TRO Control in the Land-Based Test

By

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Republic of Korea

EcoGuardian™ Ballast Water Management System
For
Final Approval

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1 INFORMATION OF THE LAND-BASED TEST

The basic information of the land-based test is shown in Table 1.1 and Table 1.2.

Table 1.1: Operating information in the land-based test

	Seawater	Brackish water
Test site	1048-4, Oryun-ri, Dosan-myeon, Tongyeong-si, Gyeongsangnam-do, Republic of Korea	
Test period	18/04/2012 ~ 21/05/2012	23/05/2012~26/06/2012
Test cycle	Cycle 1~5 (5 weeks)	Cycle 6~10 (5 weeks)
Salinity	34 PSU	21 PSU
Main ballast flow rate	250 ± 5 m^3/h	
Treated volume	- Treated : 250 m^3 - Control : 250 m^3	
Side-stream flow rate	2.5 ± 0.2 m^3/h (1% of the main ballast flow rate)	
Maximum TRO concentration at the ballast line	9 mg/L as Cl_2	
Maximum TRO concentration at the side-stream	900 mg/L as Cl_2	
Neutralizer chemical	Sodium thiosulfate ($Na_2S_2O_3$)	
TRO measuring method	- CLX online sensor - DPD (FAS titration)	
Supplied current	300 A	334 A
Supplied voltage	37 V	44 V
Power consumption	11.1 kW	14.7 kW

Table 1.2: Test cycle and test date

Test water	Test No.	Test Date	
		Ballasting (D0)	De-ballasting (D5)
Seawater	Cycle 1	18/04/2012	23/04/2012
	Cycle 2	25/04/2012	30/04/2012
	Cycle 3	02/05/2012	07/05/2012
	Cycle 4	09/05/2012	14/05/2012
	Cycle 5	16/05/2012	21/05/2012
Brackish water	Cycle 6	23/05/2012	28/05/2012
	Cycle 7	30/05/2012	04/06/2012
	Cycle 8	07/06/2012	12/06/2012

	Cycle 9	14/06/2012	19/06/2012
	Cycle 10	21/06/2012	26/06/2012

2 TEST RESULTS OF THE TRO CONTROL DURING BALLASTING

2.1 TRO Control Logic during Ballasting

TRO control logic to maintain maximum concentration 9 m/L TRO as Cl_2 is as follows:

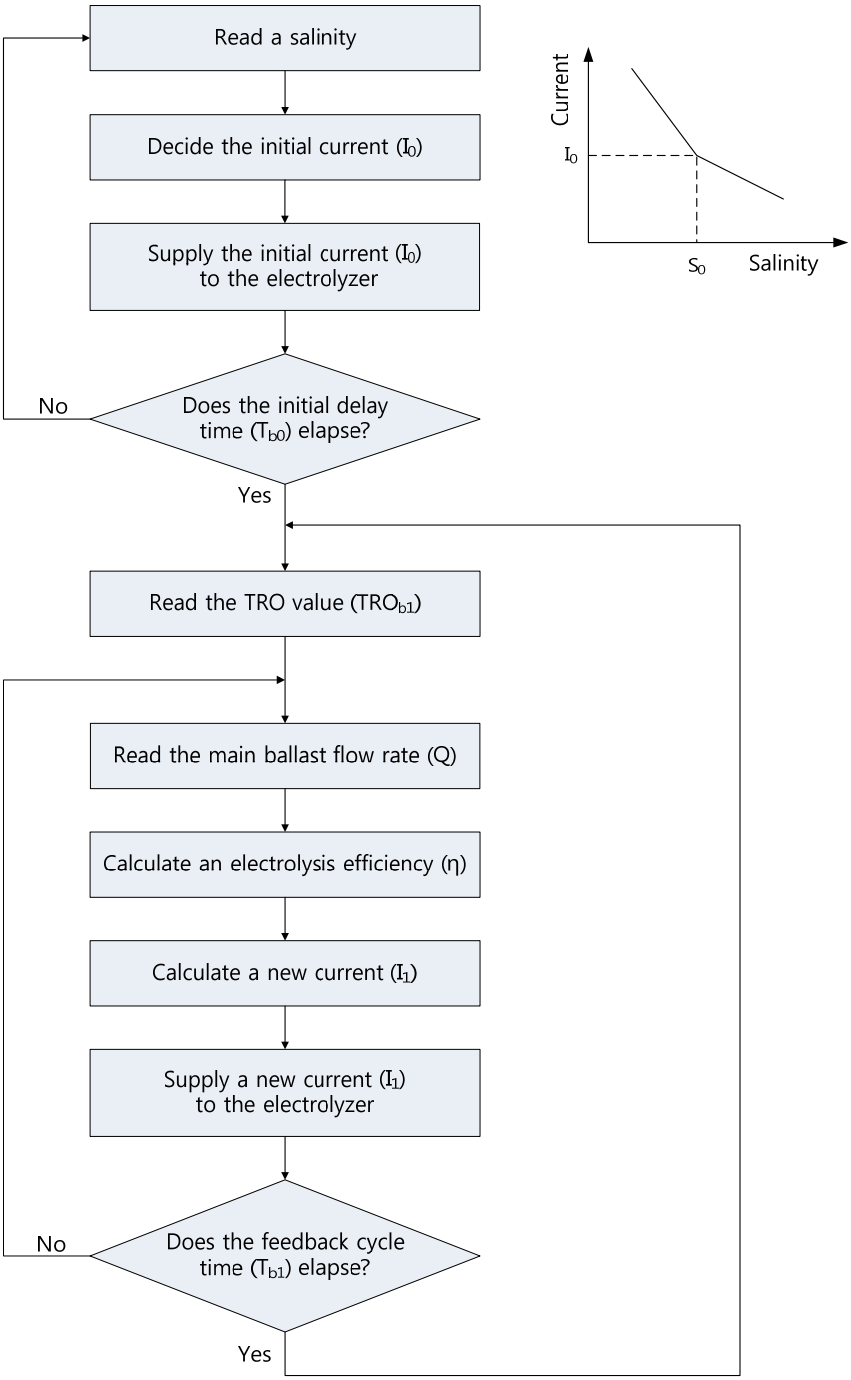


Figure 2.1: Diagram of the TRO control logic

Herein

- **Initial delay time (T_{b0}):** The time period between the ballast pump start point and the stable TRO sensor output point.

- **Initial current (I_0):** The current value which is automatically calculated and supplied according to the ballast water salinity during initial delay time.

- **Feedback cycle time (T_{b1}):** The time that the new current takes to feeds back to TRO sensor value.

- **The electrolysis efficiency (η)** and **the new current (I_1)** are calculated by Faraday's law as below:

$$\eta = \frac{F}{M/z} \times \frac{Q \times TRO_{b1}}{I_1} \qquad I_1 = \frac{F}{M/z} \times \frac{Q \times 9mg/L}{\eta}$$

Herein

- F : Faraday's constant (96485 C/mol)
- M : Molar mass of the chlorine ion
- z : Valency number of the chlorine ion
- Q : Measured flow rate of the main ballast line
- TRO_{b1} : TRO concentration measured in the main ballast line
- I_0 : Initial current supplied to the electrolyzer before the initial delay time T_{b0}
- I_1 : New current supplied to the electrolyzer after the initial delay time T_{b0}

2.2 Summary of the Test Result of TRO Control during Ballasting

Maximum dose concentration to the main ballast line is 9 mg/L TRO as Cl_2 which is controlled by using the on-line TRO sensor installed in the main ballast line.

Table 2.1: Summary of the operating data during ballasting

Test Water	Test No.	Salinity [PSU]	Water Temp [°C]	Current [A]	Voltage [V]	Power [kW]
Seawater (34PSU)	Cycle 1 (D0)	34.3	14.2	302	37.5	11.4
	Cycle 2 (D0)	33.7	14.5	271	35.8	9.9
	Cycle 3 (D0)	33.9	15.0	303	37.6	11.4
	Cycle 4 (D0)	34.0	17.5	306	36.8	11.2
	Cycle 5 (D0)	34.0	17.5	304	36.6	11.1
	Average	**34.0**	**15.7**	**297**	**36.9**	**11.0**
Brackish Water (21PSU)	Cycle 6 (D0)	21.3	20.2	336	44.0	14.8
	Cycle 7 (D0)	21.7	21.4	337	43.2	14.5
	Cycle 8 (D0)	21.6	21.6	328	43.1	14.2
	Cycle 9 (D0)	20.7	22.4	333	43.5	14.5
	Cycle 10 (D0)	21.1	22.2	337	43.4	14.6
	Average	**21.3**	**21.6**	**334**	**43.4**	**14.5**

Table 2.2: Summary of the TRO concentration during ballasting

Test Water	Test No.	TRO Concentration (mg/L as Cl_2)
Seawater (34PSU)	Cycle 1 (D0)	8.98 ± 0.37
	Cycle 2 (D0)	9.34 ± 1.16
	Cycle 3 (D0)	9.10 ± 0.11
	Cycle 4 (D0)	9.08 ± 0.16
	Cycle 5 (D0)	9.10 ± 0.14
Brackish Water (21PSU)	Cycle 6 (D0)	9.08 ± 0.10
	Cycle 7 (D0)	9.10 ± 0.30
	Cycle 8 (D0)	9.07 ± 0.05
	Cycle 9 (D0)	9.08 ± 0.09
	Cycle 10 (D0)	9.10 ± 0.11

In the test Cycle 2, the result of TRO control shows wide variation in accuracy due to the unstability of the TRO sensor affected by ORP and pH sensor.
Before the feeding water enters to the TRO sensor, the water passed through the chamber of ORP and pH sensor as below Figure 2.2. So the electric leakage from ORP and pH sensor affected the TRO sensor due to heavy rains and high humidity.

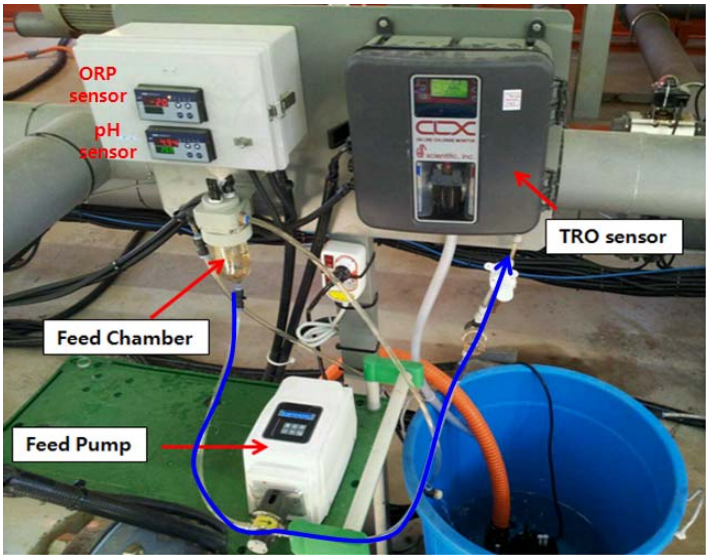


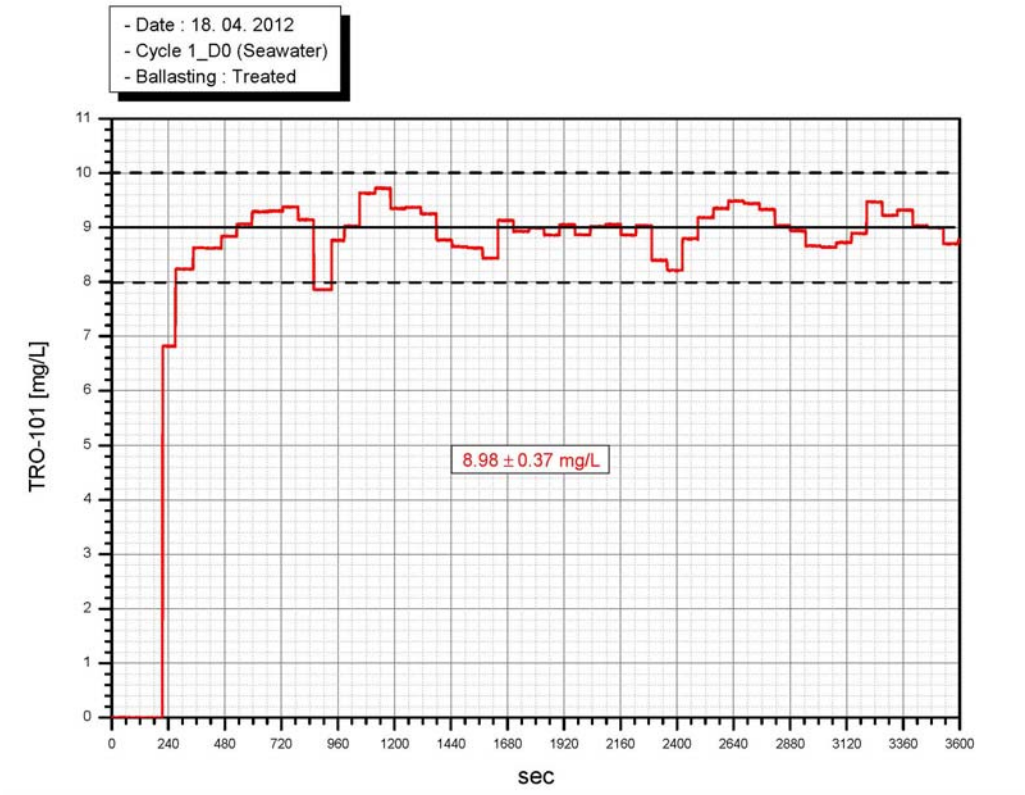
Figure 2.2: Picture of ORP, pH and TRO sensor

During operation, we found that problem and turn off the power of the ORP and pH sensor at 30 minutes after operation. After that, test result shows stable accuracy.

The detailed test record is given in section 2.3.

2.3 Graph of the TRO Concentration during Ballasting

Refer to section 6 for the more detailed test records.



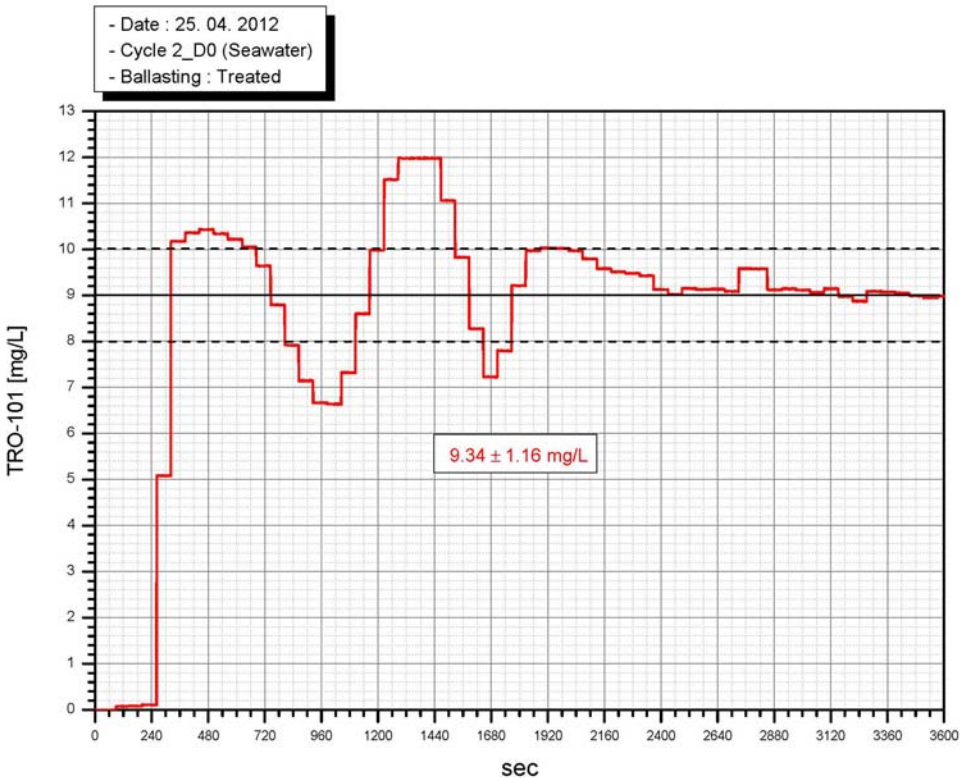
■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	290 A

■ Test result

TRO concentration	8.98 ± 0.37 mg/L as Cl_2

The result of TRO control shows satisfactory accuracy.



■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	290 A

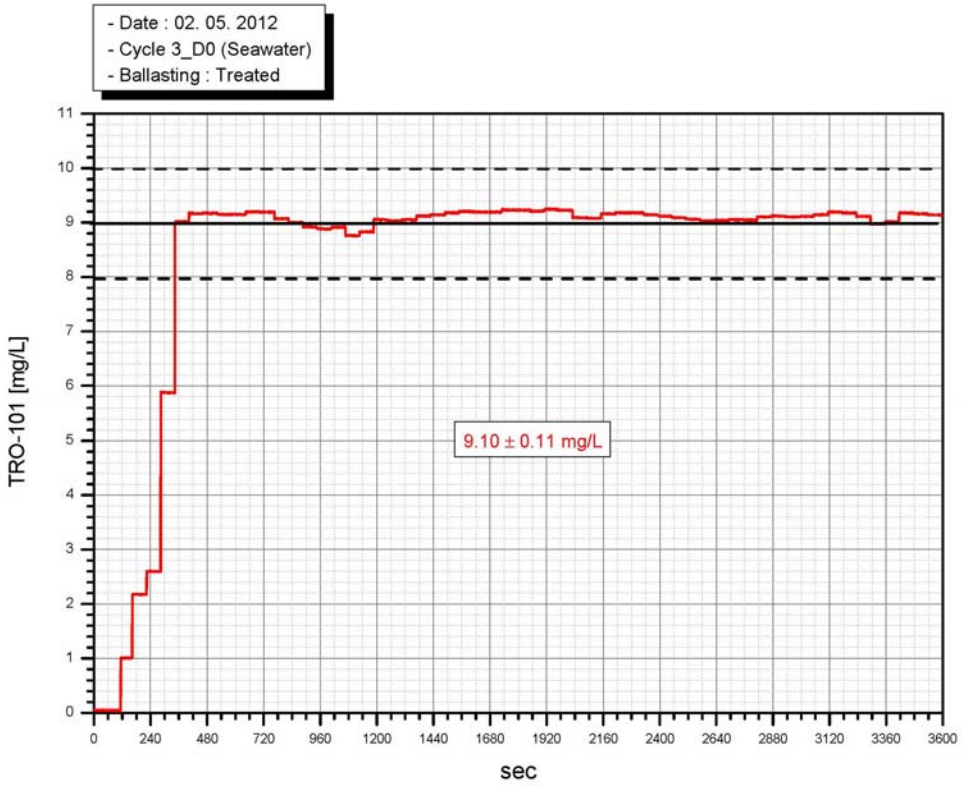
■ Test result

TRO concentration	9.34 ± 1.16 mg/L as Cl_2

The result of TRO control shows wide variation in accuracy between 300~1,700 seconds due to the unstability of the TRO sensor affected by heavy rains and high humidity.
So we isolated TRO sensor electrically from other instruments. After that, test result shows good and stable accuracy.

For the actual ship, If the measured TRO value is deviated from target TRO value by ± 10%, the alarm is activated.

If three consecutive value of TRO sensor are out of range for target TRO value by ± 10%, the system is shutdown and TRO sensor should be replaced with the spare TRO sensor.



■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	290 A

Unlike test Cycle 1 and 2, the feedback cycle time was set as 180 seconds in test Cycle 3~10.

■ Test result

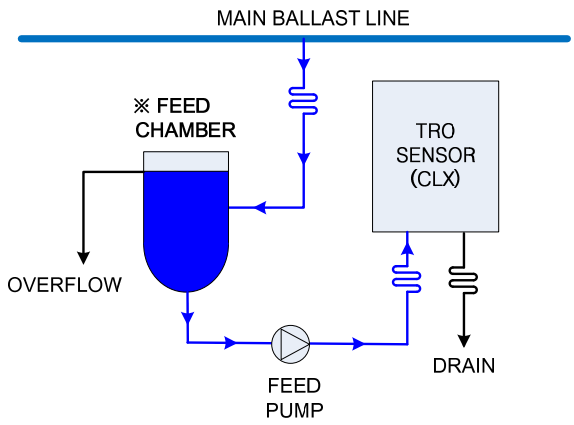
TRO concentration	9.10 ± 0.11 mg/L as Cl_2

The result of TRO control showed very good accuracy.

The accuracy of TRO sensor depends on the pressure and flow rate of the feeding flow to the sensor. But it is very difficult to control the proper feeding flow conditions because the flow conditions of the main ballast line changes continuously. Even the feed pump to TRO sensor couldn't maintain the stable feeding flow conditions.
So we devised the instrument with a feed chamber and a feed pump. This maintained stable flow rate and pressure for the feeding flow to the sensor.

The size of feed chamber is minimized. And due to the sufficient flow rate to feed chamber, the changed water volume in feed chamber is 7~10 times than the volume of feed chamber at every feeding time to TRO sensor. So the delay effect by feed chamber can be nearly eliminated.

Test result using this instrument shows very good results.



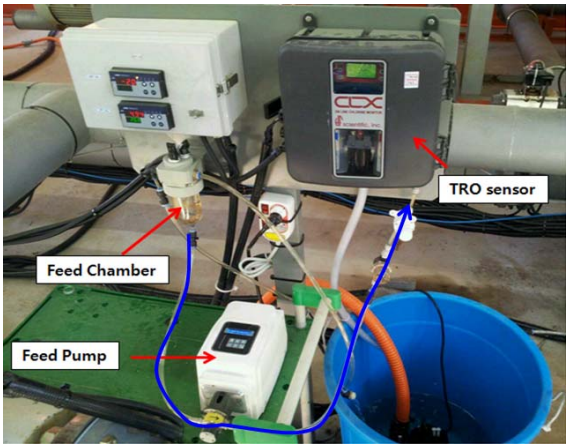
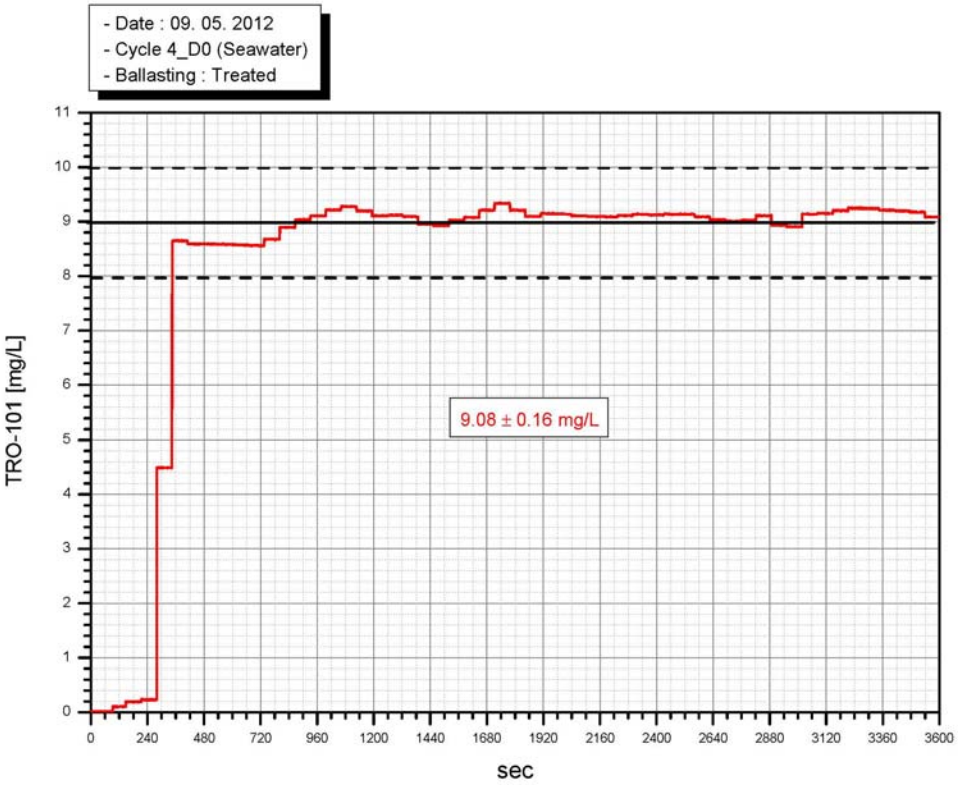


Figure 2.3: Feed chamber instrument



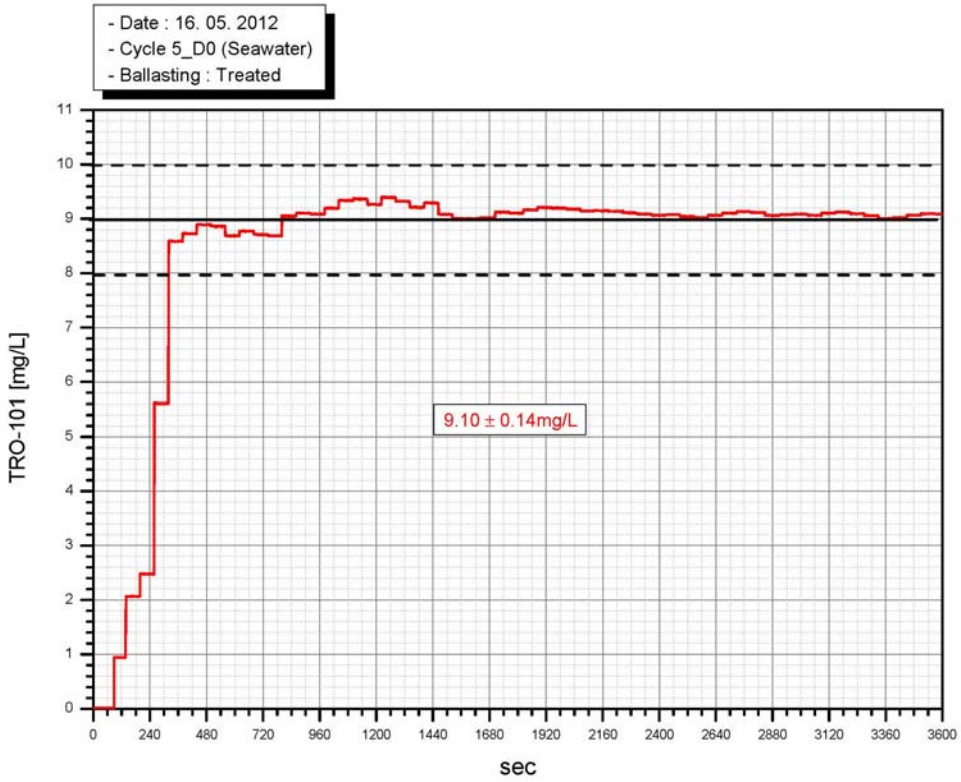
■ Set value

Target TRO concentration	9.0 mg/L as Cl_2	Initial supplied current	290 A

■ Test result

TRO concentration	9.08 ± 0.16 mg/L as Cl_2

The result of TRO control shows very good accuracy.



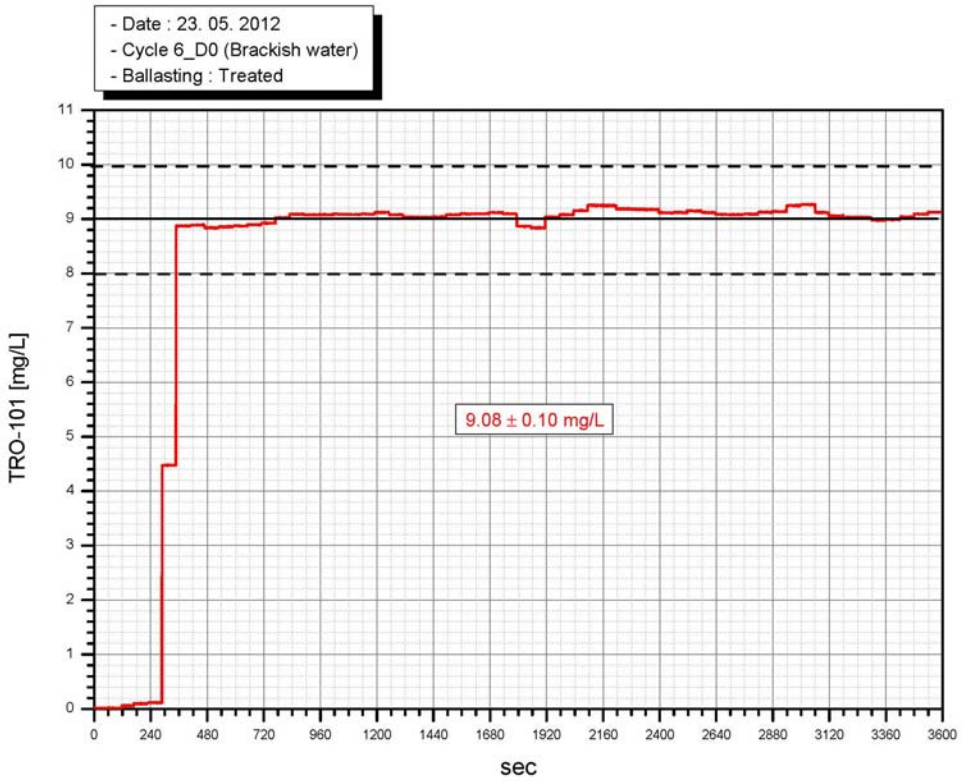
■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	290 A

■ Test result

TRO concentration	9.10 ± 0.14 mg/L as Cl_2

The result of TRO control shows very good accuracy.



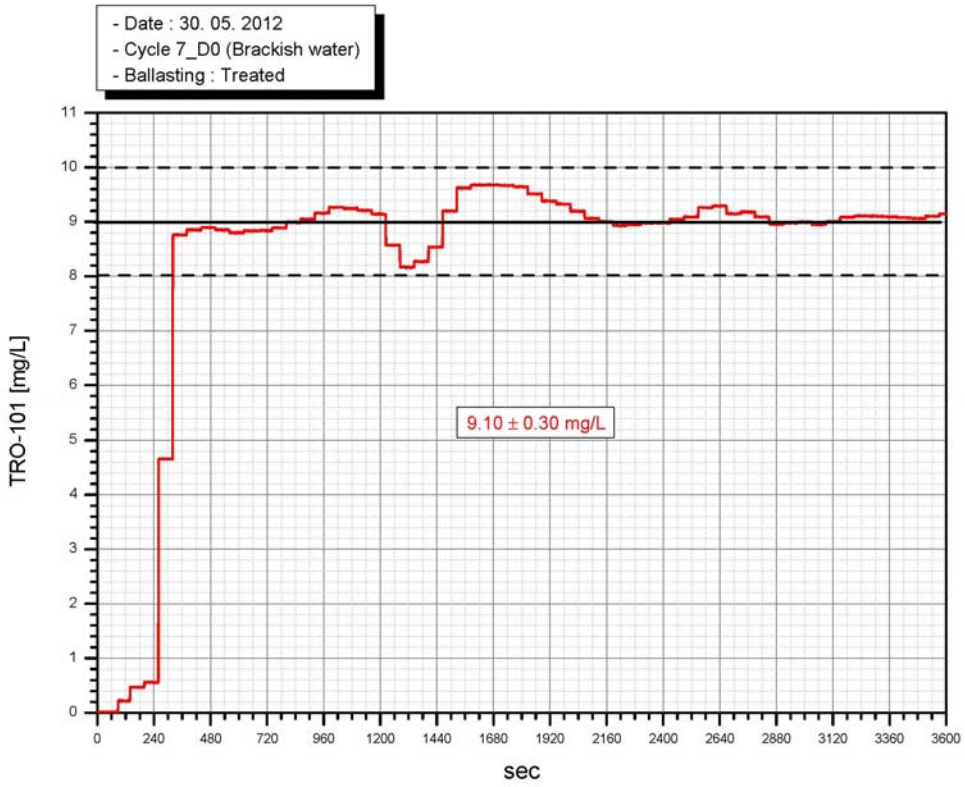
■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	320 A

■ Test result

TRO concentration	9.08 ± 0.10 mg/L as Cl_2

The result of TRO control shows very good accuracy.



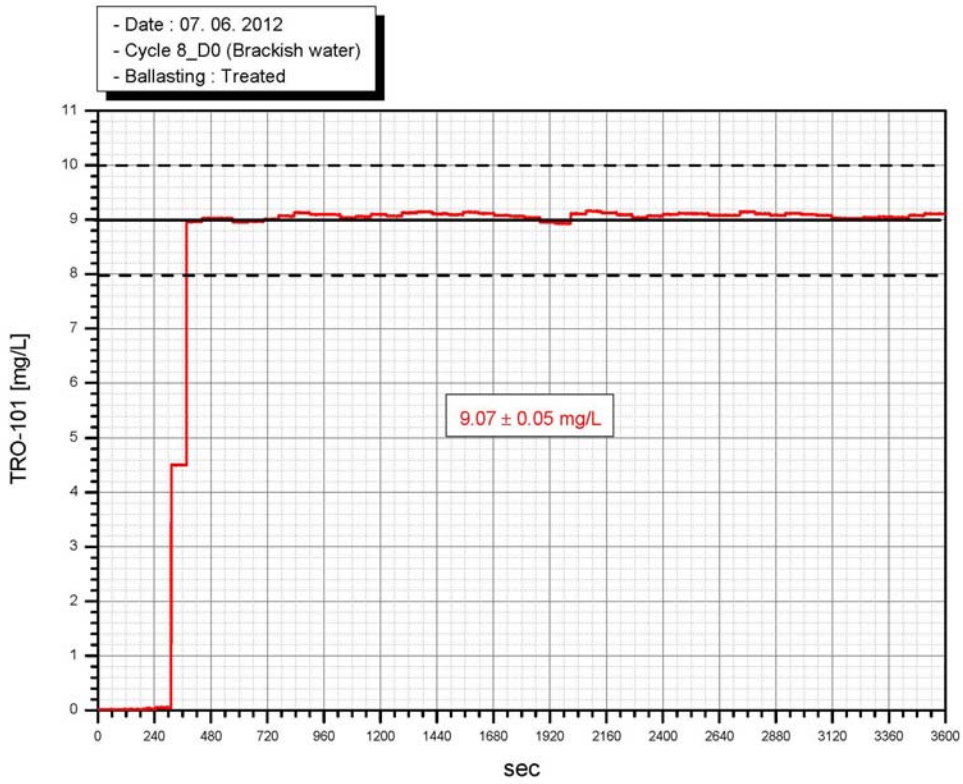
■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	320 A

■ Test result

TRO concentration	9.10 ± 0.30 mg/L as Cl_2

The result of TRO control shows good accuracy.



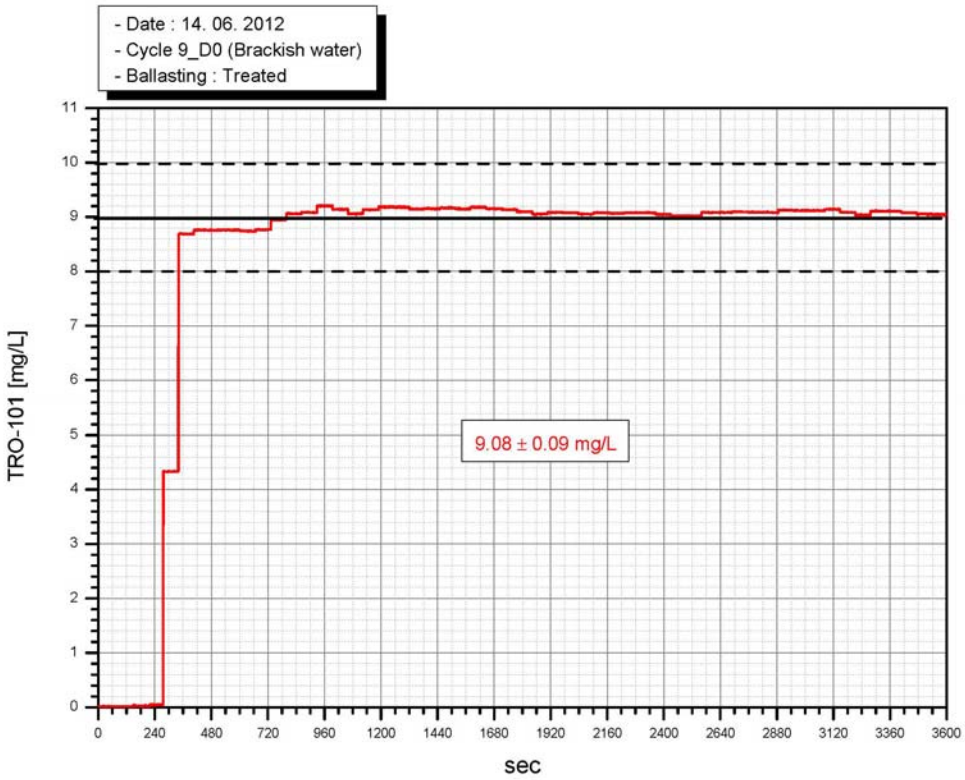
■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	320 A

■ Test result

TRO concentration	9.07 ± 0.05 mg/L as Cl_2

The result of TRO control shows very good accuracy.



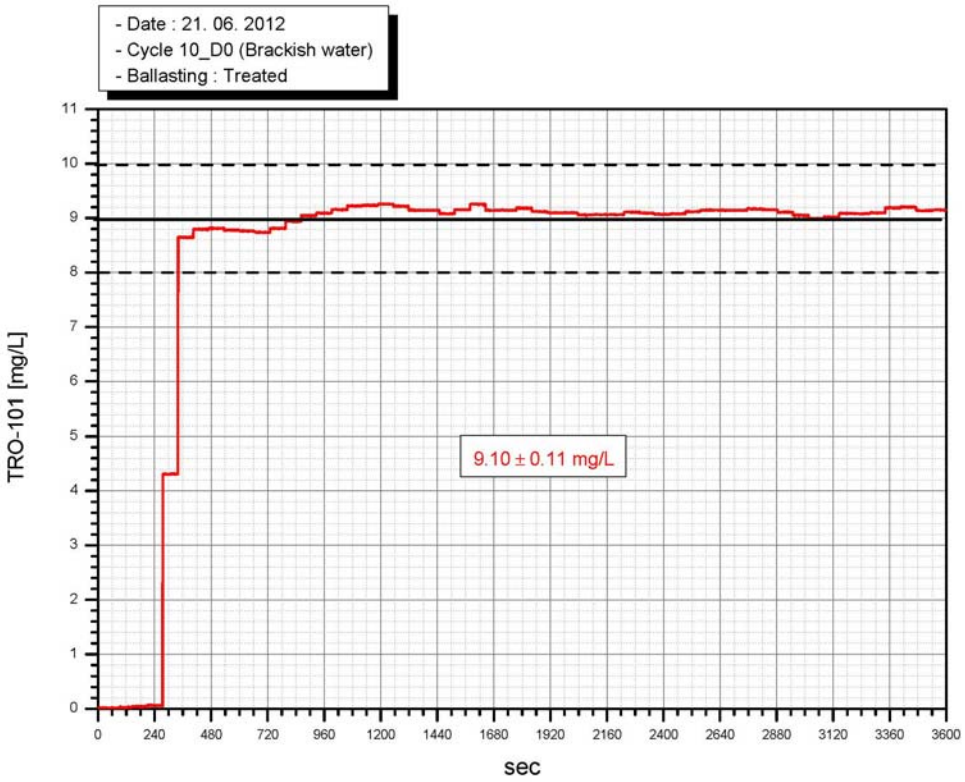
■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	320 A

■ Test result

TRO concentration	9.08 ± 0.09 mg/L as Cl_2

The result of TRO control shows very good accuracy.



■ Set value

Target TRO concentration	9.0 mg/L	Initial supplied current	320 A

■ Test result

TRO concentration	9.10 ± 0.11 mg/L as Cl_2

The result of TRO control shows very good accuracy.

3 TEST RESULTS OF THE NEUTRALIZATION CONTROL

3.1 Neutralization Control Logic during De-ballasting

To prevent the high discharge concentration of TRO at the beginning of de-ballasting, when de-ballast butterfly valve opens, the neutralizer solution is injected simultaneously. Initial injecting amount of neutralizer solution is 2.5 times as much as the theoretical value for neutralizing 9mg/L TRO as Cl_2.
Initial amount of the neutralizer solution is injected for 3 minutes after the ballast pump start to run.
After that, the injecting rate of neutralizer solution is adjusted in proportion to the residual TRO concentration before neutralization.

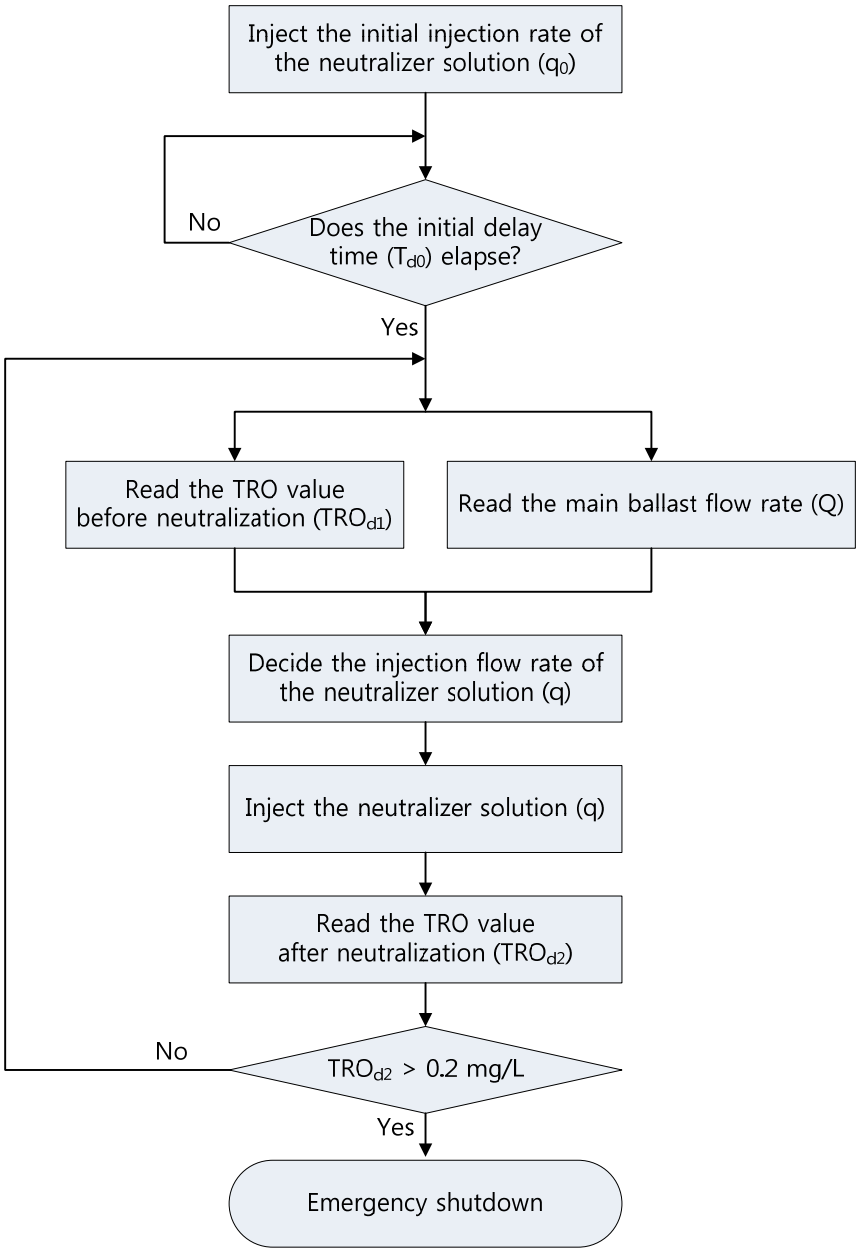


Figure 3.1: The diagram of neutralization control logic

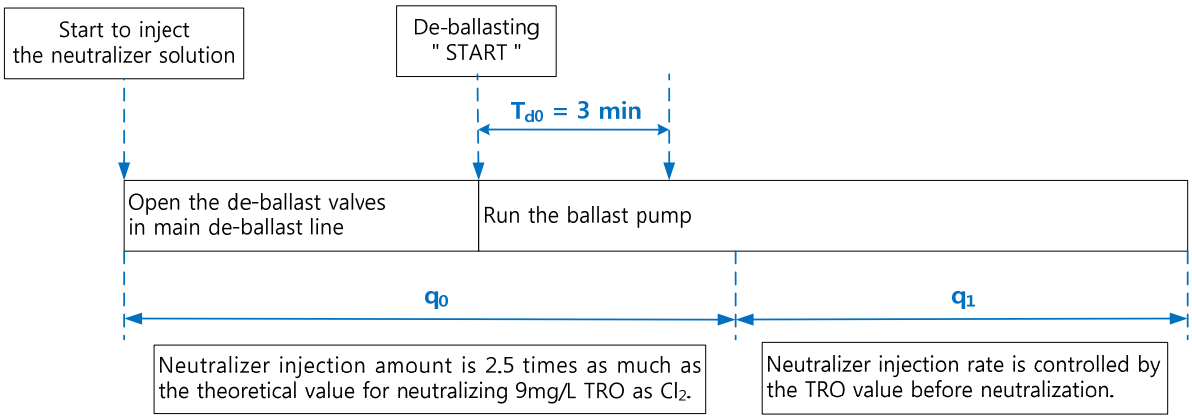


Figure 3.2: Injection point of the neutralizer solution during de-ballasting

Herein

- **Initial delay time (T_{d0}):** The time period between the ballast pump start point and the stable TRO sensor output point.

- **TRO value after neutralization (TRO_{d2})**: This value is used to check whether the TRO concentration of final discharged water is below the MADC 0.2 mg/L as Cl_2.

- **Initial injection rate of the neutralizer solution (q_0)** and **injection rate of the neutralizer solution (q_1)** after initial delay time (T_{do}) are calculated as the following formula:

$$q_0 = \frac{TRO_0 \times Q \times K \times SR}{C_n} \qquad q_1 = \frac{TRO_{d1} \times Q \times K \times SR}{C_n}$$

Herein

- TRO_0 : Default TRO value until TRO sensor outputs a stable signal
- TRO_{d1} : Measured TRO value before neutralization
- Q : Measured flow rate of the main ballast line
- SR : Times as much as stoichiometric demand of sodium thiosulfate for TRO as Cl_2
- C_n : Concentration of the neutralizer solution (25% w/v)
- K : Required sodium thiosulfate to remove one part of chlorine (0.8751), on a weight-to-weight basis

In the above, TRO_{d2} (value after neutralization) is used to check whether the TRO concentration of the final discharged water is below the pre-set limit, 0.2 mg/L as Cl_2.

3.2 Summary of the Test Result in Neutralization Control

As neutralizer chemical, sodium thiosulfate ($Na_2S_2O_3$) aqueous solution is injected into the de-ballasting line to neutralize the residual TRO. The injection rate of the neutralizer solution is controlled by monitoring the de-ballasting flow rate and the residual TRO concentration. The neutralization unit of the EcoGuardian™ system maintains below the MADC (Maximum Allowable Discharge Concentration) of 0.2 mg/L TRO as Cl_2. To comply with this condition, dosing 2.5 parts of sodium thiosulfate to 1 part of chlorine is applied.

Initial injecting rate of the neutralization solution is 2.5 times as much as the theoretical value for neutralizing 9 mg/L TRO as Cl_2.
For the actual ship, this initial TRO value will be determined by the experimental test after installing the EcoGuardian™ system on-site. Besides, the characteristics of voyage will be taken into consideration.

Table 3.1: Test result during de-ballasting

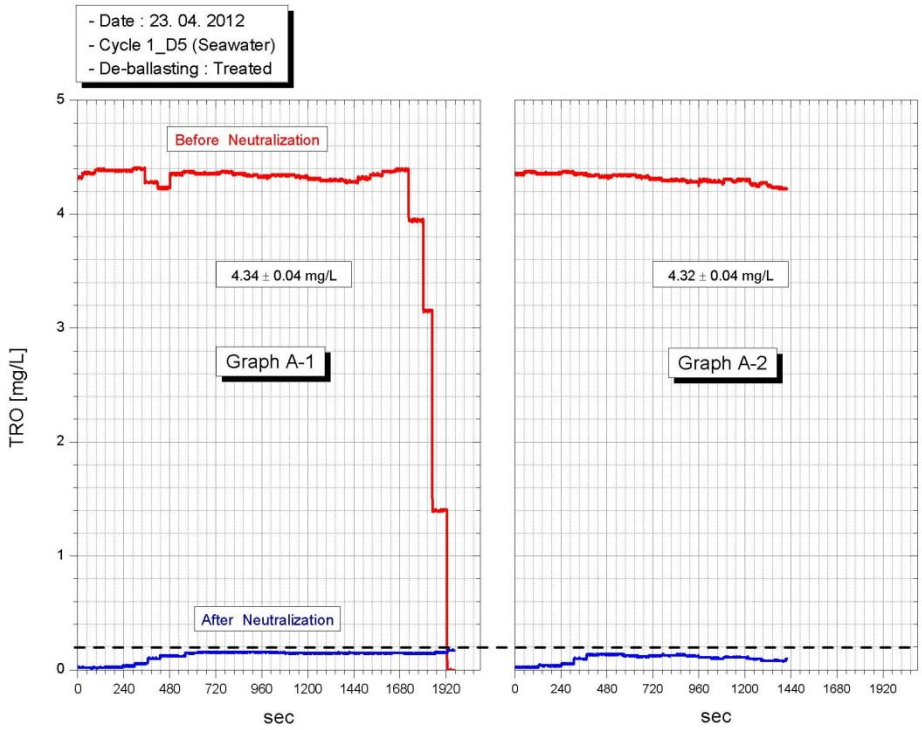
Concentration of $Na_2S_2O_3$ solution: 24.82% w/v				
Test Water	**Cycle No.**	**TRO concentration before neutralization [mg/L]**	**Injection rate of $Na_2S_2O_3$ solution [L/min]**	**Max. TRO concentration after neutralization [mg/L]**
Seawater (34PSU)	Cycle 1 (D5)	4.33 ± 0.04	0.16	**0.16**
	Cycle 2 (D5)	4.31 ± 0.29	0.16	**0.10**
	Cycle 3 (D5)	5.11 ± 0.21	0.19	**0.07**
	Cycle 4 (D5)	4.35 ± 0.25	0.16	**0.10**
	Cycle 5 (D5)	4.34 ± 0.04	0.18	**0.08**
Brackish Water (21PSU)	Cycle 6 (D5)	2.35 ± 0.05	0.09	**0.08**
	Cycle 7 (D5)	1.55 ± 0.04	0.06	**0.10**
	Cycle 8 (D5)	1.50 ± 0.07	0.06	**0.10**
	Cycle 9 (D5)	1.30 ± 0.04	0.05	**0.10**
	Cycle 10 (D5)	0.59 ± 0.02	0.02	**0.07**

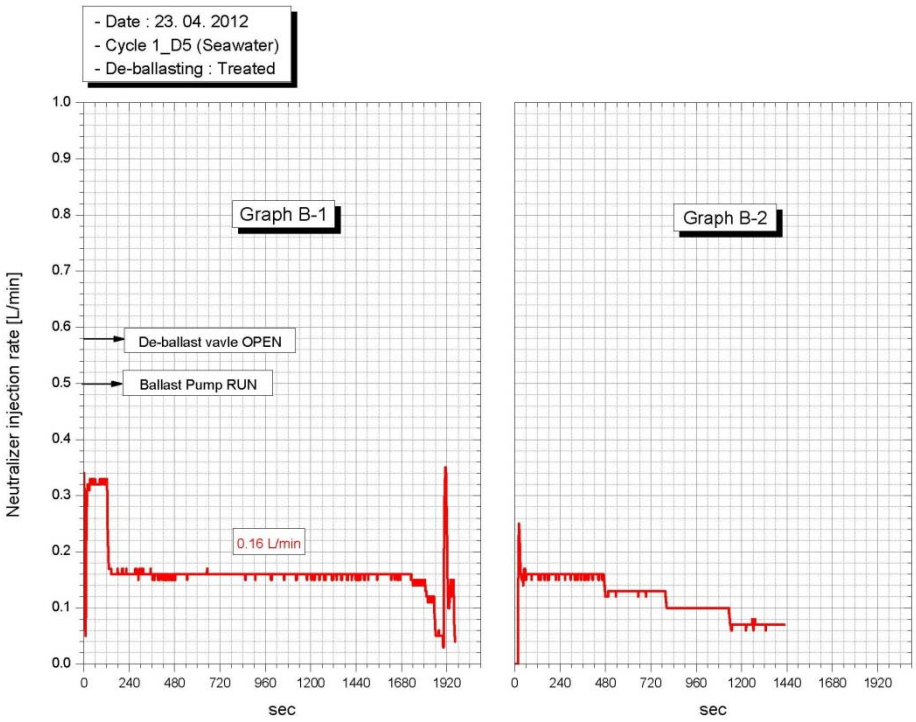
* TRO concentration values before and after neutralization are averaged on a time basis at each cycle except for the initial unstable section.

Test result shows that the TRO concentration after neutralization maintains below MADC 0.2 mg/L as Cl_2.

3.3 Graph of the TRO Concentration during De-ballasting

Refer to section 6 for the more detailed test records.





■ **Set value**

Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	2 minutes after the ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ **Test result**

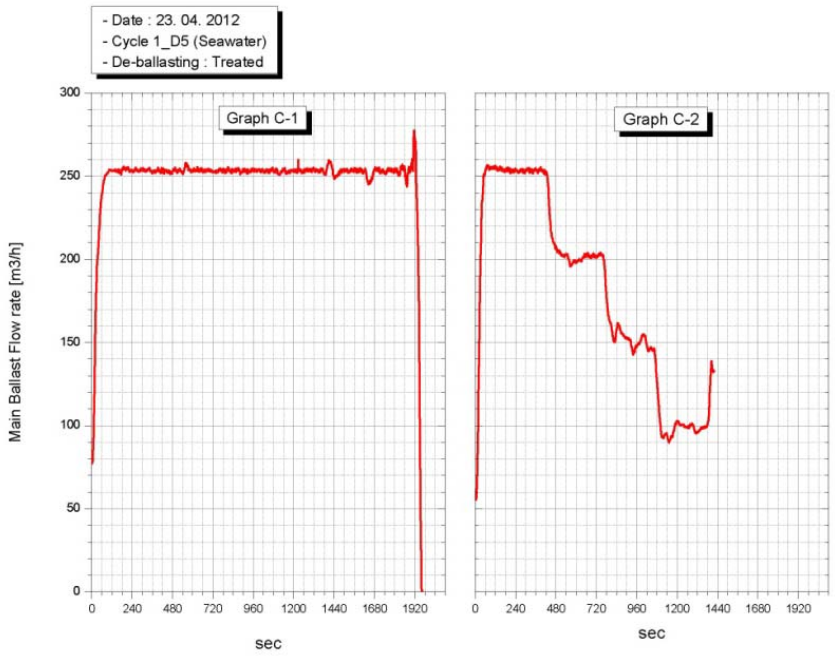
Average TRO concentration before neutralization	4.33 mg/L
Maximum TRO concentration after neutralization	0.16 mg/L

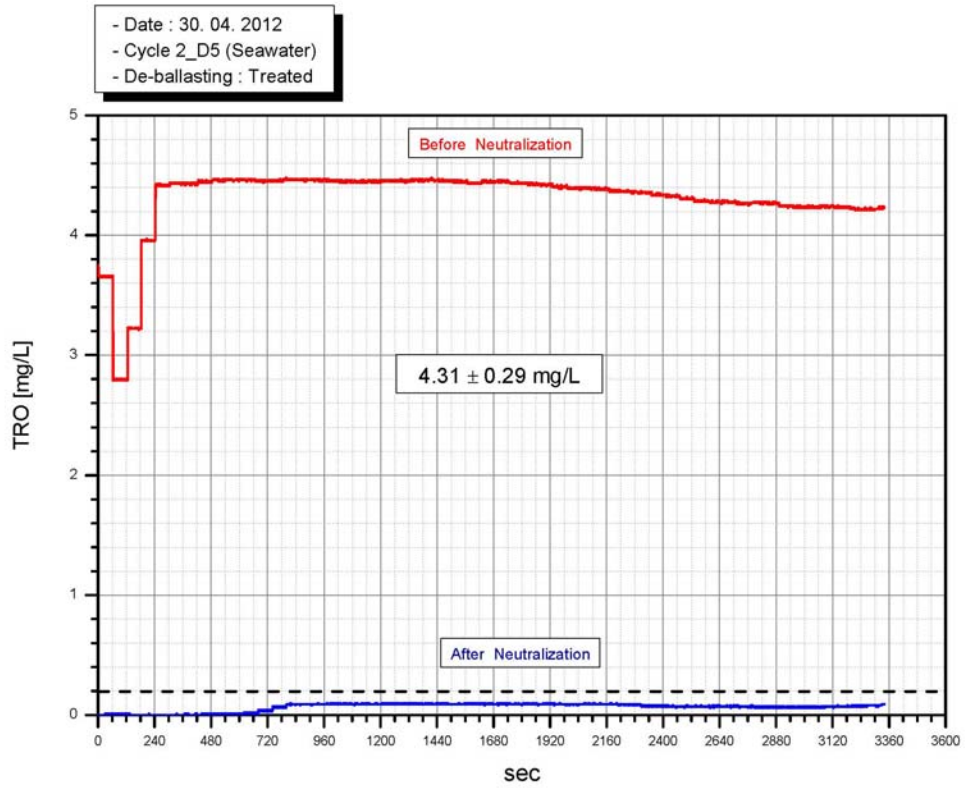
TRO concentration after neutralization is below 0.16 mg/L.

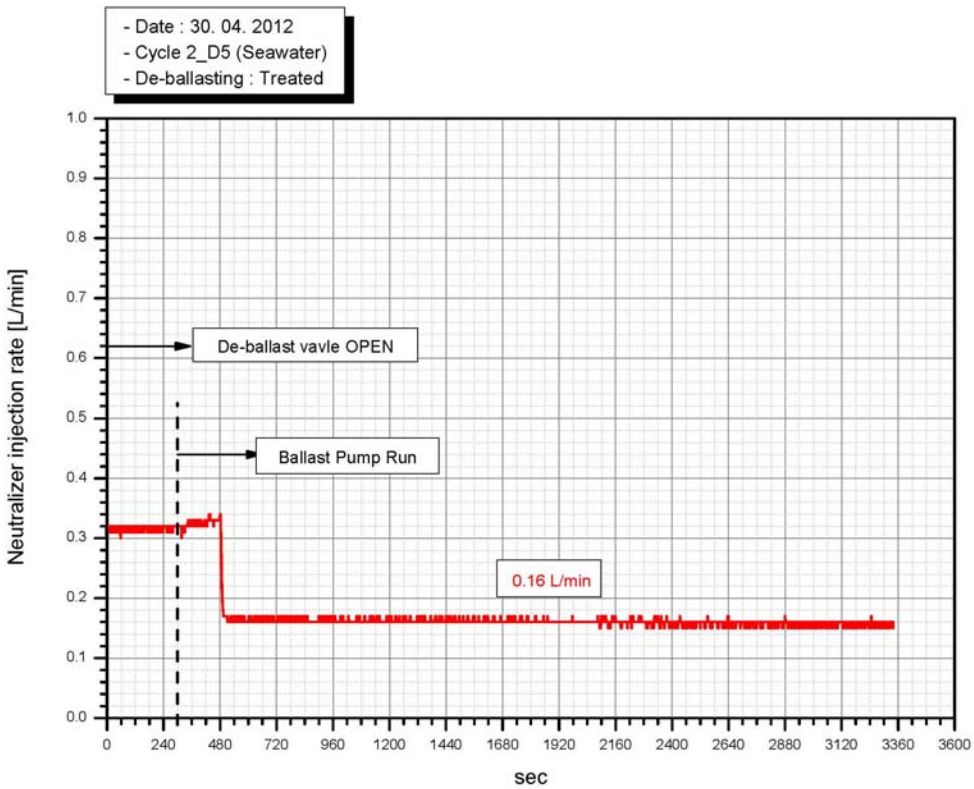
After operation for about 30 minutes from the start, we stopped the system operation because the feeding water to TRO sensor before neutralization was not supplied. (Graph A-1, B-1). And then we restarted the system with controlling the injection rate of neutralizer by manual. (Graph A-2, B-2)
In each case TRO concentrations after neutralization are below 0.16 mg/L.

Through some other tests, we found that air bubbles in the feeding tube interrupted the normal operation of TRO sensor. As measures to prevent the bubbles, we changed the diameter and length of the feeding tube. The air tube diameter was changed from 6 to 10mm. And the tube length from the sampling port to the feed pump was changed from 2.0 to 0.5m to remove the slack part of the tube.
This measures were applied to the subsequent test Cycles (Cycle 2 ~ Cycle 10).

The operator in charge of water sampling missed the mid-term water sampling. In order to secure the mid-term and last sampling time, we reduced the ballast water pump speed. So the injection rate of the neutralizer solution (Graph B-2 above) was decreased according to the main ballast water flow rate decrease. (Graph C-2 below)


- Date : 23. 04. 2012
- Cycle 1_D5 (Seawater)
- De-ballasting : Treated
Graph C-1
Graph C-2
Main Ballast Flow rate [m3/h]
300
250
200
150
100
50
0
0 240 480 720 960 1200 1440 1680 1920
sec
0 240 480 720 960 1200 1440 1680 1920
sec


- Date : 30. 04. 2012
- Cycle 2_D5 (Seawater)
- De-ballasting : Treated
Before Neutralization
4.31 ± 0.29 mg/L
After Neutralization
TRO [mg/L]
sec


- Date : 30. 04. 2012
- Cycle 2_D5 (Seawater)
- De-ballasting : Treated
De-ballast vavle OPEN
Ballast Pump Run
0.16 L/min
Neutralizer injection rate [L/min]
sec

■ Set value

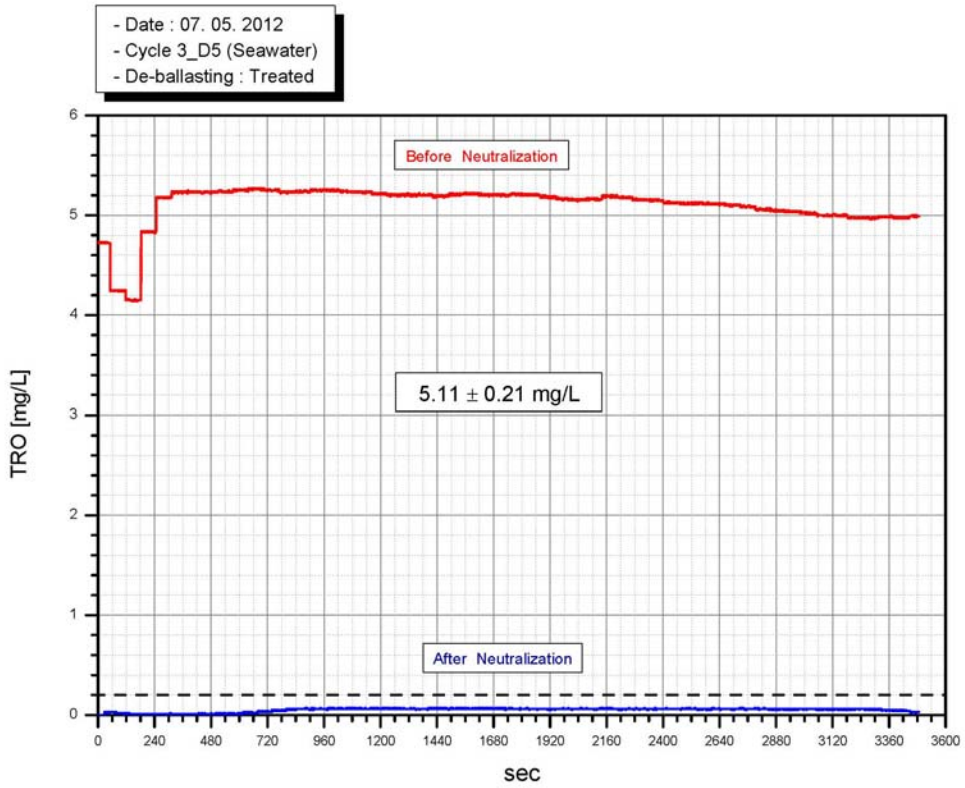
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

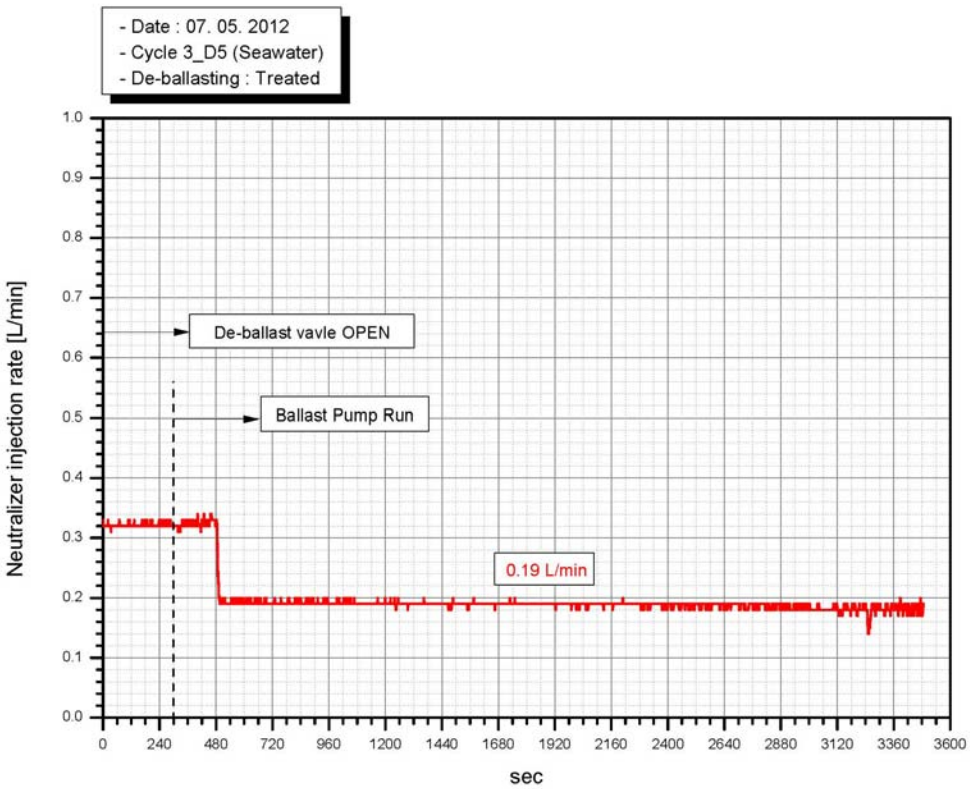
■ Test result

Average TRO concentration before neutralization	4.31 mg/L
Maximum TRO concentration after neutralization	0.10 mg/L

From test Cycle 2, when the de-ballast butterfly valve opened, the neutralizer solution was injected simultaneously to prevent the high discharge concentration of TRO at the beginning of de-ballasting.

TRO concentration after neutralization is below 0.10 mg/L.


- Date : 07. 05. 2012
- Cycle 3_D5 (Seawater)
- De-ballasting : Treated
Before Neutralization
5.11 ± 0.21 mg/L
After Neutralization
TRO [mg/L]
sec


- Date : 07. 05. 2012
- Cycle 3_D5 (Seawater)
- De-ballasting : Treated
De-ballast vavle OPEN
Ballast Pump Run
0.19 L/min
Neutralizer injection rate [L/min]
sec

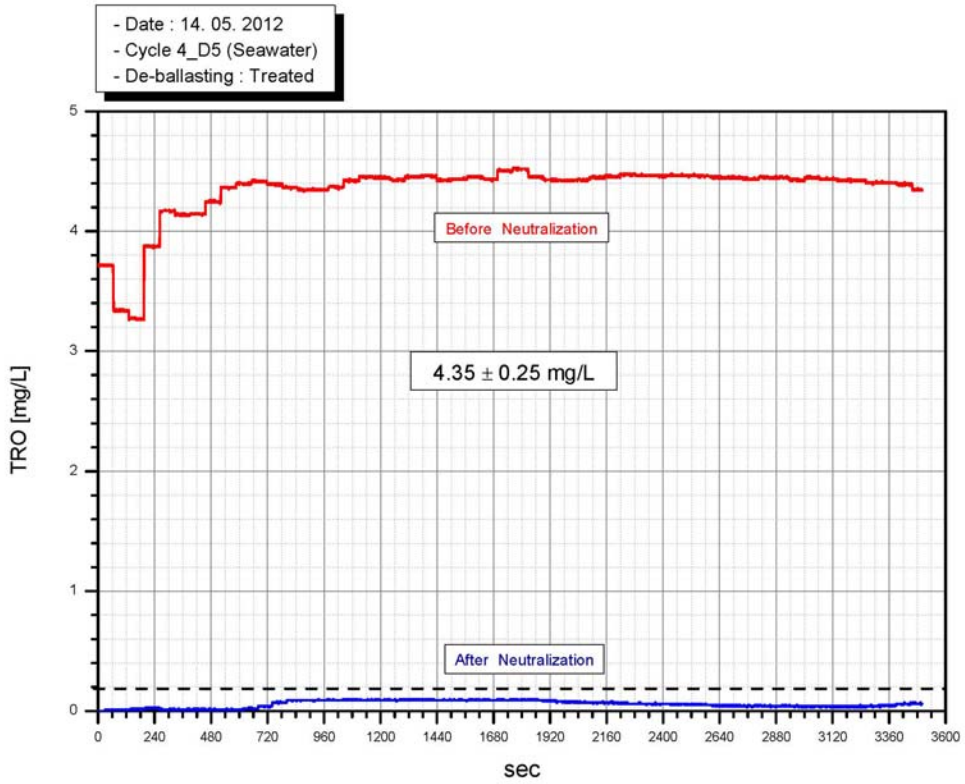
■ Set value

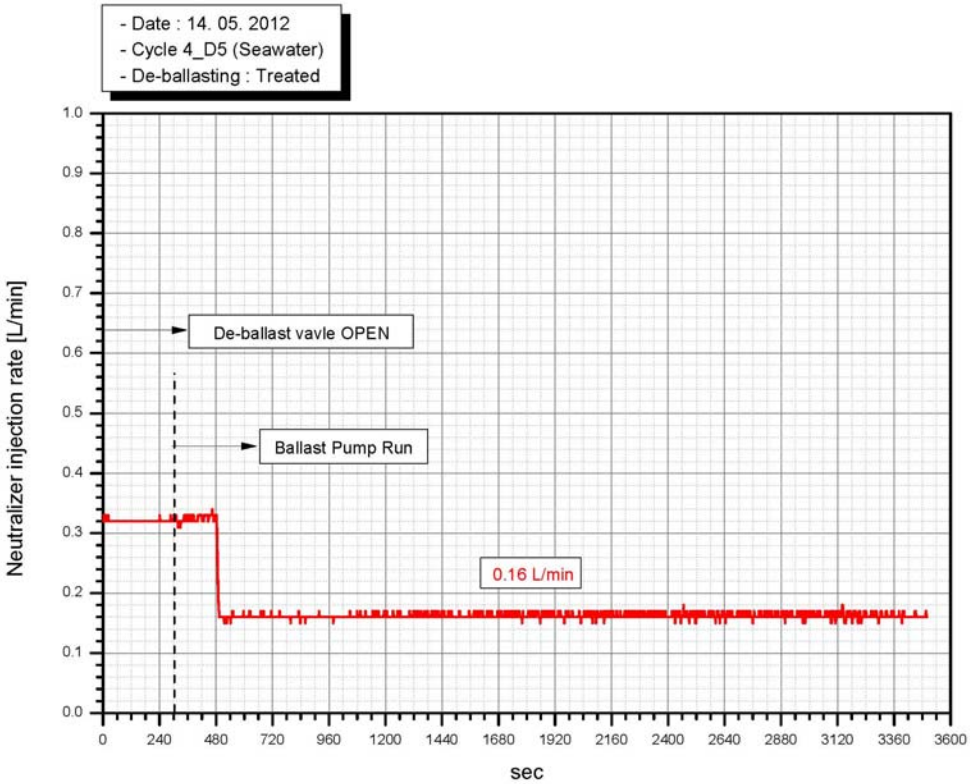
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	5.11 mg/L
Maximum TRO concentration after neutralization	0.07 mg/L

TRO concentration after neutralization is below 0.01 mg/L.


- Date : 14. 05. 2012
- Cycle 4_D5 (Seawater)
- De-ballasting : Treated
Before Neutralization
4.35 ± 0.25 mg/L
After Neutralization
TRO [mg/L]
sec


- Date : 14. 05. 2012
- Cycle 4_D5 (Seawater)
- De-ballasting : Treated
De-ballast vavle OPEN
Ballast Pump Run
0.16 L/min
Neutralizer injection rate [L/min]
sec

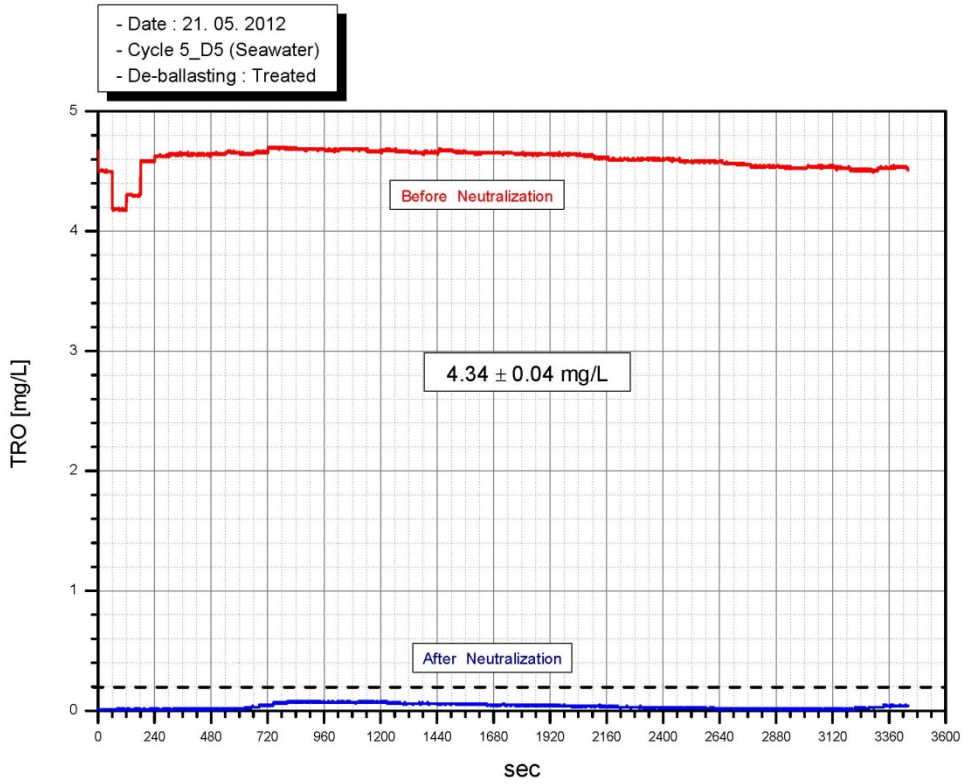
■ Set value

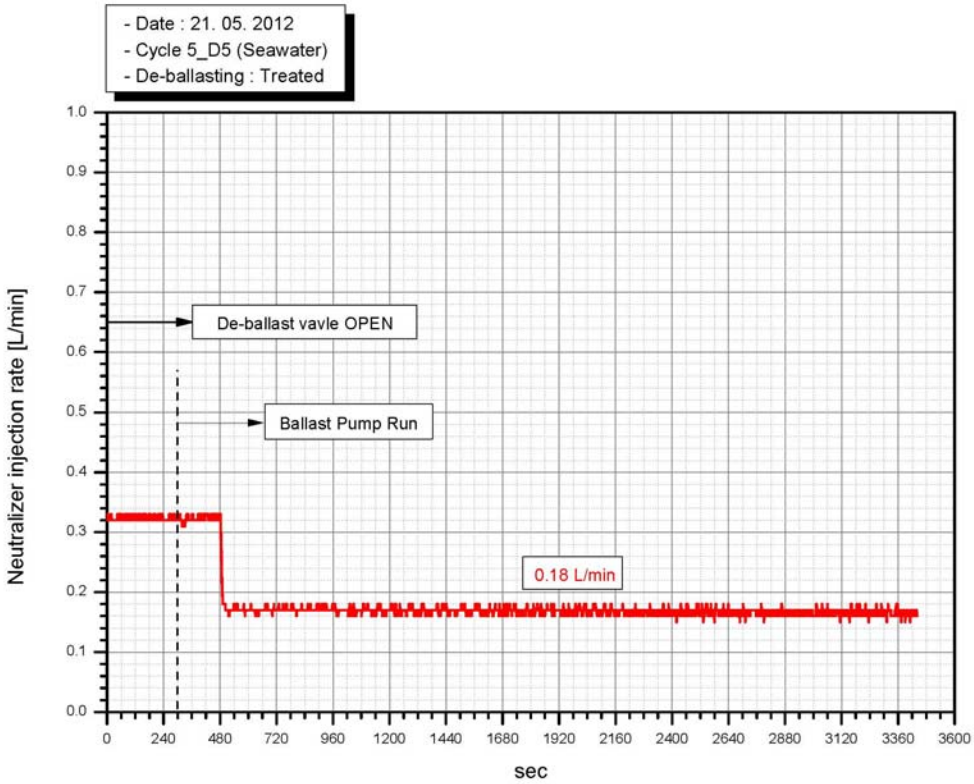
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	4.35 mg/L
Maximum TRO concentration after neutralization	0.10 mg/L

TRO concentration after neutralization is below 0.10 mg/L.


- Date : 21. 05. 2012
- Cycle 5_D5 (Seawater)
- De-ballasting : Treated
Before Neutralization
4.34 ± 0.04 mg/L
After Neutralization
TRO [mg/L]
sec


- Date : 21. 05. 2012
- Cycle 5_D5 (Seawater)
- De-ballasting : Treated
De-ballast vavle OPEN
Ballast Pump Run
0.18 L/min
Neutralizer injection rate [L/min]
sec

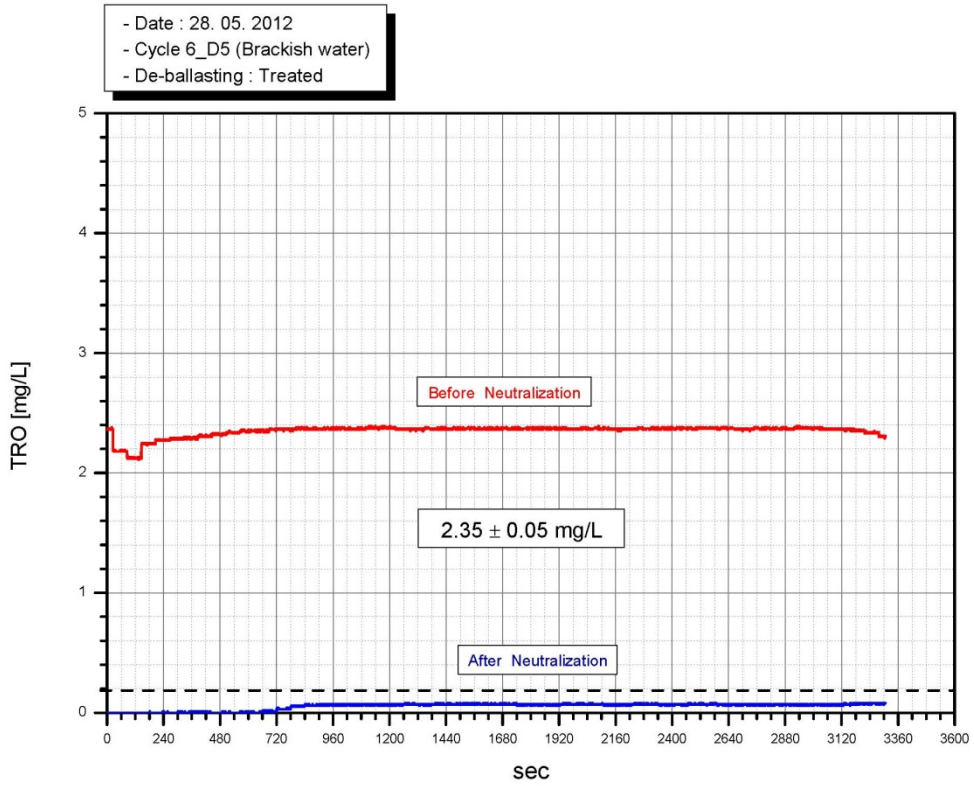
■ Set value

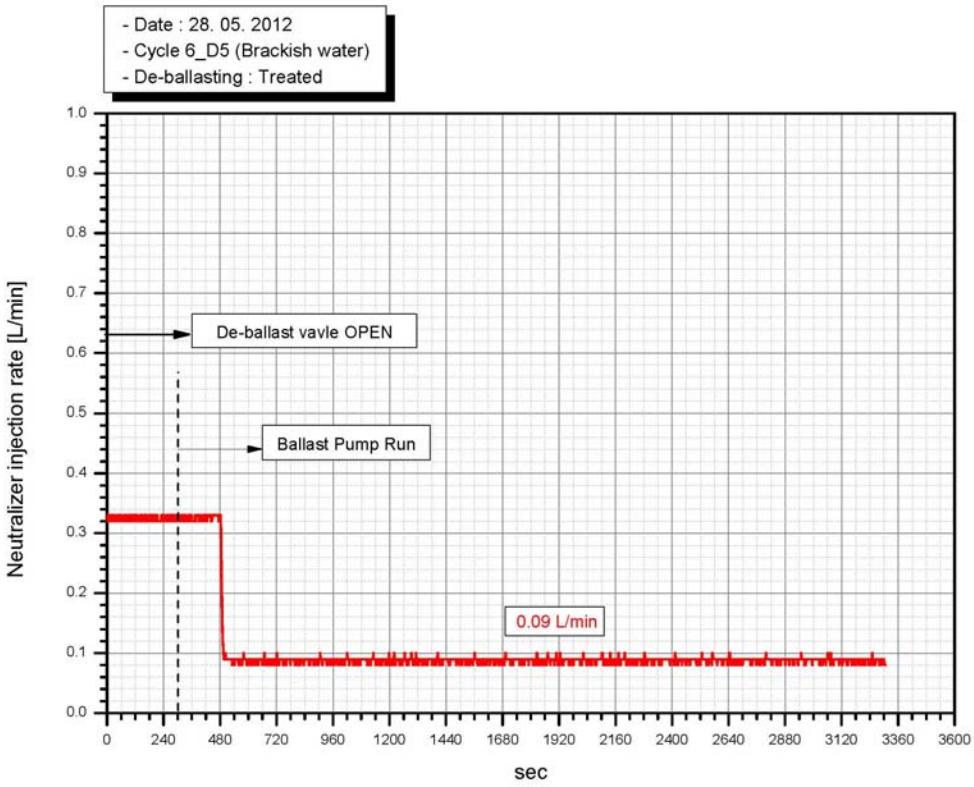
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	4.34 mg/L
Maximum TRO concentration after neutralization	0.08 mg/L

TRO concentration after neutralization is below 0.10 mg/L.


- Date : 28. 05. 2012
- Cycle 6_D5 (Brackish water)
- De-ballasting : Treated
TRO [mg/L]
Before Neutralization
2.35 ± 0.05 mg/L
After Neutralization
sec


- Date : 28. 05. 2012
- Cycle 6_D5 (Brackish water)
- De-ballasting : Treated
Neutralizer injection rate [L/min]
De-ballast vavle OPEN
Ballast Pump Run
0.09 L/min
sec

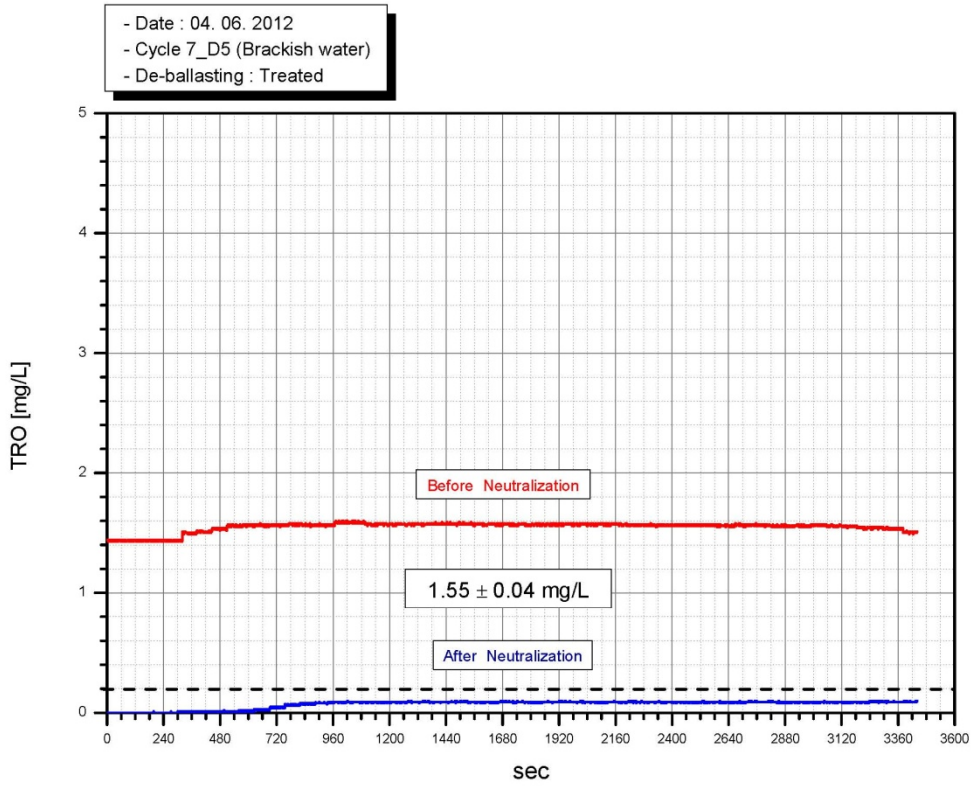
■ Set value

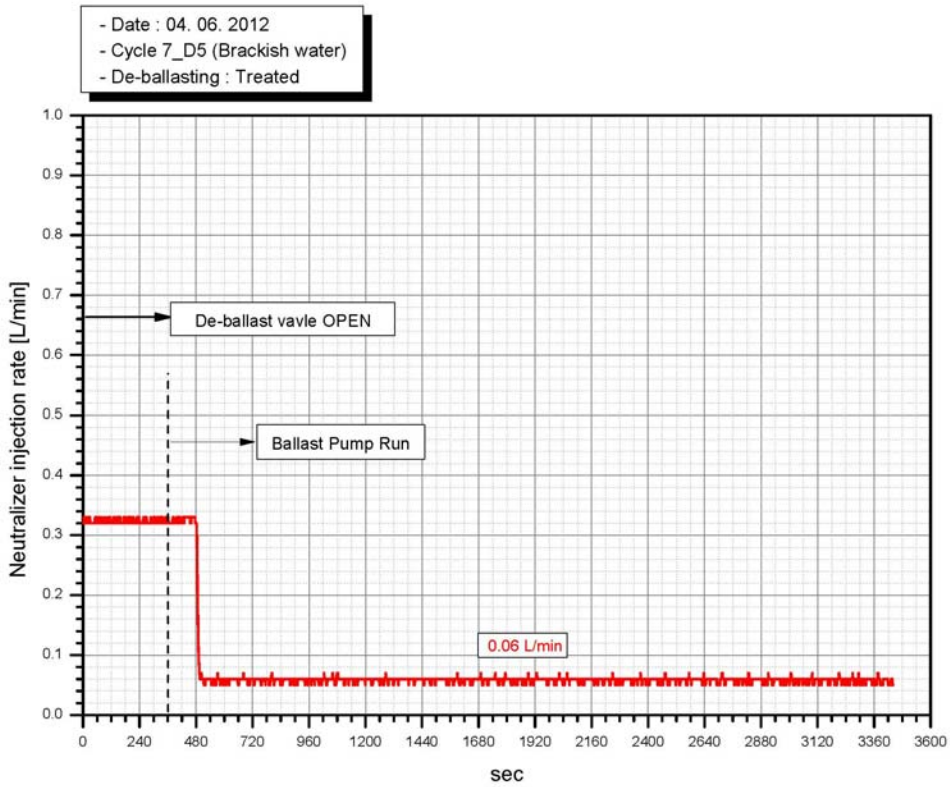
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	2.35 mg/L
Maximum TRO concentration after neutralization	0.08 mg/L

TRO concentration after neutralization was below 0.10 mg/L.


- Date : 04. 06. 2012
- Cycle 7_D5 (Brackish water)
- De-ballasting : Treated
TRO [mg/L]
Before Neutralization
1.55 ± 0.04 mg/L
After Neutralization
sec


- Date : 04. 06. 2012
- Cycle 7_D5 (Brackish water)
- De-ballasting : Treated
Neutralizer injection rate [L/min]
De-ballast vavle OPEN
Ballast Pump Run
0.06 L/min
sec

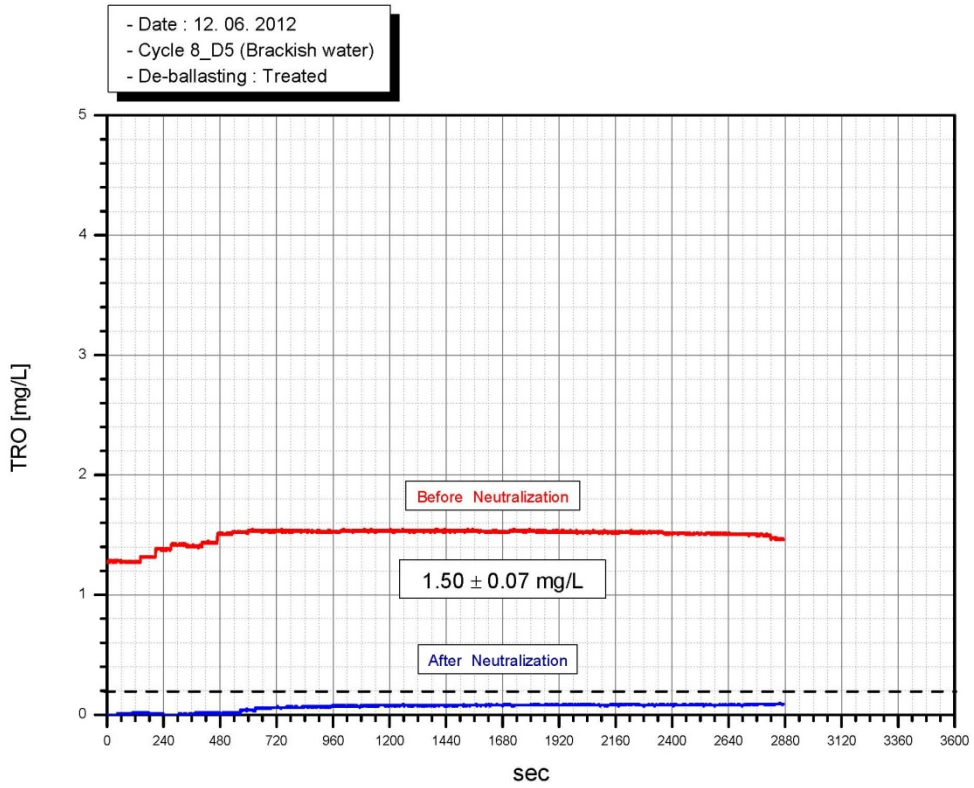
■ Set value

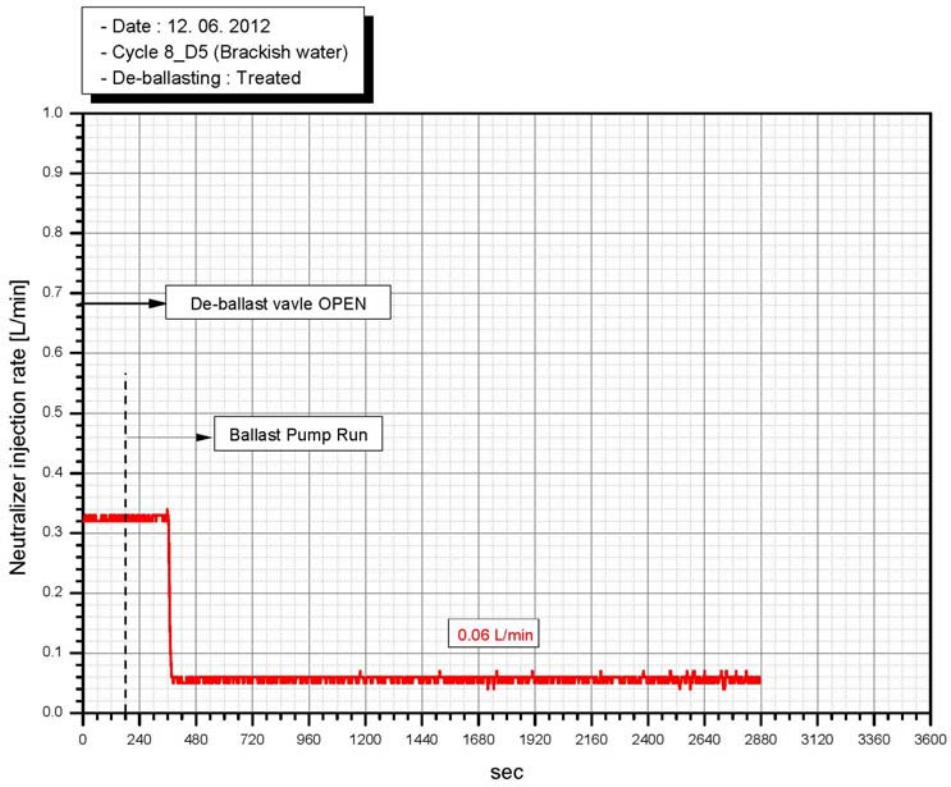
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	1.55 mg/L
Maximum TRO concentration after neutralization	0.10 mg/L

TRO concentration after neutralization is below 0.10 mg/L.


- Date : 12. 06. 2012
- Cycle 8_D5 (Brackish water)
- De-ballasting : Treated
TRO [mg/L]
Before Neutralization
1.50 ± 0.07 mg/L
After Neutralization
sec


- Date : 12. 06. 2012
- Cycle 8_D5 (Brackish water)
- De-ballasting : Treated
Neutralizer injection rate [L/min]
De-ballast vavle OPEN
Ballast Pump Run
0.06 L/min
sec

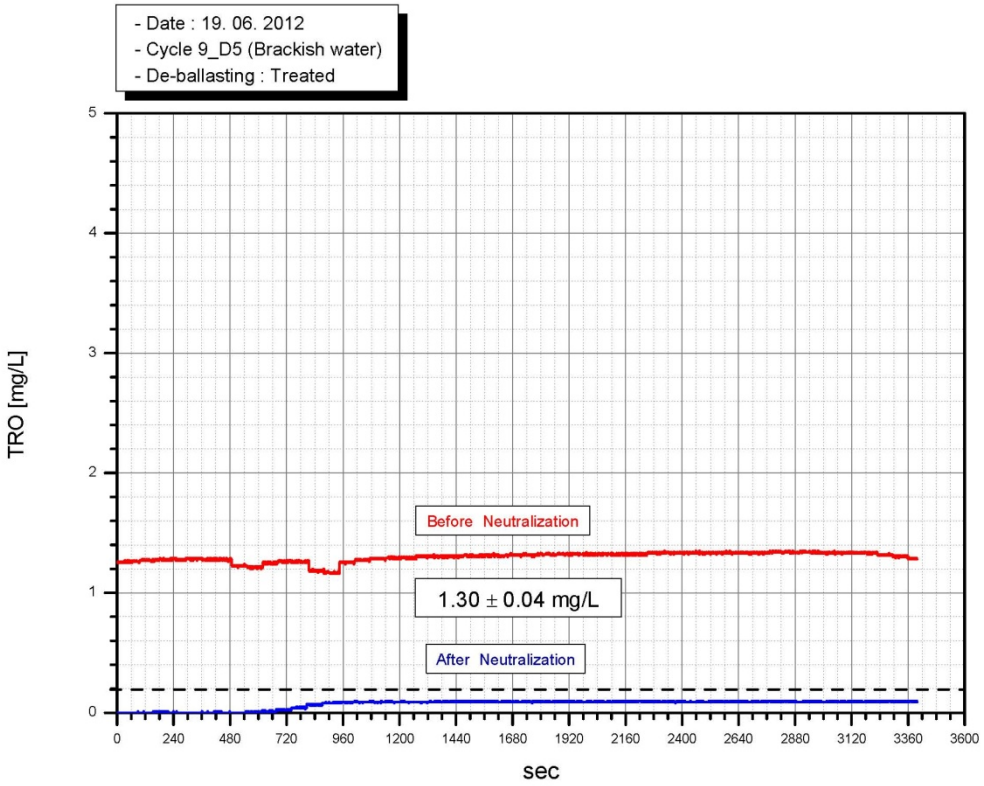
■ Set value

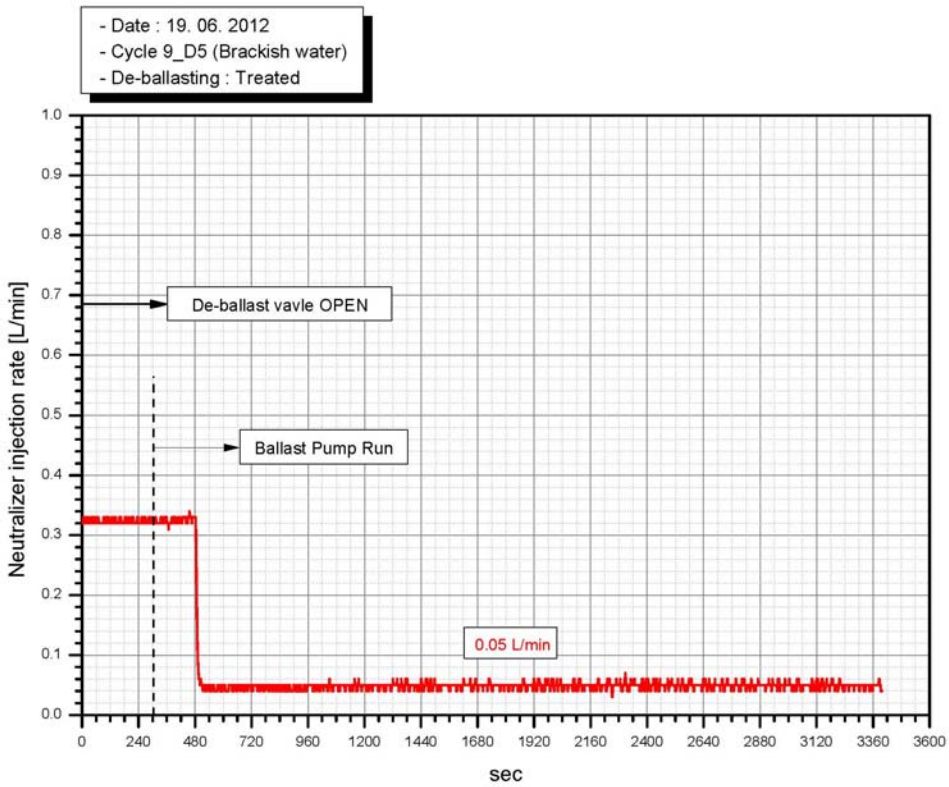
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	1.55 mg/L
Maximum TRO concentration after neutralization	0.10 mg/L

TRO concentration after neutralization is below 0.10 mg/L.


- Date : 19. 06. 2012
- Cycle 9_D5 (Brackish water)
- De-ballasting : Treated
TRO [mg/L]
Before Neutralization
1.30 ± 0.04 mg/L
After Neutralization
sec


- Date : 19. 06. 2012
- Cycle 9_D5 (Brackish water)
- De-ballasting : Treated
Neutralizer injection rate [L/min]
De-ballast vavle OPEN
Ballast Pump Run
0.05 L/min
sec

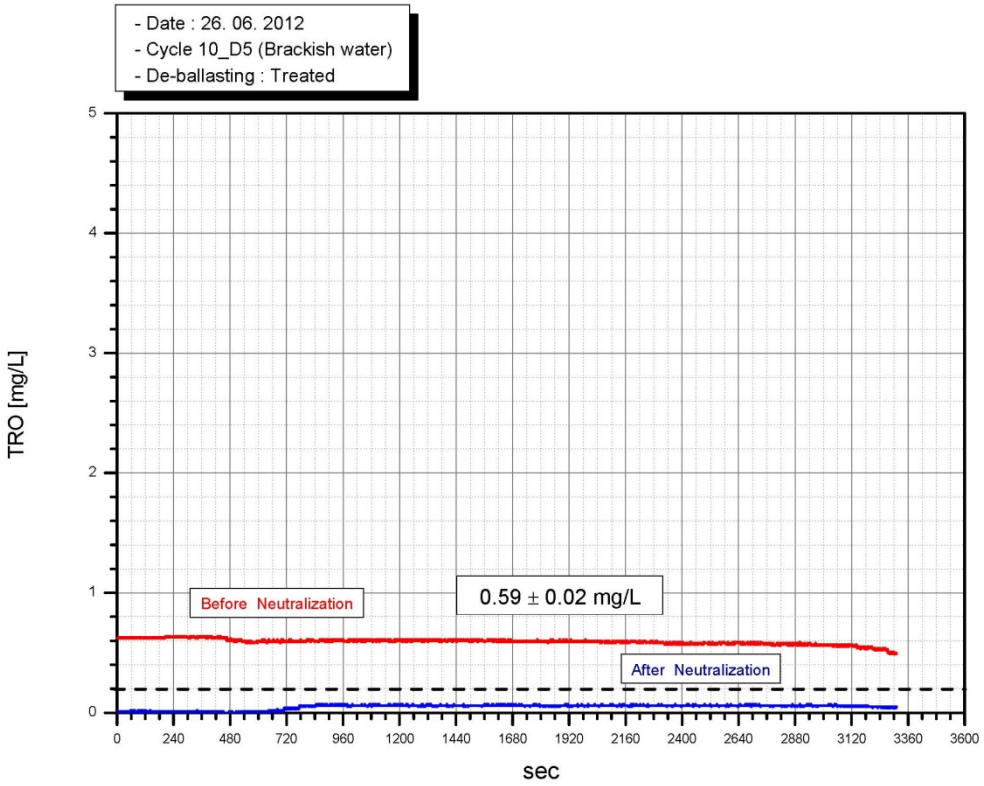
■ Set value

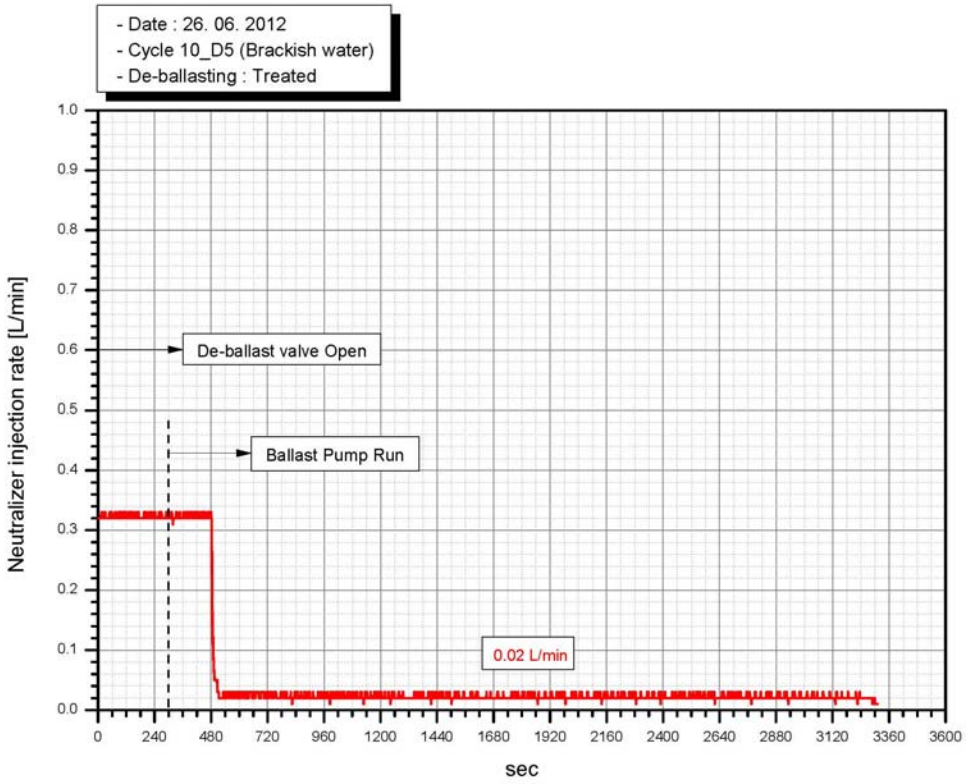
Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	1.30 mg/L
Maximum TRO concentration after neutralization	0.10 mg/L

TRO concentration after neutralization is below 0.10 mg/L.


- Date : 26. 06. 2012
- Cycle 10_D5 (Brackish water)
- De-ballasting : Treated
TRO [mg/L]
Before Neutralization
0.59 ± 0.02 mg/L
After Neutralization
sec


- Date : 26. 06. 2012
- Cycle 10_D5 (Brackish water)
- De-ballasting : Treated
Neutralizer injection rate [L/min]
De-ballast valve Open
Ballast Pump Run
0.02 L/min
sec

■ Set value

Initial injection rate of the neutralizer	2.5 times as much as stoichiometric demand for 9mg/L TRO as Cl_2
Initial injection time (T_{d0})	3 minutes after ballast pump starts to run
Concentration of the neutralizer solution	24.82% w/v

■ Test result

Average TRO concentration before neutralization	0.59 mg/L
Maximum TRO concentration after neutralization	0.07 mg/L

TRO concentration after neutralization is below 0.10 mg/L.

4 TEST RESULTS OF THE TRO DECAY

Table 4.1: TRO decay during 5 days

Seawater (34PSU)			
Day	Cycle No.	TRO [mg/L]	Average TRO [mg/L]
D0	Cycle 01	8.98	9.12
	Cycle 02	9.34	
	Cycle 03	9.10	
	Cycle 04	9.08	
	Cycle 05	9.10	
D2	Cycle 01	5.04	5.48
	Cycle 02	5.04	
	Cycle 03	6.13	
	Cycle 04	5.48	
	Cycle 05	5.69	
D5	Cycle 01	4.17	4.53
	Cycle 02	4.38	
	Cycle 03	5.15	
	Cycle 04	4.35	
	Cycle 05	4.60	

Brackish water (21PSU)			
Day	Cycle No.	TRO [mg/L]	Average TRO [mg/L]
D0	Cycle 06	9.08	9.09
	Cycle 07	9.10	
	Cycle 08	9.07	
	Cycle 09	9.08	
	Cycle 10	9.10	
D2	Cycle 06	3.49	2.51
	Cycle 07	2.66	
	Cycle 08	2.34	
	Cycle 09	2.47	
	Cycle 10	1.58	
D5	Cycle 06	2.35	1.46
	Cycle 07	1.55	
	Cycle 08	1.50	
	Cycle 09	1.31	
	Cycle 10	0.59	

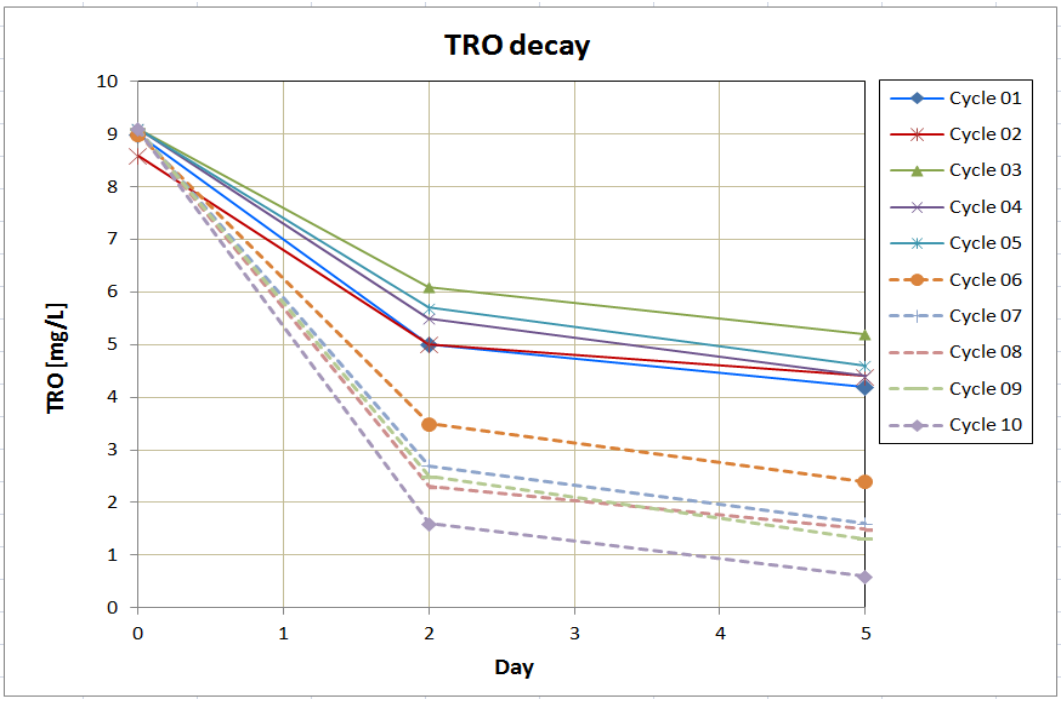


Figure 4.1: TRO decay during 5 days (Cycle 01~10)

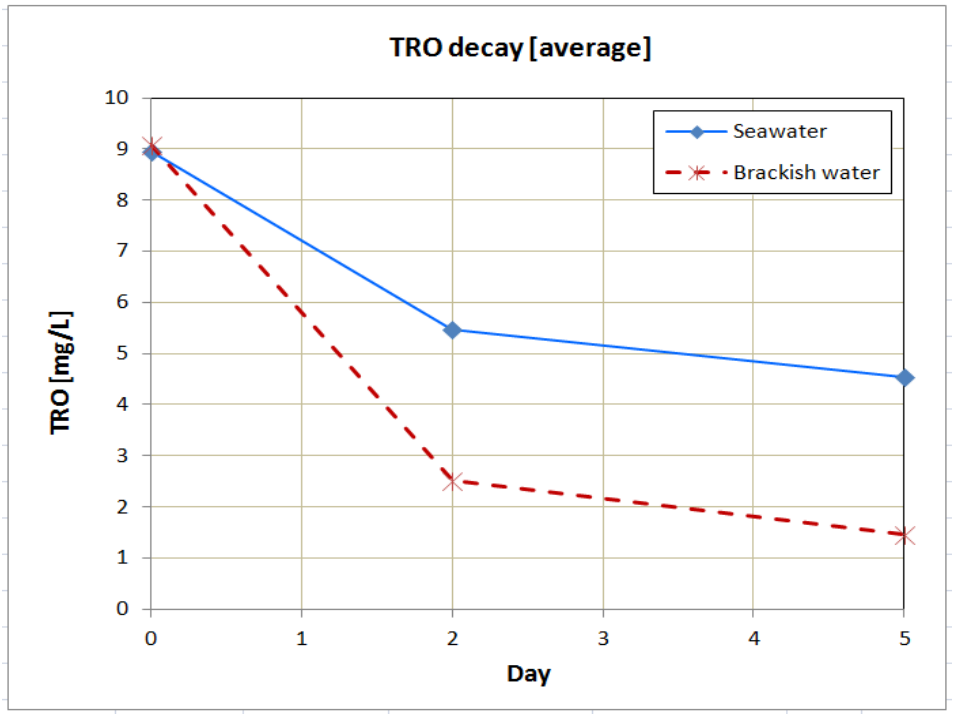


Figure 4.2: TRO decay during 5 days (Average)

TRO decay rate of brackish water was higher than that of seawater because the amount of the dissolved and particulate content in brackish water was higher than those in seawater and the temperature of brackish water in each test condition was higher that of seawater.

5 COMPARISON OF THE TRO BETWEEN CLX AND DPD MEASUREMENT

During ballasting, measuring difference between CLX and DPD is very small except for the test Cycle 2 as shown in Table 5.1.

In the case of test Cycle 2, it was difficult to measure TRO concentration with CLX because the disorder of CLX as mentioned in section 2.3.

Table 5.1: Measuring difference between CLX and DPD during ballasting

TRO concentration during ballasting (D0)							Difference between CLX and DPD [mg/L]		
Test cycle	CLX [mg/L]			DPD [mg/L]					
	B*	M*	E*	B	M	E	B	M	E
Cycle 01 (D0)	9.31	8.94	8.96	9.12	8.64	8.84	0.19	0.30	0.12
Cycle 02 (D0)	9.66	7.82	9.11	7.32	8.84	7.28	2.34	-1.02	1.83
Cycle 03 (D0)	9.14	9.17	9.03	9.24	9.00	9.00	-0.10	0.17	0.03
Cycle 04 (D0)	8.53	9.17	8.89	8.60	8.80	9.08	-0.07	0.37	-0.19
Cycle 05 (D0)	8.75	9.13	9.08	8.48	8.96	9.04	0.27	0.17	0.04
Cycle 06 (D0)	8.81	9.06	9.04	8.76	8.98	8.84	0.05	0.08	0.20
Cycle 07 (D0)	8.81	9.65	9.15	8.56	9.40	9.08	0.25	0.25	0.07
Cycle 08 (D0)	8.93	9.04	9.04	8.84	8.96	9.00	0.09	0.08	0.04
Cycle 09 (D0)	8.72	9.12	9.05	8.84	8.96	9.04	-0.12	0.16	0.01
Cycle 10 (D0)	8.78	9.11	9.13	8.56	9.04	9.12	0.22	0.07	0.01
The method of TRO measurement: ① CLX on-line chlorine sensor (Colorimetric method) ② Standard methods for the Examination of Water and Wastewater (21st Edition): 4500-Cl F (DPD ferrous titrimetric method)									

*B: Beginning (20%), M: Middle (50%), E: End (80% respectively in volume)

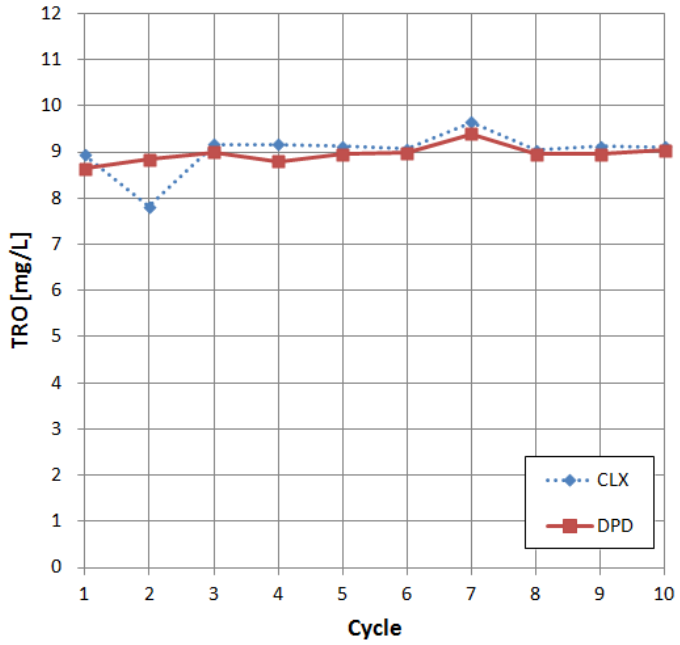


Figure 5.1: Measuring difference between CLX and DPD during ballasting

Measuring difference between CLX and DPD after neutralization is very small as shown in Table 5.2.

Table 5.2: Measuring difference between CLX and DPD during de-ballasting

TRO concentration after neutralization (D5)							Difference between CLX and DPD [mg/L]		
Test cycle	CLX [mg/L]			DPD [mg/L]					
	B	M	E	B	M	E	B	M	E
Cycle 01 (D5)	0.14	0.14	0.15	0.11	0.12	0.12	0.03	0.02	0.03
Cycle 02 (D5)	0.02	0.10	0.07	0.05	0.10	0.04	-0.03	0.00	0.03
Cycle 03 (D5)	0.06	0.06	0.06	0.05	0.04	0.04	0.01	0.02	0.02
Cycle 04 (D5)	0.07	0.10	0.04	0.09	0.11	0.02	-0.02	-0.01	0.02
Cycle 05 (D5)	0.07	0.05	0.02	0.04	0.06	0.04	0.03	-0.01	-0.02
Cycle 06 (D5)	0.01	0.07	0.07	0.04	0.05	0.06	-0.03	0.02	0.01
Cycle 07 (D5)	0.09	0.09	0.09	0.07	0.08	0.08	0.02	0.01	0.01
Cycle 08 (D5)	0.00	0.08	0.08	0.00	0.07	0.10	0.00	0.01	-0.02
Cycle 09 (D5)	0.01	0.09	0.09	0.00	0.06	0.08	0.01	0.03	0.01
Cycle 10 (D5)	0.01	0.06	0.06	0.00	0.04	0.05	0.01	0.02	0.01
The method of TRO measurement: ① CLX on-line chlorine sensor (Colorimetric method) ② Standard methods for the Examination of Water and Wastewater (21st Edition) 4500-Cl F (DPD ferrous titrimetric method)									

*B: Beginning (20%), M: Middle (50%), E: End (80% respectively in volume)

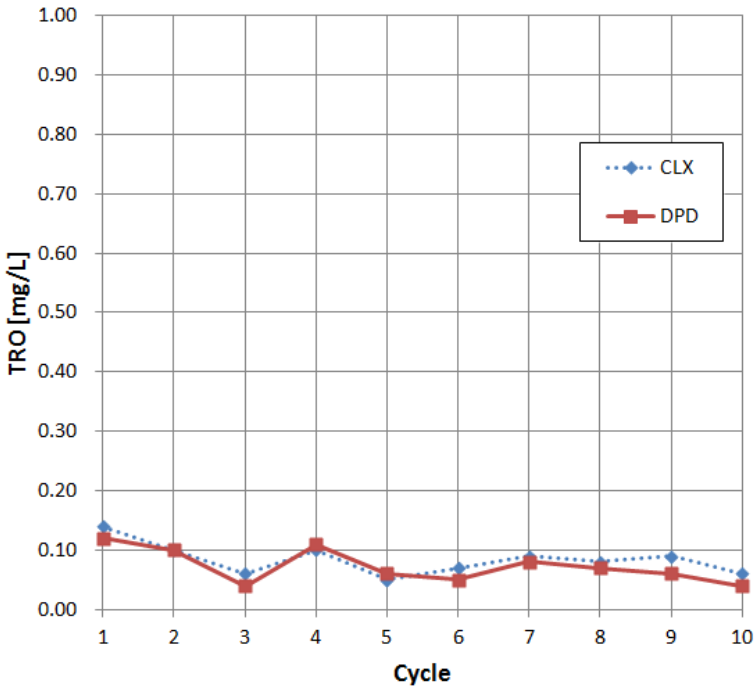


Figure 5.2: Measuring difference between CLX and DPD during de-ballasting