The effect of acid cleaning on a fine pore ceramic diffuser aeration system

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Abstract Fine pore ceramic diffuser aeration, a very competitive high efficiency system, is widely used in aerobic biological processes for providing dissolved oxygen and mixing. Concern has been registered regarding the maintenance of these systems and their susceptibility to diffuser fouling. Selected ceramic diffusers, removed from the Madison Metropolitan Sewage District (MMSD) Nine Springs Wastewater Treatment Plant, Wisconsin, U.S.A., were fractured and analyzed in an attempt to identify the elemental components of the internal foulants and to evaluate the effect of acid cleaning on diffuser performance. The fouling condition of diffusers were initially characterized by dynamic wet pressure (DWP) measurements. Microimages taken from the non acid-treated diffuser profile using scanning electronic microscopy revealed the structural difference of internal foulants which may correspond to the stage of foulant formation. For diffuser samples from the MMSD facility, calcium phosphate minerals were predominant foulants, although some calcium carbonate and organic carbon have also accumulated. The clogging of diffuser internal void space was verified by observing thin sections of diffuser cross-sections. Selected diffusers were then treated with strong acid to study its effectiveness in removing internal foulant by acid soaking. Even though the acid treated diffusers showed significant reduced DWP values, acid treatment, the common diffuser cleaning technique, does not completely remove these internal foulants. This may be the reason why the acid-treated diffusers never reached like-new conditions. Furthermore, once these acid-treated diffusers are installed back to the aeration tank, these dewatered foulant sections may very well behave as seed for future clogging.

Keywords Fine pore; ceramic diffuser; acid treatment; fouling; calcium phosphate

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Introduction

This research was prompted by fine bubble aeration system performance problems experienced at Madison Metropolitan Sewerage District's (MMSD) Nine Springs Wastewater Treatment Plant, Wisconsin, U.S.A.. Operators reported difficulty in obtaining sufficient air flow through the ceramic disc diffusers in some aeration basins six years after installation. This problem was not observed in all tanks and could not be directly related to operating procedures.

Diffuser clogging (or fouling) can be characterized by a build-up of material on the surface or within the structure of the diffuser during operation. The clogging of diffusers may cause deterioration of aeration efficiency and an increase in back pressure resulting in a corresponding escalation of power cost. Furthermore, inadequate supply of oxygen may consume a substantial amount of operating time and an effluent that may not meet the discharge permit. It was clear even in the early years of fine bubble diffusion that clogging was highly site specific and quite often difficult to forecast (Boyle *et al.*, 1983). Diffuser fouling was chronic at some plants after only a few months of operation, yet, at others, virtually no difficulties with fouling arose. Roe (1934) outlined two sources of diffuser clogging, air side and wastewater side. Impurities, such as dust, oil, inorganic fines, and wastewater solids from both directions deposited on diffuser surfaces and induced diffuser fouling.

Diffuser cleaning methods at MMSD including High Pressure Hosing (HPH) and Milwaukee Method (Surface Acid Spray followed by HPH) were applied to improve the system performance. The results showed that surface biofilms could be easily removed by applying water hosing but acid treatment on the surface did not restore the diffuser to like-new conditions. This was because a significant amount of foulant had developed below the diffuser surface. Most investigations (Houck *et al*., 1981; Rieth *et al*., 1990; Kim and Boyle, 1993) of diffuser fouling focused only on external fouling (located on the diffuser surface) and did not consider the possible effects of internal fouling. Thus, the results of these investigations have been limited in application where significant internal fouling may be present.

The objective for this research was to obtain a better understanding of the internal fouling in ceramic diffusers and the effect of acid cleaning on internal foulant removal. Selected diffusers, removed from several locations in the problem basins, were fractured and analyzed in an attempt to identify the elemental components of the internal foulants and to evaluate possible relationships between foulant components and performance. Dynamic wet pressure (DWP) is a measure of resistance to flow at a given airflow rate, expressed in centimetre of water. Organic foulant was measured by using a Total Organic Carbon (TOC) analyzer. Energy Dispersive X-Ray Spectroscopic (EDXS) analysis was used to identify inorganic foulants and to obtain diffuser profile images. Analysis of diffuser thin sections also revealed detailed understanding of internal foulants.

Materials and methods

Field diffuser collection and characterization

The wastewater level in the first pass of a selected aeration basin (three passes) at the MMSD facility was lowered to about 10 cm above the top of the diffusers. Diffuser aeration patterns were observed and were categorized as good, intermediate, and poor wastewater mixing. Diffusers located in the areas for each category were collected and returned to the laboratory in zipper storage bags to maintain moisture. The first pass of each aeration basin contained three grids of diffusers. All diffusers were labeled using numbers corresponding to their “Grid-Row-Order” position in the system. Grid number corresponded to the location of the diffuser grid measured from the head of aeration tank and the row number corresponded to the row of diffusers from the right-hand wall when facing the direction of flow. The order of diffuser was assigned according to its sequence on the row. External foulants, biofilms on the top, were washed away by high-pressure water hosing followed by a DWP measurement (EPA, 1989) for all the diffuser sample. Additional diffuser cleaning was performed as specified on selected diffusers by submerging each diffuser in 16% hydrochloride acid for a giving period of time.

Internal foulant visualization by thin section technique

Thin sections (FitzPatrick, University of Aberdeen) of a non acid-treated diffuser (G2-R2-15) were prepared by cutting off a diffuser sample with a diamond saw to a size of about 5cm × 1cm × 2cm. Rough parts on these first-cut faces were removed by using a silicon carbide disc (280 grit) and polished by a 70 mm diamond disc. Another 30 mm diamond disc was used for further polishing. Vacuum impregnation (low pressure: 10-15 mm Hg) with a mixture of resin and blue dye was applied to these polished porous diffuser samples. The resin-saturated diffuser slices were then bonded to clean glass slides. The glass slides were of a precise and standard thickness. Bonded sections were next cut with a diamond blade to form a parallel second face, leaving a slice 300-400 mm thick on the slide. These specimens were first roughly ground 100 mm thick then trimmed to a final 30 mm thick section by a precision lapping machine. Photographic images of the diffuser thin section were taken by using Nikon Optiphot-POL microscope (FX-35WA) equipped with a Photomicrographic Attachment Microflex UFX-IIA camera unit.).

Internal foulant analysis by SEM

Avoiding disruption of the foulants on the surfaces, diffuser sample profiles, acid-treated or non-treated before breaking, were obtained by first breaking the diffuser into rectangular-shaped pieces by scoring one side with a diamond grinder and cracking it. The rectangular piece was then broken into smaller pieces using a hammer and a small wedge until a properly sized sample, approximately 1.5 cm × 1.5 cm × 1.0 cm, was obtained. Care was taken at all times to avoid contamination of the pieces with dust from grinding or metal fragments from the grinder or wedge. Slices were dried at 103°C for one hour and desiccated until mounting. One side of the diffuser slice was smoothly ground on a belt sander to ensure good contact. The slice was then mounted on a 2.54 cm diameter cylindrical aluminum specimen mount using double-sided conductive carbon tape and grounded to the mount with conductive carbon paint. The carbon paint covered at least two edges of the test slice, from the top to the bottom, to provide good conductance. The specimen was then coated with carbon to a depth of 800 Å in a high vacuum carbon coater. Photographic images of the diffuser specimen were taken at high magnifications by using a Scanning Electron Microscope Model #801C-ISPS (Noran Instruments). Energy Dispersive X-ray Spectroscopic (EDXS) Analysis was also performed on the specimen using the same SEM to analyze the inorganic elements of the internal foulant found in cross-sections of the field samples.

Other analytical methods

For organic foulant analysis, selected diffuser pieces were carefully crushed to a fine powder with a hammer and brickcracker. Fouled parts and non-fouled parts of the diffuser were separated avoiding any cross-contamination. These diffuser segments were preserved in a vacuum decanter for analysis. Total carbon (TC) of these diffuser powders was then measured using a TOC analyzer specialized for solids analysis. The TOC analyzer was operated at 620°C so that all carbon content including carbonates was determined. Some of the test diffuser powders were pre-treated with acid, for analysis of organic carbon concentration only.

Results and discussion

Diffuser characterization

Diffuser DWP values were evaluated in two ways: first, by determining the DWP at one airflow (usually 1.68 standard m^3/hr of air (1 scfm)) for all diffusers after removing surface biofilm, and second, by comparing the DWP values change for each diffuser before and after acid-cleaning. For a new ceramic disc diffuser the DWP was typically 12 to 15 centimetres of water at 1.68 standard m^3/hr (1 scfm). Measured diffuser DWP values from field samples ranged from 25 centimetres of water to more than 750 centimetres of water at 1.68 standard m^3/hr of air (1 scfm). Some diffusers were so heavily fouled that airflow through the diffuser could not be achieved to measure their DWP values. After determining the field DWP value, different levels of acid cleaning were performed on some diffusers. Results from selected diffusers are listed in Table 1. It is apparent that acid soaking reduced the DWP value dramatically but not to a like-new condition (12 to 15 cm of water). After four hours of acid soaking, the test diffusers were dried and stored uncovered at room temperature for a week. This drying process apparently affected the character of diffuser foulant since the DWP value was observed to decrease to approximately like-new conditions (Table 1). This phenomenon may have been caused by the dewatering and shrinking

Table 1 DWP monitoring results from selected diffusers

Diffuser #	Airflow scfm†	Field DWP* (cm)	Acid soaked one hr**	Acid soaked two hr	Acid soaked 4 hr	Dry***
new	3.0	17.22				
	2.0	16.51				
	1.0	16.51				
G1-R6-9	3.0	83.29	59.72	60.30	69.32	24.97
	2.0	56.03	40.06	37.90	43.46	20.14
	1.0	28.68	28.68	27.56	30.02	17.73
G2-R3-40	3.0		145.87	69.27	81.03	32.56
	2.0	537.64	69.01	42.37	51.74	27.74
	1.0	206.76	40.74	27.20	30.02	20.50
G3-R3-33	3.0	284.23	90.04	68.22	67.23	25.65
	2.0	160.15	50.06	45.47	45.19	21.87
	1.0	79.40	30.40	28.58	29.67	18.42

† scfm = 1.68 m^3/hour
* DWP values were measured after removing the surface biofilms by water hosing.
** 16% HCl was used for acid soaking .
*** Diffusers were stored in room temperature for a week without cover.

of trapped materials which were not removed by the acid treatment inside the diffuser structure.

Diffuser internal foulant visualization by thin section technique

Thin sections of diffuser G2-R2-15 (DWP equaled 319 cm of water measured at 1.68 standard m^3/hr of air (1 scfm)) were prepared for light microscopy observation. Figure 1 shows a complete diffuser section (vertical cut and a horizontal cut made 7 mm below the diffuser surface). The vertical-cut image shows a well preserved diffuser profile. A band of impurities (internal foulants) occupies the diffuser internal space between 5 mm to 10 mm below the top surface while the rest of the diffuser (above and below the band) is free of significant foulant. The clean area just below the diffuser surface has been the result of regular acid washing at the top of diffuser surface by the MMSD operators. The horizontal cut through the foulant band (Figure 1) clearly shows the void space decreased by internal foulants. Higher magnification thin section images reveal that ceramic diffusers are composed of two basic parts: AlO_2 granules and a clay matrix which holds the AlO_2 granules together. Impurities closely attach to the clay matrix instead of the AlO_2 granules. This suggests the possibility that internal foulant formation is the result of impurities from wastewater that first attach to the clay matrix and then grow toward the open voids.

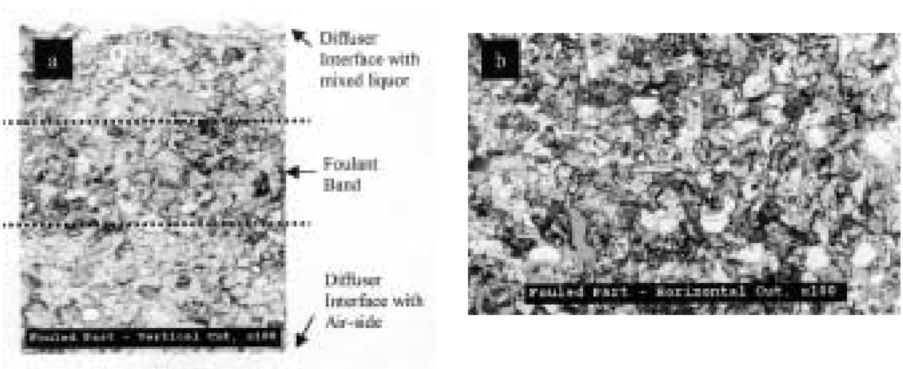

Figure 1 Light microscopy diffuser thin section – a) vertical cut (left) and b) horizontal cut through fouled section

Ceramic disc diffuser profile by SEM

Figure 2 is a photomicrograph taken from a selected piece of diffuser G3-R4-1 (heavily fouled, its DWP equaled 733.5 centimetres of water measured at 0.67 standard m^3/hr of air (0.4 scfm)). Figure 2a was taken from the lower part of the diffuser, a section which is equally free of significant foulant. The lower part of diffuser has less chance to come into contact with wastewater, and, thus, has less chance for developing internal foulant. Figure 1a shows many open spaces in the ceramic diffuser. No impurities were found in diffuser internal structure. Figure 2b was taken from the upper portion (0.5 cm below the top surface) from the same diffuser G3-R4-1. This portion of the diffuser was in direct contact with the wastewater. Suspended solids from the wastewater, biofilms on the diffuser surface and within the pores, and wastewater permeating the diffuser all may contribute to the formation of internal foulant. In Figure 2b, the internal fouling marked by bright and flower-like materials, occupies the spaces between the dark-colored ceramic bodies. These internal foulants reduce the pore volume in the upper portion of diffuser profile creating a resistance to flow and resulting in increased head loss through the diffuser at a given airflow rate. After an extended operating period, some diffusers (those with higher foulant accumulations) will have lower airflow than others. This will lead to poor airflow distribution along the header and lower oxygen transfer rates. Furthermore, the lower airflows in a given diffuser will exacerbate the fouling process.

Figure 3a was taken from a fouled portion of diffuser G2-R3-11 (slightly fouled, its DWP equaled 42.7 centimetres of water measured at 1.68 standard m^3/hr of air (1 scfm)). The void spaces between the rigid ceramic bodies were occupied by foulants. The impurities appeared to accumulate along the internal diffuser void surface and gradually filled the active void. Foulant then moved towards the remaining voids in the channels. Four elements, including calcium (Ca), phosphorus (P), potassium (K), and magnesium (Mg) were measured for this diffuser section and are shown in Figure 3b which is an EDXA dot map. The locations of calcium and phosphorus are coincident and the Ca-P distribution matches the visual image of internal foulants (Figure 3a). This suggests that calcium and phosphorus may be the major components of the internal foulant in this diffuser. The molecular configuration of the Ca-P compound, however, is still unknown. Potassium and magnesium were spread throughout the diffuser profile. There were also no observed concentrations of elements including iron, sodium, and sulfur which are not shown in Figure 3b. Two types of internal foulants were observed as shown in Figure 3. The left-side portion exhibited brighter colors and a more compacted structure than the foulant at the right-side. Also from its dot map, the compacted structure portion exhibited a higher concentration of Ca-P compounds than the portion with the loose structure. EDXA revealed that the loose structure was mainly composed of unidentified material which showed no metal element response. Two hypotheses may be suggested for these formations: (1) The loose internal fouling

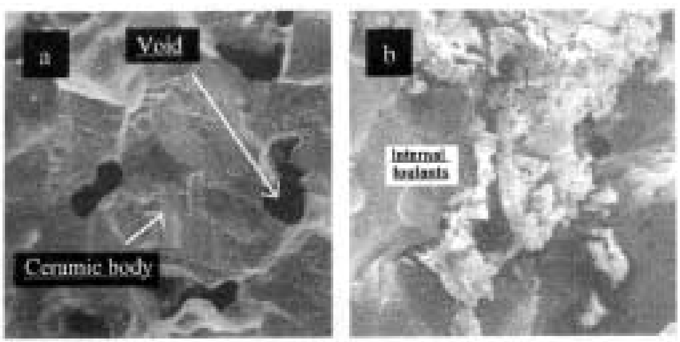

Figure 2 Diffuser profiles, non-fouled part of the diffuser (2a, left) and fouled part (1b, right)

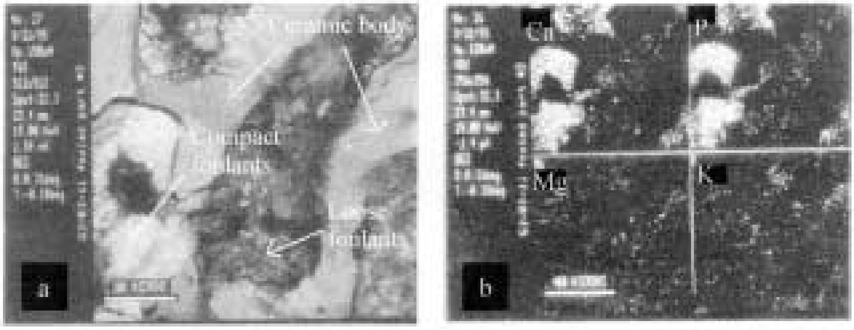

Figure 3 Internal foulant image from diffuser G2-R3-1, a) profile image (left) and b) EDXA dot map (right)

portion may be in the early stage of foulant formation. Its structure will become more compacted after a given operating period. (2) The compacted structure is composed mainly of Ca-P compounds and can be referred to as inorganic fouling. The loose portion, on the other hand, may be composed of organic material with some Ca-P compounds trapped within its structure.

Figure 4 is a photomicrograph taken from the fouled part of diffuser G1-R5-36 11 (slightly fouled, its DWP equaled 21 (before acid soaking) and 13 (after acid soaking) centimetres of water measured at 1.68 standard m^3/hr of air (1 scfm)) which was acid soaked for three hours. Compared to a non-acid-treated diffuser like that shown in Figure 2a, this diffuser has more open spaces between the ceramic bodies. It shows that the internal foulants have been attacked by the strong acid resulting in smaller foulant sections. The cracking of internal foulants is also observed. As shown in the figure, however, the acid soaking did not completely remove the internal foulants. This may be the reason why the DWP value from the acid-treated diffusers never reached a like-new condition. Furthermore, once these acid-treated diffusers are installed back to the aeration tank, these dewatered foulant sections may very well behave as seed for future clogging.

Organic foulant analysis

Several diffusers with and without acid soaking treatment were powdered in an attempt to determine the carbon composition of the internal foulants. Average TOC concentration of diffuser fouled portions and non-fouled portions were 71.4 ppm and 9.7 ppm, respectively. Even after three hours soak with 16% HCl, the fouled portion of diffusers still exhibited an average TOC concentration of 65.3 ppm. Several observations can be made from these results.

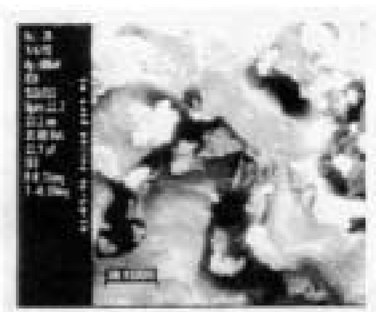

Figure 4 Diffuser fouled part (after 3 hr acid soaking)

1. The carbon concentration of the fouled sections (upper portion of diffuser) are much higher than carbon concentration in the non-fouled portions.
2. Diffusers with high organic carbon concentration appear to have higher DWP values than those with lower carbon. However, no linear relationship can be determined from these abbreviated studies.
3. One hour acid soaking with 16% HCl may not be sufficient for the foulant removal in these diffusers.
4. Even up to 3 hours acid soaking with 16% HCl could remove internal foulants only up to a point. It is speculated that for this site, most of the foulant removed was likely calcium carbonate. The majority of residual foulants consisted of organics and Ca-P complexes.

Based on these observations, it may be concluded that for the MMSD facility, acid washing/soaking may not be an optimum diffuser cleaning method for internal foulants even though this method is widely used for removing surface foulants.

The observations of ceramic diffusers at the MMSD facility indicate that, over a period of time, foulants have penetrated into the diffuser cross-section, most likely from the mixed liquor side. Penetration of mixed liquor within the diffuser will occur during power outages. In addition, wetting of the diffuser into the cross-section likely will occur during normal operating conditions, but especially as airflow is reduced. The wetting and drying cycle that will occur could conceivably result in precipitation and sorption of inorganic constituents. Furthermore, the inflow of mixed liquor could also result in the development of active biofilms within the diffuser.

Cleaning of the diffusers with high pressure hosing and surface acid sprays have apparently not resulted in the removal of foulants lodged within the diffuser cross-section. This has ultimately resulted in increased back pressure with concomitant reduced airflow to selected diffusers. A reduction in airflow to a diffuser will likely exacerbate the internal fouling process and will also result in mal distribution of airflow to the air grid. Once internal fouling has developed, it appears that rehabilitation of the diffusers is not a simple process. Extended acid soaking has not effectively cleaned diffusers to like-new condition although extensive resting may prove satisfactory.

Conclusions

Identification of internal foulants in ceramic diffusers provides additional information on the very complex phenomena of diffuser fouling. By using the diffuser thin section technique and scanning electronic microscopy equipped with energy Dispersive X-Ray Spectroscopic (EDXS) analysis, the identities of internal foulants were revealed. At MMSD, a hard water area, calcium phosphate minerals are the predominant internal foulants, although some calcium carbonate and organic carbon have also accumulated. Microimages from acid-treated diffuser profile showed that the internal foulants were attacked by the strong acid resulting in smaller foulant sections. However, the acid soaking did not completely remove the internal foulants. This may be the reason why the acid-treated diffuser never reached a like-new conditions. Furthermore, once these acid-treated diffusers are installed back to the aeration tank, these dewatered foulant sections may very well behave as seed for future clogging. Based on these findings, it was concluded that acid washing/soaking is not an optimum diffuser cleaning method for the internal foulants even through this method is widely used for removing surface foulants.

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