

Recent developments in biological techniques for air pollution control and integration into sustainable development

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1 INTRODUCTION

Over the past three decades, there has been a rapid maturing and expansion of the use of biological techniques for the control of air pollution. This is illustrated by the evolution from the simple and very crude soil biofilters treating odours described by Carlson and Leiser (1966) to the more advanced processes being researched or already deployed in the field today. Examples of the latter include biotrickling filters using mutant organisms to degrade trichloroethylene (TCE) vapours (Sun and Wood 1997), high performance

biotrickling filters treating H_2S at contact times below 2 seconds (Gabriel and Deshusses 2003), innovative foam bioreactor with improved mass transfer characteristics (Kan and Deshusses 2003), or combined advanced oxidation-bioreactor systems (van Groenestijn 2001). The success of biological techniques for air pollution control can be attributed to several reasons:

- Biotreatment of gases works well, it is often very cost effective even at low concentrations of pollutants,
- Biological treatment does not require high temperatures, it does not generate secondary pollutants such as NO_x , particulate matter, spent activated carbon, or additional CO_2 ,
- Biotreatment of gases is energy efficient and does not require additional fossil fuel,
- Biotreatment of gases is environmental friendly and is well perceived by the general public.

While treatment performance and cost are simple to measure, the “environmental friendliness” and greater environmental impact of a given technology is more difficult to quantify, because it requires a comparative assessment of the system’s construction and life, and its greater impact on greenhouse gas reduction/emission, energy use, waste generation, etc. Such evaluation is generally done using life-cycle assessments (LCA) (Graedel 1998) and is motivated by the increasing concerns for sustainable development. Sustainable development refers to “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (World Commission on Environment and Development 1987). It is a global economic, social, and environmental concept, yet it is also a controversial topic as the assessment of sustainability requires to assign sometimes subjective impact values to indicators such as resource depletion, global warming, etc. More importantly, the implementation of sustainable developments will drastically change the way we live.

Little has been done in the area of life-cycle assessment of biological techniques for air pollution control. A preconceived idea is that waste treatment is by nature a non-sustainable activity, because it deals with wastes, and wastes should be avoided in the first place, or at least minimized to achieve sustainability. This is not necessarily true as it misses the point that integrated design, rather than single unit operations should be considered. In other terms, it is the global impact of an industry or processing plant that should be considered and not the individual unit operations that make that industry, as the optimum of the sum is unlikely to be the sum of the optimum of each unit operation.

For example, consider the hypothetical case shown in Figure 1. which could be a simple processing plant, but the example applies widely. As pollutant emissions are reduced through implementation of any measure such as pollution

control, process change, product substitution, operation and maintenance, etc., the environmental impact decreases. At point A, it reaches a minimum. It is important to realize that in reality, the graph in Figure 1 probably contains numerous lines corresponding to the many different options available in terms of plant design, operating conditions, maintenance practice, pollution control technology, etc. The compounded minimum line should be considered. As the mass of pollutant emitted further decreases beyond point A, the environmental impact may increase, e.g., as a result of increased energy use, emission of greenhouse gases, or non-sustainable process changes. This should probably be avoided. As indicated by the dashed line in Figure 1, the compounded line is not necessarily monotonous, because decreasing the overall pollutant emissions may reach the limits of a given technology and require a completely different technological solution. Possible examples include a change of raw products in a processing plant, or switching from biological treatment to incineration for air pollution control.

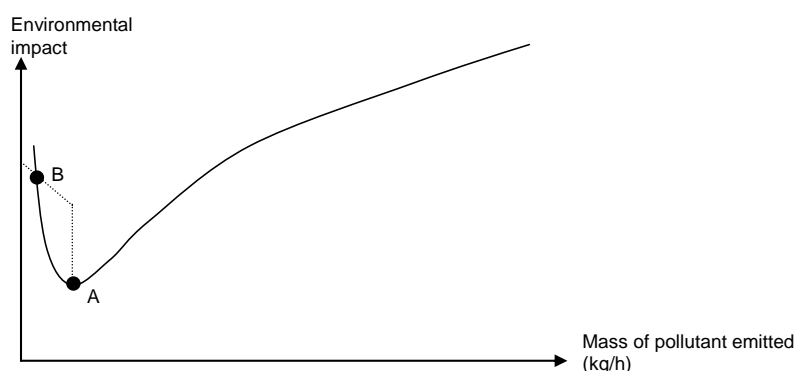


Figure 1. Hypothetical example of how global environmental impact (used here as a metric for sustainability) could be affected by pollutant emission. See text for details.

The above discussion has been remarkably absent in setting pollution control policies, probably because the concepts of sustainability are not well known and factors affecting it are not well understood. It is a general feeling of those involved in biofiltration that in many cases, air pollution control legislation is forcing tighter controls at the expenses of sustainability (point B vs. point A in Figure 1). Ideally, some kind of life-cycle assessment should be conducted as part of the development of environmental policies, however it is not. Obviously, major advances are needed before such a procedure becomes a routine. In the next sections, the impact of the selection of VOC control method on the

environmental emissions is reviewed first. Next, recent advances in H₂S control using high performance biotrickling filters are discussed. Specific aspects related to sustainability are emphasized.

2 VOC CONTROL, THE CASE FOR AVOIDING UNNECESSARY CO₂ EMISSIONS

A wide range of VOCs can be very effectively controlled using biofilters and biotrickling filters. Yet, in many cases, thermal or catalytic oxidizers are being installed to control VOC emissions, either by choice of the plant operator or because of local environmental regulations. Let's consider a hypothetical case where the air exhaust air flowrate is 50,000 m³ h⁻¹ contaminated with a VOC concentration of 1 g m⁻³, i.e., a medium-high concentration. For the sake of the example, we will consider toluene to be the contaminant, although the outcome of the discussion does not greatly depend on the nature of the contaminant. We will further assume that the plant operate 24 hours per day and 365 days per year. This represents an uncontrolled emission rate of 50 kg h⁻¹, or 438 tons per year.

If thermal oxidation is selected for the control of the exhaust, the calorific value of the air undergoing treatment will need to be increased, usually by adding natural gas or another fossil fuel. Since the concentration of toluene in the exhaust is about 40 times lower than the lower explosive limit (LEL) of toluene (1.1% by vol.), a significant amount of additional fuel will be required. In fact, thermal or catalytic oxidation in such case is really about burning fuel rather than the pollutant. As shown in Table 1, the additional fossil fuel needed for incineration will result in significant CO₂ and NO_x emissions. Surprisingly, the greater impact of CO₂ and NO_x emissions is seldom considered in the selection of the control technology, although emissions are significant. Other factors such as the manufacture and replacement/disposal of noble metals used for catalytic oxidizers would also need to be included in a more detailed evaluation.

A complete life-cycle assessment of the VOC control case is outside the scope of this paper. However, the numbers of Table 1 can be placed in perspective using the average damage cost per ton of pollutant emitted reported by Eyre et. al (1997) and Spadaro (2002). The average damage cost is a lumped cost that includes environmental damages, and costs to the society associated with morbidity and mortality. These were as follows:

- VOCs: \$1000 per ton
- NO_x: \$18,000 per ton
- CO₂: \$33 per ton

Table 1. Parameters for the hypothetical control of a 50,000 m³ h⁻¹ stream contaminated with 1 g m⁻³ VOC

Parameters	Value	Unit
Air flow rate	50,000	m ³ h ⁻¹
VOC inlet concentration	1.0	g m ⁻³
Control efficiency required	>95%	-
Mass of VOC controlled	438	tons/year
Mass of CO ₂ emitted if using thermal or catalytic oxidation ^a	40,000 – 55,000	tons/year
Mass of NO _x emitted if using thermal or catalytic oxidation ^b	53	tons/year

^aFrom fossil fuel combustion. ^bAssuming 100 ppm NO in the exhaust

The resulting damage cost of the CO₂ and NO in the case of thermal/catalytic oxidation is about \$2,500,000 per year, i.e., \$1.5M for CO₂ and \$1M for NO. In contrast, if a biological control method was used, and if it achieved only 97% removal of the VOC, the damage cost of the untreated fraction VOC would be about \$13,000 per year, and there would be of course no NO_x or CO₂ damage cost. This is markedly lower compare to conventional treatment. Obviously, the numbers above are subject to some uncertainties (Rabl *et al.* 2005), and different approaches exist for the evaluation of the global environmental impact. However, the magnitude of the difference between conventional treatment and biological treatment suggests that the topic should be further investigated, and that the results should be used in setting pollution control policies.

3 HIGH RATE BIOTRICKLING FILTERS FOR H₂S CONTROL

Odour control at wastewater treatment plants has traditionally been conducted using chemical scrubbing. However, chemical scrubbers have several significant drawbacks, including high operating costs, generation of halomethanes (WERF 1999) and the need for hazardous chemicals on-site. In the past decade, these drawbacks have motivated engineers to look into alternatives such as biological treatment. For H₂S control, biotrickling filters are the most promising alternatives.

To compete with chemical scrubbers, biotrickling filters need to be inexpensive, reliable, and able to treat the same pollutant loads as chemical scrubbers. This may be achieved by careful packing material selection and

reactor design, and optimum reactor operation and monitoring. Over the past years, the Deshusses' research group has demonstrated that existing chemical scrubbers could be converted to biotrickling filters, thereby eliminating the need for chemicals, simplifying process control needs, and improving workers' safety. Effective biotreatment of H_2S was shown in retrofitted chemical scrubbers operated at gas retention times as short as 1.6 s (Gabriel and Deshusses 2003 and 2004). Selected results are shown in Figure 2, and biotrickling filter characteristics are listed in Table 2.

Table 2. Characteristics of two of the five high rate biotrickling filters operated at the Orange County Sanitation District

Parameters	Biotrickling filter #10	Biotrickling filter #I	Unit
Air flow rate	17,000	17,000	$m^3 h^{-1}$
H_2S inlet concentration	5-40	40-100	ppm
Empty bed residence time	1.6-2.2	1.8-2.0	s
Typical H_2S removal	>95%	75-99%	-
Maximum H_2S elimination capacity	100-110	>260	$g m^{-3} h^{-1}$
Packing material	4 cm cubes, open pore polyurethane foam (EDT, Eckental-Eckenhaid, Germany), random dump		
pH of operation	1.8-2.2	1.6-2.5	-

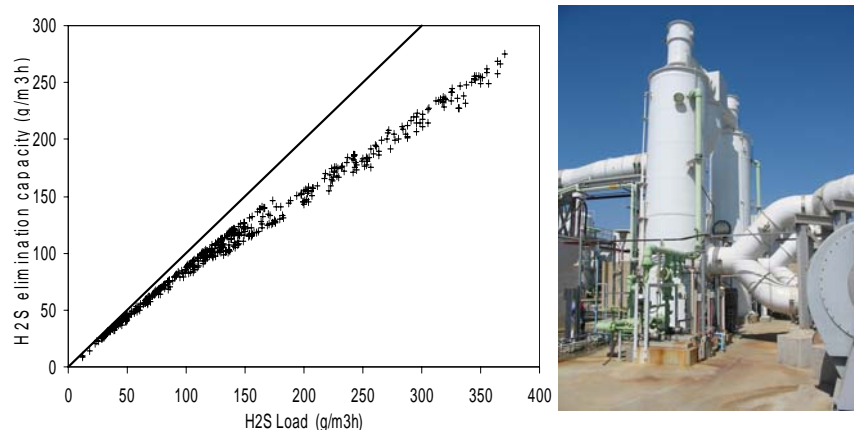


Figure 2. Left: H_2S elimination capacity (EC) vs. load data for biotrickling filter I during a 6 day period. The diagonal line represents the EC for 100% removal. Right: picture of the system.

As for the VOC case discussed before, significant differences are expected to exist in the global impact of controlling H₂S when using either chemical scrubbers or biological scrubbers. The most readily available measure for impact is the use of chemicals in the chemical scrubbers, as reported in Table 3. The chemical consumption is significant, and obviously there is an environmental toll for the production and delivery of these chemicals. Chemical scrubbing will also result secondary pollution, here halomethane emissions estimated conservatively at about 700 kg per year. Other factors that have not been considered but that require further definition include, but are not limited to, acid washes that are periodically performed on the chemical scrubbers, the global impact of manufacturing and shipping the chemicals to the wastewater treatment plant, the liability of having harsh and dangerous chemicals on site, improvements in workers health and safety, the space occupied by chemical storage. Here again, a complete evaluation is required to fully understand the complex ramifications of the choice of the method for odour control

Table 3. Cursory evaluation of the environmental factors of two of the five high rate biotrickling filters operated at the Orange County Sanitation District

Parameters	Btf #10	Btf #I	Unit
Air flow rate	17,000	17,000	m ³ h ⁻¹
Average H ₂ S inlet concentration for calculations	20	60	ppm
Caustic (25%) consumption ^a	33	100	m ³ /year
Hypochlorite (12.5%) consumption ^a	240	720	m ³ /year
Halomethane emission assuming 1 ppm emission (all as chloroform)	700	700	kg/year

^aCalculate value assuming complete conversion of H₂S to sulphate and neglecting consumption of caustic by CO₂ absorption.

4 CONCLUDING REMARKS

It is only during the past decade that one has started to seriously discuss the sustainability of selected aspects of our society. A lot of focus has been placed on the effect of pollution, highlighting the fact that pollution control is much needed. As a results, there has been very significant improvements in environmental protection. However, there has been a somewhat narrow minded opinion that more control is always better. This is not necessarily the case, especially in light of the very large differences between the global impact of biological and conventional pollutant control methods. In the present paper, the

case was made for the making of better informed decisions for the selection of pollution control equipment and for the establishment of environmental policies. This will be a first step in minimizing the impact of pollution and pollution control. In the future, even further efforts will be needed to integrate such reasoning during the design phase of industrial plants and processes, so that the sustainability of the entire process can be optimized, rather than the sustainability of individual units.

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