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Biological equipment for treating air and other gases — General requirements

Équipements biologiques pour le traitement de l'air et autres gaz — Exigences générales

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Foreword

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This document was prepared by Technical Committee ISO/TC 142, *Cleaning equipment for air and other gases*.

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Introduction

The biological exhaust air purification has experienced a very rapid spread in recent years with very positive effects in various applications.

The most important advantage is the fact that the cleaning process is natural and carried out by microorganisms. It is currently by far the most environmentally friendly exhaust air purification technology.

The main advantages of this technology are as follows:

— it is a natural process at ambient pressure and ambient temperature;

— the principle is comparable with the wastewater treatment technology which is also well-established for years;

— there is no need of additional energy in the form of natural gas or oil;

— it is a nearly CO_2 neutral air cleaning technology;

— it has low operation costs;

— it has low investment costs.

Long lasting experiences have shown that biological systems especially can be useful for the treatment of:

— odorous air from waste water treatment plants (e.g. H_2S, sulfides);

— odorous air from waste treatment plants as composting plants, anaerobic digestion plants (e.g. H_2S, NH_3, organic compounds);

— odorous air from industrial processes;

— waste air from paint houses and other industrial processes containing volatile organic compounds (VOC)[9].

Some parts of this document are based on the German Standards VDI 3477[1] (Biofilter, first published in 1984), VDI 3478-1[2] (Bioscrubber, first published in 1985) and VDI 3478-2[3] (Biotrickling filter, first published in 1985). (With permission of the Association of German Engineers VDI).

Biological equipment for treating air and other gases — General requirements

1 Scope

This document specifies the technology of biological exhaust air purification. The relevant requirements for a possible application are specified. The different variants of this technique are also presented.

NOTE The process principles of this method are described in Clause 4.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
biofilter
bioreactor treating waste gas with the aid of biofilm attached to the packing media which moisture is maintained by a prepositive humidifier or intermittent water feeding to the filter bed

Note 1 to entry: Organic materials are usually used as carrier materials. However, inorganic materials with a large inner surface area and corresponding microorganism population are also used. The materials used are usually arranged as bulk layers through which the exhaust gases flow.

[SOURCE: ISO 29464:2024, 3.5.10, modified — Note to entry has been added.]

3.2
biotrickling filter
bioreactor treating waste gas with free moving liquid layers on the surface of inert packing media to supply nutrients, take away metabolites or control pH for the biofilm attached to the packing media

3.3
bioscrubber
absorber transferring contaminants from waste gas to liquid absorbent, and removing the dissolved contaminants by suspended-growth microorganisms in a supplementary space

3.4
waste gas
odorant and pollutant-laden gas streams from industrial and agricultural processes and exhaust ventilation streams from tanks and rooms unsuited for being permanently occupied by humans

3.5
acclimation
adaptation of microorganisms to the substrate volume and composition as well as other environmental factors

3.6
absorbent
liquid suitable for collecting gas components

3.7
absorber
device in which specific substances are absorbed into an absorption liquid

3.8
absorption
selective separation of one or more components from gas mixtures by scrubbing with a scrubbing medium (typically water)

Note 1 to entry: A distinction is made between physical absorption, for the assessment of which the physical equilibrium curve is used as a basis, and chemical or biochemical absorption, during which the absorptive and absorbent enter a chemical reaction with each other and substances are converted.

3.9
absorptive
substance destined for absorption

3.10
microbial activity
biological conversion/elimination of waste gas components per unit time

3.11
support media
slatted floor or grating with sufficiently small openings to support a bed of solid particles (e.g. filter media)

3.12
C:N:P ratio
carbon :nitrogen :phosphorus ratio
ratio of biologically available carbon in the exhaust air to nitrogen and phosphorus in the filter media

3.13
pressure drop
Δp
difference between the static pressures at the inlet and outlet of a bounded flow system which is used as a measure for the energy loss caused by the flow within the system

Note 1 to entry: The pressure drop across a biofilter system is the total of the flow resistances offered by the piping, dampers, bed of media, etc[4].

Note 2 to entry: Endotoxins are released on lysis or death of the bacterial cells and can be, due to its low vapour pressure, inhaled after aerosol formation only.

3.14
moisture content
mass fraction of water related to the moist mass of the filter media

Note 1 to entry: This definition is different from that of the European odour unit, in that only the latter is traceable to a known odorant mass, defined as the EROM[5].

3.15
nutrient salt
nitrogen- and phosphorus-containing salt of inorganic ions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} which is required in major amounts to maintain the cell function

3.16
relative humidity
U
ratio of the partial water vapour pressure to the saturation water vapour pressure at a given temperature:

$$U = \left. \frac{p_{\mathrm{D}}}{p_{\mathrm{DS}}} \right|_{T}$$

3.17
pollutant concentration
ratio of pollutant mass to the waste gas volume at standard temperature and pressure conditions (0 °C, 1 013 hPa), dry basis

Note 1 to entry: The unit ppm (parts per million) (volume fraction or mass fraction) denotes the volume or mass fraction.

3.18
sorption
process by which a substance is selectively sorbed on or attached to another substance with which it is contacted

3.19
service life
duration over which the filter media retains its function at a sufficient efficiency

3.20
substrate
substances on which the microorganisms both feed and colonise, and which are suitable for synthesising cell mass or supplying energy for metabolic action

3.21
residence time
empty bed residence time
ratio of the filter volume to the volumetric flow of the fluid

3.22
water retention capacity
water storage capacity
maximum mass concentration of water that can be retained by the filter media for prolonged periods, expressed as per cent moist filter media mass

3.23
efficiency
removal efficiency, η
difference between the biofilter inlet and outlet concentrations of one or several defined waste gas constituents related to their concentrations in the raw gas:

$$\eta = \frac{\rho_{crude}^{G} - \rho_{clean}^{G}}{\rho_{crude}^{G}}$$

3.24
elimination capacity
Ev
microbially converted VOC freight per m^3 of packing or aeration tank volume in g C m^{-3} h^{-1}.

$$Ev = \frac{\rho_{crude}^{G} - \rho_{clean}^{G}}{V_{\mathrm{filter}}} \cdot \dot{V}^{G} = \frac{\eta \cdot \rho_{crude}^{G}}{V_{\mathrm{filter}}} \cdot \dot{V}^{G}$$

4 Process principles

4.1 General fundamentals

Biological air treatment systems are particularly suited to all waste gas cleaning applications involving air pollutants that are readily biodegradable[10],[11]. Biodegradation of the air pollutants is accomplished under aerobic conditions by microorganisms colonizing on solid support media or existing as activated sludge in washing liquid.

The requirements for a possible application of biological air treatment techniques are:

— Good biodegradability of the pollutants so that the biochemical conversion will take in a few seconds. Otherwise, the residence time in the filter chamber or in the scrubber would be too long and this would lead to very large filter volumes. If the degradation rate of the substances is not known pilot tests are recommended.

— Good water solubility of the pollutants, as nearly all biochemical reactions take place in an aqueous environment.

— A temperature in the mesophilic range (under special conditions also in thermophilic range possible).

— Absence of toxic compounds.

4.2 Steps involved in pollutant elimination

4.2.1 General

Biological waste gas purification is based on two steps.

A physical absorption followed by biochemical conversion of pollutants by microorganisms (enzyme catalysed reactions).

The bacteria are mainly suspended in water (bioscrubbers) or fixed on supporting elements (biotricklingfilters, biofilters).

4.2.2 Mass transfer

Mass transfer from the gas phase to the liquid phase (absorption and diffusion) is described by the simplified two-film theory[13].

In detail, the following steps take place:

— mass transfer to the gas/liquid interface;

— absorption into the liquid phase;

— mass transfer through the liquid phase to the bacterial cell;

— sorption and degradation by the cell.

The driving force is the concentration gradient between the pollutant concentration in the gas phase and the concentration in the liquid phase.

4.2.3 Biochemical conversion by microorganisms (enzyme catalysed reaction)

As in all biological purification processes (waste water/waste air cleaning, soil remediation), the substance being cleaned is biochemically processed by the microorganisms after absorption in the microorganism cell and gradually converted to yield energy for the cell and biomass. Waste air purification so far has always been an aerobic process, i.e. the substances are broken down by oxidation – ideally to yield the end products of complete oxidation, CO_2 and H_2O as well as sulphate and nitrate in the case of sulphur and nitrogen components in the raw gas.

As the waste gas passes through the filter bed or package material, the pollutants are sorbed onto the surface of the filter media where they are degraded by microorganisms in the liquid film surrounding the media.

The microorganisms involved are usually ubiquitous, i.e. microorganisms occurring everywhere in the environment. It is recommended to further increase the biodiversity of the microbial community by adding biomass, e.g. from sewage sludge or a soil slurry. The degradation of waste gas is dominated by a group of bacteria. All involved microorganisms have the capability to adapt to major changes in the nutrient supply, although sometimes this can take some time. Organic carbon compounds, for instance, are mineralized to innocuous products, ideally to carbon dioxide and water, by bio-oxidation with air oxygen. Normally, many different microorganism species are involved in the biodegradation processes.

Factors governing the rate of reaction (degradation rate) include:

— solubility of the waste gas components;

— biodegradability of the waste gas components;

— concentration and structure of waste gas components;

— type, number and activity of the microorganisms colonizing on the respective filter media;

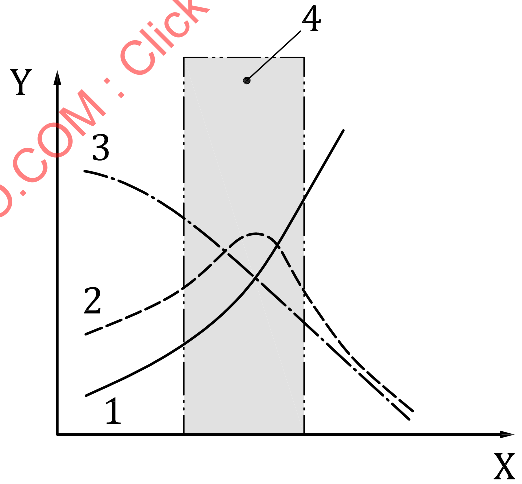
— temperature;

— pH-value;

— moisture content of the waste gas and the filter media;

— type and concentration of reaction products accumulating in the filter media.

An increase in the temperature initially accelerates the enzymatic and non-enzymatic reactions (RRT rule). If the temperature is further increased, the rate of acceleration slows down. At elevated temperatures, the enzymes start to denature and alter their shape, preventing them to perform their function. This counteracting effect reduces the overall rate of reaction, resulting in the typical profile of enzyme-catalysed reactions with a temperature optimum (see Figure 1).



Key

X temperature (°C)
Y rate of reaction
1 RRT function
2 overall rate
3 heat denaturation of enzymes
4 optimum temperature range 20 °C to 35 °C

Figure 1 — Dependence of the reaction on the temperature[1]

A changed substrate supply leads to changes in the composition of the microbial population without affecting the performance of the system. An important factor for a biological degradation is a quite constant pH value between 5,5 and 9. For special applications, for example, hydrogen sulphide elimination, a pH range from

2 to 3 is applied. The optimum range for a stable biological mass transfer shall be defined when designing the system. In the event of deviations from the design pH values, the activity of the microorganisms can decrease.

Sufficient water supply is essential to the function of the biodegradation processes. Moreover, the presence of water as a mass transfer agent is a basic prerequisite for all biodegradation processes. For this reason, the water balance/mass transfer in the filter media is of key importance.

The preferred operating temperature range of biofilters is the so-called mesophilic temperature range (roughly 20 °C to 35 °C).

The processes involved in the microbial degradation of organic carbon compounds occur in the neutral to weakly acidic pH range. The effect of the end and intermediate products of biodegradation is normally buffered by the filter media.

Biological systems also rely on a balanced nutrient supply for maximum performance. As well as carbon, microorganisms require nitrogen, phosphate, sulphur and trace elements for their metabolism.

Consistent optimum performance of the microorganisms is only ensured if the environmental conditions in the filter bed in terms of the above factors are controlled within narrow limits. As microorganisms are affected by changes in their environment, they can require some time for acclimation before they develop their full activity after biofilter startup or changes in the operating conditions.

The net conversion of pollutants in the filter bed is determined by the rate of reaction, the empty bed residence time of the gas in the biofilter and the concentration of the pollutant in the raw gas. If the biological reactions proceed relatively fast and the pollutants to be removed are sparingly soluble, transport processes of the reactants from the gas phase to the inner surface of the filter media can become rate-limiting.

The rate of the biological reactions and the reactant transport processes are temperature-dependent. In the temperature range of approximately 5 °C to approximately 40 °C, the rate of reaction generally increases with rising temperature. Above the so-called optimum temperature, however, it can decline sharply due to enzyme inactivation.

There are also microorganisms that thrive at higher temperatures (e.g. thermophilic bacteria). Such systems shall be carefully designed. Switching between mesophilic and thermophilic conditions should be avoided by all means.

Factors influencing the residence time are the volumetric gas flow, the bulk volume and the void volume of the filter bed. Because physical and chemical data such as kinetic constants and effective diffusion coefficients are only available for very few combinations of filter media and pollutants, biofilter systems are sized and designed on the basis of pilot tests run in adequately sized pilot plants.

Excessive pollutant mass flow rates and/or oxygen shortage lead to incomplete pollutant degradation and the accumulation of intermediates (e.g. formation of acids on conversion of alcohols or aldehydes).

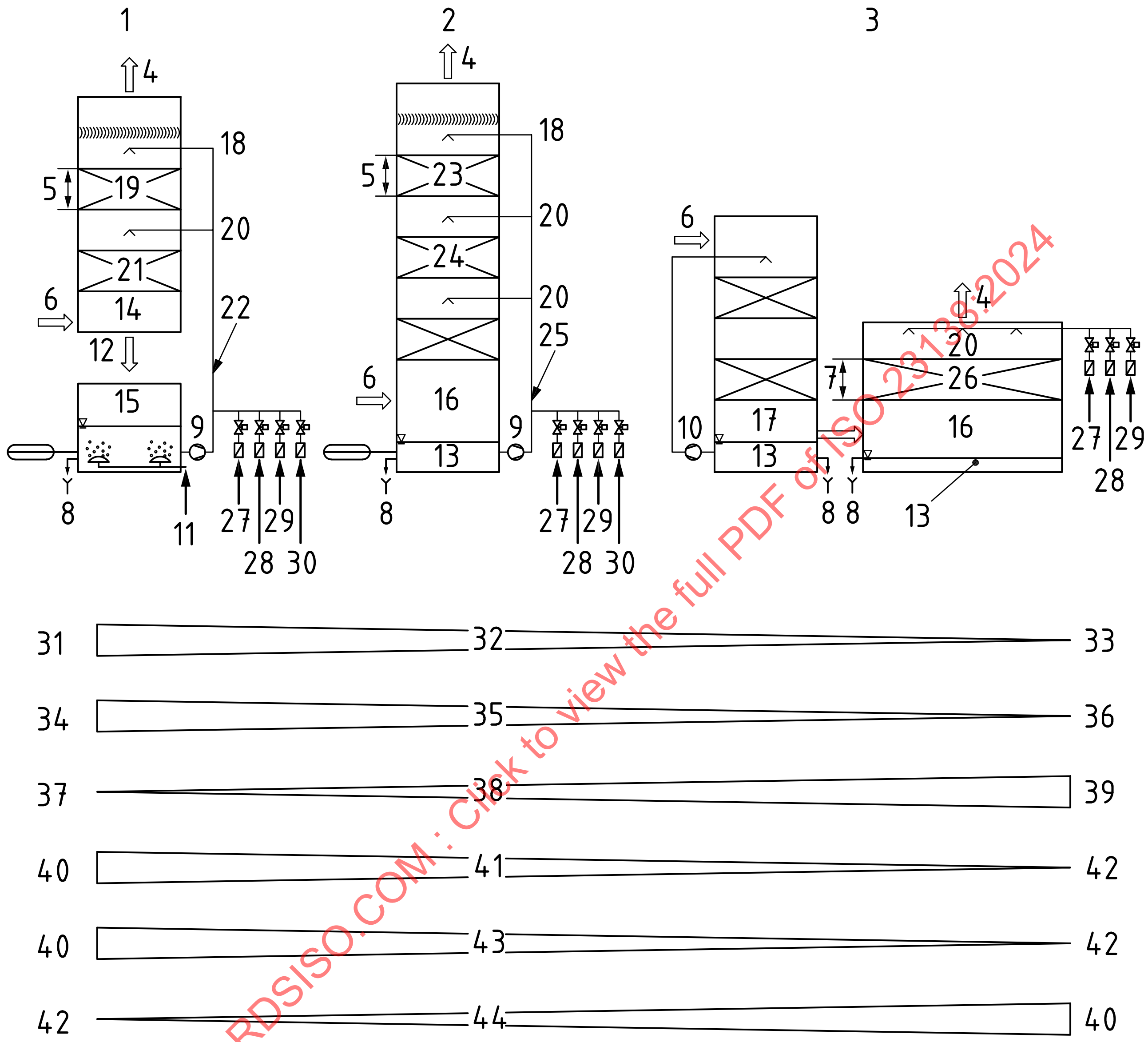
The pilot tests should be run for a sufficient period of time to make sure that the waste gas does not contain any substances likely to inhibit the microorganisms, e.g. SO_2. Depending on the application, such substances shall be removed from the inlet gas stream, for instance, in a separate upstream treatment stage, before it enters the biological waste gas treatment. The same applies to aerosols, dust and fats which tend to plug or foul the filter material.

Supplemental nutrient addition during shutdown periods - even in the case of prolonged shutdowns - is not required as long as the necessary nutrients can be obtained by the microorganisms from the support media. Inversely, proper attention shall be given to the C:N:P ratio in the case of high carbon loads of the waste gas to be treated and/or low-nutrient content of the filter media.

The microorganisms used for waste gas cleaning are so-called organo-heterotrophic microorganisms. Concerning the biochemical reaction, it can be assumed that depending on the type of compounds the degradation rate can be described either by a zero order reaction or a first order reaction.

4.3 Classification of techniques

Depending on different operation principles, there are currently three different types of biological air treatment systems (see Figure 2). The choice of the plant type depends on several parameters such as the type of the pollutants, the water solubility and degradation rate of the substances, space requirement, etc.



Key

1	bioscrubber
2	biotrickling filter
3	biofilter
4	clean gas
5	height of the package material 1,0 m to 1,5 m
6	crude gas
7	height of the package material 1,5 m to 1,8 m
8	effluent
9	pump
10	circulation pump
11	aeration
12	loaded scrubber liquid
23	package material (mainly plastic)
24	package material (mainly plastic)
25	circulation liquid
26	package material (mainly organic)
27	clean water
28	nutrients
29	acid/alcaline
30	additives (optional)
31	wet
32	humidity
33	dry
34	polar

13	swamp	35	VOC solubility
14	absorber unit	36	lipophilic
15	regeneration unit	37	suspended
16	combined absorber and regeneration unit	38	biomass fixation
17	pre-humidifier	39	biofilm
18	droplet separator injection nozzle	40	high
19	package material (plastic)	41	wastewater formation
20	injection nozzle	42	low
21	package material (plastic)	43	additive demand
22	regenerated scrubber liquid	44	risk of clogging

Figure 2 — Types of biological air treatment systems

The main distinguishing feature is whether the biodegradation is performed by suspended microorganisms (bioscrubber) or ones fixed to surfaces (biofilters and biotrickling filters).

The two latter techniques differ by either permanent sprinkling in the case of biotrickling filters or occasional sprinkling in the case of biofilters.

In the following, the three different types are more precisely described with their advantages and disadvantages.

4.4 Design parameter

The VOC concentration shall be reduced by biological processes to at least national emission limits. In the case of VOC elimination, the design of the plants is usually based on the elimination capacity and is in the range of 10 g C m^{-3} h^{-1} up to 100 g C m^{-3} h^{-1} in the case of biotrickling filter and biofilter, and 20 g C m^{-3} h^{-1} up to 200 g C m^{-3} h^{-1} in the case of bioscrubbers.

4.5 Biofilter

4.5.1 General description

This technology, which is well known since more than 40 years, is the most widespread in Europe[8],[27]. It uses solid and biologically active filter material based on organic substances.

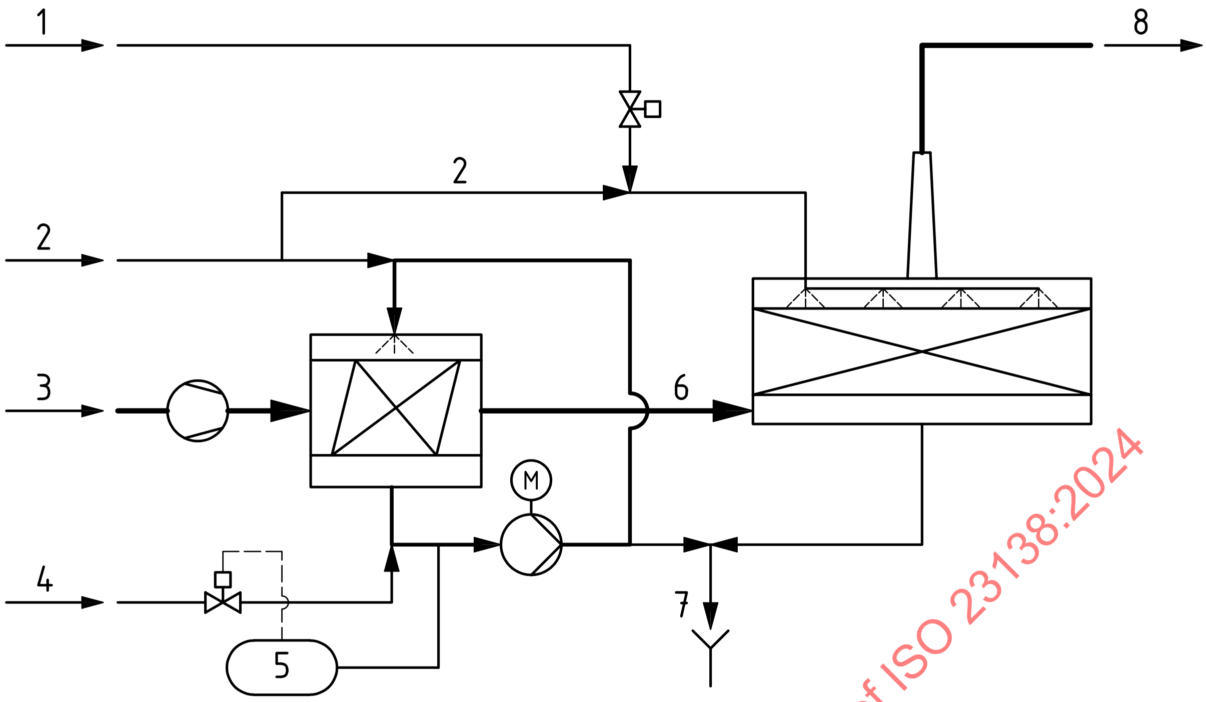
As the waste gas passes through the filter bed, the pollutants are sorbed onto the surface of the filter media where they are degraded by microorganisms in the liquid film surrounding the media.

The microorganisms involved are usually ubiquitous, i.e. microorganisms occurring everywhere in the environment. The main representatives belong to different genera of bacteria interacting in a complex way with each other forming a so-called biocenosis.

A changed substrate supply can lead to changes in the composition of the microbial population without affecting the performance of the system.

The biofilter is usually combined with an upstream scrubber which is often a bioscrubber (see Figure 3) or a chemical scrubber[28].

Biofilters can be constructed in open or closed design. Open design is commonly used for odour treatment applications, e.g. air treatment at wastewater treatment plants, composting plants[6] and agriculture[1],[7]. In recent years, closed biofilters (see Figure 5) have proven to be more advantageous. Weather effects are avoided and finer filter material with larger specific surface and higher microbial activity can be used. Furthermore, the exhaust air can be collected and discharged via a chimney. This is the reason why they are commonly used in industrial applications.



Key

1 optional nutrients
2 fresh water
3 exhaust gas
4 optional acid
5 control unit
6 humid gas
7 wastewater
8 clean gas
M motor

Figure 3 — Scheme of a closed biofilter

4.5.2 General description of the procedure

To describe the flow of gases through porous media, some simplified assumptions shall be made.

First, the gas flow through the media is assumed to be steady-state and isothermal. This means that the flow velocity at any single point of each streamline in the filter does not vary with time.

For a continuously operating biofilter, this assumption provides a good approximation.

Second, the filter bed temperature is taken to be largely constant. Temperature variations resulting from condensation processes or biochemical reactions are initially neglected. Moreover, the flow of approach is assumed to be uniform across the entire filter cross-section.

Third, the gas flow through the media bed of the biofilter is treated as incompressible fluid flow.

The microorganisms are settling on natural organic material. The choice of the right material depends on several parameters as biological activity of the material (number of microorganisms), pressure drop, pH value, specific surface, service time, essential nutrients in the material etc.

Typical support media employed are organic materials such as chopped wood and wood bark, root wood, composts of biowaste, wood bark or other origins, fibrous peat and heather which can be combined with one another or other structure-giving materials. Materials with high efficiency are usually complex mixtures of different individual materials.

Moreover, inert materials (e.g. large pored lava, expanded clay, porous concrete etc.) as well granular peat exhibiting large inner surface areas and hence, having the ability to support a large population of microorganisms are employed as support media.

All these materials are typically arranged as randomly packed beds through which the waste gas flows.

Based on the incompressibility assumption, the continuity formula provides an important relationship for the calculation of the flow velocity and hence, the residence time.

$$W \cdot A = \text{"const."} = \dot{V}$$

With:

$\dot{V}$ volume flow rate

A cross-sectional area

W flow velocity

Consequently, assuming steady-state flow, the behaviour of the flow velocities along the streamlines of an incompressible fluid is inverse to that of the surfaces through which the fluid passes.

$$W_1/W_2 = A_2/A_1$$

In the following, this simple law based on the conservation of mass is used as a basis for determining the flow behaviour in the biofilter.

The advantage of solid bed biofilters is that treatment of substances with a wider range and even with poorer water solubility is possible. This system is mainly used in industrial applications in Europe and has the best experience values in several fields.

4.5.3 Filter media

The biofilter media acts as a support for the microorganisms which colonize on the media surfaces and in the large media pores if available. This function can be accomplished by a wide variety of materials which can be either biodegradable or inert. As microorganisms tend to colonize both on biodegradable and inert surfaces, there are no restrictions on the selection of the filter media in this respect. For special applications, the filter media can have additional chemical oxidation properties such as composite cellulose fibre materials in sewer manhole filters.

In biofilters, however, organic media are preferred as they naturally possess a high density of indigenous microbes and a broad spectrum of species (microorganisms)[29]. Sometimes, mixtures of organic and inert filter media are employed to improve the structure and service life of the filter bed. In this way, the positive effects of the two material types can be combined to advantage.

Compared to suspended growth systems, microorganisms colonizing on solid (especially organic) media are less vulnerable to process disturbances such as variations in the pH, media dry-out and temperature fluctuations. This is also the reason why test cultures of microorganisms are frequently immobilized on glass beads for storage in laboratories, for instance. Both material categories (biodegradable and inert) are capable of providing improved process stability. Nevertheless, it can be assumed that media containing an organic fraction afford better protection than completely inert media. This is because organic media can normally buffer pH-relevant substances and have a higher water retention capacity than many inert materials.

4.5.4 Nutrient and nutrient salt source

In addition, the filter media can also serve as a source of nutrients and nutrient salts for the microorganisms. In odour treatment applications, the ability of the filter media to act as a nutrient and nutrient salt source plays only a minor role. However, in applications involving waste gases poor in nutrients or waste gases with high organics loads, the microorganisms rely on additional nutrient supply. This can be accomplished in part via the nutrient salts present in the filter media. However, in some cases additional fertilization of the filter media can be needed.

The ability of the organic filter media to serve as the nutrient source for the microorganisms is of particular importance during prolonged shutdowns.

4.5.5 Moisture reservoir

An important function of the filter system is to provide the filter media and the microorganisms with sufficient moisture. In case filter-humidity is too dry, it shall be moistened prior to use. While in closed biofilters less or no additional humidification is required, open biofilters need substantial and regular additional humidification. In order to avoid rapid bed dry-out, the waste gas shall be humidified to the maximum feasible level before being admitted to the biofilter.

After pre-conditioning in a humidifier or a scrubber, the waste gas should have a minimum relative humidity of 95 %. This means that the waste gas will take up the remaining 5 % as it passes through the filter bed, causing the latter to gradually dry out.

4.5.6 Regeneration, replacement and disposal of filter media

Depending on its composition and the specific application, biodegradable filter media in industrial application has a service life of about one to five years (the most common service life in practice is about four to five years). In agricultural applications the life time of wood chips is one year in maximum because of high ammonia loads in the exhaust air from animal stables. Rough root wood has a life time between five and seven years because of its low decomposition rate.

Media mixtures containing elevated inert fractions can have a considerably longer service life. Due to the biological decomposition processes occurring, the filter media undergoes gradual mineralization. In the process, the available nutrients are consumed by the microorganisms. Nutrient consumption is governed by various factors (e.g. presence of biodegradable pollutants in the waste gas, microbial activity of the filter media, temperature).

Typically, used filter material is sent for composting. An analysis of the material is carried out beforehand to ensure that all requirements for compost quality are met.

Factors effecting media life are the chemical and physical make up of the airstream and the characteristics of the media, the process of media breakdown is basically biological decomposition, and this is accelerated by presence of ammonia in the air stream and high temperature. Lignin is known to be resistant to biological breakdown so organic media with high lignin content should be favoured. As material breaks down the average particle size reduces as does the pore volume, this is typically accompanied by settlement of the media and a reduction in pore volume and an increase in back pressure. This means in effect energy usage goes up and removal efficiency due to reduced effective contact time is reduced.

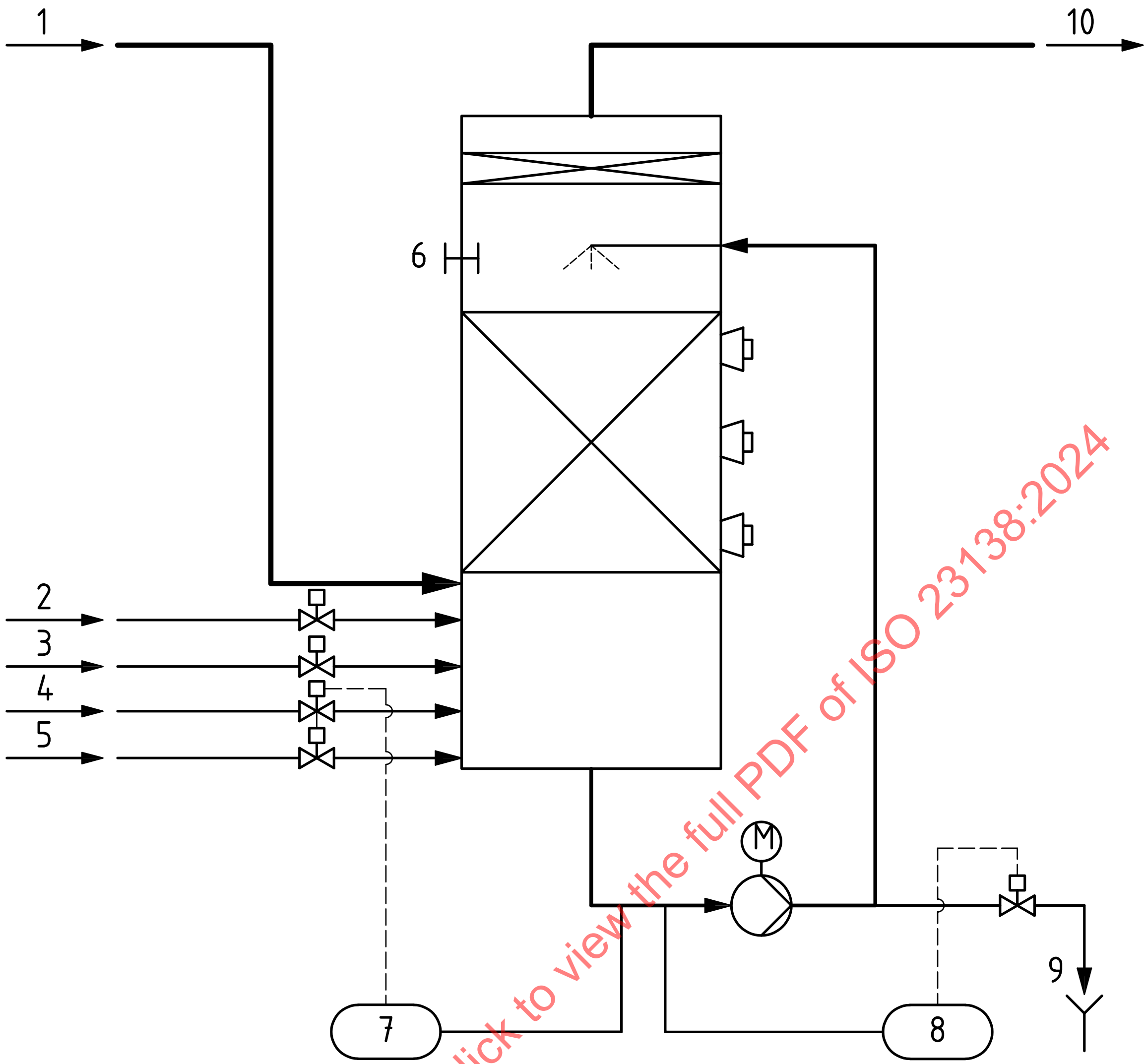
4.6 Biotrickling filter

4.6.1 General description

The biotrickling filter (see Figure 4) is in a way a mixture between biofilter (see 4.5) and bioscrubber (see 4.7). The biotrickling filter has a widely inert material as growth area for microorganisms (in contrast to the biofilter with organic filter material). Inert in this sense means not only artificial material such as plastics or ceramics but also certain natural such as lava stone which can be used as growing surface for the microorganisms. Some systems also use materials with high buffering capability such as sea shells which contain trace elements and bio stimulants especially for odour reduction[26].

Since these packing materials basically contain no or only very few nutrients for microorganisms, these materials shall be regularly supplied with nutrients.

This supply is done by regular or just occasionally sprinkling with nutrient containing water (see Figure 4). The amount of circulating water depends on several parameters but in general it is much less in comparison to the bioscrubber (see Figure 4).



Key

1	waste gas	7	control unit
2	fresh water	8	control unit
3	nutrients	9	wastewater
4	acid	10	clean gas
5	base	M	motor
6	flushing connection		

Figure 4 — Scheme of a biotrickling filter

4.6.2 General description of the procedure

The waste gas initially streams in a sufficient dimensioned pressure chamber of the biotrickling filter to secure a homogenous distribution of the air flow through the filter package. Subsequently, the waste gas passes the filter package which is irrigated permanently in most cases. A droplet catcher in the top of the biotrickling filter avoids the release of water aerosols containing microorganisms and dissolved inorganic nitrogen and sulphur compounds into the environment. For pH control, dosing of acid and base is required in most cases. Nutrients as nitrogen and phosphorous compounds need to be supplied in most cases on basis of water analyses. Waste water discharge is required to avoid accumulation of reaction products (e.g. non-degradable organic compounds, nitrates, sulfates) and suspended biomass[30]. The waste water discharge can be controlled by the conductivity, respectively. A fresh water supply is required to balance water losses by absorption of vapor and the waste water discharge.

Biotrickling filters need a regular cleaning to avoid pressure drop increase, reduction of cleaning efficiency and malfunctions as well. For this purpose, revision openings and flushing connections are indispensable.

4.6.3 Filter media

In agriculture, some hundred biotrickling filters are in use to clean exhaust air from pig stables. As filter media plastic packages with a length from 0,9 m to 1,5 m are used only. At most applications the specific surface area of the package media varies between 150 m^2/m^3 and 340 m^2/m^3. Fine pored package materials with higher specific surface areas can cause higher back pressure and can strengthen the clogging risk.

A regular cleaning of the filter package is indispensable in most cases to secure a proper function. For this purpose, a flushing connection and revision openings are recommended. According to experience, a regular cleaning once a year is common practice.

Anaerobic conditions occur due to longer residence times in larger sewer networks, especially at warm ambient temperatures. Under these conditions, hydrogen sulfide is formed in higher concentrations. Equilibrium concentrations in the gas phase can be up to several 100 ppm(v), usually also in combination with ammonia.

Large wastewater networks often require pumping stations. The indoor air concentration of H_2S and NH_3 of these buildings shall be safely limited. The waste gas (the air exchange) shall be cleaned. In a counterflow biotrickling filter with two packing beds of 4,5 m each, a room load of approximately 25 g $H_2S/(hm^3)$, a reduction of approximately 100 ppm(v) H_2S to < 600 OU/m^3 can be achieved.

Due to sulfur precipitation, sufficient and regular flushing shall be ensured.

4.6.4 Clogging in biotrickling filters for the purification of organic compounds (VOC)

Although there is no doubt about process advantages of a biotrickling filter, these techniques for eliminating VOCs are until today rare in the industrial sector compared with solid bed biofilters.

Clogging by biomass accumulation is a major obstacle for long-term, stable operation of biotrickling filters treating high loadings of volatile organic compounds (VOCs)[12]-[14],[31]. The risk of clogging arises further by increasing specific surface area and lower void ratio. For over 25 years, research groups have been working to solve this problem.

Clogging reduces pollutant removal and increases the pressure drop in biotrickling filters. Several options exist to remove excess biomass or to slow down the accumulation rate[15], but only few technical clogging prevention strategies have been implemented on a semi- and large-scale so far due to both significantly higher mechanical or chemical demands on installations and higher investment costs[16],[17]. In detail, present clogging prevention strategies can be classified as physical, chemical, biological and design strategies[10],[15],[18]-[22].

Mechanical strategies include approaches such as increasing the volume of spray liquid, temporal interruption of spraying, backflushing of the carrier material with optional injection of compressed air, moving beds, agitated beds, disc immersion methodology, squeezing of the carrier material (only for foams), washing with high-pressure nozzles, alternating flow direction, and periodic discharge of carrier material.

Chemical approaches involve increasing ionic strength as a biological stressor, temporary pH shifts, dosing of oxygen, oxidizers, surfactants or biocides, reduction of packing moisture, and combinations with ozone-forming plant stages.

Biological methods involve the use of protozoa, metazoans, fly larvae as predators to limit biofilm growth or approaches to increase biological stress. The latter approach provides variation or limitation in nutrient supply, alternating operation in parallel reactors with starvation phase or variable waste air injection heights in the filter bed. If necessary, the use of microorganisms with low biomass yield (thermophilic process control, fungi) or approaches of enzymatic quorum quenching are possible.

Other approaches include improvement of the bioreactor design, package materials, and modification of the mode and operational parameters. All of these methods involve either reduction in biomass growth or removal of excess biomass[18].

In the overall view of a waste air treatment concept, combinations of BTFs with upstream installations forming ozone or other reactive oxygen species, such as hydroxide radicals, are becoming more and more important. The presence of these reactive species acts as a biological stressor and reduces the biomass formation[20],[22]-[24].

No stable solution has yet been found for industrial applications to solve the clogging problem in the field of VOC elimination.

4.6.5 Nutrients and irrigation

A nutrient dosing is often necessary to secure an efficient system operation. Especially in cases of a non-balanced C:N:P-ratio in the raw gas hand higher loading rates a nutrient dosing is recommended. A lack of nutrient supply is probably if the total inorganic nitrogen and phosphorous in the washing liquid is less than 10 mg/l and 0,5 mg/l, respectively.

At applications to treat exhaust air from stables a nutrient dosing is not required in most cases. This is due to a comparatively low input of organic compounds on the one hand and a high ammonia and particulate matter on the other.

All biotrickling filters working to treat exhaust air from pig stables require a permanent irrigation. This is due to the comparatively low thickness of the biofilm combined with a high air loading rate up to 3 500 $m^3/(m^2\ h)$. The rapid drying-out without irrigation leads to a breakdown of cleaning efficiency.

To provide the moisture of vital importance to the microorganisms, the packing is regularly sprayed with a film of liquid to which nitrogen or phosphorus components are added as required. To keep the pH constant, usually a pH control is integrated in the trickling water circuit. The water flow is scaled in such a way that the film of moisture does not have a big scrubbing effect. This is the main difference to the bioscrubber.

In cases of high organic load and good yield, clogging problems can occur (see 4.5.4).

While the packings of a scrubber with separate regeneration are less sensitive to pollution by deposited films of sludge, biotrickling filters shall be designed and equipped in such a way that an accumulating biological film does not cause clogging of the reactor.

Clogging and deposition can be counteracted with a sufficiently high liquid input rate or by drying out the film for a fixed period.

To convert the pollutants, the microorganisms require not only the carbon from the waste air, but other components as well. These are nitrogen, phosphorus, sulfate and various trace elements. They shall be supplied from outside. The metered quantity is calculated on the basis of regular concentration measurements of nitrogen and phosphorus. To sustain micro-biological activity, a certain nutrient salt ratio (e.g. C:N:P = 100:5:1) should be upheld, but can be reduced during operation.

4.6.6 Regeneration, replacement and disposal of filter media

Normally, used packs are disposed at the local landfill. The package itself does not pose a problem to the environment, but the solids of the contamination can be considered hazardous, depending on the application. Most landfills require an analysis for the disposal of used packaging to prove that it is harmless.

4.7 Bioscrubber

4.7.1 General description

This system is a combination of two known techniques[12]. In the first stage, the pollutants are washed out in a washing system and in the second stage degradation takes place. This second stage is comparable to the biological stage of a sewage treatment plant. The degrading microorganisms are mainly suspended in the water.

An advantage of the system is that both stages (gas-liquid contact zone and regeneration zone) are based on many years of experience. Important is the possibility to control various parameters such as the pH value and the concentration of nutrient salts in the liquid phase by dosing and to be able to adjust the required oxygen content in the absorbent by aeration in the separate reaction stage.

This technique is less suitable for higher proportions of poorly water-soluble substances.

4.7.2 General description of the procedure

Figure 5 shows a typical scheme of a bioscrubber. The advantage of modern systems is also that microbial activity in the absorption zone can contribute a significant share to the required biodegradation performance with reduced clogging tendency in this zone. This requires a controlled sludge discharge by means of suitable additional systems.

The size of bioscrubbers is significantly smaller than that of biofilters and biotrickling filters. This makes bioscrubbers predestined for cleaning large exhaust air volume flows of several 10 000 m^3/h up to more than 1 000 000 m^3/h.

This technology is also used in combination with the biofilter as an upstream unit for humidifying the exhaust air and at the same time wash out and break down highly water-soluble compounds.

Basically, all known scrubber types, with or without internals, are available as absorbers, such as

— randomly packed columns,

— packed-bed columns,

— plate columns,

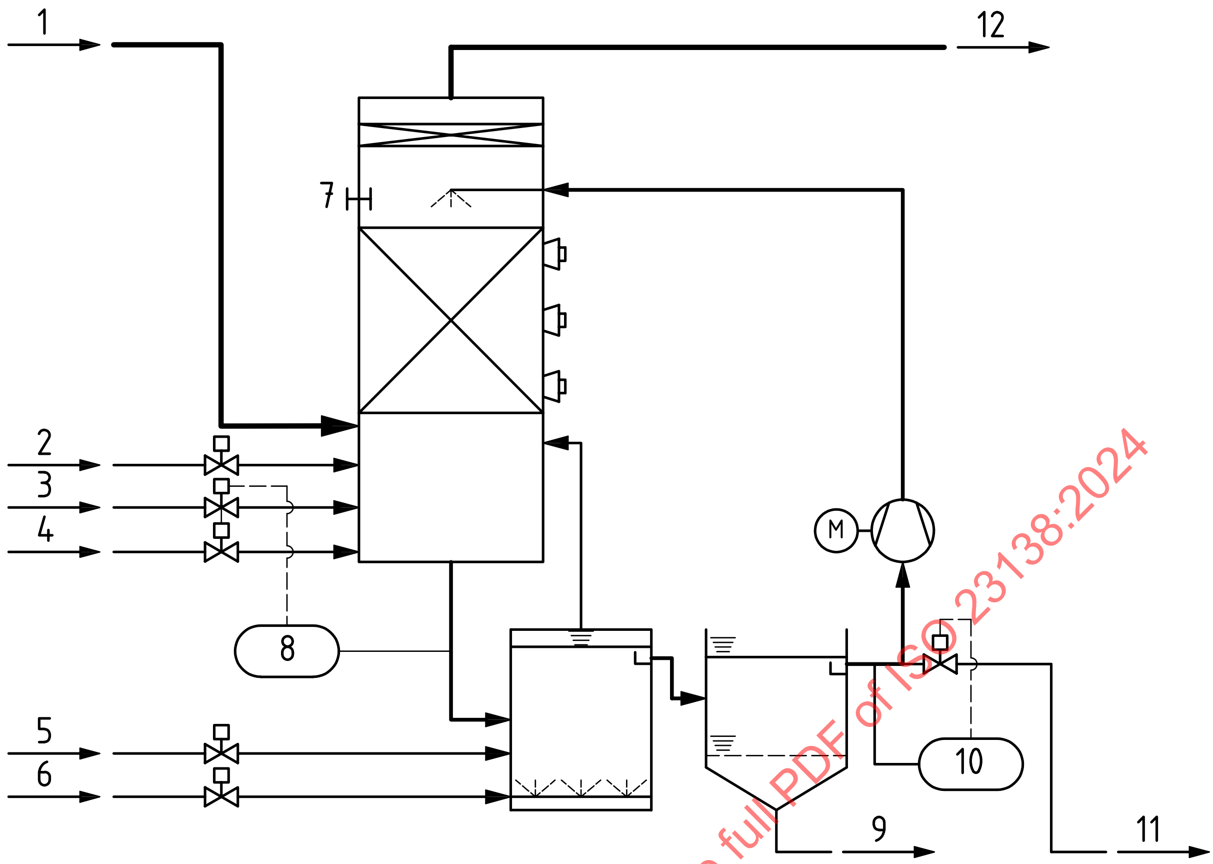
— nozzle scrubbers,

— jet scrubbers.

The degradation efficiency and elimination capacity depend considerably on the quantity and condition of the activated sludge mass, that is the microorganisms suspended in the scrubbing fluid as single organisms or in the form of sludge flakes. As not all microorganisms are able to degrade certain dissolved pollutants from the raw gas, an adaptation to the substrate supply and natural selection takes place in the scrubbing process. This takes a certain time (adaptation period).

Considerable changes in raw gas composition can trigger a readaptation with a temporary drop in scrubbing performance, which can take up to several weeks, if no countermeasures are taken.

Typical applications are waste gas cleaning in chipboard production, printing industry and H_2S-elimination.



Key

1 exhaust gas
2 fresh water
3 acid
4 base
5 nutrients
6 air
7 flushing connection
8 control unit
9 sludge
10 control unit
11 wastewater
12 clean gas
M motor

Figure 5 — Scheme of a bioscrubber

4.7.3 Nutrients and irrigation

Very similar to the biotrickling filter a nutrient dosing is often necessary to secure an efficient system operation. Especially in cases of a non-balanced C:N:P-ratio in the raw gas hand higher loading rates, a nutrient dosing is recommended. A lack of nutrient supply is probably if the total inorganic nitrogen and phosphorous in the washing liquid is less than 10 mg/l and 0,5 mg/l, respectively.

5 Application

The consideration of general process fundamentals (see Clause 4) is the essential prerequisite of a successful use of biological waste air treatment. Furthermore, short-term and significant fluctuations of the volume and mass flow of raw gas components should be avoided as far as possible. In cases of these fluctuations or more complex mixtures in raw gas, a two-stage treatment will possibly be recommendable. Concerning the sizing of exhaust air treatment systems, components with the lowest biodegradability are limiting factors. In cases of missing information, preliminary tests should be made in pilot scale (see Clause 6).