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Effectiveness of Indicatory Microorganism Removal on Trickling Filter with Biofilm in Magnetic Field

Z. Filipkowska[1], M. Krzemieniewski[2]

Olsztyn University of Agriculture and Technology. Department of Ecology,
[1] Sanitary Microbiology Unit.
[2] Department of Chemistry and Water and Wastewater Technology.
10-957 Olsztyn-Kortowo, Poland

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Abstract

The objective of this study was to define the removal rate of the indicator microorganisms on various types of trickling filters with regard to the influence of: magnetic stream and electric current passage, and the effectiveness of microorganism adsorption onto the media. The hydraulic loading in the first eight variants were changing, while variants 9-14 were peformed at a constant loading. The study results have indicated a positive influence of the extra energy sources, i. e. a magnetic stream and electric current on the process of indicatory microorganism removal from waste water.

Keywords: indicator microorganisms, sewage, removal, trickling filters, magnetic stream, magnetic field, electric current.

Introduction

Development of the facilities for waste water biological treatment consists among other things in creating better conditions for microbiological activity. Biological filters with microorganisms forming **a** biological film (biofilm) attached to filter media enhance treatment effectiveness given that: good oxygen conditions are created in the biofilm's deep layer (at the media face), more substratum is provided, the velocity of removal of the biodegradation end- products is high, and the sloughing biofilm can easily be washed out from the media.

In order to meet the above-mentioned conditions, a number of changes have been introduced in the construction of biological filters. In the case of trickling filters the **vital** innovation was the application of plastic media [1,6] characterized by low volumetric weight and high specific surface area, allowing for good microbial growth. Introduction of the new media consequently augmented the use of trickling filters. Conditions were created to combine the process of biological treatment on trickling filters with the activated sludge [2].

Based on the results of the study on submerged filters it was concluded that further development of the trickling filter should be headed towards combining biological treatment with the action of magnetic forces [5, 9, 10, **11].** Therefore, a laboratory experiment was carried out on the trickling filters. Microorganisms forming the biofilm can be positioned in **a** magnetic field induced either by a coil or as **a** result of an electric current passage in the biofilm. The modified systems were based on the naturally occurring parallelism of the electric and magnetic phenomena.

The objective of the study was to define the removal rate of the indicatory microorganisms on various types of trickling filters with regard to the influence of: magnetic field, magnetic stream and electric current passage, on the effectiveness of microorganisms adsorption onto the media.

The results were compared with the treatment capacity of the conventional trickling filter with plastic filter media.

Materials and Methods

The main element constituted the laboratory scale trickling filters, supplied with sewage from a raw-sewage tank by means of a peristaltic pump.

Sewage was discharged onto the top of filters and trickling through the filter media. The effluent was collected in glass containers serving as the secondary settlers. Four types of filters were tested; each 60 cm long and 2 cm in diameter:

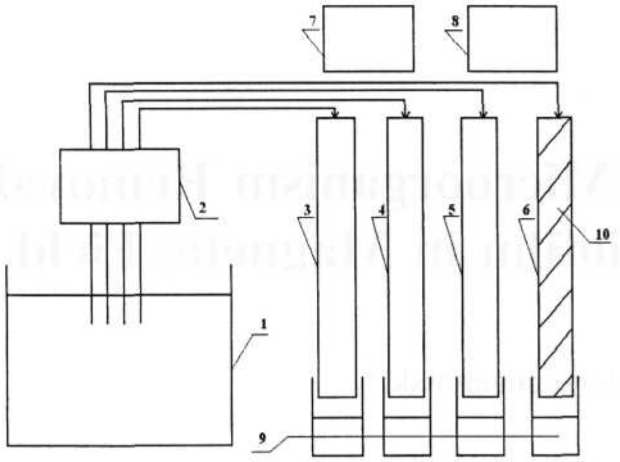

Fig. 1 - Raw - sewage tank, 2 - Pump, 3 - Biological trickling filter, 4 - Biological trickling filter with magnetic media, 5 - Biological trickling filter with electric current, 6 - Biological trickling filter with coil, 7 - Rectifier, 8 - Magnetic disintegrator, 9 - Purified - sewage tank, 10 - Coil.

1. Trickling filter with plastic media sized 8 mm and 5 mm.
2. Trickling filter with magnetic media in the form of magnet particles separated by layers of plastic in order to prevent the contact of magnet particles.
3. Electrobiological trickling filter connected to a rec tifier transforming the alternating current from the grid into the direct current. The construction of the rectifier enabled the maintenance of a constant intensity of the current and the control of the voltage between 0 and 5 V.
4. Trickling filter with inductor. The inductor was con nected to a magnetic disintegrator. The filter was under the influence of a magnetic stream.

Technological Principles

During the experiments a low temperature of sewage was maintained and the ambient temperature was between 10 and 17˚C. In the succeeding phases the organic loading of the sewage varied from 195 to 8,297 mg COD/d. The flow rates in the ensuing variants were as follows: 1 and 2 - 0.8 dm^3/d; 3 and 4 - 1.9 dm^3/d; 5, 6, 7 - 4.875 dm^3/d; 8 - 244 dm^3/d; 9 through 14-195 dm^3/d.

The hydraulic loading in the first eight variants varied from 0.3185 to 1.9407 m^3/m^2•d. Variants 9 through 14 were performed at a constant hydraulic loading of 0.3185 m^3/m^2•d.

In the first eight variants the inflowing sewage was taken from a secondary settler at the Kortowo waste water treatment plant and mixed with milk dosed at 5-20 cm^3 milk per 1 dm^3 sewage. In the remaining variants (9-14) milk was not added.

The biofilm was well developed after 30 days and the active surface area was 0.753 m^2. The reaction (pH) of the influent varied between 6.38-7.2, and of the effluent - 6.38-7.98.

Microbiological Study

The microbiological studies of the sewage treated on the trickling filters comprised of:

1. the total viable count on broth-agar after 24 h in cubation, at 37°C.
2. the number of total coliforms (MPN/cm^3) on lacto se-peptone broth acc. to Eijkman after 48 h incubation, at 37°C.
3. the number of faecal coliforms (MPN/ cm^3) on lac tose-peptone broth acc. to Eijkman after 24 h incubation, at 44.5°C.
4. the number of faecal streptococci (MPN/cm^3) on the Enterococcus selective broth acc. to Slanetz and Bartley after 72 h incubation, at 37°C.

The number of total coliforms, faecal coliforms and faecal streptococci were determined using the most probable number method (MPN) in 3 parallel replications.

Results

The microbiological study on the trickling filters demonstrated a large variation in reduction of the examined indicatory microorganisms (Tables 1-4). During the experiments various organic loadings were applied from 195.2 to 82,927 mg COD/d.

In the first two variants the hydraulic loading was low and equalled 0.3185 m^3/m^2•d; at the same time the organic loading was 195.2 mg COD/d. The most efficient in these variants was the filter with coil where the reduction of the faecal coliforms reached 90% and of the mesophilous bacteria 70%, whereas on the conventional filter it did not exceed 32%. On the conventional filter only the faecal streptococci were reduced with a high efficiency of 92%.

In variants 3 and 4 at the organic loading of 505.4 mg COD/d and the hydraulic loading 0.7564 m^3/m^2•d the faecal coliforms were present in small numbers. On all filters the bacteria considerably multiplied. Only in the fourth variant the mesophilous bacteria were removed in all filters, with the highest efficiency of the filter with the magnet media.

In variants 5, 6 and 7 the organic loadings were: 8,297, 2,340 and 4,346 mg COD/ d, respectively, with a constant hydraulic loading equal to 1.9407 m^3/m^2•d. On all filters with supplementary energy sources faecal coliforms were reduced with the highest efficiency. Faecal streptococci were reduced in 90% on the filters with an electric current and with coil, whereas on the conventional filter the reduction was below 78%. On the filter with magnet media the bacteria numbers increased considerably.

In variant 8 at the organic loading of 1,213 mg COD/d and the hydraulic loading of 0.9713 m^3/m^2•d, the highest efficiency in faecal coliform reduction was seen in the conventional filter. The faecal streptococci were reduced by 88% on this filter, by 95% on the filter with coil, and by 100% on the filter with electric current.

Variants 9 through 14 were carried out at a constant hydraulic loading 0.3185 m^3/m^2•d. The results indicate an apparent beneficial influence of the coil on the removal process of the faecal coliforms (the faecal coli as well as the faecal streptococci). The magnetic field and electric current both had a very positive influence on the reduction of the indicator microorganisms. Only the mesophilous ba-

Table 1. The total viable count at 37°C in 1 cm^3 sewage at their percentage reduction on sewage purified on filters.

No of variants / Kind of filter	I series - variable values of hydraulic loading and organic loading								Average from variants	II series - variable values of hydraulic loading and organic loading						Average from variants	Averag for study
	1	2	3	4	5	6	7	8	1-8	9	10	11	12	13	14	9-14	
Unpurifield sewage	10,000	33,500	200	550	172	8,200	31,500	-	-	13,500	23,500	625	154	164,000	33,500	-	-
Biological trickling filter	335,000a *	23,000 **31.34b**	13,300 *	300 **55.46**	33 **80.82**	2,430 **70.34**	4,000 **87.31**	- -	2* **65.06**	1,000 **92.60**	2,000 **91.49**	75 **88.00**	375 **75.66**	15,950 **90.38**	1,850 **94.48**	**88.76**	2* **76.91**
Biological trickling filter with magnetic media	100,000 *	19,500 **41.79**	26,200 *	150 **72.73**	38 **77.91**	6,100 **25.61**	- -	- -	2* **54.51**	27,500 *	8,000 **65.96**	135 **78.40**	335 **78.35**	- -	1,400 **95.82**	1* **79.63**	3* **67.07**
Biological trickling filter with electric current	585,000 *	44,500 *	18,200 *	270 **50.91**	23 **86.63**	3,480 **57.57**	1,520,000 *	- -	4* **65.03**	12,500 **7.41**	5,500 **76.60**	310 **50.40**	340 **77.93**	21,150 **87.11**	650 **98.06**	**66.25**	4* **65.64**
Biological trickling filter with coil	785,000 *	10,000 **70.51**	14,200 *	430 **21.82**	16 **90.70**	8,900 *	7,000 **87.78**	- -	3* **67.70**	4,500 **66.67**	2,500 **89.36**	65 **89.60**	170 **88.97**	15,900 **90.31**	4,400 **86.87**	**85.29**	3* **76.49**

Explanations:
a - number of bacteria
b - % of reduction
* - multiplication of the microorganisms number

Table 2. The number (MPN) of total coliforms in 1 cm^3 sewage at their percentage reduction on sewage purified on filters.

No of variants / Kind of filter	I series - variable values of hydraulic loading and organic loading								Average from variants	II series - variable values of hydraulic loading and organic loading						Average from variants	Average for study
	1	2	3	4	5	6	7	8	1-8	9	10	11	12	13	14	9-14	
Unpurifield sewage	9,000	2,500	700	11	450	3,000	45,000	1,500	-	11,000	900	25,000	4,500	2,500	2,000	-	-
Biological trickling filter	4,000 **55.56**	250 **90.00**	300 **57.15**	1,400 *	4 **99.12**	140 **95.34**	450 **88.75**	400 **73.34**	1* **79.89**	450 **95.91**	450 **50.00**	2,500 **90.00**	2,500 **44.45**	450 **82.00**	2,500 *	1* **72.47**	2* **76.16**
Biological trickling filter with magnetic media	25,000 *	250 **90.00**	700 **0**	9 **18.22**	4 **99.12**	4 **99.87**	- -	1,600 *	2* **61.44**	950 **91.67**	450 **50.00**	2,500 **90.00**	450 **90.00**	- -	4,500 *	1* **80.42**	3* **70.92**
Biological trickling filter with electric current	4,000 **55.56**	450 **82.00**	2,500 *	750 *	40 **91.12**	9 **99.46**	2,000 **99.56**	75,000 *	3* **85.54**	700 **95.64**	250 **72.23**	4,500 **82.00**	2,500 **44.45**	75 **97.00**	2,500 *	1* **78.26**	4* **81.90**
Biological trickling filter with coil	4 **99.96**	250 **90.00**	700 **0**	2,500 *	4 **99.12**	3 **99.90**	11,000 **75.56**	3,000 *	2* **77.42**	90 **99.19**	450 **50.00**	2,500 **90.00**	950 **78.89**	450 **82.00**	2,500 *	1* **80.02**	3* **78.71**

Explanations: as in Table 1

cteria were removed with the highest efficiency on the conventional trickling filter.

Discussion

The microbiological study performed on the trickling filters have shown variable efficiency in microbial reduction which was indicated by the variable results.

The least effective was the trickling filter with magnet media whose reduction efficiency was lower than the conventional filter. The active surface area of this filter was positioned in a magnetic field induced by magnets comprising the filter media. The working action of this bed is based on the phenomenon of the adsorption of microorganisms on the media [4]. The relatively low efficiency of this filter can be caused by competition for adsorption between the negatively charged substances present in waste

Table 3. The number (MPN) of faecal coliforms in 1 cm^3 sewage at their percentage reduction on sewage purified on filters.

No of variants	I series - variable values of hydraulic loading and organic loading								Average from variants	II series - variable values of hydraulic loading and organic loading						Average from variants	Average for study
Kind of filter	1	2	3	4	5	6	7	8	1-8	9	10	11	12	13	14	9-14	
Unpurifield sewage	10	95	3	3	450	25	3	0	-	140	450	14,000	2,500	1,000	2,000	-	-
Biological trickling filter	4 **60.00**	95 **0**	3 **0**	0 **100**	1 **99.78**	2 **92.00**	0 **100**	1 *	1* **64.54**	25 **82.15**	250 **44.45**	1,400 **90.00**	1,100 **55.00**	140 **86.00**	900 **55.00**	**68.93**	1* **66.73**
Biological trickling filter with magnetic media	250 *	95 **0**	3 **0**	3 **0**	0 **100**	0 **100**	0 **100**	1 *	2* **50.00**	140 **0**	45 **90.00**	1,400 **90.00**	450 **82.00**	- -	400 **80.00**	**68.40**	2* **59.20**
Biological trickling filter with electric current	10 **0**	95 **0**	3 **0**	0 **100**	0 **100**	0 **100**	0 **100**	0 -	**57.14**	110 **21.43**	75 **83.34**	1,400 **90.00**	1,400 **44.00**	150 **85.00**	900 **55.00**	**63.13**	**60.13**
Biological trickling filter with coil	3 **70.00**	95 **0**	30 *	0 **100**	0 **100**	0 **100**	0 **100**	0 -	1* **78.30**	25 **82.15**	95 **79.99**	1,400 **90.00**	200 **92.00**	110 **89.00**	2,500 *	1* **86.43**	2* **84.29**

Explanations: as in Table 1

Table 4. The number (MPN) of faecal streptococci in 1 cm^3 sewage at their percentage reduction on sewage purified on filters.

No of variants	I series - variable values of hydraulic loading and organic loading								Average from variants	II series - variable values of hydraulic loading and organic loading						Average from variants	Average for study
Kind of filter	1	2	3	4	5	6	7	8	1-8	9	10	11	12	13	14	9-14	
Unpurifield sewage	-	750	40	9	40	4	140	750	-	2,500	1,500	2,000	950	1,500	400	-	-
Biological trickling filter	- -	70 **90.67**	140 *	9 **0**	9 **77.50**	9 *	110 **21.43**	90 **88.00**	2* **75.32**	25 **99.00**	95 **95.67**	450 **77.50**	450 **52.63**	1,400 **6.67**	2,500 *	1* **66.29**	3* **70.80**
Biological trickling filter with magnetic media	- -	250 **66.67**	1,100 *	4 **56.00**	45 *	25 *	- -	90 **88.00**	3* **52.66**	250 **90.00**	450 **70.00**	1,100 **45.00**	150 **84.21**	- -	70 **82.50**	**74.34**	3* **63.50**
Biological trickling filter with electric current	- -	150 **80.00**	140 *	90 *	4 **90.00**	45 *	110 **21.43**	0 **100**	3* **77.48**	95 **96.20**	150 **90.00**	1,100 **45.00**	250 **73.69**	250 **83.34**	250 **37.50**	**70.95**	3* **74.21**
Biological trickling filter with coil	- -	250 **67.00**	140 *	9 **0**	4 **90.00**	25 *	110 **21.43**	40 **94.67**	2* **61.52**	30 **98.80**	95 **95.67**	450 **77.00**	250 **73.69**	200 **86.67**	450 *	**86.36**	3* **73.94**

Explanations: as in Table 1

water and bacteria [9]. These substances are mainly colloids such as proteins, colouring organics, or substances causing turbidity. In the first phase of the study the quantity of proteins was additionally increased by the addition of milk to the raw sewage. Organic matter in the sewage can compete with bacteria for the adsorption sites on solids and, in consequence, it can reduce bacteria removal efficiency blocking the adsorption sites on the media surface [4].

The filters with a magnetic coil and electric current demonstrated a much higher efficiency. The medium is situated in a constant-value magnetic field induced by the coil. It can be assumed that in this filter the adsorption sites on the media are re-activated and thus its surface prepared for the next adsorption cycle. Due to this, the adsorption sites are never blocked and therefore can be used many times [9].

The relatively high reduction of the microorganisms on

Table 5. Range and average percentage reduction studied group of bacteria on sewage purified on filters.

Kind of filter	Total viable count at 37°C	Total coliforms	Faecal coliforms	Faecal strepto-cocci
Biological trickling filter	31.34-94.48 **76.91** 2*	44.45-95-91 **76.16** 2*	0-100 **66.73** 1*	0-99.00 **70.80** 3*
Biological trickling filter with magnetic media	25.61-95.82 **67.07** 3*	0-99.87 **70.92** 3*	0-100 **59.20** 2*	45.00-90.00 **63.50** 3*
Biological trickling filter with electric current	7.41-98.03 **65.64** 4*	44.45-99.56 **81.90** 4*	0-100 **60.13** -	21.43-100 **74.21** 3*
Biological trickling filter with coil	21.82-90.70 **76.49** 3*	0-99.96 **78.71** 3*	0-100 **84.29** 2*	0-98.80 **73.94** 3*

the filter with an electric current can be explained by the influence of electricity on the surface charge of the media. The materials used for media construction are usually positively charged. The charge can transform into negative under the influence of electricity which is caused by the ionization of the chemical groups on the media surface. The adsorption of bacteria under an electric current action is an electrostatic process.

The surface charge of a colloidal particle is determined by a parameter called isoelectric point. At this point a particle has no electric charge. The isoelectric point of a great majority of proteins varies between 4 and 5 pH. For Gram-negative bacteria like *Escherichia coli* this pH value equals 4-5 whereas for Gram-positive bacteria like *Streptococcus faecalis* it is 3-4 [8]. In a bacterial cell proteins are present in cytoplasm, cytoderm and in cell wall. Therefore proteins determine the electric charge of a cell and its surface. At a high reaction of sewage a particle is strongly negative electrically and at lower values - positive.

Materials comprising the filter media in trickling filters have a positive surface charge. The antagonistic surface charges of the media and the bacteria induce microbial adsorption on the media. This mechanism explains why the microbial reduction on trickling filters depends on the adsorption capacity on solid surfaces.

Temperature during the experiments (around 10°C) did not stimulate microbial growth. The frequently observed occurrence of the largely multiplied microorganisms in effluent sewage (as compared to their numbers in raw sewage) was presumably caused by an excessive development of the biofilm, resulting from the accumulation of extra energy in the system.

Thickness of a biofilm depends on hydraulic loading. The hydraulic conditions in a filter can be regulated by the diversion of the flow rate. The flow intensity and the quantity of organic matter in sewage are the main factors limiting the biofilm's development. An increase of the hydraulic loading results in an augmentation of the shear forces. It is assumed that the biodegradation takes place mainly in the so-called "active layer" of the biofilm, a layer easily penetrated by oxygen. The thickness of biofilm does not exceed 2-3 mm. Any further increase in thickness is caused by a high concentration of the organic matter which in such cases will diffuse through the film. However, the depletion of oxygen occurs faster than the uptake of substratum and therefore two layers are created: an anaerobic bottom layer and an aerobic top layer. In the anaerobic layer anaerobic processes take place; no oxygen is available, methane is produced and as a result the biofilm dies out and sloughs.

Conclusions

1. The study results indicate the positive influence of extra energy sources, i.e. a magnetic stream and electric current on the process of indicator microorganism removal from waste water.
2. The trickling filter with the addition of magnet particles to the media was in the first eight variants far less efficient than the conventional trickling filter, and in the remaining variants efficiency was similar or slightly higher.
3. The reduction of microorganisms in the sewage mixed with milk was generally lower than in the non-mixed sewage.

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