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Technologies for the abatement of odours and volatile organic and inorganic compounds

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Air pollution has become a major concern worldwide. Different groups of pollutants play a role in atmospheric pollution, namely particulate matter and volatile organic and inorganic compounds (VOC, VIC). The latter are also known as odours when they generate smelling problems. This short review will mainly focus on available technologies for the removal of volatile compounds. Conventional physico-chemical techniques, such as incineration, absorption and adsorption, as well as biotechniques and innovative processes will be considered. Some important differences between those abatment technologies is the fate of the pollutant. In non-biological oxidation processes as well as in bioprocesses, the pollutants are degraded and are expected to get converted to non-toxic compounds, under optimised conditions. Conversely, in technologies based on mass-transfer, the pollutants are transfered from one-phase to another, although this may sometimes be accompanied by a chemical reaction. Other significant differences between treatment processes are the investment and operating costs as well as the recommended application range in terms of gas flow rates or pollutant concentrations, among others. Combined or multi-stage processes have also gained more interest recently, as well as some innovative bioprocesses.

Keywords: Absorption, Adsorption, Advanced oxidation processes, Biofilter, Bioscrubber, Biotrickling filter, Thermal and catalytic oxidation, Suspended-growth bioreactor.

1. Introduction

Somewhat less attention has often been paid to atmospheric pollution than to water pollution. Nevertheless, the first techniques for air pollution control were already developed almost a decade ago. Although the concentration of pollutants emitted to the atmosphere is often low, at the ppmv or even ppbv level, they may still cause significant problems to humans, animals, plants and even buildings or the like. Another important problem related to such volatile compounds is odour nuisance. Volatile compounds are not necessarily toxic or carcinogenic, but may generate significant public concern,

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whenever characterised by a low odour threshold limit. Even odours which are temporarily pleasant, may become a nuisance if one is continuously exposed to them. Their removal is therefore necessary. In order to reach high abatement efficiencies, optimised pollutant-detection methods are of prime importance, as inaccurate characterisation of the waste gas may lead to unefficient treatments (Parcsi and Stuetz, 2007). Different air pollution abatement technologies are available nowadays. The most suitable one depends on the characteristics of the effluent to be treated.

2. Nature and sources of air pollutants

The most suitable abatement technology highly depends on the nature and source of air pollution. Two major groups of air pollutants can be defined. They are, on one side, particulate matter and, on the other side, volatile organic and inorganic compounds. Some of the latter compounds are sometimes called "odours", when exhibiting odorant characteristics. Particulate matter can be removed mainly by means of cyclones, baghouses, electrostatic precipitators or scrubbers. Scrubbers are also suitable for the removal of volatile pollutants, as well as adsorption columns, thermal or catalytic incinerators and bioreactors. Besides, other less conventional techniques may also be considered.

Many different sources of air pollution exist. Giving a detailled, exhaustive, list of such sources is outside the scope of this presentation, but two general groups can be mentioned, namely mobile sources and stationary sources. Mobile sources are basically englobing all kinds of vehicles in which a (fuel) combustion process takes places. Air pollution results in such case from the release of combustion products, largely represented by particulate matter and inorganic pollutants, which do generally not cause significant odour problems. Conversely, stationary sources are major sources of odour problems and may release either particulate matter and/or volatile organic and inorganic compounds to the atmosphere. Some examples are wastewater treatment plants, composting and solid waste treatment facilities, waste gases from industries, as well as most stationary combustion processes in general (Kennes and Veiga, 2001).

3. Abatement technologies and their application range

3.1 Non-biological technologies

Although the best solution would consist in preventing or at least reducing the emissions to the atmosphere, this is not necessarily always easy or possible. Thus, abatment technologies are needed. Non-biological treatment technologies can be divided in mass-transfer based processes and destructive processes. Absorption and adsorption are two mass-transfer based processes, transfering the pollutant from the gas phase to either a liquid phase or a solid phase. Packed towers or spray towers are most often used for absorption, while adsorption does generally take place in columns packed with granular activated carbon (GAC). The simultaneous use of two GAC-columns allows to regenerate one unit while the other one still remains in operation. The best known destructive processes are thermal and catalytic incineration. The main difference between these technologies is that catalytic destruction of pollutants takes place at lower temperatures (typically below 500 °C) than thermal destruction (typically above 650 °C). The degree of destruction or removal efficiency is generally high in such technologies (> 99%). However, it is worth mentioning that in incineration processes the addition of a fuel is often necessary, while burning of such fuel will result in the release of high amounts of greenhouse gases such as carbon dioxide and nitrogen oxides, among others. Although it is not possible to define a clear application range in terms of pollutant concentrations or gas flow rates, non-biological processes are often best suited for relatively high concentrations of volatile pollutants while bioprocesses are the best choice at relatively low concentrations (Fig. 1).

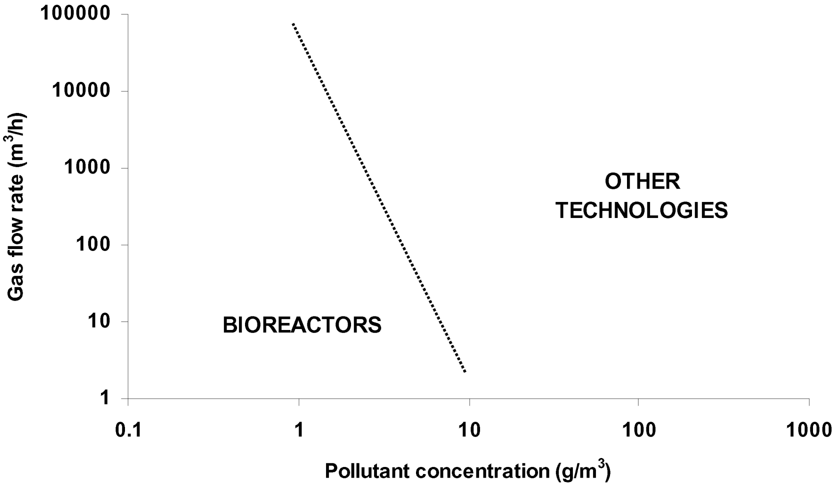

Fig. 1. Comparison of the application range of bioprocesses and non-biological treatment technologies, in terms of gas flow rates and pollutant concentrations (reproduced from Kennes et al., 2009a).

3.2 Bioprocesses

The first evidence of application of bioreactors for the treatment of odorous gases appeared in the nineteen fifties (van Groenestijn, 2005). The only reactor configuration known at that time was the classical soil biofilter, mainly used for solving odour problems at sewage treatment facilities, wastewater treatment plants or composting works. Untill the late seventies, almost no other type of bioreactor was available for air pollution control, except systems based on air diffusion through activated sludge reactors (Kennes and Veiga, 2001). A few examples of full-scale plants based on air diffusion through suspended-growth bioreactors and installed in the nineteen sixties and seventies can be found in United States (Kennes and Veiga, 2001). If the latter technology is used for polluted air treatment close to a wastewater treatment plant, the polluted air can then advantageously serve as an aeration unit for activated sludge reactors or other similar systems (Kennes et al., 2009b). Around the late-seventies and early-eighties, a few research groups decided to start more intensive research on biological waste gas treatment. Although a lot of work was still dedicated to conventional biofilters, new bioreactor configurations were proposed as well (Fig. 2). The first lab-scale, but also full-scale, biotrickling filters and bioscrubbers used for air pollution control appeared around that same period (Kennes et al., 2009b). New applications were also developed in the nineteen eigthies, mainly related to industrial waste gases. Concepts used to size and design such bioprocesses gradually switched from totally empirical to more accurate scientific and engineering concepts. Bioreactors, which were originally aimed at removing low odour concentrations, at the low-ppm level, for example at wastewater treatment plants or composting facilties, appeared at that time also to be highly effective for the treatment of other waste gases even at pollutant concentrations up to a few grams per cubic meter (Fig. 1).

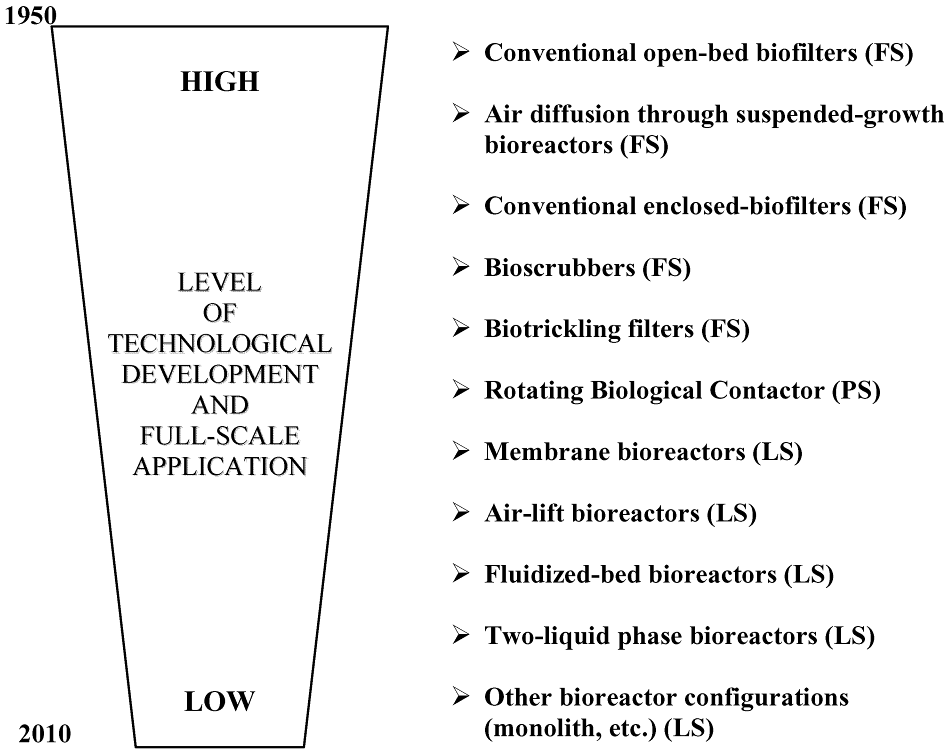

Fig. 2. Chronological development of different bioreactor configurations used for odour abatement and waste gas treatment
(FS: Full-scale, PS: Pilot-scale, LS: Laboratory-scale).

3.3 Combined processes

Besides biological and non-biological processes, several recent treatment options are based on combined processes. One possibility consists in combining several bioreactors for the treatment of mixtures of pollutants with different characteristics (Kennes et al., 2009a). This can be useful, for example, when both hydrophobic and hydrophilic compounds are present in the waste gas. Hydrophobic pollutants will better be degraded in conventional biofilters while more water-soluble ones can better be removed in trickling biofilters or bioscrubbers. Also, mixtures of sulphur compounds, such as H_2S, and VOCs can often advantageously be treated in two bioreactors in series (Rene et al., 2010). In a first bioreactor, sulphur compounds would be degraded, with a concomittant pH drop, usually inhibiting VOC-degraders but not sulphur compounds-degraders. The remaining polluting-fraction will only contain VOCs but no sulphur-compounds anymore. The latter gas mixture can then easily be treated in a second bioreactor, without any problem of acidification. Non-biological techniques can also be combined with bioprocesses. Indeed, in the previous example, mixtures of sulphur-compounds and VOCs can also be treated in an activated-carbon adsorption column followed by a biofilter. Still, other examples consist in combining advanced oxidation processes (AOP) with bioprocesses. Research presently done in our laboratory has shown that the use of an AOP as pre-treatment step in front of a bioreactor, avoids inhibitory effects in the bioreactor, during episodes of shock loads.

3.4 Other bioreactors

Besides the above mentioned techniques, some other bioreactor configurations have recently been tested as well (Fig. 2). However, so far most of them have only been used either in lab-scale research or in a very limited number of pilot-plants or full-scale applications (Kennes, 2010). Some examples are the membrane bioreactor (Kumar et al., 2010), the rotating biological contactor (Vinage et al., 2003), the airlift bioreactor (Nikakhtari et al., 2006), and the monolith bioreactor (Rene et al., 2010b). Besides, the efficiency of new modes of operation have recently been evaluated with some conventional reactors. This is the case of two-liquid-phase packed and suspended-growth bioreactors (biotrickling filters, bioscrubbers). In two-liquid-phase biotrickling filters (Montes et al., 2010) and two-liquid-phase suspended-growth bioreactors (Bailón et al., 2009), a small volume organic phase is added to the bulk aqueous phase, leading to significant improvements in performance (Kennes et al. 2009a).

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