# Clogging and cleaning of fine-pore membrane diffusers

**W. Frey* and C. Thonhauser****

* *AAB-Consulting, Hofgartenstraße 4/2, 2100 Korneuburg, Austria; (aab.frey@aon.at)*
***Institute for Geochemistry, University of Vienna, Althanstraße 14, 1090 Austria; (christian.thonhauser@univie.ac.at)*

**Abstract** Causes for the increase of the pressure loss of fine bubble diffusers made of elastomers were investigated. Methods are described for removing clogging material from membrane diffusers and/or attenuating or even avoiding the formation of clogging deposits. On the basis of some practical examples the procedure is discussed and obtained reductions of pressure losses are specified.
**Keywords** Acid treatment; aeration systems; cleaning; clogging; fouling; membrane diffuser; pressure loss

## Introduction

A prerequisite for a well-functioning activated sludge plant is an aeration system that does not show a steady increase of the diffuser backpressure.

Fine-bubble diffusers made of "rigid-porous" material are known to exhibit a rising pressure loss during the length of application (EPA 1989, Keller 1982). Observations in the last years have clearly shown, that pressure increase also occurs on membrane diffusers, in some cases already after a short period of operation (i.e. within a few weeks).

The operation of the WWTP is more or less strongly impaired depending on the extent of the blockades. The following effects are observed:

- A higher backpressure of the diffuser arises causing an increased energy demand for the blower.
- Diffuser elements are damaged. The damage reaches from overstretched and/or torn membranes to deformed and/or broken bases.
- If positive displacement blowers are installed, an overloading of the drive unit will arise which may result in a breakdown of the blower.
- If the surge point of the turbine blower is exceeded, the air supply will fail completely. Also the oxygenation is limited, because the airflow has to be reduced considerably.

## Known influences on backpressure increase

### Pore size

Since the main influence on diffuser head loss is the formation of deposits in and above the pores, it is quite obvious that membrane diffusers with larger pores will build up additional backpressure not as fast as (“high-efficient”) diffusers with fine pores.

It is still unclear, whether backpressure increase is caused by a uniform decrease of the active pore openings or by the complete closure of a considerable percentage of the pores. However, microscopic images from several clogged membranes suggest that the increase in backpressure is a function of the ratio of fully closed pores and more-or-less open ones.

### Deposits of fine-grained material from compressed air

Although possible and observed, the contribution of fine grained material (atmospheric dust, fibres from air filters, corrosion products, oil etc.) from the compressed air, deposited dry or entrapped in the water at the pore sidewalls was negligible at all plants investigated. While the total amount of material transported by the air may differ, the lack of mechanisms for the deposition of small particles from a high-speed air stream is evident, even if electrostatic phenomena in the aeration system are taken into account.

## Changes in material properties of diffuser membranes

Many studies on the loss of elasticity of membrane materials have been performed, and it is understandable, that a decreased elasticity will result in the demand for higher air pressure for fully opening the diffuser pores.

Although the occurrence of microbial digestion of softeners in the membrane material cannot be excluded, the actual influence of such processes seems to be negligible compared to the impact of the deposition of inorganic and organic precipitates in the pores.

A measurable loss of elasticity has been proven to occur over a period of several years, while backpressure increase by diffuser clogging is a short-term process (weeks to months), at least at the plants worst affected by this phenomenon.

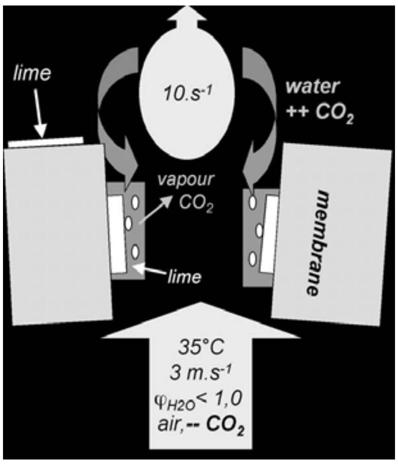
## Direct impact of microorganisms

Membrane samples from six “problem plants” investigated by means of reflective microscopy and electron beam microanalysis did not show evidence of clearly textured organic material in the relevant areas of the diffuser membrane. Even at resolutions below 1 µm, not any sign of cellular structures could be found.

Since chemical identification of the present organic matter is de facto impossible, it cannot be ruled out that a considerable part of the organic substances present in the pores originates from metabolic products of microorganisms, loosely bound to the membrane surface or even floating free in the surrounding activated sludge.

However, existing theories on diffuser fouling by microorganisms do not give a plausible explanation for the particularly tight contact of organics with the smooth surface of the membrane material. Due to the considerable air speeds in the pores, this tight contact is a necessary prerequisite for a significant contribution to diffuser head loss.

## Carbon dioxide equilibrium




Clogging of diffuser membranes by limescale and, more generally, its deposition on the membrane surface is a long-known and particularly important influence on diffuser backpressure.

Formation of limescale is linked to water hardness and the fact, that the activated sludge in the tank is carbon dioxide saturated (pH 7 or lower), while the air passing through the pores is virtually free of $CO_2$ (< 0,1 %), thus leading to a significant pH-increase in the water on the pore sidewalls and therefore to a decrease in $CaCO_3$ solubility. The presence of water on the pore sidewalls is thought to be the result of a water flow to and from the pore, induced by a pulsating pressure difference at the interval of air bubbles being formed / released (Figure 1)

**Figure 1** Theory of formation of limescale deposits: Cross-section through diffuser pore: Physical properties of the compressed air, bubble release frequency, $CO_2$ equilibrium

Although the reasons for this phenomenon are easily understandable, little attention has been given to the impact of pH in conjunction with the basic hydrochemistry of the wastewater, since

- This parameter also controls the formation of other inorganic precipitation products.
- It is possible that other, not that easily soluble, inorganic substances are formed by re-dissolution / metasomatic change of freshly precipitated limescale (e.g. earth alkali phosphates).

## Recently identified influences on backpressure increase

### Aqueous chemistry of wastewater / activated sludge

As mentioned above, the presence and concentration of certain dissolved substances in wastewater increases the risk of formation of deteriorating deposits in and on the diffuser membranes. The actual risk of clogging is strongly dependent on the pH conditions in the aeration tank which are a result of buffer capacity (carbonate hardness), microbial activity and physical properties of the activated sludge (e.g. temperature, turbulence). Since silicic acid has been identified as the most common cloggant, the problem gets even more complicated: At a lower pH, most of the potentially precipitating inorganics are kept in solution, whereas silicic acid, present in natural water, is transformed into a colloidal species or even precipitated.

Calculation of solubilities in a particular activated sludge is possible, but the results should be interpreted very cautious, even if

- Analysis data are reliable and comprehensive.
- Activities (instead of concentrations) have been calculated.
- Experimental solubilities have been applied instead of simple thermodynamical solubility products.

Nevertheless, calculations based on reliable data for all inorganic substances correlate with the relevant cloggants found in the diffuser pores and can give a rough idea, if optimising process parameters (added chemicals, nutrient concentrations, pH) is an option for the improvement of the situation.

### Physical properties of the compressed air

Although there is some chance for the formation of condensate in the aeration system, the compressed air at the diffuser elements is usually unsaturated with respect to water. In addition, air temperature at the diffuser elements may be elevated compared to the ambient air temperature. And third, the air speed in the diffuser pore is in the range of several metres per second (e.g. 2 – 5 m/s). The resulting increased evaporation rate of water in the pore leads to substances concentrations that exceed the corresponding concentrations in the aeration tank and therefore promote the non-specific precipitation of (inorganic) salts.

### Electrically charged particles in the air and colloids in the activated sludge

The properties of pressurised air also stimulate the formation of electrically charged particles (mainly air molecules) by electrostatic interaction with non-conductive parts of the aeration system.

When these charged particles are formed by friction of air with the static parts of the aeration system and finally reach the diffuser pores, colloids present in the water at the pore's sidewalls or in the close vicinity of the pore can be discharged and subsequently precipitated.

## Diffuser cleaning and maintenance – known methods

For some cleaning methods the aeration tank has to be emptied, whereas for others the plant operation can fully be maintained (Cleaning in Process, CIP). The procedures on an empty basin can be further divided into such, where the diffusers have to be deinstalled and such where the diffusers can remain installed in position. Cleaning can be carried out mechanically or chemically. Different cleaning methods have been summarised previously (EPA, 1989).

"Conventional" blockades (e.g. lime precipitation) can be removed by acid dosing (Bretscher and Hager 1983; Deutsches Patent, 1984). The method fails however in the case of non-acid-soluble bonds.

The method of removing deposits by a short-term high airflow and the associated strong stretching of the membranes (ATV, 1997) is not always successful. When applying this method, the control strategy for the plant, the effluent quality and the costs caused by the high loading of the blowers have to be taken into consideration.

More successful is the mechanical cleaning with a high-pressure cleaner. Before the cleaning, the tank has to be drained down to the diffuser level. It is recommended to leave the diffuser elements covered with water (e.g. 0.1 m). The diffusers can remain installed and should be operated with little airflow. A high-pressure water jet is applied several times onto the diffuser surfaces. It is important to work with a dirt blaster rotary nozzle.

## Recent methods of controlling membrane diffuser backpressure

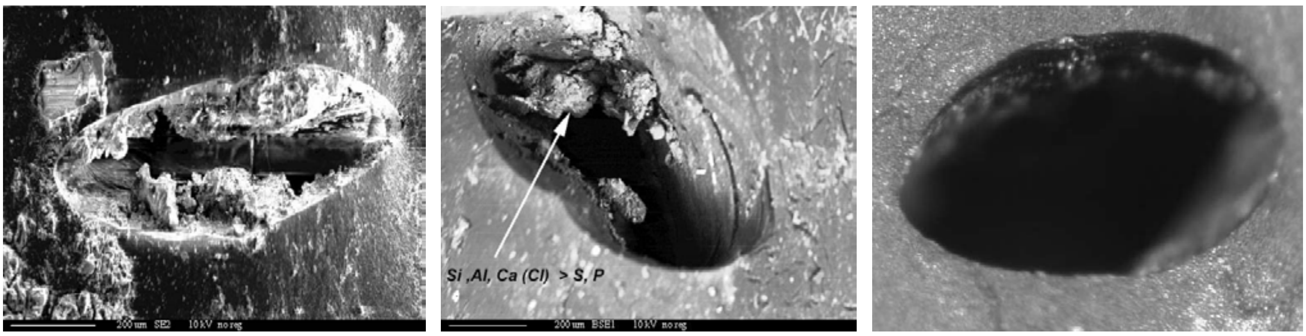
The idea of 10+ years maintenance-free fine bubble aeration systems will remain an illusion. Even if other preventive measures are taken, service intervals of 2 to 4 years seem to be realistic.
When considering maintenance procedures, the following main aspects should be taken into account:

- To keep the plant in full operation, the emptying of tanks should be avoided, whenever possible.
- In most cases diffusers and membranes are high-quality products that could serve for many years. The frequent exchange of clogged, but otherwise intact membranes can be replaced by a cleaning procedure that re-establishes a “like-new” condition of the membranes and is fully compatible with the used (membrane) materials, emphasising corrosion control.

### Cleaning in operation - CIP

The periodical cleaning of installations in contact with liquids containing organic substrate, nutrients and microorganisms is a common practice. The cleaning intervals vary from hours to month (e.g. in the food and beverage industry; “CIP- cleaning”), and highly efficient cleansers, usually alkali-based, as well as elevated temperatures are used for this purpose.

A cleaning agent and procedure have been developed, making use of the existing infrastructure and the knowledge from other industrial cleaning applications. As presented further below, cleaning success can be reported from several large wastewater treatment plants. The cleaning results have been confirmed by means of microscopy / electron beam microanalysis and backpressure measurements at a constant airflow. Figure 2 shows clogged and clean pores from plant 1.




Pore before cleaning

Pore after cleaning with ca. 1 Mol/l HCl with membrane dismantled

Pore after alkaline – oxidative “cleaning in operation”

**Figure 2** Cleaning success studies Plant 1, electron beam microanalysis

The core features of the cleaning procedure are:

- The aeration tank remains filled ("cleaning in operation").
- Vertical air-droplegs and dewatering hoses are used for supplying and removing cleaning solution and flushing water.
- The cleaning solution is pressed through the membrane pores by means of compressed air.
- Once in the pores, additional mechanical cleaning action is achieved through release of finest bubble oxygen from the cleaning solution.
- The alkaline cleanser removes organics as well as silicic acid, latter being present in the diffuser pores at virtually all "problem plants".
- Oxidative effects from the cleanser support the removal of deposited organic material.
- A non-foaming surfactant establishes an intense contact of the cleaning solution with the pore sidewalls, allowing oxygen bubbles to be released even underneath the solid deposits and blasting off major portions of the cloggants.
- Strong chelating agents promote the dissolution of acid-soluble earth-alkali salts (e.g. phosphates, carbonates).
- The cleaning agent does not affect the microbial processes in the aeration tank.

## Air humidification by means of aerosols

The potentially negative contribution of a dry, warm and high velocity air stream on diffuser fouling consists of:

- Accelerated evaporation of water in the pore (water films on the pore sidewalls) and therefore activities / concentrations of all – inorganic - species closer to their solubility product than in the activated sludge.
- Promotion of electrostatic effects (at least below ca. 60 % relative humidity), leading to electrically charged particles in the aeration system and as a consequence to the precipitation of certain colloids (organic and inorganic) in and around the diffuser pores.

Although the accelerated evaporation has been known for decades (see e.g. US patent 2,689,714, 1954), the problem of transformation of injected water from liquid to gas has not been solved so far. High air speeds in the aeration system - and the resulting short times for establishment of an equilibrium-demand µm-sized drops (aerosols).

Aerosols of fully demineralised water are generated in the air mains of two plants by means of high pressure spraying nozzles, giving a minimum 80 % of relative humidity at every point of the aeration system (conditions in the diffuser pore extrapolated / calculated).

Until now, the results have been ambivalent, additional and detailed research has to be done to make the impact of air humidification on diffuser backpressure increase more predictable. Results from test plants are discussed further below.

## Methods linked to electrostatic / colloid- precipitation processes

### Example for the relevance of electricity

At a large WWTP (Plant 1), the tanks were equipped with cathodic corrosion protection. When filtered through black ribbon paper filters, the filtrate of activated sludge contained different amounts of white, fine-grained solids, depending on where the sample was taken from the tank. Analysis data have revealed an inorganic composition of the filtered material similar to the substances identified in the pores of the clogged diffusers (mainly earth alkali phosphates and silicic acid). The dry substance of the sludge was analysed from several samples and it was found to be virtually identical for all samples and independent from the sampling point.
Laboratory scale tests with synthetic (free from solids) and permanently pH-adjusted "wastewater" and a low potential 100-Hz DC source confirmed the results from the aeration tank.

### Optimising the pH in the aeration tank

Depending on the identity of the clogging precipitates, the pH in the tank can be monitored and – if necessary – adjusted, both by microbial process control (aeration intensity and intervals) and addition of acidic or caustic agents. Especially silicic acid, ferric / ferrous and aluminium ions show a pH- dependent tendency towards colloid formation.

### Controlling colloid charge transfer processes

Certain colloids are subject to charge transfer, changing their electrical charge from positive to negative and vice versa. These processes particularly affect ferric hydroxides, formed when ferric or ferrous salts are added to the activated sludge. Ferric hydroxide colloids are charged positively and remain in the colloidal state, as long as an excess of negatively charged ions does not discharge them. In addition, negative ions (e.g. chloride, nitrate) can only discharge and precipitate ferric hydroxides if large, single charged and as a result electrically passive ions (in particular ammonium) are present in considerable amounts. Triple charged and small aluminium ions promote the preservation of the colloidal state of ferric hydroxides.

It is understandable, that e.g. the ratio of ammonium / nitrate might play a role for ferric salt's clogging potential, since a charged and µm-sized colloid can easily be precipitated and bound to the membrane surface / in the pore, while compounds precipitated elsewhere in the aeration tank are very unlikely to be entrapped at the pore walls. It has to be pointed out that investigations on issues like electrostatics in aeration systems and colloid charge transfer processes in wastewater are in progress but at the very beginning.

## Examples: Cleaning in process

Table 1 shows the data of the plants, where the method was used.

**Table 1** Plant description (chemical cleaning)

| | Plant size [PE] | Aeration tank Volume [m³] | Diffuser Type; Material | Number of Diffusers | Diffuser area [m²] | Industrial fraction |
|---|---|---|---|---|---|---|
| **Plant 1** | 4,000,000 | 12 x 28,000 | Disks 300 mm EPDM | 22,000 | 1500 | high |
| **Plant 2** | 800,000 | 4 x 11,000<br>4 x 12,500 | Plates 0.15x4.0 m Polyurethane | 2600 | 1500 | high |
| **Plant 3** | - | 2 x 3700 | Disks 220 mm EPDM | 4500 | 180 | 100% |
| **Plant 4** | - | 2 x 2500 | Disks 300 mm EPDM | 1360 | 100 | 100% |

At **plant 1**, a very uneven bubble distribution was observed. By flooding with a cleaning solution, a pressure reduction of 2.0 - 2.5 kPa on the average (airflow ≈7 m³/(diffuser·h)) could be achieved.

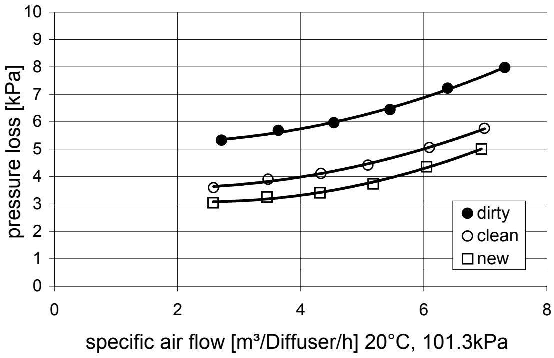
**Table 2** Pressure loss (entire diffuser elements) before and after chemical cleaning (plant 2)

| | Plant 2; Grid 1 | | | Plant 2; Grid 2 | |
|---|---|---|---|---|---|
| | Before cleaning | Lye cleaning | Lye and acid cleaning | Before cleaning | Acid cleaning |
| Head loss [kPa] | 12.0 | 8.5 | 7.0 | 13.0 | 8.5 |
| Reduction [%] | - | 29 | 42 | - | 35 |

Due to the very rapidly progressing diffuser fouling at **plant 2,** CIP cleaning was used as an emergency measure.

For one application (specific airflow 20 m³/m²/h; 20°C; 101,3 kPa) the backpressure of the diffuser elements are summarised in Table 2. The values include also the losses of the connection pipe work system, the loss of the diffuser holder and the membrane. The Dynamic Wet Pressure (DWP) (Boyle and Redmon, 1983) was not determined.

**Plant 3** is an industrial wastewater treatment plant removing crude oil arrears from borehole water. By flooding with a cleaning solution a reduction of the pressure loss from 47.1 kPa to 42.0 kPa (specific airflow approx. 2 m³/(Diffuser·h)) could be achieved.




Also **plant 4** is an industrial WWTP. The wastewater treated here originates from a synthetic fibre production and shows specific hydrochemical characteristics. In Figure 3 the pressure losses of a clogged membrane (approximately 4 years in operation) and the pressure losses of a cleaned membrane are presented, for comparison the pressure loss of a new membrane is shown, too.

**Figure 3** Backpressure versus specific airflow; Plant 4; Disk 300 mm EPDM

## Examples: Air humidification as preventive measure

At **plant 2**, where two diffuser plates with clearly different humidity were operated, a test facility did not show a significant difference in the pressure loss. An explanation for these different observations cannot be given yet. During the experiments different products and/or materials were tested. The results are presented in Table 3. The disk and the pipe diffusers worked without adjusted humidity.

**Table 3.** Results of a test installation on plant 2.

| | Plate PU low humidity | Plate PU high humidity | Disk EPDM | Pipe silicon |
|---|---|---|---|---|
| **Specific airflow rate [m³/(m² • h)]** | 45 | 45 | 65 | 29 |
| **Head loss start [kPa]** | 5.5 | 6.0 | 4.0 | 6.0 |
| **Head loss after 6 weeks [kPa]** | 9.5 | 10.0 | 6.5 | 9.5 |
| **Increase of the head loss [%]** | 73 | 66 | 63 | 58 |

Under the given test conditions all assigned diffusers showed a comparable increase of pressure over time.

At **plant 3** the humidification is carried out in the air main with 80 m length running along the tank crown, and from which the droplegs are leading directly down to the grid.

The adjustment of the quantity of water to the volumetric airflow takes place by two nozzle fittings and a bypass from the high-pressure pump. The first results after approximately 5 weeks of operation have shown that a delay of the formation of clogging deposits could be achieved. In the diffuser grid with air humidification, the pressure rose from 34.0 kPa only to 35.5 kPa, whereas it increased in the untreated reference field from 34.0 to 42.0 kPa.

## Operational criteria and economic considerations

**Acid dosing.** The cleaning of diffusers by acid dosing is usually quite simple and causes relatively small investment and operating costs. A condition for the applicability is that the blockades can be dissolved with acid. The stability of the membrane material must not be affected by the applied acid.

**Humidification**. Moistening causes relatively high investment and operating costs. At plant 3 the investment costs for demineralisation and for the high-pressure pump including pipes and nozzles amounted to about 32,000 €. The operating costs were estimated to 2000 € per year.

**Cleaning in process (CIP).** The costs of the containers, pumps and connecting lines are usually small to negligible. The costs of the cleaning solution are depending on the necessary components (dependent on the kind of the deposits) and the piping volume which has to be filled. The costs for the cleaning solution can be estimated to 300 €/m³.

## Summary and Conclusions

The main causes for the increase of pressure of fine-bubble aeration systems presented in this work are:·

- Hydrochemical characteristics of the wastewater (high concentrations potentially water-insoluble precipitation products forming content substances)
- Colloids present in the raw wastewater or formed during the treatment process, which are deposited on the membrane surfaces or in the diffuser pores (influence of electrostatic phenomena in the aeration system).
- Physical characteristics of the compressed air (temperature, relative dampness, flow rate), which result in a partial drying of the water penetrating the pore and thus increasing the concentrations of precipitates.
- Balancing of practically $CO_2$-free air with the $CO_2$-saturated wastewater and the associated deposition of earth-alkali carbonates.

For the prevention of the formation and/or dissolution, new methods were used in full-scale plants and in semi-technical test installations.

- Chemical cleaning during operation (with filled aeration tank) by flooding the aeration systems with cleaning solutions.
- Air humidification by generating aerosols from fully demineralised water.
- In the semi-technical scale: Experiments for the influence of the electrostatic phenomena in the aeration system.

At all plants presented in this work, the pressure loss could clearly be reduced. Because of the decreased pressure loss, the stress on the entire aeration system and therefore the maintenance as well as the energy costs are lessened. But most substantial is the improvement in the reliability of the plant and accordingly of the treatment process (no breakdown of the blowers ; no damage of the diffusers).

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