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Study on the control of released manganese in residuals treatment processes of water treatment plant

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ABSTRACT

Bank filtrate as an alternative for drinking water resource has a problem of high concentration of iron and manganese regardless of various advantages. The high concentration can be removed less than drinking water standard in the process of water treatment, but the removed iron and manganese are moved to residuals treatment processes as precipitation sludge or backwash water, which can make a problem if not a proper management. In order to solve this problem, this study has performed overall investigation on water quality of every process of residuals treatment, from which the relationship between the release and the process management has been figured out. This study also proposed a proper measure to control the released manganese. The investigation revealed that the release hardly occurred in exhaust resin because of high dissolved oxygen (DO) but it could happen in case of long residence more than 72 h. It also showed that the release constantly occurred in the thickener because of long residence of large amount of sludge. The iron release in the thicker was easily oxidized by DO during it raised to the upper. However, the released manganese was hardly oxidized and remained the released one even until it moved to the dewatering and returned to the thickener. As a result, it caused the significant deterioration of the residuals' quality. Aeration and pH adjustment with alkali dose were investigated in order to treat the released manganese. The alkali dose showed an optimum measure to remain the residuals quality below the standard.

Keywords: Drinking water; Released manganese; Released iron; Discharge water treatment; Thickener; Bank filtrate

1. Introduction

G City in South Korea has more than 10 years developed riverbank filtration as a part of a project to vary drinking water resources. Currently, more than half of the water resource supplied to the water treatment plants of the city has been replaced with riverbank filtration, and all the water resource will be riverbank filtration according to the city's plan in the near future. Generally, riverbank filtration secures high water quality in water intake, reduces operation and management cost, and removes pathogenic microorganisms. However, it may contain a high concentration of divalent metals, such as reduced iron and manganese, because the water quality is directly affected by the soil or geologic conditions of the penetration aquifer. In particular, the concentrations of iron and manganese are known to be tens of times higher than those of river water [1].

Manganese has been generally known to be removed by oxidation or a biological method in water treatment process [2]. In the process of removing manganese by oxidation, Mn^{2+} is oxidized using oxidizing agents, such as air, ozone, and chlorine, to flocculate precipitated particles and separate the flocculated particles through coagulative precipitation and sand filtration [3,4]. The water treatment plants in the G City have already started to apply advanced water treatment technologies, such as ozone oxidation, coagulation,

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sedimentation, sand filtration, and active carbon filtration, to effectively remove manganese without a problem in drinking water production. However, the manganese removed from the water treatment process is converted to sedimentation sludge and back-flushing water, and then flows into the residuals treatment facility. Therefore, considerable amount of iron and manganese flowing into the residuals treatment facility would be discharged if not an appropriate management. The discharged iron and manganese would be oxidized to micro-suspension particles resulting in causing not only a visually disgusting feeling but also environmental pollution in farms and water systems, failing to satisfy the residuals water quality standards [5].

On the other hand, according to the“Water Quality and Aquatic Ecosystem Conservation Act” from January 1, 2013, residuals should be appropriately treated before being discharged in South Korea. The water quality standards for residuals were significantly tightened from 2013. In addition, in cases where recycled water is reused, deterioration of recycled water quality affects the quality of purified water supplied to consumers. Therefore, the water quality should be stably managed in the residuals treatment facilities [6]. The treatment of the residuals produced in a water treatment generally consists of balancing, thickening, dewatering, drying, and disposal, and may combine all or some of the unit processes depending on the properties and quantity of generated residuals and sludge [7]. The balancing process, performed at residuals tanks and residuals sludge tanks, refers to the process to adjust the quantity and properties of residuals sludge. An exhaust resin tank accepts the sediment sludge from a sedimentation tank and a basin of wastewater accepts purified residuals from a rapid filtration tank [8]. The exhaust resin tank and the basin of wastewater control the temporal variation of residuals and maintain the treatment quantity following thickening treatment at a constant level [9].

Residuals treatment should be constantly and evenly allocated for 24 h. However, most water treatment plants have difficulties in stable residuals treatment because of the facility structure problems, insufficient operation human resources, and impossible 24-h shift work [10,11]. In addition, since residuals treatment is performed only during the regular work hours, residuals are not appropriately treated due to the overload on residuals treatment facility. Such inappropriate residuals treatment in water treatment plants causes deterioration of the quality of overlaying water and residuals, resulting in an increase of treatment cost due to excessively high water content in the final sludge [12,13]. Inappropriate operation and management of residuals treatment facility increase the residence time of the sludge in residuals treatment facility, causing release of manganese in the stagnant sludge resulting in increasing the manganese concentration in the residuals [14,15]. The acceptance criterion for manganese concentration in the residuals from water treatment plants is 2 mg/L, but the concentration is sometimes elevated to 6 mg/L in the residuals in winter when the sludge residence time is longer [16].

Many studies have been conducted on the removal of manganese in water treatment process, but most of the studies were on the improvement of drinking water quality. Little has been studied about the control of manganese in the residuals discharged from the residuals treatment facility of water treatment plants. Therefore, this study investigated the positions and causes of manganese release at individual processes of residuals treatment facility through water quality analysis at M Water treatment plant in the G City where the residuals facility are expected to have a manganese release problem. In addition, the possibility of preventing manganese release through the pH adjustment by aeration and alkaline chemical dose was investigated.

2. Methods

As shown in Fig. 1, the residuals treatment facility in the M Water treatment plant in the G City, which is the subject

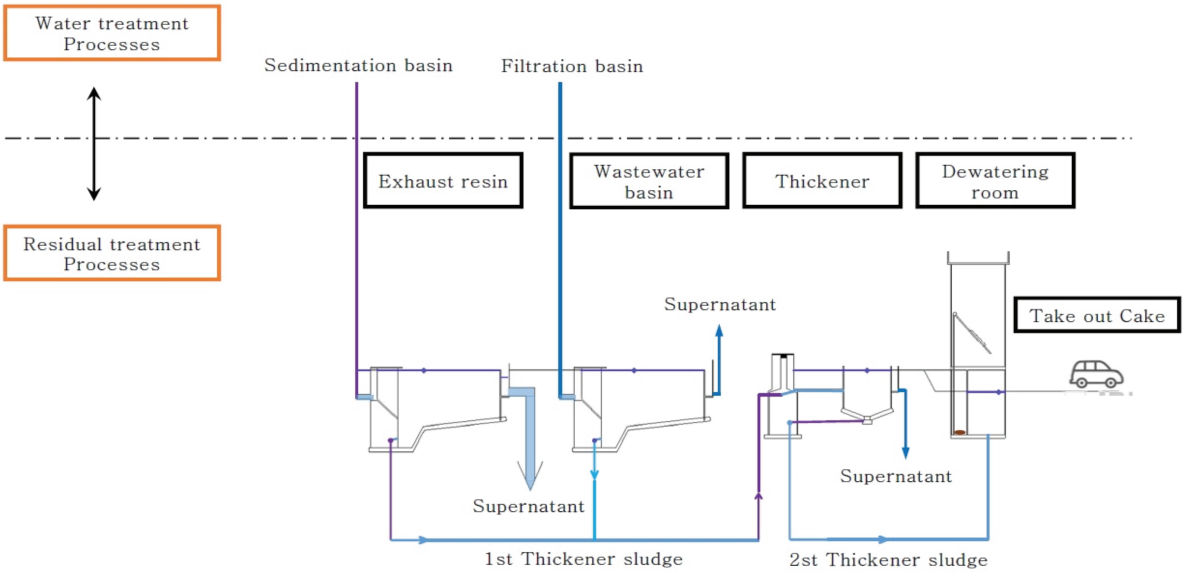

Fig. 1. Residuals treatment processes in M water treatment plant.

of the present study, transfers the sediment sludge from sedimentation basin to exhaust resin and the back-flushing sludge from sand filtration basin and activated carbon filtration basin to the wastewater basin, respectively, for sedimentation and storage. When appropriate water level and water quantity are secured at the exhaust resin and the wastewater basin and the water quality is stabilized, the overlaying water is sent to the recycling tank and the sediment sludge is transferred as primary thickener sludge to the thickener tank for reconcentration. The sludge concentrated at the thickener tank is transferred as secondary thickener sludge to the storage tank and then the dewatering room to be prepared as dewatered cake and discharged for final disposal.

In order to identify the manganese release position in the residuals treatment facility and investigate the causes, a water quality analysis with respect to pH, oxidation reduction potential (ORP), dissolved oxygen (DO), turbidity, iron, and manganese was performed at the positions of the exhaust basin, thickener, sludge before dewatering, and dewatering filtrate. The water sampling correction was conducted by visiting the residuals treatment site from 9 AM to 12 PM about two or three times per week for 60 d from December 2015 to January 2016, during which manganese release was a particular problem in the M water treatment plant. The water quality analysis was performed at the surface layer and the bottom layer of the exhaust resin and at the surface layer, the intermediate layer, and the bottom layer of the thickener tank. The pH, ORP, DO, and turbidity were measured at the site, and the iron and manganese concentrations were analyzed by taking samples to a laboratory and performing a water quality test.

As an effective method of controlling manganese released from residuals treatment facility, aeration was investigated the effect by preparing an acrylic column having a diameter of 30 mm. Aeration was performed at an aeration intensity of 10 L/min for 120 min with 25 L of sludge samples before dewatering, and water samples were taken in an interval of 30 min to analyze the water quality.

The pH adjustment by dosing alkaline chemicals, suggested in this study as another method of controlling released manganese, was tested by preparing a manganese eluate from the sludge before dewatering. The manganese eluate was prepared by mixing 500 g of sludge before dewatering and 5,000 mL of distilled water, stirring the mixture at 180 rpm for 2 h, and filtering the mixture with glass fiber filter paper. The alkaline chemicals used for the pH adjustment were NaOH, KOH, $CaCO_3$, and $Ca(OH)_2$. To gradually change the pH of the eluate, an alkaline solution was prepared and used, rather than directly adding the alkaline chemical powder. Solutions of NaOH and KOH were prepared at a concentration of 0.05 N to be added. $CaCO_3$ and $Ca(OH)_2$, having low water solubility, were respectively dispersed into 100 mL of distilled water at 2.5 mM, and the resulting suspensions were added. After adding an alkaline chemical to the eluate, the eluate was stirred at 180 rpm for 2 h and then deposited for 48 h, the minimum residence time of purification plant sludge. Then, the overlaying water was filtered using glass fiber filter paper to measure the pH and manganese concentration.

3. Results and discussion

3.1. Water quality properties at residuals treatment facility

3.1.1. Exhaust resin

Tables 1 and 2 show the water quality analysis results obtained for 60 d from December 2015 to January 2016, at

Table 1
Surface water quality of exhaust resin

Day	pH	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Iron (mg/L)	Manganese (mg/L)
12/4/2015	7.47	224	10.8	24.4	0.36	0.07
12/8/2015	7.52	213	11.2	3.2	0.17	0.05
12/12/2015	7.5	201	11.6	1.11	0.01	0.056
12/15/2015	7.37	144	12.23	2.1	0.15	0.042
12/19/2015	7.27	79	10.2	2.25	0.03	0.122
12/22/2015	7.21	73	10.7	3.47	0.11	0.11
12/26/2015	7.39	67	11.01	4.11	0.22	0.122
12/28/2015	7.19	67	11.77	0.59	0.02	0.016
12/31/2015	7.15	50	11.98	1.2	0.03	0.016
1/3/2016	7.13	52	12.61	3.54	0.08	0.029
1/7/2016	7.43	46	11.54	4.21	0.09	0.048
1/11/2016	7.59	42	10.5	4.54	0.14	0.068
1/13/2016	7.68	65	10.3	2.53	0.08	0.135
1/15/2016	7.25	160	11.2	5.25	1.35	2.34
1/19/2016	7.15	192	10.23	0.85	0.03	0.018
1/23/2016	7.36	145	11.95	1.83	0.18	0.135
1/27/2016	7.48	204	10.98	3.52	0.08	0.058
1/29/2016	7.28	180	11.5	2.84	0.12	0.098
Average	7.36	122	11.24	3.97	0.18	0.2

Table 2
Bottom water quality of exhaust resin

Day	pH	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Iron (mg/L)	Manganese (mg/L)
12/4/2015	7.43	220	10.65	10.5	0.15	0.54
12/8/2015	7.5	213	11.54	4.6	0.08	0.17
12/12/2015	7.48	203	11.8	2.11	0.05	0.148
12/15/2015	7.43	147	12.75	5.57	0.38	0.122
12/19/2015	7.45	93	10.5	2.43	0.01	0.135
12/22/2015	7.46	87	10.75	8.6	1.56	0.64
12/26/2015	7.47	79	11.05	30.48	2.57	0.919
12/28/2015	7.23	61	11.8	41.2	1.6	0.986
12/31/2015	7.22	63	12.6	10.33	0.87	0.65
1/3/2016	7.1	62	12.8	2.23	0.07	0.162
1/7/2016	7.34	52	11.65	4.6	0.08	0.09
1/11/2016	7.45	45	10.65	6.85	0.11	0.075
1/13/2016	7.6	60	10.42	2.53	0.05	0.054
1/15/2016	7.25	148	11.42	8.65	1.25	0.295
1/19/2016	7.22	180	10.25	20.5	2.31	1.25
1/23/2016	7.42	138	11.52	6.32	0.08	0.043
1/27/2016	7.45	189	11.12	10.54	0.15	0.143
1/29/2016	7.32	175	11.32	6.52	0.05	0.042
Average	7.38	123.06	11.37	10.25	0.63	0.36

the surface layer and the bottom layer of the exhaust resin located at the M water treatment plant, respectively. The average water level in the exhaust resin was 5–6 m over the analytical period. The water quality properties of the surface layer and the bottom layer were similar, except the slightly higher turbidity of the bottom layer than that of the surface layer due to the sludge existing in the bottom layer. The water quality in terms of pH, ORP, DO, turbidity, iron, and manganese were 7.1–7.6, 40–220 mV, 10.5–12.5 mg/L, 2–30 NTU, 0.01–2.57 mg/L, and 0.1–2.5 mg/L, respectively.

The ORP showed a positive value because the DO was almost saturated in not only the surface layer but also the bottom layer. The positive ORP value enabled effective prevention of iron and manganese release from the bottom sludge. However, two times between December 22–28 and January 15–19, when the sludge was not properly collected from the bottom of the exhaust resin, the iron and manganese concentrations at the surface layer and the bottom layer were increased to 1.35 and 2.34 mg/L, and 2.57 and 1.25 mg/L, respectively. This suggests that iron and manganese release problems may occur anytime when the bottom sludge is not collected at the right time.

3.1.2. Thickener tank

Tables 3–5 show the water quality analysis results obtained at the surface layer, the intermediate layer, and the bottom layer of the thickener tank during the analytical period, respectively. As shown in the tables, the water quality values of the surface layer, the intermediate layer, and the bottom layer were different in the thickener tank, in contrast to the exhaust resin. The ORP, DO, iron, and manganese concentrations of the surface layer were 80–200 mV, 8.5–10.5 mg/L, 0.02–0.08 mg/L, and 1–2 mg/L, respectively. Those of the intermediate layer were 50–200 mV, 8.1–10.4 mg/L, 0.01–2.21 mg/L, and 0.9–12.4 mg/L, respectively. Those of the bottom layer were –10 to –150 mV, 0.02–0.59 mg/L, 1.28–2.88 mg/L, and 10–24 mg/L, respectively. In the thickener, the concentration of released manganese was increased as the depth was increased from the surface layer to the intermediate layer and then the bottom layer, showing a severely high concentration of 10 mg/L or higher.

As shown in Table 3, the iron and manganese concentrations of the surface layer of the thickener were stably low, as the iron and manganese released and diffused from the bottom layer were relatively well blocked due to the high DO value and the positive ORP value. However, the iron and manganese concentrations of the intermediate layer of the thicker were high despite the relatively high DO and ORP due to the diffusion of the iron and manganese released at the bottom layer. In particular, the manganese concentration was 10 mg/L or higher in the middle of January when the sludge remained in the thickener for a long time. As shown in Table 5, the bottom layer of the thickener tank was severely anaerobic with an ORP value of –50 to –180 mV and a DO value of 0.5 mg/L, indicating a highly reductive state. Because a considerable amount of iron and manganese were released from the sludge, the iron concentration was high between the minimum of 0.1 mg/L to the maximum of 2.88 mg/L, and the manganese concentration was also high between the minimum of 8.88 mg/L to the maximum of 24.8 mg/L in the bottom layer.

3.1.3. Sludge before dewatering and dewatering filtrate

Since the sludge before dewatering was deposited and concentrated at the bottom of the thickener and then

Table 3
Surface water quality of thickener

Day	pH	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Iron (mg/L)	Manganese (mg/L)
12/4/2015	7.2	215	8.54	0.22	0.04	1.95
12/8/2015	7.2	210	8.65	0.24	0.04	1.99
12/12/2015	7.2	205	8.9	0.25	0.06	1.98
12/15/2015	7.4	156	9.75	0.75	0.02	1.95
12/19/2015	7.5	108	9.22	2.17	0.06	1.29
12/22/2015	7.4	110	9.66	1.54	0.04	1.25
12/26/2015	7.3	112	9.88	1.36	0	1.07
12/28/2015	7.3	53	10.64	0.68	0.04	0.93
12/31/2015	7.3	65	10.55	0.98	0.06	1.55
1/3/2016	7.4	78	10.4	1.63	0.07	1.95
1/7/2016	7.2	95	9.54	1.54	0.07	1.99
1/11/2016	7.1	110	8.32	1.45	0.09	1.84
1/13/2016	7.2	95	8.08	1.38	0.08	1.95
1/15/2016	7.1	203	8.25	0.52	0.02	0.68
1/19/2016	7.1	180	7.85	0.48	0.04	1.94
1/23/2016	7.2	150	8.02	0.29	0.02	1.25
1/27/2016	7.3	220	9.32	1.25	0.04	1.99
1/29/2016	7.2	195	9.15	1.85	0.02	1.04
Average	7.26	142	9.15	1.03	0.05	1.59

Table 4
Middle water quality of thickener

Day	pH	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Iron (mg/L)	Manganese (mg/L)
12/4/2015	7.3	212	8.75	2.35	0.12	1.88
12/8/2015	7.3	206	8.98	2.48	0.1	2.01
12/12/2015	7.3	202	9	2.43	0.09	2.14
12/15/2015	7.5	146	11.12	3.43	0.01	1.84
12/19/2015	7.7	111	9.8	1.68	0.01	1.36
12/22/2015	7.5	108	9.45	9.87	1.23	9.56
12/26/2015	7.4	106	9.16	132	2.16	10
12/28/2015	7.5	50	10.4	1.93	0.05	0.95
12/31/2015	7.5	35	10.3	101	1.24	6.54
1/3/2016	7.5	20	10.2	111	1.65	8.95
1/7/2016	7.4	32	9.21	115	2.21	8.65
1/11/2016	7.4	45	9.3	120	2.58	8.54
1/13/2016	7.3	35	9.1	110	1.98	12.4
1/15/2016	7.6	130	8.6	2.53	0.05	1.43
1/19/2016	7.3	185	8.4	1.52	0.01	1.33
1/23/2016	7.4	200	8.2	3.25	0.02	1.69
1/27/2016	7.9	165	9.92	2.85	0.06	2.45
1/29/2016	7.4	198	10.3	2.03	0.04	1.83
Average	7.46	121.44	9.46	40.30	0.76	4.64

Table 5
Bottom water quality of thickener

Day	pH	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Iron (mg/L)	Manganese (mg/L)
12/4/2015	7.7	–165	0.43	25.6	1.45	12.3
12/8/2015	7.7	–155	0.36	30.5	1.38	11.5
12/12/2015	7.7	–145	0.35	33.9	1.38	10.5
12/15/2015	7.5	–114	0.52	221	1.68	16.8
12/19/2015	7.4	–58	0.58	29.1	2.14	20.5
12/22/2015	7.4	–104	0.05	151	2.11	22.5
12/26/2015	7.5	–154	0.06	205	1.86	24.8
12/28/2015	7.7	8	0.021	191	1.54	19
12/31/2015	7.6	–15	0.15	189	1.64	20.6
1/3/2016	7.4	–65	0.78	181	1.67	23.2
1/7/2016	7.6	–105	0.06	188	2.54	24.3
1/11/2016	7.7	–180	0.02	190	2.88	18.9
1/13/2016	7.8	–130	0.08	210	2.23	22.1
1/15/2016	7.5	–145	0.45	180	1.54	15.4
1/19/2016	7.5	–80	0.32	88	1.28	16.3
1/23/2016	7.7	–118	0.59	60	1.48	8.88
1/27/2016	7.5	–158	0.45	195	2.1	16.4
1/29/2016	7.7	–129	0.32	100	1.98	12.4
Average	7.59	–111.78	0.31	137.12	1.83	17.58

transferred to sludge storage tank and stored for a certain period of time, the sludge was severely anaerobic with a low DO value and a negative ORP value, as shown in Table 6. The ORP, DO, iron, and manganese concentrations of the sludge before dewatering were –95 to 165 mV, 0.02–0.48 mg/L, 0.1–2.52 mg/L, and 9.54–18.32 mg/L, respectively.

The concentrated sludge transferred from the sludge storage tank to the dewatering equipment was mixed with an anion polymer coagulation agent to be dewatered at belt-press dewatering equipment. Table 7 shows the water quality of the dewatering filtrate. Since the iron and manganese were partially removed from the dewatering filtrate to the dewatered cake by the coagulation agent, the iron (0.8–3.5 mg/L) and manganese (1.4–4.6 mg/L) concentrations of the dewatering filtrate were lower than those of the sludge before dewatering.

3.2. Released manganese control

As described above, most of the water resource flowing into the M water treatment plant at the G City was replaced with riverbank filtration, and a considerable amount of iron and manganese removed by the treatment process flowed into the residuals treatment facility as they are contained in the sediment sludge and back-flushing residuals. As a result, the problem of iron and manganese release was raised in the residuals treatment facility after the thickener. In particular, the concentration of manganese released from the bottom layer of the thickener and the storage tank was at a severely high level of 10 mg/L or above.

The released iron concentration in the sludge was not at a severe level because it could be easily oxidized by DO in the residuals treatment process. However, the concentration of manganese was so high from the bottom layer of the thickener to the storage tank and the dewatering equipment that the residuals water quality criteria might be threatened. Therefore, an experiment was performed in this study to examine the possibility of controlling the released manganese concentration by the pH control through aeration and alkaline chemical dose.

3.2.1. Aeration

The sample of the sludge before dewatering was taken by 25 L from the storage tank where the manganese concentration was the highest. The sample was put into an acrylic column of a 300 mm diameter prepared for the experiment and aerated at an aeration intensity of 10 L/min for 120 min. Water samples were taken in an interval of 30 min to analyze the water quality, and the water quality analysis results are shown in Fig. 2. As shown in Fig. 2, the DO was increased from 0.3 to 9.4 mg/L, and the ORP was converted from a negative value (–83 mV) to a positive value (15 mV) within 30 min of aeration. As a result the iron concentration was decreased from 3.88 to 0.17 mg/L. For the following 120 min of aeration, the DO was kept at a saturated level, and the iron concentration was kept at a very low level about 0.17–0.18 mg/L.

While the released iron was controlled by aeration relatively easily, manganese showed a different behavior. Although the DO was almost at a saturated level by the aeration for 120 min, the manganese concentration was decreased from the initial concentration of 18.3 mg/L only to 8.8 mg/L, which was because the manganese released by reduction is not easily oxidized. Therefore, alkaline chemicals were added in the present study to control the manganese concentration by controlling the pH, thereby controlling the oxidation of the released manganese.

Table 6
Sludge water quality before dewatering

Day	pH	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Iron (mg/L)	Manganese (mg/L)
12/4/2015	7.26	–114	0.45	15.32	0.49	10.08
12/8/2015	7.48	–125	0.23	11.84	0.41	12.232
12/12/2015	7.57	–138	0.16	7.66	0.29	14.913
12/15/2015	7.62	–165	0.08	24.75	1.02	16.534
12/19/2015	7.35	–135	0.03	2.26	0.1	14.136
12/22/2015	7.23	–155	0.02	2.54	0.2	15.214
12/26/2015	7.45	–145	0.05	5.84	0.35	10.55
12/28/2015	7.48	–142	0.04	4.52	0.45	12.323
1/3/2016	7.54	–128	0.02	8.32	0.98	16.23
1/7/2016	7.63	–132	0.23	20.3	1.35	8.045
1/11/2016	7.58	–95	0.25	10.35	0.35	10.25
1/13/2016	7.6	–122	0.48	5.45	0.53	14.35
1/15/2016	7.58	–110	0.03	8.95	0.15	10.25
1/19/2016	7.28	–108	0.15	15.45	2.52	18.32
1/23/2016	7.49	–98	0.28	20.48	1.85	12.45
1/27/2016	7.62	–130	0.02	6.48	0.98	9.54
1/29/2016	7.58	–129	0.11	8.89	1.25	14.35
Average	7.49	–127.71	0.15	10.55	0.78	12.93

Table 7
Water quality after dewatering

Day	pH	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Iron (mg/L)	Manganese (mg/L)
12/4/2015	7.48	150	10.12	95	2.15	2.856
12/8/2015	7.52	142	10.85	84	2.07	2.563
12/12/2015	7.56	133	11.2	69.72	1.8	1.359
12/15/2015	7.72	111	10.5	147.8	3.08	4.338
12/19/2015	7.83	58	10.05	24.19	0.83	1.013
12/22/2015	7.74	68	10.12	18.32	1.56	2.356
12/26/2015	7.65	38	10.32	135.4	3.85	5.42
12/28/2015	7.62	24	10.44	100.2	3.21	4.38
1/3/2016	7.58	56	10.28	56.3	1.23	2.21
1/7/2016	7.52	110	10.21	50.3	0.68	1.021
1/11/2016	7.42	75	10.03	58.9	1.35	1.425
1/13/2016	7.65	108	10.83	120	0.84	1.495
1/15/2016	7.42	120	9.84	40.5	1.35	3.984
1/19/2016	7.53	118	9.56	23.5	2.18	2.845
1/23/2016	7.56	132	11.32	110	3.45	4.592
1/27/2016	7.84	89	10.32	143	0.65	1.342
1/29/2016	7.68	98	10.12	80.5	2.08	3.849
Average	7.61	95.88	10.36	79.86	1.90	2.77

On the other hand, to investigate the effect of aeration to improve the sedimentation of the sludge, the sludge volume was measured by depositing for 60 min the sludge samples that underwent no aeration, or aeration for 2, 5, 12, and 24 h. Fig. 3 shows the results. As shown in Fig. 3, the samples that underwent aeration showed better sedimentation than that of the sample that did not undergo aeration, and the sedimentation was improved as the duration of aeration was increased. The sedimentation of the sludge sample that underwent 12 h of aeration was 46.2% better than that of the sludge sample without aeration. In addition, the manganese concentration of the supernatant of the samples that underwent aeration was measured after 60 min of sedimentation. The result shown in Table 8 indicates that the manganese concentration of the supernatant of the sample that underwent 12 h of aeration was 56.8% lower than that of the sample without aeration.

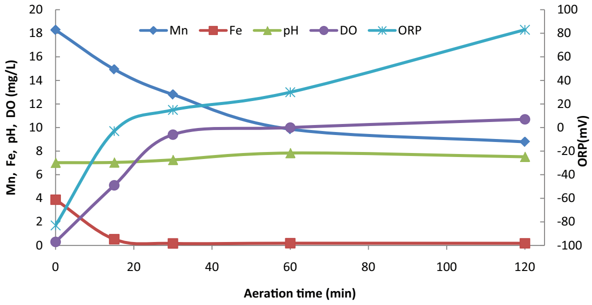

Fig. 2. Variation of sludge water quality with aeration.

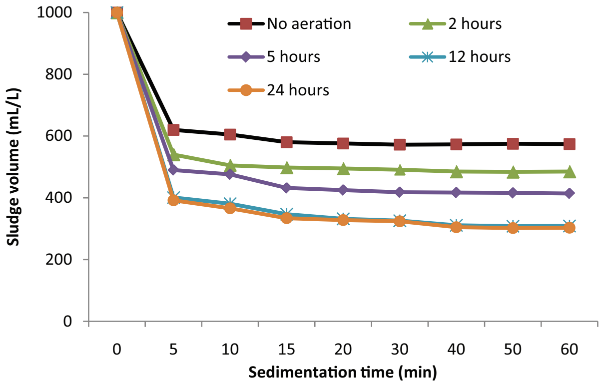

Fig. 3. Variation of sludge volume with aeration and sedimentation time.

3.2.2. pH control by addition of alkaline chemicals

The alkaline chemicals, NaOH, KOH, $CaCO_3$, and $Ca(OH)_2$ were added to the manganese eluate prepared from the sludge before dewatering at a concentration of 0–25 mg/L. Table 9 shows the changes of the pH and the manganese concentration after the addition. The pH was increased and the manganese concentration was drastically decreased as the amount of added alkaline chemicals was increased with respect to all the alkaline chemicals. The water pH was overly increased to 9.57 and 9.78 by NaOH and KOH, respectively, while $CaCO_3$ increased the pH to 8.52 when the added amount was the same. This suggests that $CaCO_3$ may be better used as an alkaline chemical for manganese control than NaOH or KOH, because the residuals pH should not exceed 8.5 in Korea according to the residuals water quality criteria.

When dissolved, $CaCO_3$ produces CO_3^{2-} ion that binds to Mn^{2+} to form $MnCO_3$ sedimentation. The solubility product of the $MnCO_3$ sediment is relatively low, and thus the manganese release from these ions was extremely low at pH 7 or above. The elevation of pH by CO_3^{2-} ion produced from $CaCO_3$ was not as high as that by the OH^- ion. When $Ca(OH)_2$ was added and the mixture was stirred at 180 rpm for 2 h and then deposited for 24 h, the pH of the overlaying water was increased to 9.6. The manganese concentration was decreased to 0.1 mg/L when $Ca(OH)_2$ of 20 mg/L was added.

Table 8
Supernatant manganese after sedimentation with aeration time

Aeration time (h)	Supernatant manganese (mg/L)
0	18.3
2	8.8
5	8.2
12	7.9
24	7.8

Table 9
Variation of pH and manganese with alkali dose

		Dose (mg/L)					
		0	5	10	15	20	25
NaOH	pH	7.33	8	8.42	8.69	9.03	9.57
	Mn (mg/L)	15.52	8.78	6.15	1.85	1.76	1.34
KOH	pH	6.82	6.94	7.76	8.26	9.5	9.78
	Mn (mg/L)	16.21	10.14	7.46	2.85	2.32	1.56
$CaCO_3$	pH	7.42	7.51	7.56	7.78	8.14	8.52
	Mn (mg/L)	15.23	10.87	7.42	2.87	1.21	1.12
$Ca(OH)_2$	pH	6.5	6.9	7.9	8.7	9.2	9.4
	Mn (mg/L)	6.2	2.2	1.6	0.2	0.1	0

4. Conclusions

As riverbank filtration containing a considerable amount of iron and manganese is used as a water resource, the effect of the iron and manganese removed from the water treatment process on the residuals treatment facility was investigated, and the measures to the relevant problems were developed in this study with the following conclusions.

- The DO was high and the ORP value was positive at the surface layer and the bottom layer of the exhaust resin storing the sedimentation sludge produced from the water treatment process. Therefore, the release of iron and manganese from the sludge was insignificant. However, when the sludge had a long residence time due to inappropriate sludge management, iron and manganese were released from the bottom of basin, and their concentrations were relatively high.
- In the thickener to which the sludge was transferred from the exhaust basin, the bottom layer was severely anaerobic and the concentrations of released iron and manganese were at a severely high level. The intermediate layer also showed a severely high level of iron and manganese concentration despite the high DO level, as iron and manganese were diffused from the bottom layer. The iron concentration at the intermediate layer and the surface layer was kept at a level lower than the water quality criterion as the iron was oxidized by the air, while the concentration of the reduced and released manganese was kept at a high level.
- The sludge before dewatering was severely anaerobic and showed severely high iron and manganese concentrations as in the case of the sludge at the bottom layer of the thickener. The iron and manganese concentrations in the dewatering filtrate were slightly lower because the iron and manganese were partly removed by a coagulation agent.
- The iron was easily removed by aeration, but the manganese was not easily removed. The aeration improved sludge sedimentation: 12 h of aeration improved the sludge sedimentation by 46.2% in comparison with the sludge without aeration. The manganese concentration of the overlaying water was decreased after the aeration by 56.8% in comparison with the sludge without aeration.
- Addition of alkaline chemicals enabled effective control of released manganese by increasing the pH. While NaOH and KOH increased the pH excessively to 9 or above, $CaCO_3$ appropriately increased the pH up to 8.52.

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