

THE POSSIBILITIES OF TREATMENT OF STORMWATER POLLUTED WITH BIOFUELS IN THE LAMELLA OIL SEPARATOR

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Abstract

Laboratory tests were conducted simulating the process of polluting stormwater with fuels and afterwards treating this sewage in the separator of oil derivative substances. The diesel oil - ON and the pure biofuel - BIO 100, available on the market, were the subject of the tests. Depending on the kind of fuel, the differences in the concentration of oil derivative substances in the “treated” sewage were in the range of several hundred percent. Such big differences show the necessity for examination whether the assumptions accepted while designing separators will also be correct in the case of treating stormwater polluted with contemporary fuels available on the market, including biofuels.

Keywords: stormwater, biofuels, separators of oil derivative substances

1. INTRODUCTION

From the ecological point of view the quality of stormwater requires its purification before introducing it to the receiver. It is also a legal requirement.

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The parameters of stormwater disposed to a receiving body are stipulated in the Decree of the Minister for the Environment of 18 November 2014 on the conditions to be met as regards the release of sewage into water or onto land and on substances that are particularly harmful to the aquatic environment. For example, in the case of oil derivative hydrocarbons, the maximal permissible concentration in treated sewage introduced into water amounts to 15 mg/l.

Complying with these requirements boils down to the application of appropriate treating devices, such as for example oil derivatives separators. It is obvious that while selecting them one should consider the quantity and the quality of inflowing stormwater and the nature of pollution in it. Yet, normally appropriate field studies are not conducted due to their considerable complexity and data referring to the amount (rain intensity, a run-off coefficient) and the quality of untreated sewage are taken from relevant literature.

Tests are not usually performed while checking if treated sewage satisfies the above mentioned requirements. According to the ordinance quoted above, for devices with a nominal capacity of 300 litres per second, the quality of treated sewage is assessed indirectly, only on the basis of periodical surveys of treating devices.

It concerns the lack of necessity to perform analyses of the quality of discharged treated sewage. Presumably, a properly selected and correctly used separator guarantees desirable treatment quality. In turn, appropriate operation of a separator itself is confirmed, above all, by a producer's statement of compliance with standard PN-EN 858 or a relevant agreement.

Yet, data taken from literature do not necessarily correspond to real conditions. It can be the reason for the fact that e.g. in discharges of rainfall water the permissible concentration of oil derivatives is exceeded although on the basis of periodical surveys one can still assume that the sewage fulfils the requirements of the environmental law. On the other hand, it can be a legal obligation for the operation of treating devices that there should be no oil derivatives in untreated sewage [2].

Numerous studies have shown that with the exception of stormwater discharged from petrol stations, concentration of oil derivatives are not practically exceeded [5,6].

Large-scale studies of the stormwater quality and the efficiency of separators operation were performed at the Koszalin University of Technology [7]. During 14 months, 10 series of tests were performed on samples of stormwater discharged to the Slupia river, within Slupsk boundaries, treated in four coalescing separators. The concentration of hydrocarbon was exceeded in treated sewage only once out of 40 series of tests. But it is worth emphasizing

that in most cases there were no reports that oil derivatives had been exceeded even in untreated sewage.

Other studies were performed at the Lodz University of Technology [1]. The quality of stormwater from urban, industrial and road catchments were tested. Research lasted for almost two years and the concentration of oil derivatives in discharged stormwater never exceeded the concentration permitted by law.

However, the lack of exceeding values of oil derivatives in untreated sewage, does not give grounds to draw conclusions about the efficiency of removing these substances in the treating devices that were used. Moreover, the nature of pollution in rainfall sewage can also differ from the standards (performance tests of separators, pursuant to standard PN-EN 858, are conducted by means of marine bunker fuel, whose properties responsible for separation processes differ significantly from fuels currently used on the market). It is particularly related to fuels with an increasing number of biocomponents and pure biofuels.

Analyzing the basic process used in separators for the separation of oil derivatives from stormwater i.e. flotation, one can distinguish properties of separated substances that have a major impact on the process - the density and the ability to create an emulsion, i.e. the droplet size that fuels form in water (formula 1). For example, in the case of oil fuel, 80% of droplets (by volume) are greater than 90 μm and 30% are greater than 150 μm [3].

But in literature there are no reports regarding the size of droplets formed in water by biofuels. The question of the possibility of treating stormwater polluted by biofuels in existing treating devices is still open.

2. THEORETICAL FUNDAMENTALS OF STORMWATER TREATMENT

Stormwater treatment is based on two basic processes - sedimentation (for removing suspensions heavier than water - sand, dust) and flotation (for removing pollutions lighter than water - oils, petrol).

When we assume that particles are small, their flotation takes place with a laminar flow, and the viscosity resistance is shown by the equation given by Stokes - $\lambda_c = 24/\text{Re}$ (Re - the Reynolds number).

With this assumption the speed of flotation is calculated from the equation [8]:

$$V_s = \frac{(\rho - \rho_{cz}) \cdot g \cdot d_p^2}{18 \cdot \eta} \quad (1)$$

where:

V_s [m/s] - speed of sedimentation;

- ρ [kg/m³] - liquid density;
 ρ_{cz} [kg/m³] - density of oil;
 g [m/s²] - gravitational acceleration;
 d_p [m] - diameter of particles;
 η [kg/ms] - coefficient of dynamic viscosity.

2.1. Stormwater treating devices and the construction and the operating principle of a lamella clarifier

Oil derivative separators are used in treating stormwater from oil derivatives. There are two basic groups:

- Gravity separators
- Coalescence separators

The operation of gravity separators consists in separating substances of different densities solely under the influence of the gravity force (the difference between the uplift and the gravitation forces). Releasing oils and oil derivatives takes place as a result of tranquilizing the flow and decreasing the flow speed of sewage. Fats and other light substances (oil, petrol) appear and accumulate on the surface of sewage.

In coalescence separators, gravity flotation is supported by the process of coalescence, i.e., the fusion of fat particles into larger drops which can then be separated from sewage thanks to gravitation. The main difference in the construction of coalescence separators lies in the application of different elements supporting the process of coalescence. These can be coalescence filters e.g. filter mats and sponges (in so-called coalescence separators) or lamella packets (in lamella clarifiers).

The operating principle of a lamella clarifier is analogous to that of a multistream clarifier. In the clarifier, sewage flows through lamella sections, made of a great number of slanted plates. During the flow through the lamella section in a state of laminar flow, the oil droplets undergo the flotation process.

For these separators, knowledge of the speed of flotation of the oil droplets is the basis for determining the efficiency of wastewater treatment.

During laminar flow of waste water through the separator, as in the case of a classical settling tank, these oil particles are removed, whose speed of flotation is higher than the hydraulic load of the clarifier surface. During the flow through lamella sections tiny oil droplets settle on the bottom parts of lamella plates. On reaching defined sizes, separate oil particles float along the bottom parts of plates towards the water surface creating an oil film on it.

The scheme of a lamella clarifier and sections of a lamella section are presented in figures 1 and 2.

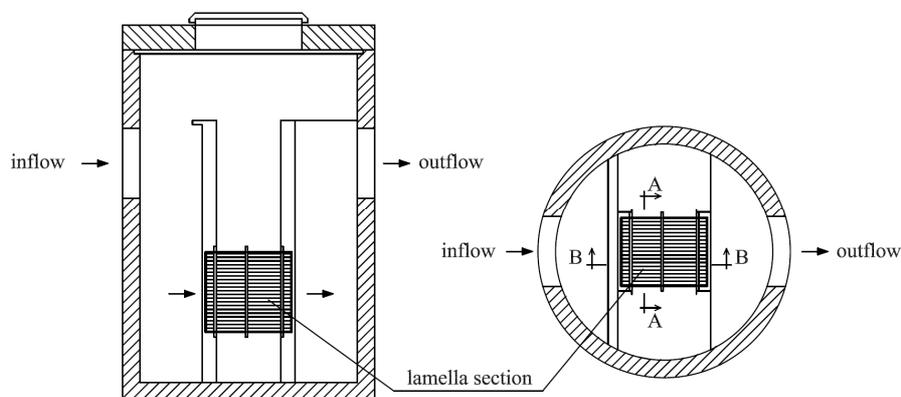


Fig. 1. The scheme of a lamella clarifier

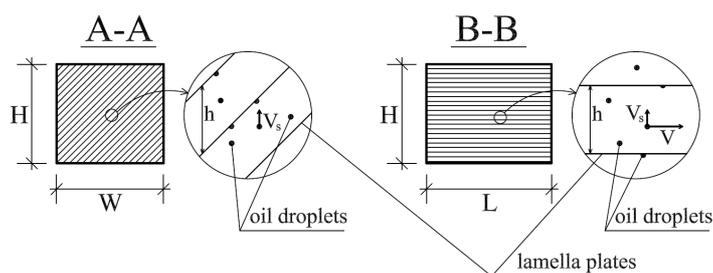


Fig. 2. The scheme of a lamella section

According to equation (1), the speed of flotation mainly depends on the density of separated substances and the size of formed particles. A comparison between speed of flotation and the hydraulic load of the clarifier surface makes it possible to calculate the theoretical efficiency of removal of contaminants in the lamella separator.

In Table 1 the theoretical separation efficiency for market fuels - biofuel BIO 100 and diesel oil ON - was calculated.

The calculations were made for different sizes of oil particles.

The coefficient of dynamic viscosity of water was accepted for $t = 10\text{ }^{\circ}\text{C}$ - $\eta = 0.001308\text{ kg/d m}$.

The density of biofuel - BIO 100; $\rho_{\text{BIO}} = 892\text{ g/dm}^3$.

The density of diesel oil - ON; $\rho_{\text{ON}} = 820\text{ g/dm}^3$.

The calculations were made for the separator with the nominal capacity $Q_n = 10\text{ l/s}$, with typical dimensions of the lamella sections: $H = 700\text{ mm}$ (height); $L = 500\text{ mm}$ (length); $W = 400\text{ mm}$ (width).

Vertical space between lamellas is 2 cm.

On this basis (for $Q = 0,01 \text{ m}^3/\text{s}$)

- hydraulic load - $H_L = Q/A$ (A - the surface of lamella plates; $A=WLH/h$)
 $H_L = 0,00143 \text{ m/s}$;
 - the velocity of sewage flow through a lamella section - $V=Q/BH$, $V=0,035 \text{ m/s}$;
 - the residence time of sewage within a lamella section - $t=L/V$, $t= 14 \text{ s}$
- were calculated.

Table 1. Flotation speed of particles and the theoretical separation efficiency for wastewater contaminated by BIO 100 and ON

Particle size	Flotation speed BIO100	Separation efficiency BIO100	Flotation speed ON	Separation efficiency ON
μm	m/s	%	m/s	%
10	0.0000045	0.3	0.0000075	0.5
30	0.000041	3	0.0000675	5
50	0.000113	8	0.000187	13
100	0.00045	31	0.00075	52
150	0.00101	71	0.00169	100
200	0.0018	100	0.0030	100

3. METHODS AND SAMPLE PREPARATION

In order to examine the real conditions of pollution and treatment of stormwater laboratory tests were conducted, simulating the process of polluting stormwater with fuels and afterwards treating these sewage in the separator of oil derivatives. Pure biofuel (BIO100) and diesel oil (ON) available on the market underwent these tests.

Sewage runoff was simulated by mixing water with fuels. Two mixtures of fuel with water were prepared. The ratio of water to fuel is presented in table 2. Solutions prepared in this way were mixed with the frequency of 350 1/s and amplitude of 8 (the maximal possible frequency and amplitude) for 1 minute in an Elpin+shaker.

Table 2. Ratio of fuel to water in the tested solutions

Solution	H ₂ O ml	Fuel ml
BIO/20	980	20
ON/20	980	20

Processes in the separator were also simulated. After mixing, gradual treatment of wastewater from oil-derived substances started, as a result of the flotation

process. Analyses were made after different separation times. The concentration of TPH (total petroleum hydrocarbons) in the solutions BIO/20 and ON/20 were determined indirectly, by measuring COD.

But because the standardized indicator for the evaluation of the quality of stormwater is the concentration of oil derivatives, and in the experiment the degree of a sample pollution was defined differently, so it was necessary to determine the quantification of oil derivatives included in ON and BIO 100 as COD.

In order to do it, two standard solutions of ON and BIO 100 were prepared in which COD for known concentrations of oil derivatives in sewage was determined. The method for preparing them is shown in Table 3. In Table 4 there is a list of the coefficients of COD into TPH conversion that were obtained.

Table 3. Concentration of TPH in standard solutions

Solution	H ₂ O	Fuel	Concentration of TPH
	ml	ml	mg/dm ³
BIO	990	10	892
ON	990	10	820

Table 4. The examination of the quantification degree of oil derivatives in fuels as COD.

The polluting substance	TPH [mg/dm ³]	COD concentration [mg/dm ³]	TPH/COD [-]	The average coefficient of conversion TPH/COD [-]
BIO	892	2136	0.4176	0.459
BIO	892	1780	0.5011	
ON	820	659	1.2443	1.242
ON	820	661	1.2405	

The size of oil particles in the generated solutions was determined in the measuring device - Mastersizer 2000.

4. RESULTS

The results of the analyses for the ON/20 and BIO/20 solutions are compiled in Table 5 and presented in Figure 3. Additionally in Table 5 there is a list of the diameters of BIO 100 oil particles measured in the Mastersizer 2000. Normal distribution of particle sizes was observed. The table below shows only the diameters for the maximum distribution.

Table 5. The Influence of separation time on the concentration of oil in wastewater contaminated with BIO 100 and ON

Fuel	BIO 100		ON	Ratio TPH _{BIO} /TPH _{ON} [-]	
	Separation time [min]	TPH [mg/dm ³]	Diameters of oil droplets [µm]		TPH [mg/dm ³]
	0	20 000		20 000	1
	5	1444	30	196	7.37
	10	681		93	7.32
	20	518		81	6.40
	30	370		26	14.23
	40	269		15	17.93
	50	212		bdl	-
	60	185	10	bdl	-

bdl - below the determination limit

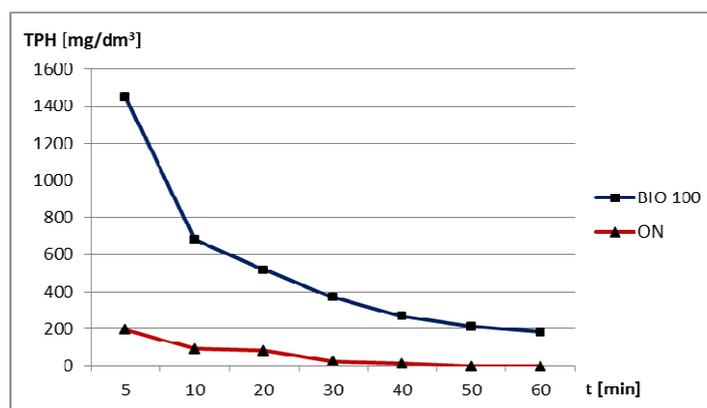


Fig. 3. The influence of separation time on the concentration of oil derivatives (TPH) for sewage polluted with BIO 100 and ON

5. DISCUSSION

As a result of mixing water and fuels, mixtures with different degree of oil droplets dispersion were created. In the samples obtained, which were supposed to simulate stormwater polluted with different fuels available on the market, one could observe a different concentration of oil derivatives. When the initial concentrations in a sample for the diesel oil - ON and the biofuel - BIO 100 and the mixing conditions were the same, depending on the separation time, the concentration of oil derivatives in the samples polluted with biofuel was about 6.5 to almost 18 times higher than in the sewage polluted with diesel oil.

Furthermore, after a period of 50 minutes of separation in the sample contaminated with ON there were practically no oil-derived substances, in a sample contaminated with BIO 100 the concentration of petroleum substances still exceeded 200 mg / dm^3 .

Taking into account that the difference in the density of ON and BIO 100 is only 60%, the results obtained indicate that the created mixture of water-BIO100 is more durable and oil droplets are much smaller. According to Table 1 for wastewater contaminated with BIO 100, the efficiency of separation in the separator analysed would amount to only 3% for $d_p = 30 \text{ }\mu\text{m}$ and 0.3% for $d_p = 10 \text{ }\mu\text{m}$.

6. CONCLUSIONS

The degree of pollution with oil derivatives of stormwater discharged to a receiving body is influenced by both the degree of pollution of untreated stormwater and the conditions of its treatment in a wastewater treating device.

There were distinct differences in concentrations of oil derivatives in the sewage polluted with diesel oil and biofuel. In real conditions, it can lead to exceeding the concentration of oil derivatives in the stormwater discharged from the surfaces polluted with fuels containing a high amount of biocomponents and biofuels.

It is also clearly indicated by the calculated theoretical ability to remove oil derivatives, which for biofuels- for the measured sizes of oil particles - is only 3% and 0.3%.

However, one cannot categorically claim what time, frequency, and amplitude of mixing set in a shaker correspond to real conditions of mixing stormwater with oil derivatives in rain water sewers.

One cannot assume either that stormwater is always as much polluted with oil-derivatives as in the experiment. Such high concentrations of oil derivatives in sewage can occur in reality practically only as a result of an emergency or uncontrolled oil spill. Besides such situations, the concentration of oil derivatives in discharged stormwater rarely exceeds the concentration permitted by law (see point 1).

But taking into account so high differences in concentrations of oil derivatives in "treated" sewage polluted with diesel oil and biofuel and the fact that performance tests of separators, are conducted by means of marine bunker fuel, whose properties responsible for separation processes differ significantly from biofuel, it would be advisable to research whether the assumptions applied in designing separators of oil derivatives will also correspond to the pollution of sewage with fuels currently used on the market.

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MOŻLIWOŚCI OCZYSZCZANIA W SEPARATORZE LAMELOWYM ŚCIEKÓW OPADOWYCH ZANIECZYSZCZONYCH BIOPALIWAMI

Streszczenie

Dobór urządzeń oczyszczających ścieki opadowe powinien uwzględniać zarówno ich ilość i jakość. Z reguły jednak, nie przeprowadza się odpowiednich badań terenowych, a dane dotyczące ilości (natężenie deszczu, współczynniki spływu) i jakości ścieków nieoczyszczonych przyjmuje się na podstawie danych literaturowych. Charakter zanieczyszczeń w ściekach opadowych również może odbiegać od „zanieczyszczeń literaturowych”, które np. nie uwzględniają zawartych w paliwach biokomponentów.

Uwzględniając fakt, że zgodnie z normą PN-EN 858 separatory testowane są przy użyciu oleju żeglugowego typu diesel, którego właściwości odpowiedzialne za procesy separacji znacznie odbiegają od obecnie stosowanych paliw rynkowych, może to być przyczyną nieoptymalnego doboru urządzeń oczyszczających ścieki opadowe, odprowadzane ze zlewni znacznie zanieczyszczonych substancjami ropopochodnymi np. stacji i terminali paliw.

Przeprowadzono badania laboratoryjne symulujące warunki mieszania wód opadowych z paliwami i następnie oczyszczania ich w separatorze substancji ropopochodnych. Badaniu poddano rynkowy olej napędowy i czyste biopaliwo. Otrzymano wyraźne różnice stężeń substancji ropopochodnych w „oczyszczonych” ściekach. Mogą one wskazywać na konieczność zbadania, czy założenia przyjęte przy projektowaniu separatorów będą prawidłowe przy oczyszczaniu ścieków opadowych zanieczyszczonych współczesnymi paliwami rynkowymi.

Słowa kluczowe: ścieki opadowe, biopaliwa, separatory substancji ropopochodnych

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