Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.860402

53 (2015) 2092–2099
February

Taylor & Francis
Taylor & Francis Group

Cause of scum formation on the water surface of flocculation basin in water treatment plant

Dong-Heui Kwak

Department of Environmental and Chemical Engineering, Seonam University, Namwon 590-711, Republic of Korea
Tel. +82 63 620 0223; Fax: +82 63 620 0211, C.P.: +82 10 3678 5468; email: kwak124@hanmail.net

Received 4 May 2013; Accepted 24 October 2013

ABSTRACT

Scum is often found on the water surface of flocculation and sedimentation basin in water treatment plants, although water treatment facilities should always be in clean condition. A series of analytical experiments were conducted on the raw water and scum to investigate the cause and characteristics of scum formation in the Seokseong water treatment plant, which has been experiencing scum treatment problems. The measurements results in the field indicated that the raw water in the receiving well was oversaturated with dissolved oxygen by the pressure of the intake pumping and conveyance. The oversaturated oxygen triggered micro-bubbles because of the sudden decrease in surface tension that is caused by the coagulant dose. Observations of the experimental facilities revealed that bubbles are generated originally on the surface of a floc, and the flocs are acting as a nucleation of the bubble formation. The chemical composition of scum consists of various hydrophobic compounds, similar to the sludge in the sedimentation basin. These findings led us to conclude that with an exception of the nucleation of bubble formation, the mechanism of scum formation is similar to the particle separation of the flotation process in the water treatment plant. Therefore, scum formation may be prevented or reduced if excessive increase in pipeline pressure is avoided when mixing with air during processes of intake pumping and conveyance.

Keywords: Scum; Bubble; Float; Hydrophobicity; Surface tension; Flotation

1. Introduction

Scum refers to a mass or accumulated layer of impure solid matter on the surface of water, which is usually formed together with various kinds of matters, such as oily compounds, grease, low density solid, algal debris, etc. with or without foams and bubbles. Scum, however, is often found on the water surface of the flocculation and sedimentation basin in drinking water treatment plants. For drinking water treatment plants, facilities and structures are required to be maintained with clean condition from the viewpoint of aesthetics as well as sanitation. In general, the continuous efforts to remove scum hardly keep the surface of water clean in water treatment plants that contain the factors of scum formation whose cause still remains unidentified.

On the other hand, scum is much more common in wastewater treatment and anaerobic digestion [1,2]. The examination of the mechanisms for stable foam formation revealed that stable foam comprises three components of air bubbles, surfactants and hydrophobic cells in activated sludge systems [3]. In natural water body in warm seasons, shallow lakes also present cyanobacterial blooms, composed mainly of *Anabaena* and *Microcystis*, and surface scum is common in eutrophic freshwaters [4]. A green scum containing toxic cyanobacter cells, which is known to have neurotoxic effects causing gastroenteritis and liver damage, was observed over the clarifier and accumulated in drinking water treatment processes [5].

Meanwhile, many researchers have studied the influence of the physical properties on bubble formation [6]. During the flotation process, the particles are mainly hydrophobic, which enhances their capture by air bubbles, but there are particles of less hydrophobicity that can still be transferred to the froth, because they can be entrained in the wake of rising bubbles [7]. Especially, in the long distance of conveyance pipe line, the change of water temperature leads oversaturated water to form bubbles and combine with flocs [8]. Otherwise, oversaturation from coagulation can lead to form CO_2 bubble by converting bicarbonate alkalinity to carbon dioxide by acidification [9].

On the basis of the results of many studies related scum matter, we can suggest that the following mechanisms are mainly responsible for the main factors of scum formation in drinking water treatment plants [1]. The formation of bubbles attaching on the surface of particles at the point of coagulation process, especially: There are several kinds of sources of bubble formation, such as CO_2 gas from coagulation, N_2 gas from chlorination, oversaturation of air by high pressure etc. in drinking water treatment processes [2]. The composition and/or physiochemical characteristics of particles having tendency to attach with bubbles: The change of surface tension and the hydrophobicity of particle in water can give a rise to bubble formation and act like the nucleation of bubble formation on the surface of particle.

Despite previous studies on scum and bubble-like foam formation, we still need to understand more about the cause and factors of scum formation in drinking water treatment plants. Furthermore, some scum problems are occurring even in drinking water treatment plants where surfactants or foaming microorganisms are hardly found. This study examines the cause of scum formation in drinking water treatment plants. Through the estimation of the operation data, a series of pilot plant experiments and chemical composition analysis of water and particles, a systematic investigation was conducted to investigate: (i) the main source of bubbles, (ii) the method of starting (triggering off) a bubble, and (iii) the main chemical functional group of scum and raw water.

2. Materials and methods

2.1. Water treatment plant

Observation and measurement were conducted in the Seokseong Water Treatment Plant (SWTP, Republic of Korea, 273,600 m^3 day^{-1}), which was designed for typical conventional drinking water treatment processes. As shown in Fig. 1, raw water originated from the Daechung Lake in the upper stream of the Keum River and flew into SWTP in order as follows: intake pump station (IS), receiving well (RW), flash Mixing chamber (MC), flocculation basin (FB), sedimentation basin (SB), filtration chamber (FC), and clear water storage (CS). Additionally, the pilot plant (24 m^3 day^{-1}) was set up on the vehicle equipped with a bubble supply device and conducted a series of experiments with two sources A and B for water and particles collected from SWTP. For the chemical composition analysis, the source A was located before

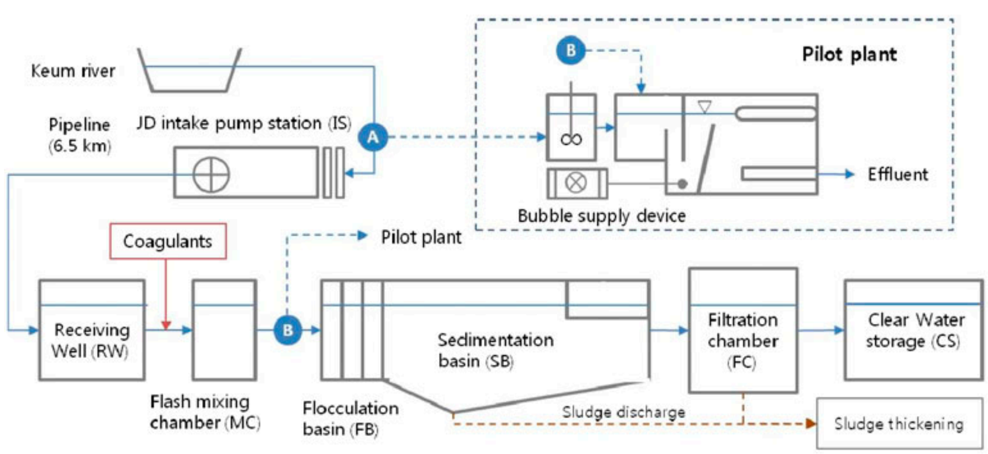


Fig. 1. Schematic diagram of pilot plant and SWTP.

IS without DO oversaturated yet, and the source B was between MC and FB with DO oversaturated. Table 1 listed raw water quality of SWTP, which was characterized as a mixture of typical lake and stream water.

2.2. Measurement and analysis methods

Liquefied chlorine was injected to oxide the ammonia ions at the point of intake well in the IS during the winter time and also to sanitize intermittent algae growth on the wall of the water treatment structure. Polyaluminum chloride was used as coagulant in the SWTP and in the additional pilot plant experiments.

Table 1
Raw water quality of the SWTP

Description mean value (range)	Description mean value (range)
pH 7.8 (7.2–8.7)	Dissolved oxygen 9.6 (7.7–12.7) mg/L
Water temp. 15.5 (14.3–17.7)℃	Conductivity 268 (195–371) μm hos/cm
BOD 3.2 (2.1–4.3) mg/L	COD 5.8 (2.9–8.3) mg/L
Suspended solid 15.3 (2.9–25.3) mg/L	Total coliforms 915 (95–2,658) MPN/mL
Total nitrogen 3.688 (0.583–4.832) mg/L	Total phosphorus 0.150 (0.035–0.350) mg/L
Ammonia 0.779 (0.188–1.890) mg/L	*Chlorophyll-a 34.2 (12.5–60.8) mg/m^3

Note: Period of data: 1991–2010.
*2001–2010.

On the basis of analysis of the annual operation data (2008), the source of bubble formation was evaluated in various types of gases suspected to generate during the coagulation, chlorination, intake pumping, etc. The pilot plant experiments were carried out intermittently under the same conditions as the SWTP. For the flotation experiments, additional bubble supply devices were applied with a typical bubble volume concentration of 5,000 mL/m^3 [10].

The water quality was measured by Standard Methods for the Examination of Water and Wastewater [11]. The chemical composition of water and scum was analyzed using FT-IR (Fourier transform infrared ray) spectroscopy (Nicolet 520P, Polaris/ICON) and FT-NMR (nuclear magnetic resonance) spectrometry (ARX-R300, Bruker, Germany). The changes in surface tension were measured with the interface tension meter (Fisher Scientific Manual Model 20, USA). The bubble size distribution of scum was investigated and compared with the bubble-floc agglomerates of the DAF process using the laser beam particle resoler of "Eye Tech" by ANKERSMID in the Netherlands.

3. Results and discussion

3.1. Scum production and source of bubble formation

The monthly scum production was calculated by measuring the accumulated height of scum on the surface of flocculation basin equipped with barrier to block the scum carry over (see Table 2). The amount of monthly scum production was large during the months of April, May, October, and November in the spring and fall. The seasonal pattern of scum production implies the influence of algal biomass or flowing

Table 2
Scum production of the SWTP

Month	Q (m^3/month)	V_{ts} (m^3/month)	V_{sc} (m^3/month)	W_{sc}/W_{ts} (%)	W_{ts}/Q (kg/m^3)	V_{sc}/Q (mL/m^3)
Jan.	1,568,498	189.0	3.4	1.43	0.14	2.17
Feb.	1,474,200	225.1	3.2	1.31	0.16	2.19
Mar.	1,559,261	244.7	15.0	4.79	0.19	9.60
Apr.	1,523,318	182.6	21.7	8.86	0.14	14.26
May.	1,577,742	231.2	23.4	7.90	0.17	14.85
Jun.	1,518,514	222.6	12.6	4.52	0.17	8.27
Jul.	1,641,723	275.7	12.5	3.86	0.20	7.61
Aug.	1,663,652	298.1	3.3	0.94	0.21	1.98
Sept.	1,793,704	228.4	12.1	4.34	0.14	6.74
Oct.	1,760,770	270.3	40.5	12.32	0.16	23.02
Nov.	1,546,486	238.2	18.9	6.59	0.17	12.22
Dec.	1,519,466	209.0	7.4	2.93	0.15	4.84

Note: Q: flow rate, W: dry weight, V: volume, sc: scum, ts: total solid (scum + sludge).

out of its sediments by turn-over in Daechung lake, which was the main source water of the SKS water treatment plant. The causative matter is discussed in the following section of the scum composition.

The causes of the bubble formation in the SWTP can be assumed as follows: (i) carbon dioxide gas is generated from the decrease of alkalinity and the oxidation of organic matters by coagulation and chlorination, (ii) nitrogen gas is formed by chlorination of ammonia, nitrite, and nitrate in the raw water, and (iii) oxygen gas is generated from air dissolution by intake, conveyance, mixing, and etc.

First, there was no possibility of carbon dioxide emission according to the calculation results from the operation data of chemicals consumption in the SWTP. Secondly, while the chemical reaction between ammonia and chorine is taking place, the chorine makes chloramines with ammonia and oxides ammonia to nitrogen gas at the final stage. The trend of nitrogen gas production was different from the scum production, which was calculated using the data of ammonia concentration and pre-chlorination dosage. Finally, the bubble formation by oxygen gas was measured in this study. The profile of DO by the water treatment processes showed noticeable changes from the flash mixing chamber to the sedimentation basin (Fig. 2). This means that the high pressure of conveyance pipeline by intake pumping inducing dissolving air has caused the bubble formation from the oxygen oversaturation. According to the operation data, three or four pumps were operated continuously among the six intake pumps of the JD IS, and the pipeline pressure at the discharge point of pump depending on intake pump operation was ranged in 8.2–8.8 kg/cm^2 under three pump operations and in 8.6–9.5 kg/cm^2 under four pump operations.

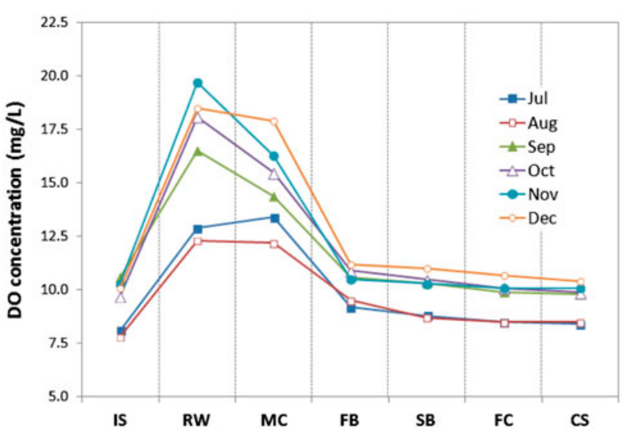


Fig. 2. Change of DO concentration by the water treatment processes.

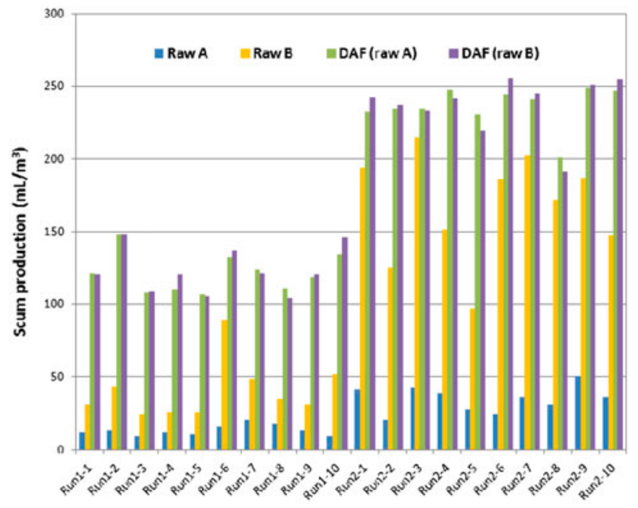


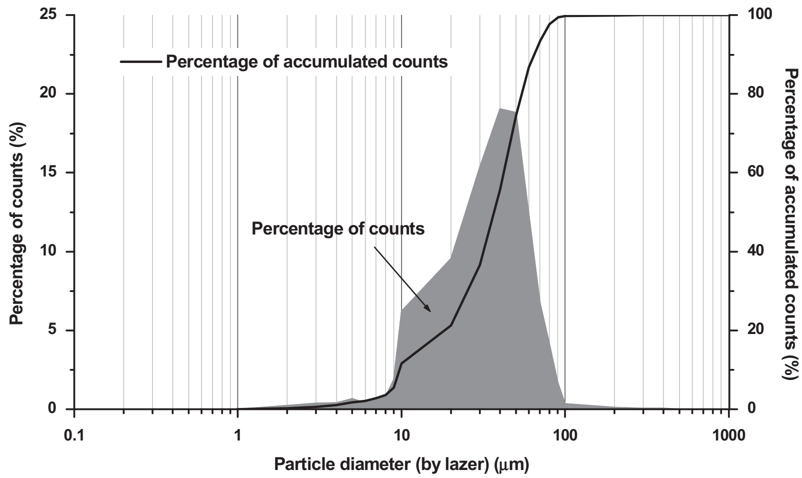
Fig. 3. Comparison of scum production for sources A and B in SWTP and pilot plant. Note: Run1: SS 2.9–3.1 mg/L, on Aug., Run2: SS 4.8–5.2 mg/L on Oct., 2011, respectively.

To verify the suggestion that bubbles were derived from the oversaturation by the high pressure of conveyance pipeline, a series of experiments were carried out using the pilot plant. The comparative experiments applying two different samples of raw water (A and B in Fig. 1) as before and after oxygen oversaturation by the pressurization of pipeline revealed a meaningful difference in two raw waters, The site A produced much less amount of scum than the site B. Bubbles were hardly observed in raw water of the site A, while a great amount of bubbles were observed on the surface of flocs and columns in the site B (Fig. 3).

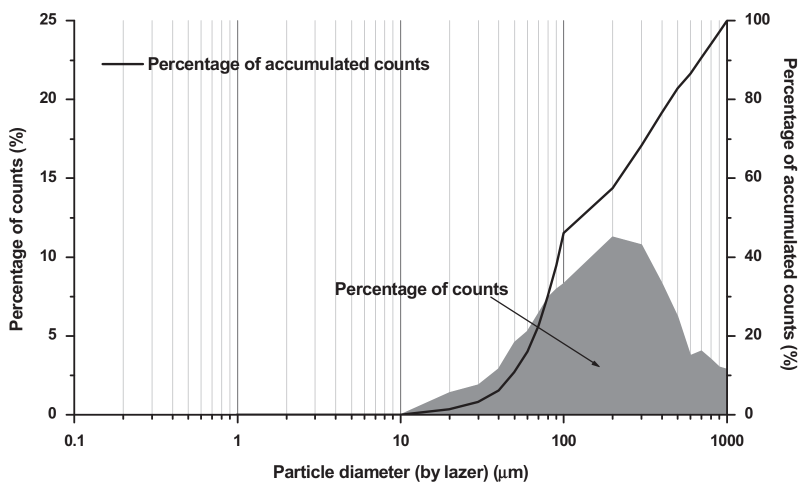
3.2. Bubble size and nucleation

We measured the bubble size distribution of scum to look into the difference from the bubble size distribution of DAF process. The mean bubble size of scum was somewhat larger, and the size of bubbles was distributed wider than the typical DAF process as shown in Fig. 4.

The exact point of bubble formation does not coincide with the decompression site of water treatment processes. Only a few large bubbles are seen at the receiving well, whose diameter is greater than thousands of micrometers. While the high pressure of conveyance pipeline is decompressed at the discharge outlet of the receiving well, fine bubbles were observed not in the receiving well but in the water flowing from the distribution channel to the flocculation basin after flash mixing the chamber.



(a) Scum



(b) DAF

Fig. 4. Comparison of bubble size distribution between scum and DAF.

Therefore, the measurement and observation of the bubbles contained scum led us to assume that there is another factor triggering fine bubble formation caused by the oversaturation of air. Many researchers have reported that nucleation is an element of bubble formation, related to the hydrophobicity of solid surfaces [12,13]. Furthermore, according to Jenkins et al. [14], decrease in surface tension makes a favorable condition for bubble formation: for instance, bubble production is increased temporarily due to biodegradation by-products of organic compounds. It is also known that coagulants such as alum change the interface characteristics in water treatment processes, and that decrease of surface tension gives rise to fine bubble formation [15].

We measured surface tension in each of the processes of the SWTP. The surface tension was found to decrease rapidly as it passes the flash mixing chamber where coagulant was injected (Fig. 5). The results indicated that the decrease in surface tension in the course of coagulation acted as a trigger bubble formation and the flocs formed by coagulation gave the hydrophobic surface to generate a bubble in flocculation basin.

3.3. Composition of scum and hydrophobicity

As described in the previous section, the decrease in surface tension caused by coagulant seems to act as a nucleation function of bubble formation. At the same time, matured flocs in flocculation basin provided sufficient interface of liquid and solid, and then, fine bubbles were generated on the surface of flocs. In addition, the chemical property of the surface of flocs

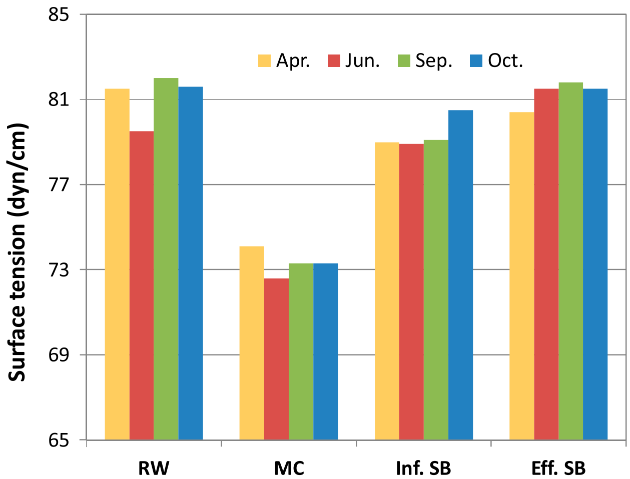


Fig. 5. Change of surface tension by the water treatment processes.

is an important factor of scum formation, which is related to hydrophobicity of particles [16].

The chemical composition of scum was analyzed to verify whether flocs in water treatment processes are hydrophobic or not by using FT-IR spectroscopy and FT-NMR spectrometry. The spectrum of scum analyzed by FT-IR was similar to sludge as shown in Fig. 6, and there were various hydrophobic compounds, such as alkanes, polysaccharides, carboxylic ion salts, etc. The two spectra showed a similar pattern in which the peaks have smooth curves at the range of wavelength 3,000–3,600 (polysaccharides), three peaks at wavelengths of 1,032, 1,100, and 2,900 (alkane series), and a peak at wavelength 1,650 (carboxylic acid salts). On the contrary, we hardly found peaks of hydrophilic compounds, such as carboxyl ion, amine group, alcohol, and so forth in the FT-IR spectrum of scum and sludge.

Furthermore, the raw water of the three main points in the water body were also analyzed, considering that the source water of the SWTP was classified roughly into two types as lake water and stream water. The lake water contained a large number of algae cells and by-products, and the stream water was influenced by nonpoint source pollution and municipal wastewater because the stream flowed through urbanized and industrial areas. The spectrums of the raw water and the lake water showed peak curves similar to scum containing the three main compounds while the stream water did not have the curve of polysaccharide.

FT-NMR analysis was also carried out to verify the results of FT-IR analysis and to investigate the hydrophobic property of the sediments in the main source

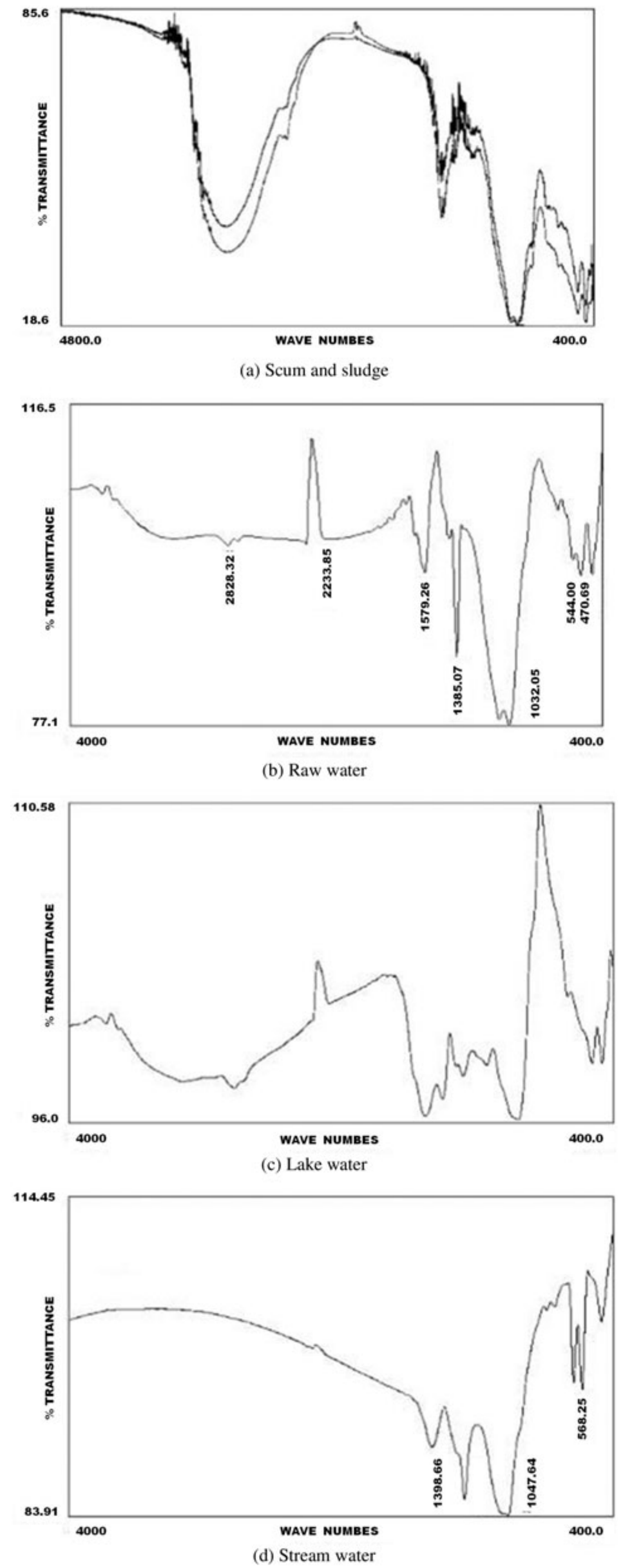


Fig. 6. Peak curves analyzed by FT-IR spectroscopy.

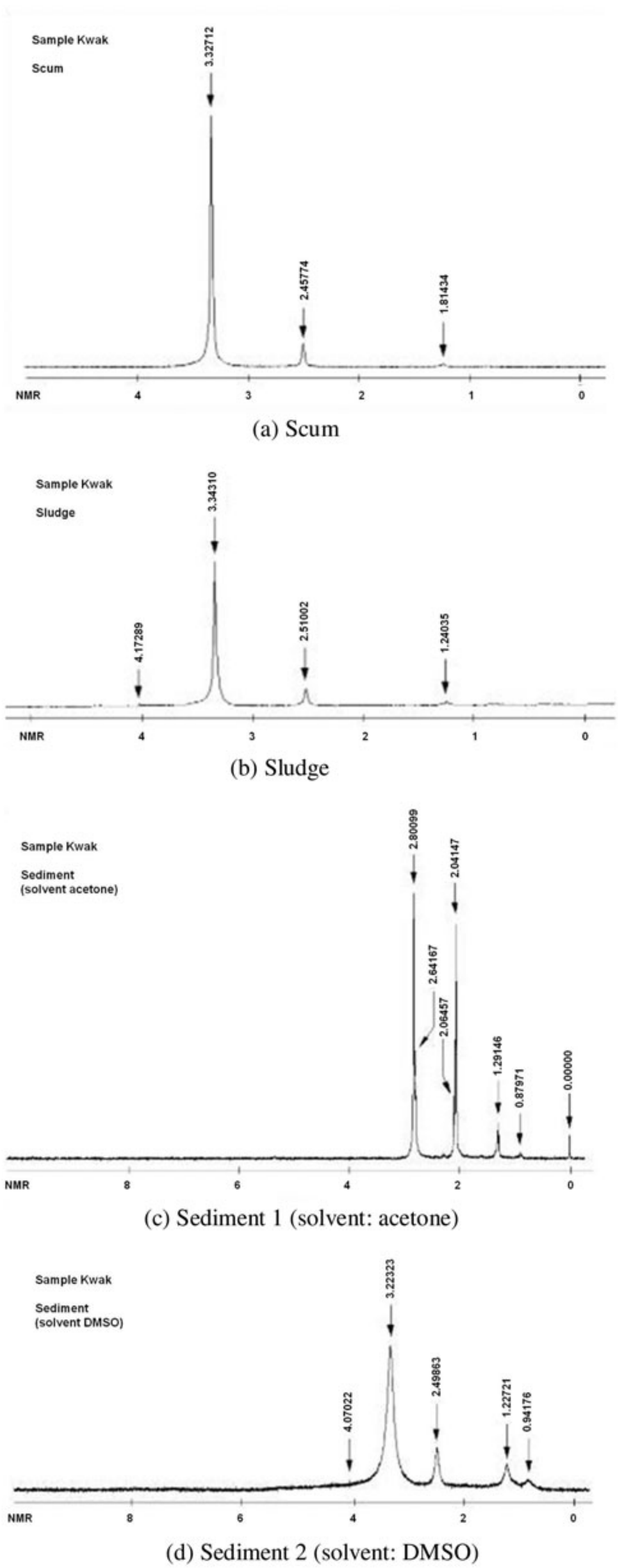


Fig. 7. Peaks analyzed by FT-NMR spectrometry.

water (Daechung Lake). The FT-NMR peaks in Fig. 7(a) and (b) show a similarity of scum and sludge. The peaks at 0.86 and 1.24 ppm in Fig. 7(c) and (d) sampled from the sediments are thought to be small molecule compounds derived from δCH3 or δCH2 while the peak at 3.34 ppm is derived from δH2O (water) and the peak at 2.51 ppm is derived from δH (solvent).

4. Conclusions

The cause of scum formation in the drinking water treatment plant was investigated through a series of pilot plant experiments and chemical composition analysis in the SWTP on the basis of operation data analysis. The measurement results of the water treatment processes indicated that bubbles are formed from the oversaturated dissolved oxygen. The pilot plant experiments proved that the source of bubbles is the oversaturated air caused by the high pressure of conveyance pipeline from the intake pumps operation.

Micro-bubbles were observed not in the receiving well where the pressurized raw water in the conveyance pipeline was decompressed instantly but in the flocculation basin after alum dosing. The results of observations and experiments led us to conclude that the oversaturated air is stimulated to form bubbles by the decreasing surface tension derived from the coagulants and that bubbles are generated mostly on the surface of flocs where is the interface of liquid/solid. Finally, the results of the chemical analysis using FT-IR spectroscopy revealed that scum contains various hydrophobic compounds, such as alkanes, polysaccharides, and carboxyl ion salts.

Therefore, to prevent or to reduce scum formation, operators need to avoid excessive increase in pressure of pipeline as mixing with air during processes of intake pumping and conveyance and further researches are required to establish uncertainty of causes and factors for scum formation in the water treatment plants in detail.

Acknowledgments

This research (NRF-2012R1A1A4A01010342) was supported by the National Research Foundation of Korea (NRF) with grants from Ministry of Education in Korea, 2013. In addition, I appreciate to Dr Mi-Sug Kim in Korea Urban Regeneration Technology Institute who gives us professional advice to complete this paper and experiments.

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