A statistical perspective on biofilter performance in relation to the main process parameters and characteristics of untreated flows

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ABSTRACT

A large number of olfactometric measurements of odour removal efficiency of municipal waste organic fraction and green waste composting installations were compiled and analysed graphically. The number of measurements and installations is >50 for treated gas characteristics and >15 for filter media characteristics. All installations concerned were located in the Netherlands and Belgium. All untreated and treated gas odour concentrations were measured in duplicate or triplicate, according to olfactometry standard EN13725 or its predecessor NVN2820. The data were then analysed using graphical methods to identify trends and relation between effectiveness of performance and a large number of operational parameters and characteristics, including: • Area flow loading ($m^3 \cdot m^{-2}$ filter area·$hour^{-1}$) • Contact time • Temperature of untreated flow • Odour concentration of untreated flow • Ammonia concentration of untreated flow • Dry matter content of filter media • pH of filter media

1 INTRODUCTION

Biofilters are widely used to treat odorous process flows from composting installations used for processing the organic fraction of municipal waste and green wastes (separately collected vegetable, fruit and garden waste). The main objective of treatment is reduction of odour emissions and their related impacts.

The criteria for satisfactory treatment result vary from country to country. For example:

- The Netherlands Emissions Guideline (Infomil, 2000) considers an odour concentration in the treated gas of < 2500 $ou_E \cdot m^{-3}$ indicative for an efficient biofilter.
- In Germany (30.BimSchV, 2001) a biofilter is expected to produce treated gas flows with a concentration of < 500 $ou_E \cdot m^{-3}$.
- In Spain Odournet consultants frequently see environmental license conditions and contract conditions for waste management installations that require the concentration from biofilters not to exceed 1000 $ou_E \cdot m^{-3}$.

These widely differing performance criteria beg the question: *What is a consistently attainable endpoint for treatment of organic fraction and green waste composting process flows in biofilters?*

This question leads to the related question: *Which are the parameters that determine the effectiveness of treatment of a biofilter?*

A large number of supposedly relevant parameters have been identified in literature (IPPC BREF, 2003). Some of these factors relate to the design parameters of the biofilter, and others to the characteristics of the raw gas to be treated.

1. **Biofilter design parameters:**
   a. **Area flow loading**. The volume flow of gas treated by 1 square meter of biofilter surface, typically expressed as $m^3 \cdot m^{-2} \cdot hour^{-1}$. This design parameter may vary over a range of 50 to 600 $m^3 \cdot m^{-2} \cdot hour^{-1}$. In practical applications for composting installations a range of 100 to 200 $m^3 \cdot m^{-2} \cdot hour^{-1}$ is more typical.
   b. **Time of residence**. The time that the gases remain in contact with the filter medium is a function of the area flow loading and the filling height of the media material. The parameter is expressed in seconds. As the actual biological oxidation occurs in the liquid adhered to the media, the time permitted for transfer of odorous components from the gas to the liquid phase is of obvious importance. Typically, the gas retention time in the biofilter media is between 30-60 seconds.
   c. **Temperature of filter media**. The temperature of the filter media must be suitable for the biomass to thrive. At low temperatures, the metabolism will occur at a slower rate. At higher temperature, above the mesophile range of 10 to 45ºC, the population will shift from mesophile to thermophile species, while at even higher temperatures biomass will not be able to exist. Typically, the optimum temperature in a biofilter is considered to be within the range of 30 to 38ºC.

2. **Biofilter media characteristics:**
   a. **Type of filter media**. There is a wide range of filter media, most of organic origin, e.g. peat, heather, wood chips, root chips, bark chips, compost, etc. Inorganic media are used in some cases, *e.g.* extruded clay pellets, lava rock, typically mixed with some organic material. The media provides for the basic life support of the biomass, and can contribute by providing: physical support surface, moisture, nutrient supply and pH control.
   b. **Nutrient availability**. The biomass should satisfy part of its nutrient requirements by using the components provided by the raw gas flow. However, these may not provide a balanced diet and deficiencies in nutrients such as phosphorus, nitrogen and trace elements may limit biomass development. In that case nutrient availability must be supplemented from the media of by irrigation with a nutrient solution.
   c. **Dry matter**. The dry matter content should be such that the filter structure has a homogeneous structure, while not becoming soggy, with the risk of creating anaerobic zones. An optimum dry matter content is typically in the range of 25 to 40%, in the experience of Odournet, while the literature indicates a wider range of 40-60% dry matter (IPPC BREF, 2003).
   d. **Irrigation water**. The quality of the water used for irrigation can have an impact on the availability of nutrients. Well water usually contains high iron levels, which can bind phosphate and cause a nutrient deficiency in the biofilter.
   e. **pH**. The optimum range is between pH 6 and 8. When the acidity moves outside this optimum range the filter can still function, but the population will become more specialised and hence limited in its biodiversity, which may influence its effectiveness.
   f. **pH buffer capacity**. Some materials have a larger capacity to buffer pH in situations where acids are being formed by the biological oxidation of reduced sulphur compounds (*e.g.* H_2S) and ammonia (NH_3).
   g. **Nitrate**. The total content of ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-), expressed as $NH_4^+NO_x$-N in g per kg wet material, can impact on the microbial activity. Literature values indicate that at values in excess of 4 $g \cdot kg^{-1}$ wet material the nitrification in the filter is completely inhibited. An alternative indicator is that a concentration in excess of 6 $g \cdot litre^{-1}$ of nitrate in the liquid fraction cause a reduction in microbial activity. A range of between 0.25 and 3.5 g of $NH_4^+NO_x$-N per kg wet material should be maintained.

h. **Sulphate**. High concentrations of sulphate (SO_4^{2-}), formed by biological oxidation of reduced sulphur compounds can cause low pH and an excess of conductivity, which in turn indicated suboptimal osmotic conditions for the biomass.

i. **Conductivity**. The electric conductivity of the media is indicative for the salinity of the liquid in the media. If the salinity, or the concentration of dissolved ions, becomes too high, the osmotic properties of the liquid become unfavourable for microbial activity. As a rule of thumb the electrical conductivity should be less than 1000 $\mu S \cdot cm^{-1}$.

3. **Raw gas characteristics:**

a. **Temperature**. The raw gas should enter the biofilter at a temperature that is suitable to maintain the optimum media temperature as discussed above.

b. **Relative humidity**. The raw gas should enter the biofilter media fully saturated with humidity to avoid any drying out of the filter. Drying out of the filter media is the most common cause of biofilter failure, in the experience of Odournet consultants.

c. **Odour concentration**. The odour concentration of the raw gas will determine the job at hand of the biofilter. As the range of odorants can be extremely variable it is difficult to provide a full discussion. Generally speaking, biofilters typically achieve higher efficiencies when used at higher concentrations (100000 to 1000000 $ou_E \cdot m^{-3}$) than at lower concentrations. Compounds that are less soluble are treated with less efficiency, for obvious reasons.

d. **Absence of toxic or inhibiting compounds**. Toxic compounds in the raw gas should be avoided (CO, chlorinated compounds). Large concentrations of less odorous compounds, such as CH_4, may reduce the effectiveness of the filter in treating the more odorous compounds.

This paper explores the data obtained from a large number of measurements conducted in the Netherlands and Belgium in a variety of biofiltration units servicing composting processes. Some of the units were assessed repeatedly over a period of approx. 5 years. The measurements were all conducted by dynamic olfactometry according to the EN13725:2003 standard, in laboratories with an accredited quality system according to ISO17025.

The concentration of the treated gas in relation to some of the parameters discussed above is explored in a number of graphs, to provide an insight based on statistics obtained under real-world conditions. As these observations were obtained from actual performance evaluations, and not from a controlled experimental setup, it was not possible to keep all variables constant and vary one parameter of interest.

Covariance between non-independent variables is therefore a factor to be kept in mind.

2 MATERIALS AND METHODS

2.1 Olfactometry

The odour concentrations in $ou_E \cdot m^{-3}$ of raw gas and treated gas flows, collected before and after the biological treatments, were measured in strict adherence to the NVN2820:1996 and later the EN13725:2003 standard for olfactometry (Van Harreveld, 1998). All measurements were conducted in laboratories with a quality system according to ISO17025 in place, and accredited on this basis by the Accreditation Council of the Netherlands, under the umbrella of European Accreditation.

All measurement results are based on a minimum of duplicate samples, and typically on triplicate samples of raw gas and treated gas. The geometric mean of the individual measurements is presented in the graphs. The measurements were conducted during the period between 1995 and 2000.

3 RESULTS AND DISCUSSION

3.1 Treated gas odour concentration in relation to area flow loading

Figure 1 shows the relation of outgoing odour concentration at different levels of area loading, in the range between 40 and 350 $m^3 \cdot m^{-2} \cdot hour^{-1}$.

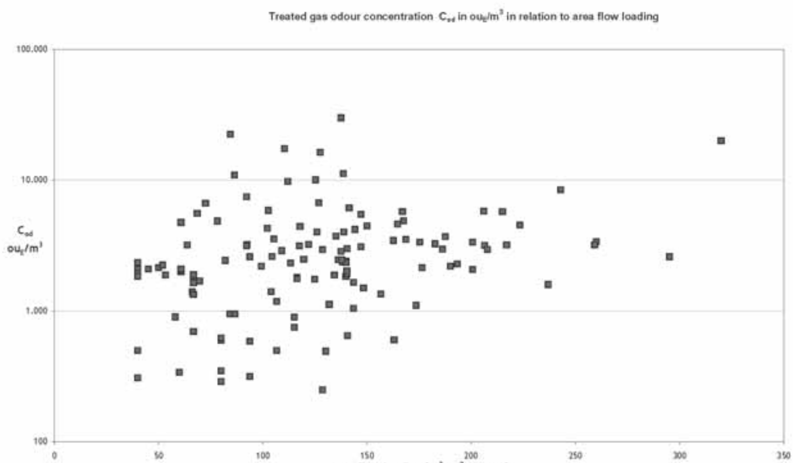

Figure 1. Relation between the odour concentration in the treated gas and area flow loading.

The graph in Figure 1 does not show a clear correlation between area flow loading and treated gas odour concentration in the range considered. However, concentrations of the treated gas below 1000 $ou_E \cdot m^{-3}$ are only seen to occur at area flow loadings below approximately 180 $m^3 \cdot m^{-2} \cdot hour^{-1}$.

3.2 Treated gas odour concentration in relation to residence time

Figure 2 shows the relation of outgoing odour concentration at different residence times, in the range between 20 and 90 seconds.

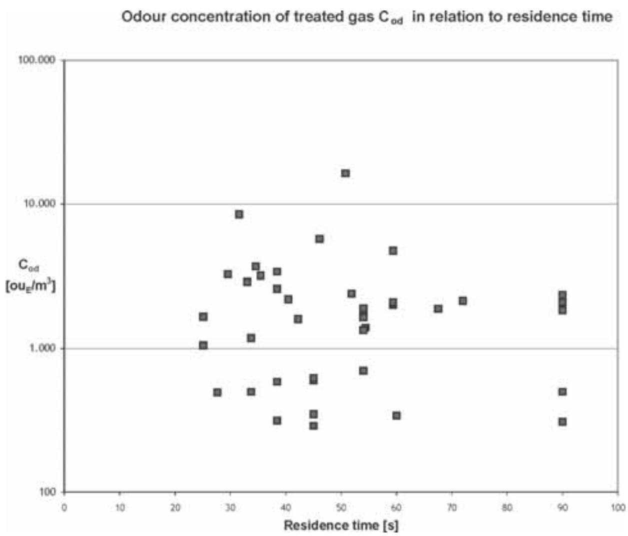

Figure 2. Relation between the odour concentration in the treated gas C_{od} in $ou_E \cdot m^{-3}$ and residence time in seconds.

The graph does not show a clear correlation between residence time and treated gas odour concentration in the range considered.

3.3 Treated gas odour concentration in relation to the temperature of the raw gas

Figure 3 shows the relation of outgoing odour concentration at different temperatures of the raw gas, in the range between 24 and 8ºC.

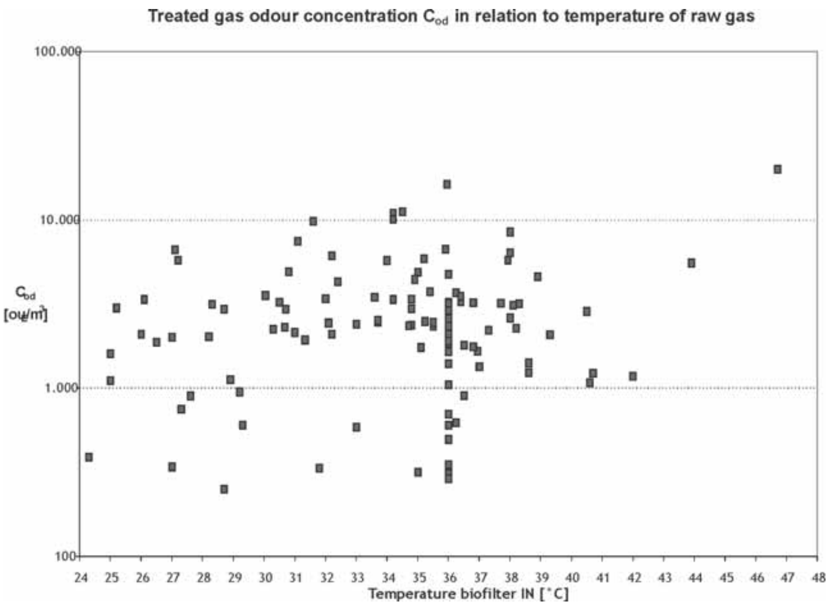

Figure 3. Relation between the odour concentration in the treated gas and the raw gas temperature.

The graph does not show a clear correlation between raw gas temperature and treated gas odour concentration in the range considered. It should be emphasized that the large majority of the observations are below 40ºC. Treated gas concentrations below 1.000 were not observed at temperatures in excess of 37ºC.

3.4 Treated gas odour concentration in relation to dry matter content of the media

Figure 4 shows the relation of outgoing odour concentration at different levels of dry matter content of the media, in the range between 25% and 40%.

The graph does not show a clear correlation between dry matter content and treated gas odour concentration in the range considered, although less favourable treated gas values appear to occur at low dry matter content. It should be noted that the range considered coincides with the range of advisable values.

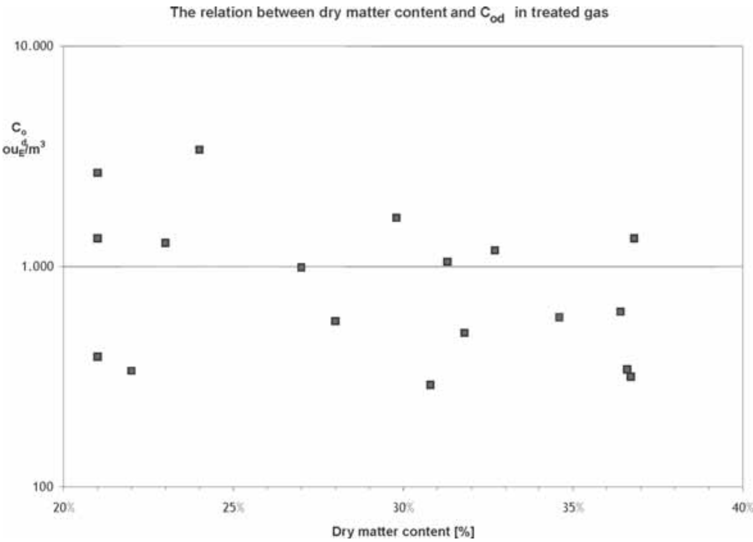

Figure 4. Relation between the odour concentration in the treated gas and dry matter content of the media.

3.5 Treated gas odour concentration in relation to pH of the media

Figure 5 shows the relation of outgoing odour concentration at different levels of pH of the media, in the range between 5.0 and 7.5.

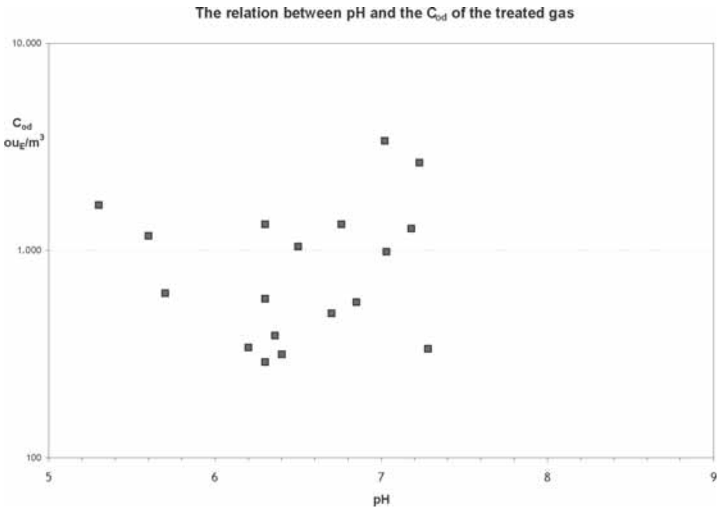

Figure 5. Relation between the odour concentration in the treated gas and pH of the media.

The graph does not show a clear correlation between pH and treated gas odour concentration in the range considered, although less favourable treated gas values appear to occur at the extremes of the range considered. It should be noted that the range considered almost coincides with the range of advisable values of pH between 6 and 8.

3.6 Treated gas odour concentration in relation to raw gas ammonia concentration

Figure 6 shows the relation of outgoing odour concentration at different levels of raw gas ammonia concentration, in the range between 0 and 120 ppm, with one observation at approximately 200 ppm.

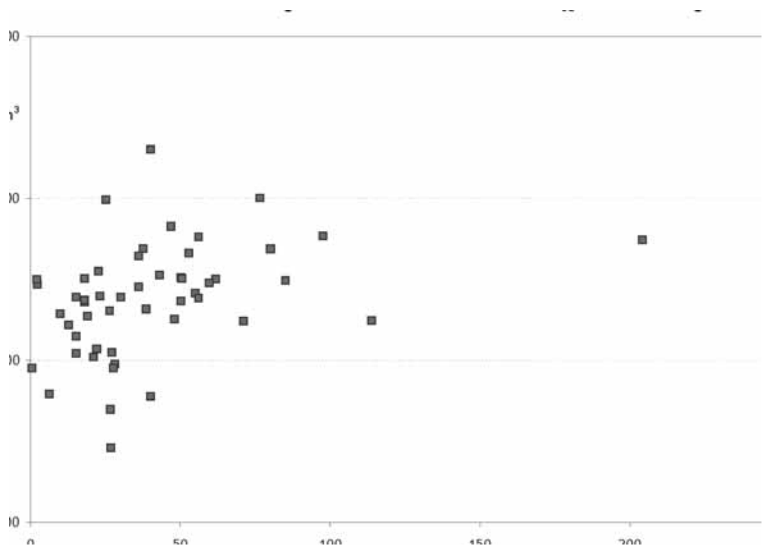

Figure 6. Relation between the odour concentration in the treated gas and ammonia concentration.

The graph does not show a clear correlation between the ammonia concentration in the raw gas and the treated gas odour concentration in the range considered.

Even at concentrations in excess of 50 ppm, that are generally considered undesirable, the treated gas odour concentration appears to remain at fairly typical levels. However, it should be noted that these are snapshot values. The detrimental effect of sustained high ammonia loads will show itself with time, when the electrical conductivity is increased due to increased levels of $NH_4^+NO_x$-N, leading to reduced microbial metabolism and hence treatment capacity. For the observations presented in the figure above information on the standing time of the filter medium is not available.

3.7 Treated gas odour concentration in relation to the concentration of the raw gas

Figure 7 shows the relation of outgoing odour concentration at different concentrations of raw gas odour concentration, in the range between a few thousands and 500000 $ou_E{\cdot}m^{-3}$.

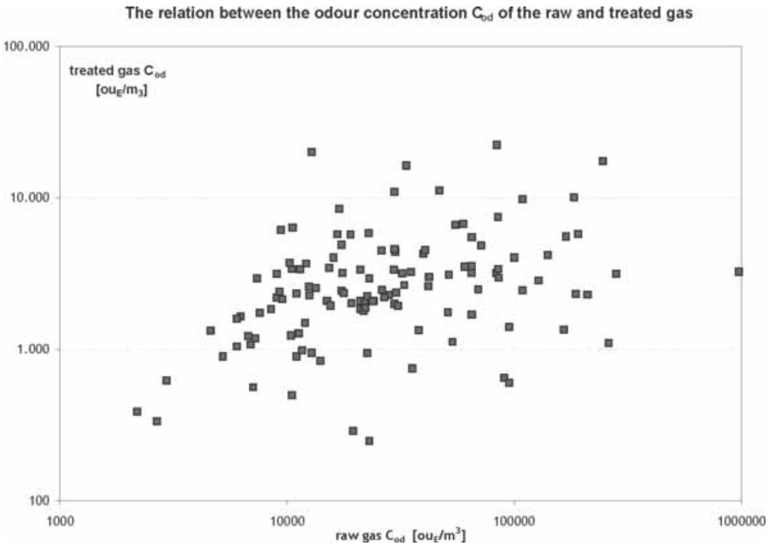

Figure 7. Relation between the odour concentration in the treated gas and the raw gas.

Even at very high raw gas concentrations, of several hundreds of thousands of $ou_E{\cdot}m^{-3}$, the treated gas will have a concentration rarely exceeding 10000 $ou_E{\cdot}m^{-3}$.

Of the measured odour concentration in the treated gas (n = 123) of biofilters treating organic green waste, 4% of the odour concentrations in the treated gas were found to be less than 500 $ou_E{\cdot}m^{-3}$, a requirement often derived from German regulations. Only 14% of treated gas measurements was < 1000 $ou_E{\cdot}m^{-3}$, while 52% was < 2500 $ou_E{\cdot}m^{-3}$, a criterion used in the Netherlands for a as indicative for a well functioning biofilter.

Based on the same data, the removal efficiency of the biofilters is plotted in relation to the odour concentration of the raw gas in Figure 8.

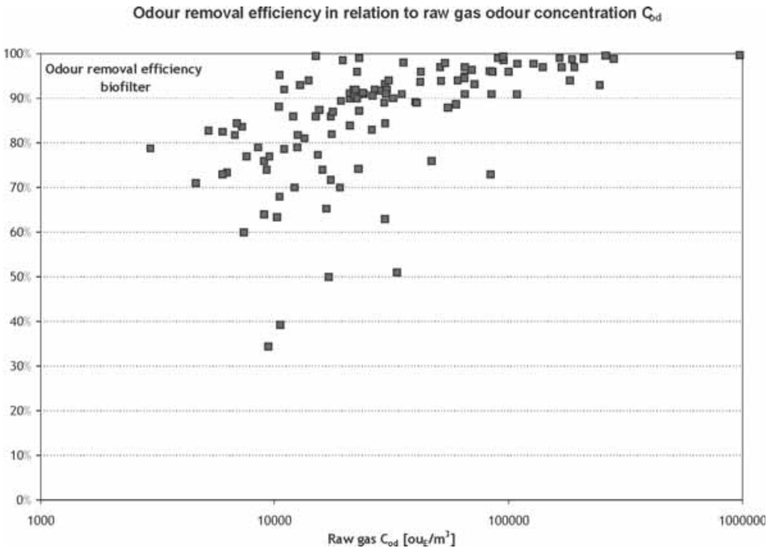

Figure 8. Relation between the odour removal efficiency an the odour concentration in the raw gas.

The graphs show that biofilters have a capability to treat a wide range of raw gas odour concentrations with a remarkably consistent efficiency, typically at >80%. The lower efficiencies are presumably an indication for suboptimal operational conditions, as they typically occur at lower odour loads.

4 CONCLUSIONS

The observations presented in this study lead to the following conclusions:

1. Biofilters appear to be a very robust treatment method suitable for reducing odour emissions in raw gas from green waste and organic fraction composting processes, ranging from a few tens of thousands of $ou_E \cdot m^{-3}$ to half a million of $ou_E \cdot m^{-3}$ with odour removal efficiencies in the majority of cases in excess of 90%.
2. For the parameters considered in this study, which were generally within the suggested range of values in the literature, no clear relation between the parameter value and the treated gas odour concentration could be observed.
3. The values of residual odour concentration are often in excess of the targets that are applied in various countries as emission criteria for composting odours after treatment with biofiltration. Of the data considered:

a. 4 % satisfied the German criterion of $C_{od,\ treated} < 500\ ou_E{\cdot}m^{-3}$
b. 14 % complied with the criterion of $C_{od,\ treated} < 1000\ ou_E{\cdot}m^{-3}$ that is often seen in Spanish waste management contracts and environmental licences.
c. 52 % of the observations was found to satisfy the criterion of $C_{od,\ treated} < 2500\ ou_E{\cdot}m^{-3}$ that is mentioned in the Netherlands Emission Guideline as indicative for a well functioning biofilter.

4. A performance criterion more restrictive than a treated gas concentration of $C_{od,\ treated} < 2500\ ou_E{\cdot}m^{-3}$ appears to be too restrictive and not viable as a value that operators need to attain consistently.

5 ACKNOWLEDGEMENTS

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