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THE APPLICATION OF UASB REACTOR IN MEAT INDUSTRY WASTEWATER TREATMENT

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The meat industry is a branch of the food sector, which significantly affects the degradation of the environment. Consuming large amounts of water consequently produces significant quantities of water which are characterised by a high organic content and high concentration of suspended solids, inorganic salts and nutrients. The study attempted to determine the influence of the HRT and OLR on biogas production and the treatment of wastewater from the meat industry, and it was found that the most preferred treatment process carried out was at HRT 3d (OLR-0.55 kgCOD/m^3d). The anaerobic process under HRT 3 d obtained a considerable degree of the removal of organic pollutants from raw wastewater designated as COD (79%), BOD (77%) and TOC (73%). The concentrations of COD and BOD were 350 mg/dm^3 and 363 mg/dm^3 respectively. The value of TOC reached a level of 142 mg/dm^3. Due to its poor quality, effluent from a UASB reactor cannot be discharged into natural water without additional treatment processes. The addition of reverse osmosis in the meat industry wastewater treatment is suggested.

Keywords: meat industry wastewater, reactor UASB, hydraulic retention time, biogas

1. INTRODUCTION

The intensive development of the food sector in Poland was recorded after the year 2004. Grants from the European Union allowed a lot of investments to increase production and improve product quality. Currently the meat industry in the country comprises about 3500 enterprises of various fields and business profiles. This sector of the economy is characterised by a strong fragmentation

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and dispersal, and includes both small family companies dedicated exclusively to slaughtering, as well as big establishments and companies [1-4].

The meat industry generates a large amount of wastewater which represents a serious problem due to its high levels of organic matter which demand effective and high cost treatments.

This wastewater is high in dissolved and suspended organic matter, in particular proteins and fats are high in organic nitrogen and grease, and many of them contain a significant amount of pathogens. Table 1 presents the qualitative characteristics of wastewater produced in the meat industry.

Slaughterhouse and meat industry wastewater are strong and unpleasant, comprising urine, blood washed from carcasses, floors, utensils, and undigested food from the paunches of slaughtered animals [3,7-8].

Table 1. Pollution concentration in raw wastewater (for a wastewater treatment plant whose daily flow is bellow 2000 m^3) [2,4,14]

Pollution indices	Concentration of pollution in raw wastewater mg/dm^3		Permissible standards mg/dm^3 [7,8]	
	Range	Mean value	Sewage system	Natural receiver
pH	6-10	-	6-9,5	6,5-9
COD	1600-8000	4800	1000	125
BOD	1200-5000	3100	700	25
Total nitrogen	50-400	225	50	30
Total phosphate	15-100	58	15	5
Total suspension	100-2000	1050	350	50
Ether extract	1000-1500	1250	100	50

The quantity of wastewater will mainly depend on the slaughterhouse design, operation practices, and the cleaning methods used. Wastewater generation rates are usually expressed as a volume per unit of product or per animal slaughtered, and there is a reasonable degree of consistency between some of the values reported from reliable sources for different animal types.

The average amount of water produced in the meat plant is 150 m^3/d which corresponds to the size of a population equivalent (EP) of BOD_5 by 9500 [1,4].

In wastewater treatment, biological processes are mainly used for the removal of organic pollution. However, aerobic processes are not regarded as a suitable treatment option because of high-energy requirements for aeration, limitations in liquid-phase oxygen transfer rates and large quantities of sludge production.

Anaerobic degradation is a technology which combines the treatment of residues or wastewater with the production of methane, a renewable energy resource with less greenhouse emissions when compared with fuel alone. The anaerobic granular sludge bed technology refers to a special kind of the reactor

concept for the "high rate" anaerobic treatment of wastewater. The concept was initiated with the upward-flow anaerobic sludge blanket (UASB) reactor. The wastewater is distributed into the tank at appropriately spaced inlets. The wastewater is passed upwards through an anaerobic sludge bed where the microorganisms in the sludge come into contact with wastewater. The resulting anaerobic degradation process is typically responsible for the production of gas (e.g. biogas containing CH_4 and CO_2). The upward motion of the released gas bubbles causes hydraulic turbulence that provides reactor mixing without any mechanical parts. At the top of the reactor, the water phase is separated from sludge solids and gas in a three-phase separator [9-10].

The study used the UASB reactor filled with granular sludge. The sludge granules are dense, multi-species, microbial communities, and none of the individual species in the granular ecosystem is capable of degrading complex organic waste.

According to the multi-layer model, the microbiological composition of granules is different in each layer. The inner layer mainly consists of methanogens that may act as nucleation centres necessary for the initiation of granule development. H_2-producing and H_2 -utilising bacteria are the dominant species in the middle layer, and a mix of species take the predominant position in the outermost layer. To convert a target organic material to methane, the spatial organisations of methanogens and other species in anaerobic granules are essential [5,10,15].

2. MATERIAL AND METHOD

2.1. Material

The wastewater came sampled from the meat-processing plant near Czestochowa whose activity covers the slaughtering and processing of pigs. The values of the basic and eutrophic pollution indicators were high and ranged widely during the whole production cycle. The wastewater had a brown colour and smelled bad and was also characterised by a tendency to rot and foaming. The characteristics of the raw wastewater are presented in Table 2.

Table 2. Characteristics of wastewater from a meat industry plant near Czestochowa

Pollution indices	Concentration of pollution in raw wastewater	Permissible standards-natural receiver mg/dm^3 [14]
COD, mg O_2/dm^3	1630-1670	125
BOD, mg O_2/dm^3	1480-1520	25
Chloride, mg Cl^-/dm^3	750-790	1000
pH	7.28-7.33	6.5 – 9
VFA, mgCH_3COOH/dm^3	840-857	-
Ammonia nitrogen, mg NH^+_4 /dm^3	490	30

Ether extract, mg/dm^3	1138-1250	50
TOC, mg C/dm^3	760-810	30

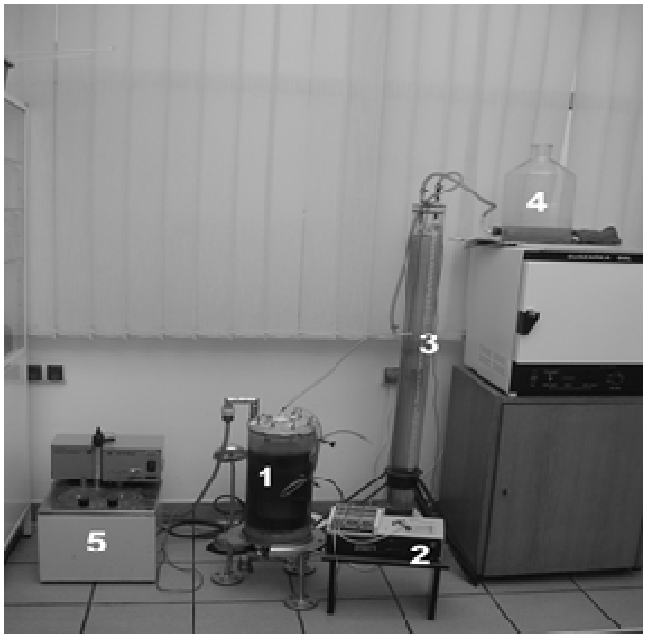
2.2. Reactor UASB

In the experiment, an upflow anaerobic sludge blanket bioreactor (UASB) was used. The UASB reactor has a cylindrical shape with a total volume of 11.8 dm^3. The reactor tank was made of plexiglass. The produced biogas was collected in a calibrated glass cylinder which was filled with acidified aqua de-ionized water (Fig.1).

The reactor was filled up with anaerobic granular sludge at a concentration of 20 g/dm^3. The anaerobic granular sludge used in the research, was picked up from an anaerobic IC reactor at the wastewater treatment plant at Zywiec SA brewery. Typically, granules have a spherical form with a diameter range from 2 mm to 6 mm. The characteristics of anaerobic granular sludge are presented in table 3.

Table. 3. Characteristics of anaerobic granular sludge

Parameter	Unit	Value
Total suspensions	g/dm^3	80,93
Organic matter concentration	g/dm^3	10,96
Mineral compounds	g/dm^3	69,97



1. UASB bioreactor
2. peristaltic pump
3. biogas tank
4. balance tank
5. thermostat

Fig. 1. The installation for the treatment of meat industry wastewater in UASB bioreactor

2.3. Analytical methods

The raw meat industry wastewater and the effluent from the UASB reactor were sampled periodically for pH value, alkalinity, COD, BOD_5 ammonia nitrogen, volatile fatty acids (VFA), TOC, ether extract and chloride analyses.

The chemical oxidation demand (COD) determinations were made by means of the test method on the HACH-DR 4000 spectrophotometer. The biochemical oxidation demand in five days (BOD_5) was measured with an OxiTop respirometer. The alkalinity and chloride were measured according to the standard methods [6]. The pH value was determined with a Cole Parmer pH-meter. Ammonia nitrogen and VFA were determined with the distillation method using a Büchi 323-Distillation Unit. The TOC was analysed using Kiper TOC 10C Analyzer PX-120 (autosampler AS40-Dione). The lipid content (ether extract) was determined by two methods: direct extraction and Soxhlet extraction. The composition of the biogas was analysed using Geotechnical Instruments GA 2000.

3. RESULTS AND DISCUSSION

In the research, the most advantageous parameters of the meat industry wastewater anaerobic treatment were estimated. HRT was a very important parameter in the anaerobic bioreactor due to its influence on the treatment efficiency as well as the size of the bioreactor and engineering design. In this study, the UASB reactor operated under HRTs of 6, 4, 3, 2 d with an increase of the OLR (organic loading rate) from 0.27 kgCOD/m^3 d to 0.82 kgCOD/m^3 d respectively.

During the process, the HRT value equalled 6 days, the COD and BOD removal efficiency were at the level of 85% and 82% respectively. Shortening of the HRT from 6 to 4 days caused an increase in the OLR from 0.27 kg COD/m^3d to 0.4 kg COD/m^3d and decreased the COD removal by 3%. Therefore, COD and BOD concentrations of effluent were 295 mgO_2/dm^3 and 318 mgO_2/dm^3 respectively.

The next reduction of the HRT to 3 days, caused an increase in the OLR to 0.55 kg COD/m^3d. Effluent from the UASB reactor had the following parameters: COD - 350 mgO_2/dm^3 and BOD - 363 mgO_2/dm^3.

During the treatment process, the meat industry wastewater had a 2 day retention time, or the quality of effluent changed for the worse. The COD removal efficiency decreased from 79% to 65%. The values of the treated wastewater were as follows: COD - 573 mgO_2/dm^3 and BOD - 588 mgO_2/dm^3. The dependence of COD and BOD removal on the HRT is shown in Fig. 2 and Fig.3 respectively.

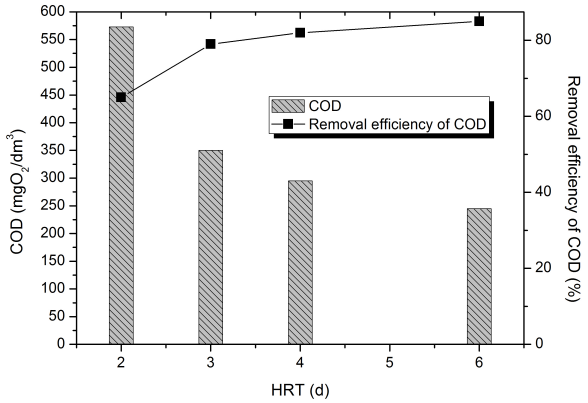


Fig. 2. The influence of the HRT on the degree of COD removal efficiency and the volume of effluent COD

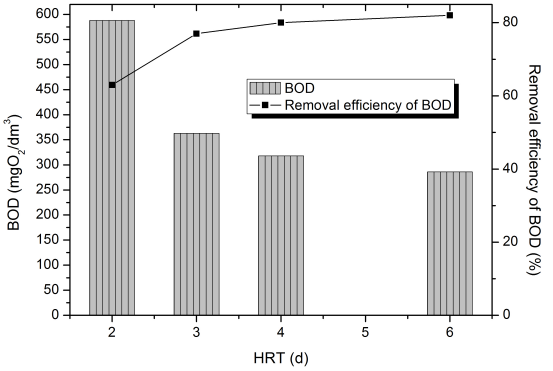


Fig. 3. The influence of the HRT on the degree of BOD removal efficiency and the volume of effluent BOD

The total organic carbon (TOC) is the most relevant parameter for the global determination of organic pollution of wastewater. The TOC removal efficiency under the HRT of 6 days achieved a value of 84% (TOC in treated wastewater - 84 mgC/dm^3). For the shorter hydraulic retention time (4 d) the treatment efficiency was 3% lower and the effluent TOC value was around 100 mgC/dm^3. During the fermentation process under the HRT of 3 days, a gradual reduction of the treatment efficiency was still observed. Effluent TOC increased to the level of 142 mgC/dm^3. At the HRT of 2 days the TOC removal efficiency was 13% lower as compared to the treatment process under the HRT of 6 days. Worse effluent quality was found (TOC effluent 174 mgC/dm^3).

During all the experiments, the VFA/alkalinity ratio, which properly represents fermentation, was estimated. The maximum value above which the process of inhibition takes place is assumed on the level of 0.3, the highest value of the VFA/alkalinity ratio (0.27). At the HRT of 3 d and HRT of 4 d the constant level ranged from 0.22 to 0.23.
Table 4 presents the influence of the HRT on the investigated parameters in the anaerobic treatment of meat industry wastewater.

Table. 4. The influence of the HRT on the parameters investigated in the anaerobic process

Pollution indices	Raw wastewater	Effluent from UASB reactor			
		HRT 2 d	HRT 3 d	HRT 4 d	HRT 6 d
COD	1630-1670	573	350	295	245
BOD	1480-1520	588	363	318	286
pH	7.28-7.33	7,8	7,6	7,5	7,42
Chloride, mg/dm^3	750-790	750	760	750	753
VFA/alkality	0,7	0.22	0.23	0.23	0.27
Ammonia nitrogen mg/dm^3	490	140	124	132	129
TOC mg/dm^3	528	174	142	100	84
*Ether extract, mg/dm^3	1138	-	220	-	-

* the measurement of ether extract was performed only for raw wastewater and treated wastewater with the most preferred HRT

The value of ammonia nitrogen in anaerobic conditions should be increased. However, the studies reported its removal. The explanation for this may be the presence of sulphur-free purple bacteria that had developed in the reactor (probably *Rhodobacter, Rhodobium, Rhodopseudomonas, Rhodospirillum*). These are microorganisms capable of degrading nitrogen under anaerobic conditions.

Additional parameters were monitored during the fermentation process: daily biogas production and biogas yield. It was observed that the daily biogas production increased along with a decrease in HRT (Fig. 4).

During the fermentation process under the HRT of 2 days, daily biogas production was the highest (2606 cm^3).

An increase in the HRT to 4 and 6 days caused a decrease in the production of biogas. The daily biogas production from the HRT of 4 d and HRT of 6 d was correspondingly lower by 24.7% (1960 cm^3) and 48.2% (1350cm^3) when it was compared to the HRT of 2 d.

A very important parameter monitored during the treatment of meat industry wastewater was the biogas yield. At the longer HRT of 4 d and 6 d, the biogas yield was on the same level (0.49 dm^3 biogas/gCOD$_{removerd}$) whereas a lower value was achieved at the HRT of 3 d and HRT of 2 d. At the HRT of 3 d and HRT of 2 d, the biogas yield was 0.45 dm^{3}biogas/gCOD$_{removed}$ and 0.41 dm^{3}biogas/gCOD$_{removed}$ respectively.

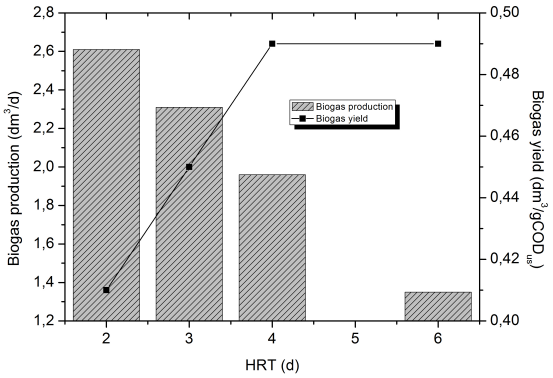


Fig. 4. The relationship between the daily biogas production, biogas yield and hydraulic retention time

The generated biogas in the methane fermentation process of wastewater from meat industry plants was characterised by a high methane content (75% vol.). Carbon dioxide and oxygen in the analysed biogas were 15.5% and 1.5% respectively. The biogas also contained tracers such as unwanted hydrogen sulphide (62 ppm) and carbon monoxide (62 ppm).

4. CONCLUSION

The study attempted to determine the influence of the HRT and OLR on the treatment of wastewater from the meat industry and biogas production. The most important results are:

- the maximum COD and BOD removal efficiencies were 85% and 82% at the HRT of 6 days;
- the removal of organic pollution decreased with the shortened HRT;
- the daily biogas production decreased with an increase in the HRT;
- the biogas yield decreased with the shortened HRT;
- at the longer HRT of 4 d and 6 d, the biogas yield was on the same level (0.49 dm^3 biogas/$gCOD_{removered}$) whereas lower values were achieved at the HRT of 3d and HRT of 2d (0.45 dm^3 biogas/$gCOD_{removered}$ -HRT 3d and 0.41 dm^3 biogas/$gCOD_{removered}$ -HRT 2d);
- The generated biogas in the methane fermentation process of wastewater from the meat industry plants was characterised by a high methane content (75% vol.);
- it was found that the most preferable treatment process be carried out at the HRT of 3 d (OLR - 0.55 kgCOD/m^3d);
- the methane fermentation process under the HRT of 3 d obtained a considerable degree of the removal of organic pollutants from raw

wastewater designated as COD (79%), BOD (77%) and TOC (73)%; The concentrations of COD and BOD were 350 mg/dm^3 and 363 mg/dm^3 respectively. The value of TOC reached a level of 142 mg/dm^3;

- due to the poor quality, permeate from the UASB reactor cannot be discharged into natural water without additional treatment processes. RO and stripping processes are suitable for the post-treatment of anaerobic effluent.

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ZASTOSOWANIE REAKTORA UASB DO OCZYSZCZANIA ŚCIEKÓW Z ZAKŁADÓW MIĘSNYCH

Streszczenie

W badaniach podjęto próbę określenie wpływu czasu zatrzymania ścieków z zakładu mięsnego w reaktorze UASB na efektywność ich oczyszczania oraz na wielkość dobowej produkcji biogazu. HRT zmieniano w zakresie od 2 do 6 dób co wiązało się ze zmianą obciążenia komory ładunkiem zanieczyszczeń z 0.27 kgChZT/m^3d do 0,82 kgChZT/m^3d. Stwierdzono, że wraz ze skracaniem czasu zatrzymania z 6d do 2d, jakość ścieków ulega pogorszeniu, ale ilość produkowanego biogazu zwiększała się. Zaobserwowano, że wielkości współczynnika biogazu ulegała obniżeniu. Stwierdzono, że najkorzystniej prowadzić proces oczyszczania badanych ścieków przy HRT równym 3 doby z uwagi na dobre efekty oczyszczania i wysoki współczynnik produkcji biogazu wynoszący 0,45 dm^3biogazu/g$ChZT_{us}$. Prowadzenie procesu fermentacji przy tak ustalonych warunkach pozwoliło na wysoki stopień usunięcie zanieczyszczeń oznaczanych, jako ChZT (79%), BZT_5 (77%) i OWO (73%). Stężenie ChZT ścieków oczyszczonych wynosiło 350 mg/dm^3, BZT_5 463mg/dm^3 a OWO 142 mg/dm^3. Pomimo wysokiego stopnia usunięcia zanieczyszczeń z badanych ścieków nie ma jednak możliwości odprowadzenia ich do odbiornika naturalnego. Proponuje się, aby w kolejnych etapach badań podjąć próbę doczyszczania ścieków w procesie odwróconej osmozy co w przyszłości może pozwolić na zamknięcie obiegu wody na terenie zakładu.