TREATMENT OF POLLUTANT EMISSIONS IN A BIOTRICKLING FILTER WITH A MOVING BED – PILOT VERIFICATION

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Abstract

This study was aimed at testing a possibility of using a biotrickling filter with a moving bed for simultaneous treatment of waste air and waste water. For those purposes a laboratory biotrickling filter with a moving bed was constructed. After inoculating of the laboratory biotrickling filter long-term organic load tests were performed aimed at finding the maximum organic load of biotrickling filter which the biotrickling filter is operated with with high efficiency. The aim of the second test was testing the possibility of simultaneous removal of some odour compounds from waste air and waste water treatment. On the basis of operating parameters of the laboratory biotrickling filter and results of the long-term organic load tests two pilot biotrickling filters with a moving bed were designed and constructed. Subsequently they were installed in operating conditions in production of driving wheels and in a farm.

The efficiency of removal of organic compounds for organic load (OL 35 resp. 30 $g_C.m^{-3}_{filtre\ media}.h^{-1}$) in laboratory resp. operating conditions was about 96%. Simultaneous waste air and waste water treatment increased stability of the biotrickling filter and enabled removal of ammonia from the waste air whereas the efficiency removal of organic pollution waste water expressed as COD achieved 90%. The results confirmed suitability of using the biotrickling filter with moving bed for simultaneous waste air and waste water treatment.

Keywords: biotrickling filter with moving bed, waste air treatment, odour compounds

1. Introduction

Since 2007 DEKONTA, a. s. has been engaged in solving the research project entitled "Research and development of a combined biofilter for treatment of waste gas and water from livestock production" within the research and development programme „CONTINUOUS PROSPERITY" of the Ministry of Industry and Trade of the Czech Republic (no.2A-1TP1/004). The objective of the project is the research and development of technologies for removing harmful and odour compounds from waste gas originating from a range of production operations using wastewater. Biotrickling filter with a moving bed for treatment of waste gas and water has been constructed.

Biofiltration is a biological means of treatment of waste air utilizing microorganisms enabling biodegradation and biotransformation of pollutants. Polluted air is filtered through the biotrickling filter filled with highly porous matter, which is covered by a biomass layer. When filtering the gas through the biotrickling filter, the pollutant is absorbed into the recirculating liquid and adsorbed into the surface of the biomass at the same time and subsequent biodegradation of the pollutant occurs.

The recirculating liquid enables effortless control and regulation of the whole process. It provides sufficient humidity and even supply of nutrients, dissolved oxygen and pollutant for the microorganisms. Replacing clean water in a biotrickling filter with wastewater reduces operational costs as well as the level of pollution of the used wastewater.

A biotrickling filter with mechanical removal of excess biomass by means of stirring the medium has been designed in order to eliminate the issue of fouling of the biotrickling filter medium by biomass.

The objective of the third stage of the project was the verification of functionality of the biotrickling filter with a moving bed in operational conditions. The biotrickling filter was installed at the air escape from steering wheels production and at and air escape from pig house in factory farming.

2. Materials and Methods

Device Description

Within the 3rd stage of the project a bench and pilot operation biotrickling filter with a moving bed has been constructed. The biotrickling filter with a moving

bed was built using a stainless column with a conic bottom. The column is separated by a perforated partition and thus divided into a top and a bottom part. The bottom part of the column serves as a retention tank for the recirculating liquid. The top part of the column is equipped with special pressed plastic pieces which serve as a carrier for the biomass. A multiple blender handles the movement of the liquid. The shaft of the multiple blender runs through the column lid and it is anchored in the perforated partition. The medium of the biofilter is stirred regularly by means of the multiple blender.

The waste air from production is fed into the biotrickling filter by means of an adjustable exhaust ventilator via a system of flaps enabling to change the current of the air through the column – i.e. to adjust it as a parallel flow or a counter flow. Circulation of liquid in the biotrickling filter is ensured by the circulation pump. The pH of the liquid is controlled automatically within the set range of 6.6 – 7.8. Feed regulation of hydroxide of acid solution is handled by the membrane controlled volume pump IWAKI ES-B16VC-3.

Figure 1. Scheme and view over biotrickling filter with moving bed pilot

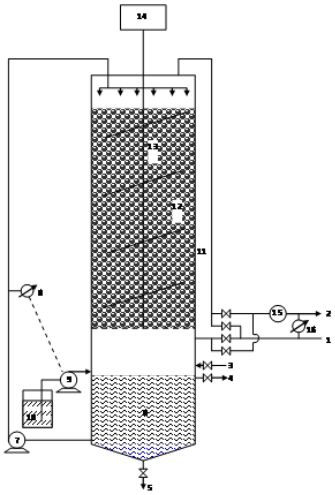


Table 1. Operational parameters of the biotrickling filter with a moving bed

		Bench BTF	Pilot BTF
Column diameter	(m)	0.5	1.0
Height of medium	(m)	1.0	2.0
Medium volume	(m^3)	0.2	1.6
Air flow	($m^3.h^{-1}$)	20 - 50	150 - 500
Stirring speed	(min^{-1})	9	9
Stirring frequency	(day^{-1})	2x 5 min	2x 5 min

Analytical Methods

Determination of concentration of organic compounds and CO_2 at the input and output from the biofilter was done by means of the portable device Ecoprobe 5. Ecoprobe 5 mobile analyzer is equipped with a photo-ionization detector, which ensures the measuring of the overall concentration of organic compounds (TOC) in the air including chlorinated hydrocarbons. Photo-ionization detection with calibration to isobutylene was used in order to detect volatile organic compounds. In the event of measuring one organic compound, its concentration may be determined by means of tabulated recalculation factor from the detector response. For a mixture of organic compounds the recalculation factor has to be determined by comparison with parallel measuring by means of a flame ionization detector (FID). The recalculation factor has been determined by comparison with measuring by a portable flame ionization detector (FID) CxHy VAMET 20 calibrated for propane. The input concentration was measured directly at the input into the biofiltering device. The output concentration was measured directly behind the biofiltering device.

Sorption tubes Gastec for ammonium with the scope of 2.5 -60 ppm were used for one-time detection of emissions of inorganic compounds(NH_3) A sample of the air was taken by means of a manual calibrated pump Gastec 100S.

The method of COD_{Cr} analysis was carried out in a laboratory in compliance with the ČSN ISO 6060 standard. This method is based on the principle of chemical oxidation of organic compounds contained in water by means of a strong oxidizing agent (dichromate). Excess levels of dichromate were detected by a titrant agent by a solution of ammonium ferrous sulfate after adding ferrion.

Detection of ammonia nitrogen in water is based on the reaction of ammonia and hydroxide of alkali metals with sodium-tetraiodomercurate with the presence of the iodide of the Millon's base, which creates yellow-brown colloid solution at small concentration of ammonia, whose colour intensity may be determined spectrophotometrically.

Pilot Testing

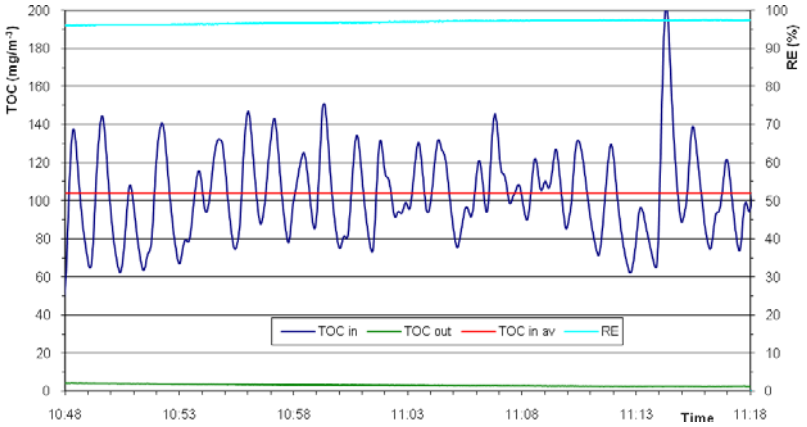
A bench biotrickling filter was installed within the pilot tests at the air exhaust from the production line of steering wheels and a pilot biotrickling filter was installed at the pig house exhaust. Upon the installation and testing the tightness of the biotrickling filter with a moving bed the medium of the filter was inoculated with a BIOTECH preparation. BIOTECH had been resuspended in 80 and 200 litres of the base BSM media solution and then applied in the biotrickling filter. No minerals or trace elements were added during the experiment, only pH of the recirculating liquid was regulated within the range of 6.6 – 7.4 with addition of solutions of KOH and/or H_2SO_4.

The following parameters were being monitored during the long-term test: airflow speed at the output from the biotrickling filter, loss of pressure, TOC concentration or NH_3 or CO_2 at the biotrickling filter output and input and those values were then used in order to calculate the following operational parameters: airflow, retention average time, organic load, elimination capacity, efficiency of elimination and specific production of CO_2.

3. Results and Discussion

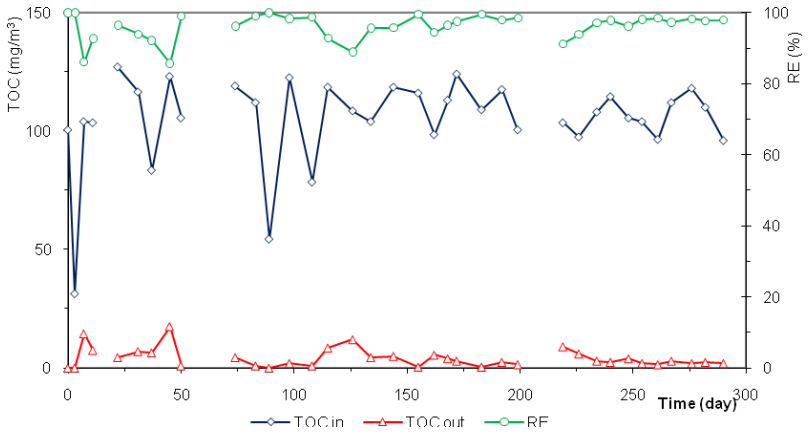
Bench Biotrickling Filter

Waste air from the steering wheels production line contained, based on the GC-MS analysis a mixture of volatile organic compounds containing 85 - 90 % of n-butyl acetate, 4% of toluene, 1-2% of benzene and 6 % of xylene, the rest was a mixture of oxygenous derivatives of lower hydrocarbons. The concentration of organic compounds on the input fluctuated significantly in approximately 2-3 minutes period (see graph no. 1). This fluctuation corresponded to the feed of new blend into the device for steering wheels production, milling and air exhaust, removal of the steering wheel and cleaning the mould. Apart from this fluctuation of organic compounds concentration on the input into the biotrickling filter, the concentration on the input was also dropping due to the two-directional operation in night hours and/or at weekends and long term decrease also appeared in relation to the scheduled or unplanned interruption of operation necessary for maintenance of the production line.



Graph 1 Changes in TOC emissions concentration at BTF MB input and output with the line in operation (TOC_{in}, TOC_{out},) and TOC removal efficiency (RE)

The average concentration of organic compounds expressed as TOC at the biotrickling filter's input during the operation of the line was within 100 – 110 $mg.m^{-3}$. The airflow varied between 15 $m^3.h^{-1}$ and 50 $m^3.h^{-1}$. During the experiment the production line was temporarily shut down three times, each time for about three weeks, which is why the TOC concentration at the biotrickling filter's input basically dropped to zero during these days.
(see Graph 2).



Graph 2 Overall changes in TOC emissions concentration at BTF MB input and output (TOC_{in}, TOC_{out},) and TOC removal efficiency (RE)

In Graph 2, three temporary shutdowns of the production line are evident. The biotrickling filter was always put into operation after the approximately three-week-long shutdowns without any manipulation with the biotrickling filter, i.e. no re-inoculation with a new bio-preparation was done. The original removal capacity values, or the original removal efficiency, were reached within 2 – 5 days, the effectiveness of eliimination of organic substances in biotrickling trickling reaching 90 – 95% immediately after the line was put back into operation. Due to the very high efficiency of the elimination of organic compounds, the removal capacity curve almost exactly copies the organic load curve, which means that the biotrickling filter was operated in a state of equilibrium (steady state) for the whole time of the experiment.

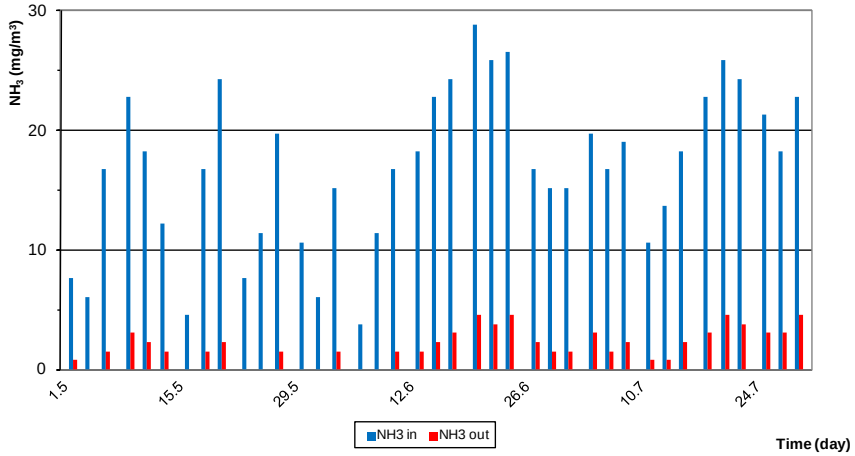
The average airflow ranged from 30 – 50 $m^3.h^{-1}$, which corresponds to the mean value of the retention period of 25 – 14 s. Pressure loss changed only as a result of airflow change. Pressure loss growth as a result of excessive growth of redundant biomass did not occur due to the mechanical removal of the redundant biomass by means of stirring the medium of the biotrickling filter regularly. In the case of the biotrickling filter with a moving bed, the pressure loss was constant during the experiment. It only changed in dependence on the airflow.

Pilot biotrickling filter

The waste air which was being exhausted from the sited of the large-scale pig house contained mainly ammonium emissions. The ammonium concentration at the biotrickling filter output ranged from 5 to 25 $mg.m^{-3}$ as the result of variable intensity of the pig house ventilation. The removal of the ammonium from the waste air can be divided into two processes. During the first stage the ammonium is absorbed in water, which caused an increase in pH, which is why pH was regulated by means of a dilution of sulphuric acid. During the second stage the ammonium ions are utilized by micro-organisms for the growth and creation of new biomass. In order to ensure that the ammonium is removed from the waste air by the microbial activity, molasses was fed into the biotrickling filter in regular intervals. Molasses serves as a primary source of

carbon and energy in the metabolism of the micro-organisms present. The ammonium ions are utilized as the preferred source of nitrogen. The addition of biomass into the re-circulating liquid was to substitute the use of waste water with high COD content, which was unfortunately unavailable. The amount of the re-circulating liquid was kept at the constant level of 200 litres by means of surface floats. The water that evaporated during biofiltration was automatically replenished through an electro-valve from the water main. Water evaporation was about 40 litres a day.

The changes in ammonium concentration at the input and output of the biotrickling filter and the efficiency of ammonium removal are shown in Graph 3.



Graph 3 Development of ammonia concentration on the input and output from the biotrickling filter

Detection of concentration of ammonium ions in the recirculating liquid was carried out in order to find out whether the elimination of ammonia may be ascribed to the mere absorption of ammonia into the recirculating liquid. The results of this finding including the determination of COD have been summarized in Table 2.

Table 2. COD_{Cr} values on the input and output (i.e. after and before adding molasses) and NH_4^+ values in the recirculating liquid.

Date	COD_{Cr} (mg.l^{-1})			NH_4^+ (mg.l^{-1})	
	INPUT	OUTPUT	RE (%)	Calculated	Measured
16/5/2011	24 050	2 390	90,1	267,4	54
30/5/2011	25 170	2 640	89,5	581,6	42
13/6/2011	22 960	2 690	88,3	944,5	36
27/6/2011	23 780	2 470	89,6	800,3	43
4/7/2011	24 240	2 850	88,2	906,3	40
18/7/2011	26 490	3 260	87,7	1137,4	37

Theoretical concentration of ammonium ions in the recirculating liquid was calculated by the difference between the values of the mass flow rate of ammonia on the input and output from the biotrickling filter and multiplied by the number of hours of the monitored period and divided by the volume of used water for this period. Theoretical concentration of ammonium ions in the recirculating water represents the maximum value of ammonium ions concentration, which was achieved by absorption of ammonia from the air into the recirculating water supposing that any ammonium nitrogen wouldn't be utilized by microorganisms. The results in Table 2 above show that for all measurements there was a 80 - 90% removal of ammonium nitrogen from the recirculating liquid. The efficiency of COD elimination was 90% on average.

4. Conclusion

Bench biotrickling filter

The results of the bench tests of the biotrickling filter with a moving bed of the bench BTF were great and beyond expectations. The efficiency of elimination of organic substances was 96% for the whole period of operation of the biotrickling filter, even at very high air flow rate 50 $m^3.h^{-1}$, when the average time of retention of air in the biotrickling filter was only around 14s. Organic load in this case was between 28 – 30 $g_C.m^{-3}_{of\ medium}.h^{-1}$ and elimination capacity reached almost the same values: 27 – 29 $g_C.m^{-3}_{of\ medium}.h^{-1}$.

For the whole operation period, the biotrickling filter was in a steady-state condition and it was not necessary to take any interventions into the biofiltration process not even at restart after app. three three-week long interruptions of production line operation, during which no carbon source was present in the air. Based on these results, the biotrickling filter may be definitely recommended for treatment of emissions of organic substances from operation of a product line for steering wheels.

Pilot biotrickling filter

Pilot tests of the pilot biotrickling filter with a moving bed intended for removal of odours from intensive breeding of pigs (from a pig house) were carried out in the second half of this year and in this case the dominant compound of the odour was ammonia. The results of ammonia removal achieved 90% ammonia removal occurred.

Comparison of results of the calculated maximal concentration of ammonium ions in recirculating water, which was achieved by absorption of ammonium from air into the recirculating water provided that no ammonium nitrogen was utilized by the microorganisms and, with the values of the actual concentration of ammonium ions in recirculating water partially proves 80 – 90% efficiency of removal of ammonium nitrogen by microorganisms.

Note.: The device was registered in the Czech Republic for the industrial and legal protection under the ref. no. PV 2010 - 294

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