A MODEL OF A BIOFILTER FOR MECHANICAL PULPING WASTE-WATER TREATMENT

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ABSTRACT

VOC emissions are released from mechanical pulping process and can be abated by different cleaning technologies. VOC emissions origin both from grinding process and waste water treatment. In Europe the estimated annual total NMVOC emissions from mechanical pulping process is approx. 7.000 tons.

Biofiltering is one of the most promising abatement techniques available. This because its reduced CO_2 emissions and its long life.

In the paper a pilot application to a mechanical pulping waste water system is considered.

Mechanical pulping emissions are Volatile Organic Compounds, VOCs. Today VOCs are a main issue in environmental control.

The role of Biofiltering in VOC abatement is pointed out in the paper.

In the paper a model and a pilot implementation of the Biofilter are introduced. The results of the biofilter used in waste-water treatments are then shown.

Keywords: VOC emissions, Mechanical Pulping, VOCLESS

1. INTRODUCTION

Volatile Organic Compound (VOC) emissions are limited by international standards such as the EU VOC solvents emissions directive 1999/13/EC or Section 183(e) of the Clean Air Act in the United States).

One industry with a VOC emission problem is the pulp and paper industry that is not yet regulated by VOC emission limits.

In order to reduce VOC emissions, there are several solutions. One of these is the use of Biofilters.

Such a solution is relatively new and is based on the oxidations of VOCs by a population of microorganisms.

Since its first application in the 1970s (Reinluft), there has been a growing interest in Biofilter applications and their modeling and simulation.

This is because Biofilters reduce CO_2 emissions and they have low operating costs and a long working life. They are simple to manage and they, unlike incinerators, are $C0_2$ free.

Modeling and simulation have been considered in many environmental sectors (Bruzzone et al., 2009a) (Bruzzone et al. 2009b) and also in the field of biofilters. In Jacob et al. (1996), a dynamic simulation of biofilters is considered. The aim is to build and validate an analytical model based on the balance equations, from which a partial differential and algebraic equations are derived. The model is validated for the processes of denitritation and denitrification using data from a pilot plant. The model is solved using numerical methods by applying the methods of lines and an approximated method to reduce model complexity. The results obtained are good, but required more deeper analysis to be used in controlling biofilters.

In Mohseni and Allen (2000), a mathematical model for a mixture of hydrophilic and hydrophobic VOCs is considered. This mixture refers clearly to the pulp and paper industry, where such emissions are typical. The two main processes of VOC diffusion through a biofilm and their degradation are modeled.
The model parameters are determined by experimental data from a pilot plant.

The results of the model are then compared to data in the literature giving better results.

Noteworthy is the fact that the presence of hydrophilic VOCs can affect the abatement of hydrophobic VOCs. This model could be useful for use in the pulp and paper industry and also in mechanical pulping. However, analysis and modeling has been limited to only 2 substances and for softwood only.

In Easter et al. (2005), the use of biotechnologies in the abatement of VOCs and odours from wastewater is considered. In particular, the collection system is also considered because of its role in odour diffusion.

In the paper, design parameters such as Empty Bed Residence Time, EBRT:

$$EBRT = \frac{AD}{Q}\ [s],$$

where A is biofilter surfaces m^2, D is biofilter bed depth m, Q is odor flow m^3/s.

Also, volumetric Loading Rate is considered:

$$LR = \frac{Q}{A}\left[\frac{m}{s}\right]$$

Other parameters such as temperature, ph and moisture control, airflow distribution, leachate and drenage , and media selection are considered.

VOC concentration is not treated because in this study airflow composition is known and then parameters are computed.

Results are considered for different kinds of media and for both biofilter and biotowers. It is important to know the composition of the air stream in input of the biofilters, in the design process.

In the paper, a model and a pilot implementation of the biofilter are shown.

The results of the biofilter used in waste-water treatments are then considered.

Abatement emissions are considered a concern in mechanical pulping waste-water VOCs.

Biofilter tests are part of a LIFE+ project, VOCless Pulping Waste Waters (LIFE09 ENV/FI/000568).

In the following paper, after a brief description of the LIFE project, the biofilters developed in the project are shown.

Then results of a field test at a Mechanical Pulp plant are also given.

2. THE VOCLESS PULPING WASTE WATERS

The VOCless Pulping Waste Waters project is concerned with VOC emissions and odour problem in Mechanical Pulping. In particular, this project considers the VOC and odour emissions from mechanical pulping waste-waters.

The project starts from the results of a previous VOCless project where all VOC emissions from mechanical pulping in general were considered. During this project, VOC measurements showed that emissions from waste-waters accounted for the same amount as that emitted directly from the pulping process.

Therefore, the aim of this project is find the best technological solution to minimize such an amount of VOC emissions from waste-waters.

In order to do this, the pilot testing of several solutions was carried out. The pilot biofilters were designed, implemented, and tested for this project.

The VOCless project faces the increasing problem of VOC emissions reductions demanded by International Legislation. VOCs are known to be the cause of smog formation, odour problems, and other harmful effects.

The interesting aspect of the considered project is that in mechanical pulping VOCs are natural, so they are not controlled by VOC legislation (that applies only to anthropic VOCs). Nevertheless, mechanical pulping VOCs are emissions from industrial production, so their emissions should be considered also in this case.
Therefore, the only solution, since VOCs are natural is an end-of-pipe technology.

3. DESCRIPTION OF THE BIOFILTER

In the following, the biofilters considered are presented. The following part of the paragraph is part of the Meehanite report from the VOCless Waste Waters project. Biofilters lend themselves to all waste gas cleaning applications involving air pollutants that are readily biodegradable. Biodegradation of the pollutants is accomplished by micro-organisms colonising on a solid support media. The typical support media employed are chopped wood and wood bark, composts or other origins, fibrous peat and heather that may be combined with one another or other structure-giving materials. Moreover, inert materials exhibiting large inner surface areas (lava, expanded clay) and hence, the ability to support a large population of microorganisms are employed as support media. All these materials are normally arranged as randomly packed beds through which the waste gas flows. As the waste gas passes through the bed of media, the pollutants are sorbed onto the surface of the filter media where they are degraded by micro-organisms. For optimum growth and metabolic activity, the micro-organisms rely on defined environmental conditions (moisture, pH, oxygen content, temperature, nutrients, etc.) which must be controlled within narrow limits. As micro-organisms are affected by changes in their environment, they may require some time for acclimation before developing their full activity after the biofilter start up or changes in the operating conditions. Transport of the pollutants from the gas phase through the aqueous phase surrounding the filter media and from there to the bacterial cells involves the following individual steps:

- Mass transfer to gas/liquid interface
- Absorption into the liquid phase
- Mass transfer through the liquid phase to the bacterial cell
- Sorption and degradation by the cell

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

- Concentration and types of waste gas component
- Type, number, and activity of the micro-organisms colonising on the respective filter media
- Temperature
- Moisture content of the waste gas and the filter media
- pH value
- Solubility of the waste gas components
- The type and concentration of any reaction products accumulating in the filter media.

The net conversion of pollutants in the filter bed is determined by the rate of reaction, the residence time of the gas in the biofilter, and the concentration of the pollutant in the crude 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 may become rate-limiting.

The filter media may also serve as a source of nutrients and nutrient salts for the microorganisms. In applications involving waste gases poor in nutrients, intermittent operating conditions and waste gases with high organics loads, the micro-organisms rely on additional nutrient supply. This can be partly accomplished via the nutrient salts present in the filter media. However, in some cases subsequent fertilization of the filter media may be needed. These parameters of the biofilters were observed and some additional nutrients were added.

Another important function of the filter media is to provide the micro-organisms with sufficient moisture. Otherwise the micro-organisms would have to be continuously sprayed with water. The filter media has an optimum moisture level at the time it is being placed in the biofilter. In order to preclude rapid bed dry-out, the waste gas to be treated must be humidified to the maximum feasible level before being admitted to the biofilter. After pre-conditioning in a humidifier, the waste gas is normally about 95% water-saturated. This means that it will take up the remaining 5% as it passes through the filter bed causing the latter to dry out. Filter bed dry-out can be counteracted by providing for additional irrigation of the filter media. A particular problem encountered with organic filter media is that it develops increasing hydrophobic effects as the moisture content decreases. This means that material that has become overly dry is no longer amenable to humidification. In most cases, it has to be removed. Overly wet filter media, on the other hand, will lead to water-logging. Under these conditions, the pores of the filter media are filled with water and thus blocked for the gas flow. This does not only affect the removal efficiency but also leads to oxygen depletion and hence insufficient oxygen supply for the microorganisms. While part of the microbial population can adapt its metabolism to anaerobic conditions, this results in metabolic end products which are similar to those formed by decaying organic materials and have a very unpleasant smell. This effect can be reversed by drying the filter media. Because of these facts the humidity of the biofilters was carefully observed by an online data logger and regular pilot plant check-up visits.

3.1. Filter characteristics

For the filter media to accomplish its manifold functions, it must exhibit specific material properties. It may well be possible that the specific requirements rule out one another. In such cases, an optimum trade-off tailored to the specific application will have to be made in media selection: A uniform structure favours uniform flow distribution and hence uniform contacting conditions. This, in turn, improves the degradation efficiency of the biofilter and minimizes the pressure drop. A sufficient pore volume reduces the pressure drop across the bed of media and hence the energy consumption. In addition, it improves the drainage effect of the media and prevents water logging. Depending on the type and condition of the filter media, the void volume may range between 20% and 80%. A large inner surface of the bed of media can be achieved by selecting either fine-sized media or media with a large pore volume. The large inner surface is required to ensure good sorption performance of the biofilter on the one hand and create the conditions necessary for a high microbial density on the other. Basically, all surfaces of the media particles, except for extremely small pores, are suitable to support microbial growth. Here, it should be noted that a fine-sized material causes a higher pressure drop than a coarse material. As the filter media inevitably undergoes decomposition and becomes progressively finer in the course of biofilter operation, the use of fine-sized media from the beginning results in a shorter service life.

3.2. Bio filter control and maintenance

Biochemical measures mainly relate to the addition of supplemental nutrients to the filter media and buffering undesirable changes in pH. The objectives of both measures are identical. They must reach the filter media surface, influence it and have a long-term effect in order to minimize treatment intervals. For this reason, granular additives that have a depot effect are preferred for both measures. For pH adjustment, water-soluble granular and powdered lime was added to the filter media.

Ph and moisture were monitored regularly during the pilot site visits by manual measurements. Additional powdered lime dissolved in water was added periodically in both bio-filters.

Temperature monitoring of the filter material and raw gas was done by online measurement at several points with thermal couples. A channel heater was assembled to control the raw-gas temperature.

3.3. Description of the pilot plant

Two small-scale biofilter pilot plants were built up for the pilot tests to be carried out at the aerobic waste-water treatment plant at the Stora Enso Anjala pulp mill. Both pilot plants were of the same size but the content of the filter material varied between them. The Meehanite pilot biofilter plant is in the scale of 1 to 500 of the full-size application. The first site for the pilot biofilter was the air flow of the cooling tower with an airflow of some 10 m^3/s. The air flow of biofilter pilot plant is designed for an air flow rate of 70 - 140 m^3/h**.** A schematic drawing of a the pilot biofilter is presented in Figure 1.

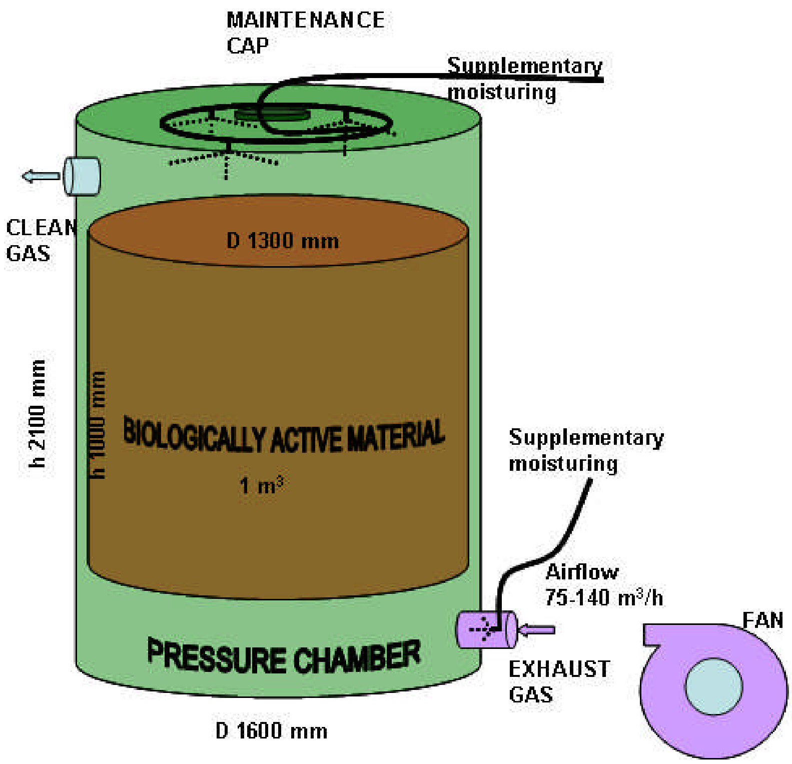

Figure 1. Schematic drawing of the principle features of the compact filter as a piloting biofilter

The exterior dimensions of the cylindrical shaped pilot biofilter are as follows: the diameter 1.6 m, and the height 2.1 m. The air flow direction is vertical from bottom to top. The surface area of biofilter bed is 1.3 m^2 and the bed thickness can vary from 1 000 to 1 500 mm. The biofilter contains a pre-filter stage as well. This acts as a humidifying and normalizing scrubber, and avoids unpleasant pH peaks that originate from the waste-waters of the refinery and grinding plants. The waste-water itself is neutralized already in the pump station, and the filter material pH is controlled regularly and modified when needed. The inlet exhaust gas was preheated when required by the channel heater (25-30 °C). A photograph of the Meehanite biofilter pilot plant is presented in Figure 2.

Figure 2. The Meehanite biofilter pilot plant.

3.4. Experimental Results

The 2 biofilters were used for the abatement of emissions from the cooling tower and from the micro bed bioreactors. Data from the two points of emissions are shown in Table1.

Table 1 . Parameters of the biofilter pilot plants.

Pilot site	Cooling tower 5.7.-19.7.2011.		Microbed bioreactors 20.7.-16.8.2011	
Biofilter 1 / Biofilter 2	**Bio 1**	**Bio 2**	**Bio 1**	**Bio 2**
Air flow temperature (°C) before biofilter	30-40		30-40	
Air flow temp. °C after biofilter	28-33	26-34	28-34	20-34
Biofilter bed temp. (°C)	25-32	26-32	26-34	26-34
Humidity (%)	99.9		99.9	
Pressure (Pa) approx.	2300		200-2500	
Air flow (m^3/h)	20		66	

Table 2: Biofilters performances at the waste-waters treatment plant

Site	Unit	VOC-concentration			Cleaning rate
		date	before	after	
			mg/Nm³	mg/Nm³	%
Cooling towers	Biofilter 1	6.7.2011	3.7	4.8	*
		19.7.2011	2.5	0.63	75
	Biofilter 2	5.7.2011	3.3	0.70	79
		19.7.2011	3,.4	0.66	81
MBR-1	Biofilter 1	21.7.2011	11.1	3.5	68
		2.8.2011	18.1	4.7	74
		17.8.2011	29.9	13.6	55
		30.8.2011	25.0	13.9	*
		31.8.2011	12.9	2.9	78
	Biofilter 2	21.7.2011	12.1	4.4	64
		2.8.2011	10.0	2.8	72
		17.8.2011	22.0	13.0	*
		31.8.2011	11.7	6.6	*

* malfunction

CONCLUSIONS

Two pilot biofilters were tested at a aerobic waste water treatment Mill in Finland. Pre-measurements were made and the pilot biofilter plants were placed at the cooling tower and the MBBR basin where the highest VOC concentrations appeared. Two small-size biofilter pilot plants were constructed. Different compositions and moisture of bacteria carrier material were tested. The pilot tests began in May and were completed at the end of August.

At the sites, the incoming VOC concentrations were different being higher at the MBBR site. An unexpected concentration of methane for aerobic biological wastewater treatment was detected. That presented a challenge in interpreting the measurement results.

The cleaning efficiency rate of the biofilters was on average 80% at the cooling tower, and the cleaning efficiency rate of the biofilters at the MBBR basin was about 70%. Cleaning rates were better with higher initial concentrations and averaged towards 70 to 75%. The cleaning rates probably fluctuated because of the varying composition and texture of the bacteria carrier material in the biofilters.

Overall, the biofilter tests showed good performance and sustainable working. It is obvious that the biobed material must be prepared and matured in good time prior to the actual exposure for a continuous run. The bioreactor material should always be reserved for the loading of an extra filter batch in the case of a malfunction in the process.

The test results showed that no extra pre-filter e.g. neutralization of the inlet gas is needed for the biofilters. The maximum specific air flow of 100 m³/h per square metre of filter area cannot be exceeded and a minimum depth of one metre of filter material is needed to reach an acceptable 80% cleaning efficiency.

As a future development, a model could be tested in other waste-waters treatment plants and it could optimised by using simulations.

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