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EFFECT OF MUNICIPAL WASTEWATER CONTAINING OILS ON ACTIVATED SLUDGE UNDER AEROBIC CONDITIONS

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Abstract
The research focused on the effect of edible oil, a commonly available food product which occurs in municipal wastewater in its unchanged form, on the biological activated sludge treatment. Biodegradation was carried under aerobic conditions at a low contaminant load. Two types of wastewater were assayed. W1 contained oil emulsion, NH_4Cl and KH_2PO_4. W2, apart from the oil emulsion, contained other sources of carbon, macro and microelements. COD and BOD reductions for W1 fell within the ranges of 63.5%-70.5% and 77.8%-81.8%, respectively. A higher effectiveness was found for W2 i.e. 71.9%-77.25 (COD) and 86.4%-95% (BOD). Despite the different COD reduction in W1 and W2, the COD that remained in the treated W1 and W2 was comparable. This indicates that the biodegradation of edible oil present in the wastewater using unadapted activated sludge still resulted in high COD which might have been caused by both the intermediate products of oil biodegradation and reduced effectiveness of biodegradation of other medium components caused by oil addition.

Streszczenie
Badania dotyczyły wpływu oleju jadalnego, powszechnie dostępnego produktu spożywczego, występującego w ściekach komunalnych w formie niezmienionej na biologiczne oczyszczanie metodą osadu czynnego. Biodegradację prowadzono w warunkach tlenowych przy niskim obciążeniu. Zastosowano dwa rodzaje ścieków. W1 zawierały emulsje olejową oraz NH_4Cl i KH_2PO_4. W2 oprócz emulsji olejowej zawierały też inne źródła węgla oraz makro i mikroelementy.
Stosując W1 jako pożywkę uzyskano redukcję COD w granicach od 63.5 do 70.5 %, a BOD od 77.8 do 81.8 %. Dla W2 uzyskano wyższą efektywność biodegradacji tj. Od 71.9 do 77.2 % (COD) oraz od 86.4 do 95 % (BOD). Pomimo różnych stopni redukcji COD w ściekach W1 i W2, wielkość COD pozostałego w oczyszczonych ściekach W1 i W2 była porównywalna. Wynika stąd, że po biodegradacji oleju zawartego w ściekach przy użyciu nieadaptowanego osadu czynnego nadal pozostawało wysokie COD, które mogło być spowodowane zarówno półproduktami biodegradacji oleju, jak i pogorszeniem się efektywności biodegradacji pozostałych składników pożywki w wyniku wprowadzenia do niej dodatkowo olej.

Keywords: **Wastewater treatment; Aerobic processes; Activated sludge; Edible oils.**

1. INTRODUCTION

Vegetable oils constitute the basic food product consumed in households, but are also used in the food, cosmetic and pharmaceutical industries well as the production of paint and varnish. The need to look for new resources makes vegetable oils interesting in terms of their possible use as biomass fuel in diesel engines after the esterification of higher fatty acids. All this makes oils and fats occur in the natural environment as well as municipal and industrial wastewater in the unchanged or changed (after thermal treatment) forms.

Oils and fats present in wastewater biodegrade under aerobic, anaerobic and aerobic-anaerobic conditions. Fats biodegradation may be limited by their physical and chemical properties e.g. insolubility in water [1]. The process starts with the enzymatic hydrolysis which removes fatty acids from the glycerol molecules of triglycerides [2, 3]. Under aerobic conditions, further

biodegradation of fatty acids by ß-oxidation involves splitting off of two-carbon fragments and forming intermediate products i.e. acids with shorter chains by two atoms of carbon and acetyl-CoA. The anaerobic process involves three main stages: hydrolytic, acidogenic and methanogenic [4]. The process is slow [5]. The final products in the aerobic process are carbon and water, while in the anaerobic one – carbon and methane.

The wastewater containing oils and fats may adversely affect the operation of both municipal and industrial, mechanical and biological wastewater treatment plants. During biodegradation under aerobic conditions, the proper aeration of activated sludge wastewater mixture might pose a problem as oil contaminants form a lipid layer around activated sludge flocks [6]. This prevents organisms from getting sufficient amount of oxygen, notably activated sludge [7]. It also reduces the cell-aqueous phase transfer rates: substrates, products, oxygen [6]. Irrespective of the process parameters, the layer is also responsible for the flotation and leaching of biomass from a secondary settling tank [6, 7]. A sudden introduction of oil contaminants into a municipal wastewater treatment plant may cause a sudden and long shock to activated sludge, trickling filter systems and sludge digester [8]. Industrial wastewater is of high organic load, contains lipids, pectins, sugar, tannins polyphenols, polyalcohols, votatile acids [8]. Problems with biodegradation are related to the inhibitive properties of some wastewater components e.g. long-chain fatty acids and intermediate products of their biodegradation [5, 9, 10]. In case of industrial wastewater, they are additionally related to the high toxicity of phenols [8]. There are more negative phenomena apart from the problems with the biological section of a wastewater treatment plant e.g. overgrown bar screens, channels and walls of particular equipment in the mechanical section. Oils and fats stick to the walls which results in unpleasant odour after some time. The acids cause corrosion of concrete and metal canals [8]. Edible oils themselves, regarded as nontoxic food products, may pose some hazard when suddenly entering the natural environment [11].

The research was aimed at finding the effect of model wastewater containing rapeseed oil, a popular type of oil produced in Poland, in the unchanged form on biodegradation carried out by unadapted activated sludge at a low substrate loading. It corresponded to sudden inflows of oil contaminants into a municipal wastewater treatment plant.

2. EXPERIMENTAL

Wastewater characteristics

The tests were carried out on two types of model wastewater prepared in a laboratory. Wastewater 1 (W1) was composed of nitrogen and phosphorus compounds at a suitable ratio of C:N:P. The other wastewater (W2) contained oil, organic matter, macro and micro elements. Its composition was similar to that of municipal wastewater. Table 1 gives the characteristics of both types of wastewater. They contained popular rapseed oil as their specific component which was added in the form of emulsion. It was prepared in an InterSonic IS 5.5 ultrasonic washer and lasted for 24 h (based TOC change).

Table 1.
Characteristics of wastewater during cultivating of microorganism

W1	W2
0.01 % oil emulsion	0.01 % oil emulsion
	340 $mg \cdot l^{-1}$ enriched broth 30 $mg \cdot l^{-1}$ urea 50 $mg \cdot l^{-1}$ sodium acetate 250 $mg \cdot l^{-1}$ starch
139 $mg \cdot l^{-1}$ NH_4Cl 64 $mg \cdot l^{-1}$ KH_2PO_4	6 $mg \cdot l^{-1}$ $CaCl_2 \cdot 2H_20$ 50 $mg \cdot l^{-1}$ $MgSO_4 \cdot 7\ H_20$ 7 $mg \cdot l^{-1}$ KCl

Tests

The tests were carried out in 2-liters cylindrical glass bioreactors which were fed with raw wastewater and activated sludge once a day, aerating it with aquarium pumps. Magnetic stirrers mixed thoroughly the contents and ensured a good contact of microorganisms with the wastewater. The process stopped after 24 h followed by activated sludge sedimentation and samples were taken for chemical analysis. Afterwards, the wastewater and activated sludge left in the bioreactor was replaced with another portion of raw wastewater and activated sludge. Different volumetric ratios of raw wastewater and activated sludge used resulted in different contaminant loadings, but the total volume of the bioreactors was 2 l each time (W1 – 0.03-0.11 $gBOD/g_{TS} \cdot d$, W2 – 0.04-0.17 $gBOD/g_{TS} \cdot d$). In order to get comparable loadings, higher concentrations of activated sludge were used for W2.

Activated sludge was collected in a municipal wastewater treatment plant located in Silesia, southern Poland. Apart from zooglea, microscopic tests of the activated sludge revealed other microorganisms: mobile ciliates (such as *Paramecium sp. Aspidisca costata*), sedentary ciliates (e.g. *Vorticella convallaria*), rotifers, single flagellates and diatoms as well as few

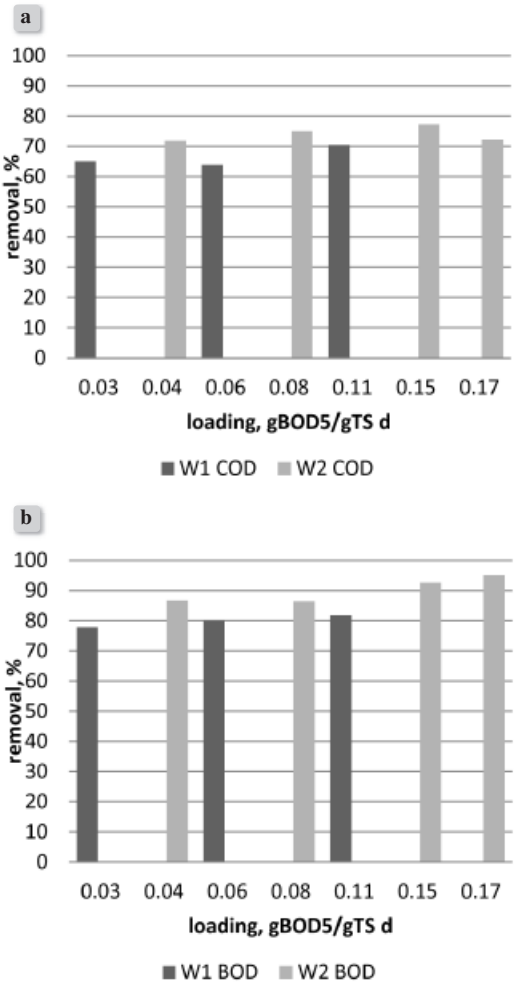

Figure 1.
Effectiveness of the reduction in organic compounds a) COD, b) BOD_5

filamentous bacteria. The sludge flocks were of medium size, brown and green in colour.

The research covered a number of analyses of raw and treated (filtered) wastewater. The total concentration of organic matter was assayed as COD (NOVA 400 spectrophotometer, Merck) and BOD (Oxi Top vessels, WTW). The physical parameters i.e. temperature, pH and oxygen concentration were measured with an Elmetron set equipped with measuring electrodes. The dry weight of activated sludge was determined by the gravimetric method at 105°C.

3. RESULTS AND DISCUSSION

The investigation into the biodegradation of model wastewater W1 and W2 with rapeseed oil was carried out at low loadings of 0.03-0.11 gBOD/g_{TS}·day and 0.04-0.17 gBOD/g_{TS}·day. Tables 2, 3 and Fig. 1 give the

Table 2.
COD in raw and treated wastewaters

loading gBOD/g_{TS}·day	W1		W2	
	raw $mgO_2 \cdot l^{-1}$	treated $mgO_2 \cdot l^{-1}$	raw $mgO_2 \cdot l^{-1}$	treated $mgO_2 \cdot l^{-1}$
0.03	1300	453	-	-
0.04	-	-	1650	464
0.06	1358	489	-	-
0.08	-	-	2025	505
0.11	1329	392	-	-
0.15	-	-	1718	391

Table 3.
BOD_5 in raw and treated wastewater

loading gBOD/g_{TS}·day	W1		W2	
	raw $mgO_2 \cdot l^{-1}$	treated $mgO_2 \cdot l^{-1}$	raw $mgO_2 \cdot l^{-1}$	treated $mgO_2 \cdot l^{-1}$
0.03	180	40	-	-
0.04	-	-	300	40
0.06	200	40	-	-
0.08	-	-	440	60
0.11	220	40	-	-
0.15	-	-	400	30
0.17	-	-	600	30

results for W1 and W2, respectively. COD in the raw wastewater (W1) ranged from 1300 to 1337 $mgO_2 \cdot l^{-1}$ while for the treated wastewater it was 392-489 $mgO_2 \cdot l^{-1}$ (Table 2 and 3). Similarly, BOD was 180-220 mgO_2·l-1 and 40 $mgO_2 \cdot l^{-1}$ respectively, regardless of the loading. The use of a medium that contained only edible rapeseed oil as well as NH_4Cl and KH_2PO_4 resulted in COD and BOD reduction of 63.5-70.5% and 77.8-81.8%, respectively (Fig. 1).

Since the other medium additionally contained other sources of carbon than oil, COD and BOD in the raw wastewater were higher than in W1 and ranged from 1648 to 2025 $mgO_2 \cdot l^{-1}$ and 300 to 600 $mgO_2 \cdot l^{-1}$, respectively (Table 2 and 3). COD and BOD for the treated wastewater fell within 391-505 $mgO_2 \cdot l^{-1}$ and 30-6 $mgO_2 \cdot l^{-1}$, respectively. Despite the higher COD and BOD in the raw wastewater, the process parameters, including loadings, were comparable because higher concentrations of activated sludge were used. For W2, a higher effectiveness of biodegradation was observed i.e. 71.9-77.2% (COD) and 86.4-95% (BOD) (Fig. 1).

The biodegradation of oil components is preceded by enzymatic hydrolysis. Its course in municipal wastewater described by the kinetic model has been reported in the literature [3]. A process like that can take place as early as in a sewerage system so the wastewater that reaches a treatment plant can already be putrefied. While treating W1, oil was the only source of carbon. That substrate is not available to all organ-

isms. The literature describes various bacterial strains used to biodegrade oils and fats in wastewater or soil. Under aerobic conditions, they can be *Rhodococcus sp*., *Nocardia amarae*, *Microthrix parvicela* and *Acinetobacter sp.* [2], and thermophilic aerobic ones – *Bacillus, Thermus and Actiomycestes* [12]. Nevertheless, the best effects are achieved using a mixed culture as activated sludge, especially if it is adapted [2].

W2, unlike W1, apart from oil contaminants contained other organic matter, such as broth (composed of peptone and meat extract), urea, sodium acetate and starch. They were probably the primary source of carbon. Meanwhile, oil hydrolysis took place resulting in higher fatty acids which could be biodegraded. The process consisted in the formation of intermediate products i.e. acids whose chains were shorter by two carbon atoms [2, 13].

Despite the different COD reduction in W1 and W2, COD that remained in the treated W1 and W2 was comparable. This indicates that COD left after the biodegradation of oil present in the wastewater using unadapted activated sludge was still high and might have been caused by both the intermediate products of oil biodegradation and reduced effectiveness of biodegradation of other medium ingredients due to the additional introduction of oil. Thus, in order to find out which intermediate products cause COD left after W2 biodegradation, a quality and quantity chromatographic analysis of treated wastewater should be made, especially as the treatment of W2 without an addition of edible oil by activated sludge in the flow mode produced a stable BOD reduction of around 95%.

4. CONCLUSIONS

Although edible oils are not toxic products, their sudden and large release into the natural environment or wastewater treatment plant may cause disturbances in biological processes. The use of wastewater containing edible oil, NH_4Cl and KH_2PO_4 only, produced COD and BOD reduction of only up to 70.5% and 81.8%, respectively. The other type of wastewater yielded better results, but still the treated wastewater contained intermediate products that increased COD and BOD.

A longer contact time between activated sludge and oil enables microorganisms to adapt to the biodegradation of that type of contaminants, and the biodegradation of oil along with wastewater containing other sources of carbon as well e.g. municipal wastewater, produces a varied composition of activated sludge. Such activated sludge should cope better with the biodegradation of oil in the future.

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