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M. KRZEMIENIEWSKI*, M. JĘDRZEJEWSKA*,
M. DĘBOWSKI*

ANAEROBIC TREATMENT OF WASTEWATER FROM YEAST FACTORY IN UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR PACKED WITH STEEL ELEMENTS

The usability of a mesophilic upflow anaerobic sludge blanket (UASB) reactor containing steel elements for the treatment of organic compounds and sulphate-rich effluent from the yeast industry was evaluated. The experiment was conducted on a laboratory scale in two UASB digesters. The first of the digester reaction tanks contained anaerobic activated sludge, the second one was additionally packed with steel elements. The results obtained indicated that removal efficiency of organic compounds (expressed as COD) in the reactor without steel elements approached 38%, while in the reactor containing steel elements it was on the level of 50%. The sulphate reduction effectiveness was 50% and 89%, respectively.

SYMBOLS

EGSB – expanded granular sludge blanket reactor,
UASB – upflow anaerobic sludge blanket reactor,
SRB – sulphate-reducing bacteria,
MPB – methane-producing bacteria,
COD – chemical oxygen demand.

1. INTRODUCTION

Anaerobic digestion processes offer great potential for treatment of high-strength industrial wastewaters, especially from such sectors as distillery, sugar industry, dairy industry, fruit processing, potato processing, brewery or slaughterhouse [1]. Anaerobic processes are mainly applied as pre-treatment steps allowing us to decrease organic compounds loading by 70–90%. Then aerobic activated sludge systems are used.

* University of Warmia and Mazury in Olsztyn, Department of Environmental Protection Engineering, Institute of Environmental Engineering System, ul. Warszawska 117 A, 10-701 Olsztyn, Poland.

Biomass growth is a basic criterion of classification of anaerobic reactors [2]. Anaerobic activated sludge systems (contact process), anaerobic filters, moving-bed reactors (fluidised-bed reactors), UASB reactors or EGSB are considered to be the most common reactors where biomass growth takes place [3]–[6]. Some modification and combination of the mentioned technologies are additionally employed.

Over last 15 years a significant progress in anaerobic wastewater treatment was observed. It is encouraged by monitoring improvement and better understanding of the mechanisms of anaerobic treatment and anaerobic bioreactor control [7], [8]. In 1996, 900 full-scale anaerobic installations were sufficiently operated in the world [9].

Nowadays, UASB digesters are widely used for treating both high-strength wastewater and various types of wastewaters [3], [10]. In 1993, about 200 wastewater treatment plants with UASB reactors were exploited, most of them operating in Germany where this bioreactor was invented [11], [12]. In the Netherlands, 50 such bioreactors of the volume of 100–1500 m^3 operate, in Great Britain, their number is as low as five, but they are efficaciously used for treating pulp and paper effluents as well as the wastes from citric acid and food production. Some authors have reported that UASB bioreactors can be used for the treatment of wastes with high concentration of sulphates, even as high as 1000 mg $S–SO_4^{2-}/dm^3$ [10], [13], [14].

High concentration of sulphates is caused by sulphuric acid (H_2SO_4), one of a major component in various processes. In yeast industry and distillery, treacle is used as a source of sugar for yeasts. Sulphates appear during treacle pre-treatment where sulphuric acid is used for decreasing the medium reaction (to pH of 4.5–5.5) and for inhibiting bacterial growth. Anaerobic treatment of the wastewaters with high concentrations of sulphates leads to sulphide accumulation as a result of sulphate reduction. Undissociated (as a gaseous compound) and dissociated hydrogen sulphide causes a lot of problems of both physiochemical character, e.g. corrosion, formation of malodorous compounds, and chemical character, e.g. an increase in COD concentration in the effluent [15]. This poses a lot of problems with the sulphate reduction on microbiological level. The literature findings indicate that non-ionized hydrogen sulphide has a toxic impact on methanogenic microorganisms [10], [16]–[19] and on sulphate-reducing microflora [10], [19]. Additionally, sulphate-reducing bacteria (SRB) compete with methane-producing bacteria (MPB) for accessibility of electrons which results in a decrease in methane content in biogas.

Up to the present some experiments allowing us to assess the treatment efficiency of the effluents with a high sulphate concentration in UASB reactors were conducted [13], [15], [20], [21]. In most cases, toxic impact of the hydrogen sulphide on the granular anaerobic microflora was observed. Moreover, this compound was more toxic at the alkaline reaction than at neutral or acid reaction [22]. The toxicity of hydrogen sulphide increased at sulphate concentration above 1000 mg $S–SO_4^{2-}/dm^3$ [10]. The possibility of treating high-strength wastewater from yeast production in anaerobic filters under mesophilic conditions was investigated. The organic compounds concentration (expressed as COD) ranged from 11000 to 88000 mg O_2/dm^3 and sulphate concentration – from 1200 to 1500 mg $S–SO_4^{2-}/dm^3$ [23]. This method proved to be highly effective.

Because of the differences in concentration of pollutants the wastes from yeast factory can be divided into the wastes obtained after rotation and the rest. Depending on the production rate, the wastes are subjected to rotation 2–4 times a day which results in their highest pollutant loading. Such wastes have acid reaction and include highly concentrated organic compounds from treacle production. Some of the pollutants are non-metabolised non-saccharic substances that cause a dark colour of wastes. Moreover, the wastes contain highly concentrated nitrogen compounds, phosphorus compounds, sulphate compounds, metabolites of yeast, and large amount of albuminous colloids. These pollutants are mainly water-soluble organic compounds. According to literature BOD_5 ranges from 3500 to 18000 mg O_2/dm^3, COD from 5000 to 80000 mg O_2/dm^3, total nitrogen from 500 to 1200 mg N_{tot}/dm^3, total phosphorus from 10 to 50 mg P/dm^3, sulphate from 600 to 2000 mg SO_4^{2-}/dm^3 and pH from 4.8 to 6.5 [23]–[26].

Although anaerobic systems of wastewater treatment are highly recommended in yeast waste treatment, this method is not frequently employed in other plants because it is responsible for generation of hydrogen sulphide in high concentrations. Many authors report that the investigations are still carried out and there is a need to find favourable solution in order to decrease or totally eliminate adverse effects of anaerobic treatment of such kind of wastes [10], [15], [27].

We have studied the impact of steel elements on the efficiency of treating yeast wastes in the UASB reactor. This is an improvement of the anaerobic digestion that can decrease sulphate concentration at limited concentration of molecular oxygen.

2. MATERIALS AND METHODS

The experiments were performed in a dynamic system. Laboratory research station consisted of two UASB bioreactors with steady-state flow (figures 1 and 2). The bioreactors have a working volume of 10 dm^3, a conical base, 1.1 m in height and 0.14 m outside diameter. Raw wastes from the influent tanks were supplied to the reaction tanks by means of stub pipes of an internal diameter of 0.012 m that were attached to the bottom part of the digesters. The necessary mixing degree was achieved mainly through the upward wastewater flow. Treated wastes were collected in the upper part of the reactors by means of the stub pipes (of the same diameter), then they were collected in the effluent tanks. In the top part of the reactor, there was a metal cover to biogas collection. The reactors were equipped with valves that made the control of the sludge concentration in the reaction tank possible. Each of UASB reactors were inoculated with anaerobic activated sludge collected from UASB reactor that operated in a fruit-juice factory wastewater plant. In the second digester, the same sludge and the spirals made of steel wire, 2.2 mm diameter, 0.54 m^2 contact surface and 54% iron contents, were used. Peristaltic

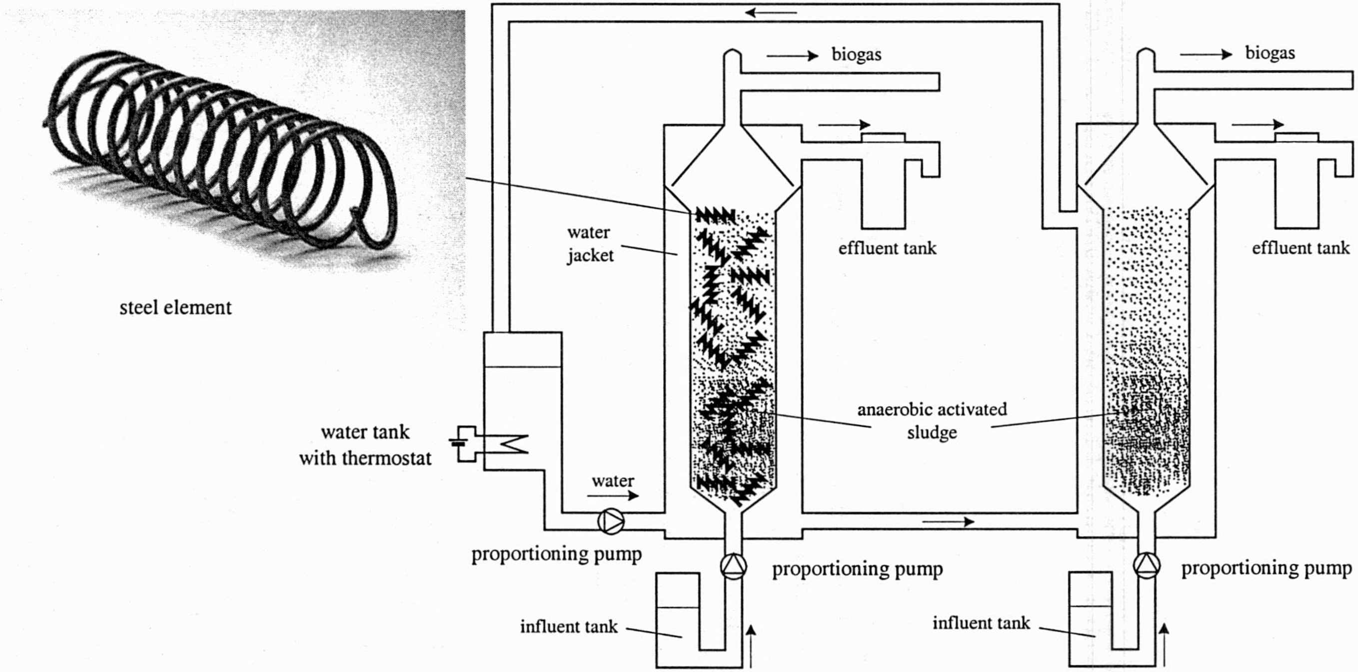

Fig. 1. Scheme of the installation

pumps pumped the yeast wastes from the bottom part of the UASB bioreactor to the upper part. The rate of wastewater flow was controlled by pump drivers. Pump working time was 2 min and then there was 10 min break. Hydraulic loading during the experiment was maintained on the level of 0.0144 m^3/d.

1. reaction tank
2. gas chamber
3. heating jacket
4. wastewater influent stub
5. wastewater effluent stub
6. gas effluent stub
7. heating water influent stub
8. heating water effluent stub
9. pH-meter port
10. thermometers
11. effluent stub

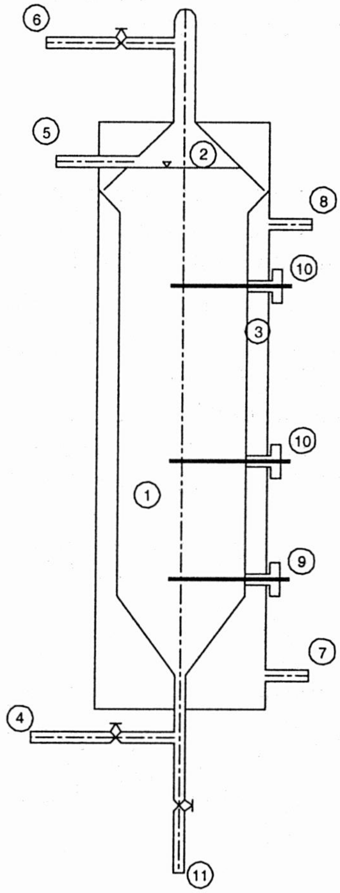

Fig. 2. Scheme of the UASB reactor

The samples analysed were taken directly from raw waste tanks and treated waste containers once a day. Organic carbon concentration (COD) as a basic component of carbon compounds in wastewater and sulphate concentration were analysed. The reaction (pH) was controlled in the influent and the effluent in order to maintain optimal conditions for the fermentation process. The content of total ferric ions was measured in effluents from both reactors to control corrosion rate. In order to avoid an overload of anaerobic sludge, raw wastes supplied to the reactors were diluted with water to maintain COD on the level of about 2–4 times lower than that of raw wastes. Additionally, the treated wastes were recirculated. Lower sludge loading allowed better sludge adaptation to this kind of wastes, as well.

The wastes were assayed for the concentration of the COD and total ferric ions according to standard methods. Sulphates were determined using HACH DR/2000 spectrophotometer, by the 8051 method with Sulfa Ver 4 reagent. pH of the wastes was measured using HANNA/ HI 8818 pHmeter.

3. RESULTS

The yeast wastes were treated under anaerobic conditions in UASB bioreactors. Pollutants concentrations measured in the wastes (after I rotation) were in the range of typical literature values [23]–[26]: COD concentration, 11000 mg O_2/dm^3; total nitrogen, 1096 mg N_{tot}/dm^3; total phosphorus, 15.6 mg P/dm^3; sulphate, 1500 mg SO_4^{2-}/dm^3; pH of the wastes, 6.03. Raw wastes were diluted to maintain COD on the level of ca. 2708–5173 mg O_2/dm^3.

During anaerobic treatment of yeast wastes the efficiencies of COD removal and sulphate removal were higher in the UASB reactor packed with steel elements than in the UASB reactor (figures 3, 4; tables 1, 2).

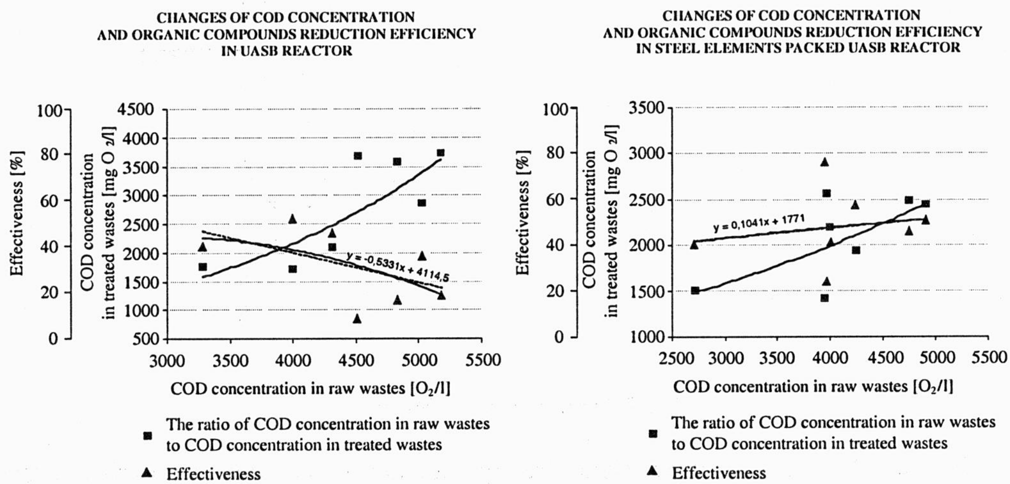

Fig. 3. Variations of COD concentration in treated yeast wastes

At anaerobic sludge loading of 0.06 g COD/g d.m.·d, COD-utilizing rate ranged from 50 to 60% in the UASB reactor without steel elements. An increase in activated sludge loading to 0.09 g COD/g d.m.·d caused a decrease in COD removal efficiency to 19% (table 1). Downward tendency of treatment efficiency is represented by the equation $y = -0.5331x + 4114.5$ (a negative value of a slope of a straight line (–0.5331) testifies to this tendency, see figure 3).

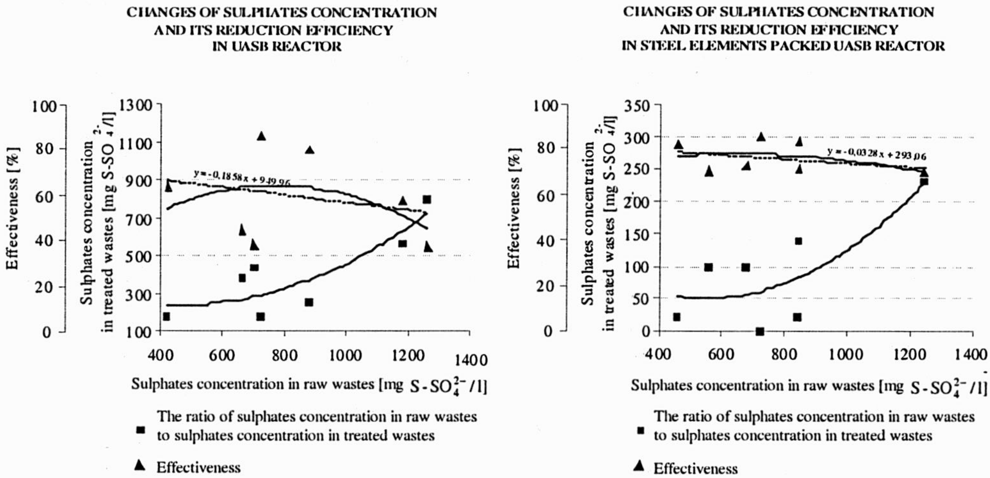

Fig. 4. Variations of sulphates concentration in treated yeast wastes

Table 1

COD concentrations and effectiveness of COD removal in UASB reactors

Type of reactor	Concentration of COD influent [mg O_2/dm^3]	Concentration of COD effluent [mg O_2/dm^3]	COD removal [%]
UASB reactor	3997	1700	57.5
	4315	2087	51.6
	3286	1764	46.3
	5023	2868	42.9
	5173	3726	28.0
	4826	3565	26.1
	4516	3669	18.8
UASB reactor packed with steel elements	3997	2200	44.9
	3953	1408	64.4
	2708	1503	44.5
	4242	1948	54.1
	4744	2480	47.7
	4909	2439	50.3
	3969	2558	35.5

Table 2

Sulphate concentrations and effectiveness of sulphate removal in UASB reactors

Type of reactor	Concentration of sulphate influent [mg S–SO_4^{2-}/dm^3]	Concentration of sulphate effluent [mg S–SO_4^{2-}/dm^3]	Sulphate removal [%]
UASB reactor	720	180	75.0
	700	440	37.1
	660	380	42.4
	880	260	70.4
	1180	560	52.5
	1260	800	36.5
	1180	420	64.4
UASB reactor packed with steel elements	720	0	100
	840	20	97.6
	460	20	95.6
	560	100	82.1
	840	140	83.3
	1240	230	81.4
	680	100	85.3

In the UASB reactor packed with steel elements, no downward tendency of treatment effectiveness with the increase in activated sludge loading was observed. At lower sludge loading, i.e. 0.05 g COD/g d.m.·d, the removal efficiency of organic carbon compounds ranged from 40% to 50%. An increase in activated sludge loading to 0.09 g COD/g d.m.·d did not cause any significant changes in COD removal efficiency (table 1). An insignificant increase in the reduction efficiency of pollutants is represented by the equation $y = 0.1041x + 1771$ (a positive value of a slope of a straight line (0.1041) testified to this increase, see figure 3).

Thus, higher performance of COD removal in the UASB digester packed with steel elements was observed on a constant level of 40–60%.

Anaerobic treatment in USAB reactor without steel elements allowed partial sulphate reduction. 50% sulphate removal efficiency at sulphate loading of 2.6–10 g SO_4^{2-}/d was measured. An increase in sulphate loading to 18 g SO_4^{2-}/d decreased the effectiveness of sulphate reduction to 36.5% (table 2), which was confirmed by a slope of a straight line represented by equation $y = -0.2068x + 971.27$ (figure 4).

Variations in sulphate loading from 6.6 to 18 g SO_4^{2-}/d in the system packed with steel elements did not change significantly the efficiency of sulphate reduction. During the experimental period sulphate removal effectiveness was constant and ranged from 85 to 95%. This testifies to a positive effect of steel elements in the bioreactor on the sulphate-utilizing rate. Sulphate removal under the circumstances is represented by the equation $y = -0.0328x + 293.06$ (figure 4). If at sulphate loading exceeded 14 g S–SO_4^{2-}/d, an insignificant decrease in the removal efficiency of yeast wastes was observed (table 2).

pH of the influent ranged from 6.03 to 7.5; and pH of the effluent, from 8.47 to 9.3. An increase in pH in reactor proved that anaerobic microflora of activated sludge developed properly.

During our investigations the content of ferric ions in effluent from UASB digester varied between 0.5 and 4.4 mg of the total iron per 1 dm^3. Corrosion of steel elements in the second UASB reactor was the source of considerable amount of iron in the effluent, i.e. 12.9–15.7 mg of the total iron per 1 dm^3.

4. DISCUSSION

This study was conducted to compare the process performance of two UASB reactors for high-strength organic and sulphate-rich wastewater treatment and to determine the impact of the steel elements on the effectiveness of COD and sulphate removal from yeast wastes.

Anaerobic yeast waste treatment seems to be the best method because the waste from yeast production does not consist of toxic substances, but are rich in nutrients and organic compounds (COD : N : P ratio is about 100 : 5 : 0.2). The disadvantage of such wastes is high concentrations of sulfates which promotes hydrogen sulphide formation [23]–[26].

Many authors reported that during anaerobic treatment of yeast wastes, the removal of organic carbon compounds (expressed as COD) approached 70%. A longer retention time (> 4.5 d) is responsible for a higher removal effectiveness (over 80%) [25]. It was demonstrated that during anaerobic treatment of yeast wastes in the digesters with full mixing and at organic loading of 2 kg COD/m^3·d and high gas productivity, removal efficiency was lower than 60%. Aerobic–anaerobic methods allowed us to obtain 78% removal of COD [25]. It is often reported that fluidised-bed reactors or anaerobic filters used for treating a diversified range of industrial high-strength wastewaters make an increase in removal effectiveness under anaerobic conditions possible [25]. At a hydraulic load as high as 50 kg COD/m^3·d, the efficiency of COD removal reached 60%.

In the present experiment, two UASB bioreactors were used. The authors tried to assess the impact of steel elements on the removal efficiency of carbon compounds (as a COD) and to compare the results obtained with those for UASB reactor without steel elements. The removal efficiency in the UASB reactor packed with steel elements at sludge loading increasing from 0.05 to 0.09 g COD/g d.m.·d was on a constant level lower than 60%. In the reactor without steel elements, where activated sludge loading was increased from 0.06 to 0.09 g COD/g d.m.·d, the efficiency of COD removal decreased from 50% to 20%.

The factors affecting the rate of COD removal from high-strength sulphate-containing wastewaters can be itemized as follows:

1. The volumetric loading of sulphates introduced into reactor.
2. The sulphate concentration/COD ratio of the influent.
3. The level of undissociated sulphide in post-reaction mixture [10].

In the present experiment, the wastewater of the sulphate concentration ranging from 500 to 1200 mg $S\text{–}SO_4^{2-}/dm^3$ was treated in UASB reactors. Thus, based on the available literature, it could be assumed that COD removal in both digesters was not caused by methane-producing microorganisms, but by sulphate-reducing microorganisms (SRB) [10], [15], [22], [28].

Sulphides are considered to be one of essential nutrients for methane-producing microorganisms although only low concentrations are required for their optimal growth. Toxic effect of sulphide is not observed, provided that its concentration in the environment is not high [22]. Under anaerobic conditions sulphides are produced by SRB that use sulphates or the other sulphur compounds as electrons acceptors during the oxidation of molecular hydrogen or organic compounds present in a treated wastewater. In the presence of the sulphates, thiosulphates or other sulphur compounds, MPB have to compete with SRB for available hydrogen and acetic acid. The outcome of this competition determines the end product of the anaerobic mineralization. If MPB predominate, then methane is the main component of biogas, but when SRB predominate the main component is hydrogen sulphide. The competition between both groups of the microorganisms in anaerobic digesters was reported by many researchers [10], [16], [21], [22], [28], [29], [30] who observed that during anaerobic treatment of sulphate-rich wastewater under mesophilic conditions, hydrogen is almost completely oxidized by SRB [10], [20], [31]. In the anaerobic reactors, also acetate is degraded by SRB. SRB win the competition which can be explained by their better growth. On the other hand, the outcome of this competition for an available acetate between bacteria from both types is less clear and predictable [22].

Hydrogen sulphide exerts an inhibitory effect on methanogenesis and is supposed to be determined by the concentration of undissociated hydrogen sulphide, which, contrary to sulphide ions, can permeate the cell walls [10], [22]. The concentration of undissociated hydrogen sulphide and environment reaction are interrelated with each other. Up until now a lot of publications about a toxic effect of sulphide on the methane-producing bacteria have been known [10], [17], [32], [33], [34].

Due to treating sulphate-rich wastewater in UASB reactors, SRB predominate over MPB which can be even absent in anaerobic microflora. This is confirmed by two facts: 1) no methane in the biogas and 2) high concentration of sulphide in both – undissociated and dissociated forms, which inhibited the growth of methane-producing bacteria. The inhibition of growth of the MPB, and especially those from *Methanosaeta* sp. genus that contribute to microbial-aggregate formation, resulted in a different type of anaerobic sludge in USAB reactors [10]. During our investigations this sludge did not form any granular seeds but occurs as semi-fluid.

Electrochemical iron corrosion in wastewater is similar to corrosion in water solutions. However, besides electrochemical corrosion, biological corrosion is very significant in wastewater because of wide range of microorganisms living there. Most of microorganisms do not directly contribute to this process, but their indirect influence is a result of metabolism or accumulation of some substances [35].

Iron corrosion due to activity of SRB is well known. Such genera as *Desulfovibrio, Desulfobacter, Desulfotomaculum* can be numbered among anaerobic chemoorganotrophs from SRB group. These microorganisms can live only under anaerobic conditions or at defficiency of oxygen (E_h below 200 mV) and pH ranging from 5.5 to 8.5. Moreover, carbon compounds, carbon dioxide, sulphates and growth regulators are necessary to maintain their growth. Iron corrosion caused by SRB is a sequence of reactions leading to ferrous hydroxide and ferric sulphide formation. Hydrogen sulphide as an aggressive gas that appears during dissimilatory sulphate reduction additionally stimulates corrosion process [35], [36]. In the present experiment, an increase in removal efficiency of carbon compounds in UASB reactor packed with the steel elements was caused by an increase in microorganism activity during corrosion of these elements.

According to literature findings an adverse effect of hydrogen sulphide that is observed during sulphate-rich wastewater fermentation can be mitigated by passing wastewater through the bed filled with ferric oxide pellets [10], [37]. In the present experiment carried out in the UASB system packed with steel elements, recycling wastes were in contact with atmospheric air which led to formation of ferrous oxides. Ferrous oxides oxidized hydrogen sulphide present in wastes, reducing its inhibitory effect on microflora. This allowed us to obtain higher effectiveness of yeast waste treatment compared to the effectiveness of the treatment in the digester without steel elements.

In anaerobic UASB reactor operating at the loading of 1.94 kg COD/ $m^3 \cdot d$ and 1.37 kg S–SO_4^{2-}/$m^3 \cdot d$, removal efficiency of COD was 90% and the sulphate reduction was as high as 94% [10]. However, high COD reduction was due to installation of a hydrogen sulphide-stripping device in order to neutralize its unfavourable impact on activated sludge. In the UASB reactor system, the load of organic compounds of 25.5 kg COD/$m^3 \cdot d$ was removed in approximately 84%. When reactor operated at lower sulphate loading (0.373 kg S–SO_4^{2-}/$m^3 \cdot d$) sulphate reduction approached even 92% [10].

UASB reactor without steel elements and UASB reactor packed with steel elements operate at the volumetric COD loadings of 6.48 kg COD/$m^3 \cdot d$ and 5.76 kg COD/$m^3 \cdot d$, respectively. Sulphate loadings in both reactors were, respectively 1.15 kg S–SO_4^{2-}/$m^3 \cdot d$ and 1.09 kg S–SO_4^{2-}/$m^3 \cdot d$. In the system without steel elements, COD removal achieved 38% and the sulphate reduction approached 50%. It should be noted that in the UASB reactor with steel elements, the effectiveness of COD removal was maintained on the level of 50% and sulphate reduction was on the level of 89%. Favourable influence of steel elements on the sulphate reduction in wastewater can be explained by higher activity of SRB in the presence of iron ions and neutralization of toxic effect of hydrogen sulphide by the products of corrosion.

5. CONCLUSIONS

• During yeast wastewater treatment in UASB digesters COD reduction and sulphate elimination were observed. Higher effectiveness of pollutant removal was obtained in the UASB reactor packed with steel elements.

• The UASB reactor packed with steel elements and supplied with a sulphate-rich wastewater allowed 50% removal of organic compounds and 80% sulphate reduction. In the bioreactor without steel elements, waste treatment was not so efficient, because COD removal and sulphate reduction were on the level of 38% and 50%, respectively.

• Independently of the changes in pollutant loading, digester with steel elements operated in a constant way. Simultaneously with an increase in pollutant loading a significant decrease in the effectiveness of COD and sulphate removal was observed in the UASB reactor without steel elements.

• Iron ions from steel corrosion resulted in a higher effectiveness of treating yeast wastes in the UASB reactor with steel elements; an average content of total iron in the effluent from such reactor was over 20 times higher than the same content of iron in the effluent from UASB digester without steel elements.

• No considerable changes in pH of treated wastes were observed.

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BEZTLENOWY PROCES OCZYSZCZANIA ŚCIEKÓW Z WYTWÓRNI DROŻDŻY W REAKTORZE FERMENTACYJNYM TYPU UASB WYPEŁNIONYM ELEMENTAMI STALOWYMI

Celem badań było określenie wpływu stalowego wypełnienia bioreaktora UASB na proces redukcji zanieczyszczeń ze ścieków drożdżowych. Eksperyment przeprowadzono w skali laboratoryjnej, w dwóch reaktorach typu UASB. Komora jednego reaktora zawierała beztlenowy osad czynny, podczas gdy wypełnienie drugiego stanowiły dodatkowo kształtki stalowe. Zanieczyszczenia organiczne, wyrażone jako ChZT, w reaktorze bez elementów stalowych były usuwane w 38%, natomiast w reaktorze z kształtkami stalowymi – w 50%. Efektywność redukcji siarczanów wyniosła odpowiednio 50 i 89%.