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Necessity of meat-processing industry's wastewater treatment—a one-year trial in Serbia

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ABSTRACT

The emission of untreated or insufficiently treated wastewater is very common in developing countries and consequently has harmful effects on the environment. The aim of this study was to analyse 24 physico-chemical parameters in raw wastewater and effluent after tertiary treatment (denitrification and disinfection) derived from meat-processing plants in Serbia during four sampling campaigns conducted for one year. The biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were measured at high concentrations up to 6,960 and 14,160 mg/L, respectively, indicating a large amount of uncollected blood, solubilized fat, urine and faeces in discharged wastewater. Required limits of emission in all samples according to the European and national legislation for most of the studied parameters were exceeded. According to the obtained results, there is an imperative need for pretreatment of wastewater from meat industry before discharging it into the sewer. The applied wastewater treatment improved the quality of water by reducing BOD_5 and COD values to 97.97 and 98.08%, respectively, while phosphorus removal efficiency varied from 15.29 to 68.48%.

Keywords: Meat industry; Wastewater; Slaughterhouse wastewater; Water quality

1. Introduction

The meat industry, an important branch of the food industry with significant water consumption, presents one of the major sources of the organic pollution and leads to the degradation of the environment to a large extent [1,2]. The most significant environmental issues associated with meat-processing industry are water usage, solid waste and by-products, emission of high organic strength wastewater, emission of odours to air and the energy consumption [3]. Almost half of the water consumed in the United States is used in raising animals for food. Most of the water is used for carcass washing, hair removal from hogs, cleaning and sanitizing of both equipment and facilities and finally, for

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cooling of compressors and pumps [4]. Accordingly, during the production or cleaning, fats and/or blood are becoming a part of the wastewater system. The problem might occur if fats melt in hot water and consequently become more difficult to separate them from the water. Therefore, the discharged effluents from slaughterhouses and meat-processing facilities increase the deoxygenation of rivers and lead to the contamination of groundwater and ultimately drinking water [5,6]. For that reason, the characterization and the treatment of wastewater from the meat-processing industry have to arouse growing concerns among the agro-industrial sector and the policy-makers especially in the developing countries.

The wastewater derived from the meat-processing facilities and slaughterhouses consists of a variety of organic and inorganic pollutants. Besides the blood, which is one of the major dissolved pollutants, wastewater also contains a high concentration of etheric extract, suspended solids and biogenic matter, pathogenic and non-pathogenic viruses and bacteria, parasite eggs, detergents and disinfectants [1,7]. Moreover, high loads of nitrogen and phosphorous in wastewater effluents have become a major cause of eutrophication of surface waters [8]. Also, these wastewaters remain high-strength wastes (fat, grease, hair, feathers, flesh, manure, grit, undigested feed etc.), in comparison to domestic wastewaters, based on the concentrations of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen and total phosphorus (TP) [9]. Blood, solubilized fat, urine and faeces are the primary sources of BOD_5 and COD in meat-processing wastewaters. The meat industry has the potential to generate large quantities of solid wastes and wastewater with a BOD_5 as high as 8,000 mg/L or 10–20 kilograms per metric ton (kg/t) of slaughtered animal [10]. The highest COD strength of any liquid effluent derived from slaughterhouses has blood with a COD up to 375,000 mg/L [5,11]. Therefore, the efficacy of blood collection is a significant factor in the determination of the amount of BOD_5 and COD in the meat-processing wastewater [10].

High levels of COD, BOD_5, nitrogen, TP as well as fat, grease and pathogen micro-organisms should be reduced by the adequate treatment technologies. However, small slaughterhouses usually discharge wastewater directly, without any treatment, into municipal sewer systems [5] or in some cases into water bodies. The treatment of wastewater derived from meat-processing industry consists of a combination of physical, chemical and biological processes and operations and can be divided into three steps: primary, secondary and tertiary treatment [12,13]. The primary treatment includes equalization of waste flows, neutralization, the separation of large materials, the partial removal of suspended solids, fats and oils mostly by sedimentation and the standardization of composition and flow rate. During the secondary treatment, biological processes are used for elimination of biodegradable organic matter leading to the reduction of COD and BOD_5. The tertiary and/or advanced treatment involves chemical coagulation, flocculation, sedimentation and filtration. In addition to disinfection, sterilization, advanced oxidation processes and activated-carbon adsorption are frequently applied. The purpose of the tertiary treatment is to produce an effluent water of high quality by removal of nitrogen, phosphorous and other specific pollutants [12–14].

In the developing countries such as Serbia, the emission of untreated or insufficiently treated wastewater is very common. Mostly, very scarce treatment of wastewater is applied, and livestock farms and slaughterhouses usually do not have facilities for treatment and disposal of manure and wastewater. In the sampling campaigns, conducted in the spring, summer and autumn of 2013 and the winter of 2014, the wastewater was collected from four representative meat-processing industry pilot plants in the Province of Vojvodina, Republic of Serbia. The aim of this study was to determine physico-chemical characteristics of raw wastewater and effluent after tertiary treatment (denitrification and disinfection) from meat-processing industry in order to get deeper insight into the current quality issues and to evaluate the efficacy of the applied treatment methods.

2. Material and methods

The largest number of meat-processing plants in Serbia is situated in the Province of Vojvodina, Republic of Serbia. The wastewater samples discharged from four meat-processing plants in the Province of Vojvodina were collected during four sampling campaigns, in the spring, summer and autumn of 2013, and the winter of 2014. The number of samples was limited due to the refusal of meat-processing companies to provide the wastewater. Hence, four grab samples per season were collected from four meat-processing plants. Also, four additional samples from meat-processing plant with the wastewater treatment technology were collected after the applied treatment.

In order to obtain truly representative samples, wastewater was taken in the peak load time for each meat-processing facility based on the previous research [15]. Grab sampling was applied as the required method in this situation, when it is necessary to obtain the wastewater quality at peak flow and to evaluate the wastewater treatment efficiency [16].

The only one, out of four meat-processing plants, had wastewater treatment technology. The wastewater treatment of the selected meat-processing plant included primary, secondary and tertiary treatment. The primary treatment of the raw wastewater was consisted of the coarse solid separation, flotation and sludge separation. The secondary treatment included pre-oxidation treatment followed by the biological oxidation processes. Finally, sedimentation, denitrification and disinfection were applied as the tertiary treatment. Those processes were applied to the directly discharged raw water from the meat-processing facility. After applied treatments, effluent was discharged into the lake.

The wastewater samples for laboratory analysis were collected in sealed 1-L glass bottles and stored at 4˚C before analyses. The chemical analysis included pH, temperature, electrical conductivity, BOD_5, COD, dissolved oxygen (DO), permanganate index, ammonia (NH_3-N), nitrite (NO_2-N) and nitrate nitrogen (NO_3-N), TP, orthophosphates (PO_4-P), chlorides (Cl^-), total chlorine (TC), sulphates (SO_4^{2-}), TSS, total hardness and the concentrations of metals was performed according to the Standard Methods for the Examination of Water and Wastewater.

Conductivity and DO were determined *in situ* using portable Multi 340i Wissenschaftlich-Technische Werkstatten Gmbh device. Biological oxygen demand (BOD_5) was determined using the BOD Trak™ method. The Hach BOD Trak apparatus is based on the manometric principle of operation. The COD, NH_3-N, NO_2-N, NO_3-N, TP, PO_4-P, TC and SO_4^{2-} concentrations were measured with UV/vis spectrophotometer (DR 5000, HACH, Germany). Precision and accuracy of the methods were verified with the certified reference materials: Demand WP, Simple Nutrients WP, Complex Nutrients WP (RTC, UK).

For the determination of metals, the wastewater samples were spiked with 5 ml of HNO_3 and digested using the microwave-assisted digestion system MWS-3+ (Berghof, Germany). The analysis was done on Thermo atomic absorption spectrometer and accuracy was evaluated with the certified reference materials LGC6175 (LGC, UK) and SPS-WW2 Batch 110 (SPS, Norway). The recoveries ranged from 89 to 97%. The procedure was described in detail by Mihajlovic et al. [17].

The total phenol content (TPC), the chromium (VI) and oil and grease concentrations in the samples were measured using standard methods EPA 420.1, EPA 7916A and EPA 1664, respectively. The determination of anionic surfactant as methylene blue active substances (MBAS) and nonionic as potassium picrate active substances (PPAS) were done applying EPA 425.1 and the method obtained by Favretto et al. [18].

The correlations between the average capacity of facilities per day and laboratory analysis for pollutant concentrations were done using Pearson's correlation coefficients by IBM SPSS software (a significance threshold of $p = 0.05$ was retained).

3. Results and discussion

Policy-makers worldwide are setting more stringent environmental standards for discharge of wastewaters from different kinds of industry [19]. Serbia as a developing country and candidate for membership in European Union is in the process of implementation of EU legislation. Although, at the meat industry level, each plant is obligated to quarterly monitor wastewater quality, the data are scarce. Therefore, a one-year trial of quality of meat-processing wastewater was conducted.

The temperature of the samples varied from 16 to 35.2˚C while the BOD_5 and COD concentrations reached the highest values in the second sampling campaign. In this study, BOD_5 and COD values were measured at high concentrations up to 6,960 and 14,160 mg/L, respectively, indicating the presence of a large amount of organic matter such as uncollected blood, solubilized fat, urine and faeces in discharged wastewater. The obtained results pointed out the absence of primary treatment which would result in reduction of BOD_5 up to 200–250 mg/L [20].

Wastewater effluents often contain high amounts of dissolved salts from domestic sewage. Electrical conductivity of water is a useful indicator of salinity or total salt content. The high salt concentrations in waste effluents can increase the salinity of the receiving water, which may result in adverse ecological effects on aquatic biota. The electrical conductivity values were high and ranged from 895 to 4,690 μS/cm in the wastewater samples during four sampling campaigns within this study. The variation of conductivity in the samples was caused by variation of the ion content and the obtained results were even higher than the reported values for slaughterhouses in Africa [21]. The biological nutrient removal could decrease conductivity in wastewater samples [22].

The concentration ranges of measured physico-chemical parameters in raw water samples at selected sampling sites are presented in Table 1. The required emission limit values specified by the national environmental regulation (the Republic of Serbia, No. 67/2011) [23] relating to wastewater, whose pollutants originate mainly from slaughterhouses, meat processing,

Table 1
Concentration ranges of selected physico-chemical parameters in wastewater samples (N = 16)

	Sample 1		Sample 2		Sample 3		Sample 4		
Parameter	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	ELV[a]
pH	7.09–7.63	7.43 ± 0.27	7.29–10.03	8.66 ± 1.94	6.88–8.25	7.3 ± 0.65	7.23–7.80	7.50 ± 0.25	6.5–9
Conductivity (μS/cm)	1,117–3,540	2,102.25 ± 1,025.86	2,950–3,910	3,430 ± 678.82	2,450–4,690	3,505 ± 939.98	895–1,797	1,175.25 ± 418	
DO (mg/L)	0.23–4.56	2.18 ± 1.81	0.45–1.18	0.81 ± 0.52	0.42–3.07	1.40 ± 1.22	0.34–4.59	1.94 ± 1.98	
NO_3-N (mg/L)	0.10–27.90	8.95 ± 12.84	0.10–2.50	1.30 ± 1.70	0.50–3.50	1.95 ± 1.57	0.10–0.90	0.62 ± 0.36	
NO_2-N (mg/L)	0.02–1.25	0.41 ± 0.58	0.04–0.75	0.39 ± 0.50	0.05–0.94	0.28 ± 0.44	<0.01–0.35	0.10 ± 0.16	
NH_3-N (mg/L)	15.50–52.40	39.27 ± 16.95	8.92–9.40	9.16 ± 0.34	23.60–90.50	66.30 ± 29.95	2.90–5.70	4.18 ± 1.16	15
TP (mg/L)	9.52–27.05	20.04 ± 7.62	21.32–61.61	41.46 ± 28.49	14.22–33.82	24.66 ± 8.05	1.43–11.08	6.32 ± 4.41	2
Perm. index (mg/L)	69.30–260.20	117.05 ± 96.23	137.70–367.30	252.50 ± 162.35	98.20–371.20	233 ± 127.10	7.70–97.40	50.82 ± 40.31	
BOD_5 (mg/L)	720–2,490	1,329 ± 802.79	1,516–6,960	4,238 ± 3,849.49	1,264–3,820	2,651 ± 1,057.24	384–1,084	729.50 ± 300.85	25
COD (mg/L)	1,255–3,580	2,064.25 ± 1,035.23	1,880–14,160	8,020 ± 8,683.27	1,901–5,680	3,867.50 ± 1,595.16	526–1,580	1,081.50 ± 484.60	150
SO_4^{2-} (mg/L)	38–64	53.50 ± 12.04	5–10	7.50 ± 3.53	10–100	43.75 ± 41.51	3–24	11.75 ± 8.81	
TSS (mg/L)	106–420	275.50 ± 131.40	486–1,955	1,220.5 ± 1,038.74	158–1,450	862.25 ± 602.31	43–340	129 ± 141.91	35
Cl^- (mg/L)	50–290	190 ± 100.99	20–120	70 ± 70.71	80–1,000	322.50 ± 451.84	100–200	167.50 ± 47.17	
PO_4-P (mg/L)	2.56–9.11	7.01 ± 3.00	10.55–12.50	11.52 ± 1.38	6.24–16.68	10.16 ± 4.85	1.45–4.11	2.99 ± 1.11	
TC (mg/L)	<0.02–0.3	0.13 ± 0.13	<0.02–0.7	0.35 ± 0.49	<0.02–2.3	0.93 ± 1.06	<0.02–0.2	0.09 ± 0.09	0.4
Al (mg/L)	<1		<1		<1		<1		
Ca (mg/L)	13.76–127.6	77.76 ± 51.40	36.23–74.7	55.46 ± 27.20	29.1–261.70	111.23 ± 103.89	13.36–91.6	41.54 ± 34.62	
Mg (mg/L)	9.71–41.13	26.59 ± 12.97	13.28–27.49	20.38 ± 10.05	8.92–46.71	26.27 ± 16.14	5.43–27.39	15.42 ± 9.36	
Cr(VI) (μg/L)	<0.2		<0.2		<0.2		<0.2		
TPC (mg/L)	<1		<1		<1–2	0.5 ± 1	<1–2	0.5 ± 1	
Oil & Grease (mg/L)	50–185	128.75 ± 58.93	195–220	207.50 ± 17.68	<20–265	158 ± 113.13	120–245	192.50 ± 52.68	20
PPAS (mg/L)	<1		<1		<1		<1		
MBAS (mg/L)	<2–95	45 ± 47.08	68–124	96 ± 39.60	8–76	49.25 ± 29.81	<2–120	63.25 ± 52.17	

[a]Emission limit values according to the regulation of the Republic of Serbia, No. 67/2011.

including the intestines processing as well as the production of finished meat products were also presented in Table 1. Although the content of aluminium, chromium(VI) and nonionic surfactants were under the limit of the detection in all measured samples, other monitored parameters varied at a very wide range both between the different samples within the same sampling campaign as well as between the samples from the same facility during different sampling campaigns. Depending on the number of the non-processing days in a month, meat-processing wastewater flow rates from the same facility could be highly variable. The water consumption and production of waste are relatively constant during the killing and the processing in comparison to the clean-up period that follows. Although nonionic surfactants were below the limit of the detection in all samples, anionic were measured up to 124 mg/L MBAS. Anionic surfactants are widespread in the cleaning products and the determined mean values (45–96 mg/L MBAS) cause the serious concern due to the fact that anionic and nonionic surfactants in concentration greater than 0.1 mg/L could lead to the chronic toxicity to aquatic species [24]. Fats, as part of BOD_5 in meat-processing wastewaters, are normally determined indirectly as the concentration of oil and grease. Therefore, the high concentrations of oil and grease in all samples were expected and only in the sample 3 during the autumn campaign were under the limit of the detection, probably due to the reduced workload of that facility. However, most of the measured parameters were above the required emission values prescribed by the Urban Waste Water Treatment Directive (91/271/EEC) of European Comission, German Wastewater Directive (*Abwasserverordung-AbwV*) as well as the Regulations of the Republic of Serbia, No. 67/2011 and 48/2012 [23,25,26].

The significant source of nitrogen in wastewater from meat-processing industry is blood and manure. Generally, nitrogen occurs in several forms, including ammonia. The NH_3-N is the leading toxic pollutant in meat-processing industry and at high effluent concentrations could have harmful effects to aquatic organisms, by reducing the level of oxygen in the water bodies. The content of NH_3-N varied greatly in all raw water samples, while it was completely removed in the treated effluents from the meat-processing plant with the wastewater treatment technology. Although the wastewater treatment plants are indispensable to provide and secure the reduction and the elimination of the majority of organic and inorganic pollutants, only sample 1 was treated before being discharged to the recipient.

The raw wastewater (sample 1) and water after the tertiary treatment (denitrification and disinfection) derived from the meat-processing pilot plant, with this specified treatment technology, were analysed in order to investigate the efficiency of the applied wastewater treatment processes on the physical and chemical characteristics of the wastewater discharged from the meat-processing industry.

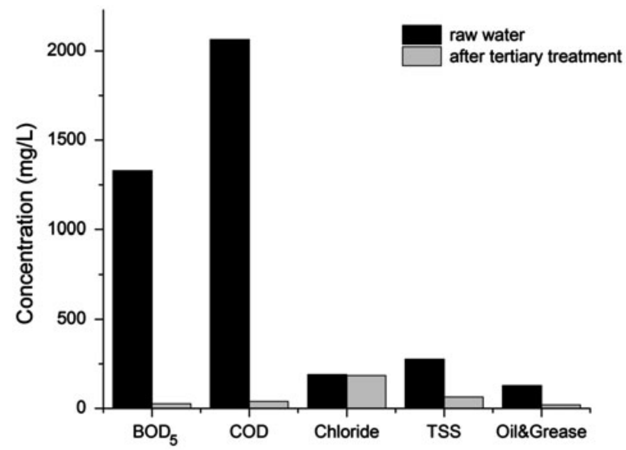

Fig. 1. Comparison of selected parameters in raw and treated water sample from the meat-processing company.

The applied denitrification and disinfection treatment improved the quality of water by reducing BOD_5 and COD values to 97.97 and 98.08%, respectively, while the chloride concentrations remained constant (Fig. 1). During the denitrification treatment process, a large group of heterotrophic facultative anaerobic bacteria, such as *Paracoccus denitrificans* and various *Pseudomonas*, enables the reduction of nitrate to molecular nitrogen [27]. Therefore, the denitrification process was important in NO_3-N concentration's reduction. Disinfection as the final stage in the wastewater treatment process was used in order to limit the effects of organic material, suspended solids and other contaminants as well as to provide a degree of protection from contact with pathogenic organisms. The oil and grease were removed completely in treated water samples and the content of TSS decreased 2.5–5.6 times. However, the TP removal efficiency varied from 15.29 to 68.48%. After applied tertiary treatment, almost all parameters (except for TP concentrations) met the criteria prescribed by the Regulation of the Republic of Serbia (No. 67/2011), the Urban Waste Water Treatment Directive (91/271/EEC) of European Commission and German Wastewater Directive (*Abwasserverordung-AbwV*) [23,25,26].

The last step planned in the tertiary treatment within meat industry facility was adsorption with activated carbon. Activated carbon was proved as powerful adsorbent for the removal of various inorganic and organic compounds from wastewater samples [28]. However, that stage of treatment was not applied during sampling campaigns because of the high costs. Therefore, alternative low-cost adsorbents based on biomass should be developed and used as commercial products.

Pearson's correlation coefficients by IBM SPSS software with significance threshold of $p = 0.05$ showed no connection between the average capacity of facilities per day and the laboratory analysis for pollutant concentrations.

Changeability of the analysed samples represents a problem in the situations when drawing certain conclusions is needed. It is known that diffusely distributed polluters, no matter how small they are, have an additive effect and a significant outcome on the environment. In this respect, it is clear why this sampling campaign was needed and important in order to comprehend the potential hazards meat industry wastewater has on the environment. This is of the utmost importance, given the fact that in Serbia almost none of the meat-processing facilities conduct proper wastewater treatment.

4. Conclusions

The wastewater from four meat-processing facilities was analysed during a one-year study in order to comprehend the potential hazards of meat industry wastewater on the environment in the Province of Vojvodina, Republic of Serbia. The obtained results suggest that heavily polluted wastewater with a high content of blood, suspended solids, inorganic salts and nutrients was discharged directly to the municipal sewerage or natural recipients. The applied denitrification and disinfection treatment improved the quality of water by reducing BOD_5 and COD values, while the efficiency of TP removal varied.

Serbia has more than 3,000 meat-processing plants, where only 5% has some purification wastewater system and this contamination represents great problem not only for citizens but also for nature itself. Moreover, as a developing country and a candidate to become a member of the European Union, Serbia is now in the implementation process of the European Water Framework Directive, whose major goal is to secure a "good chemical and ecological status" of the rivers and lakes. Accordingly, the advanced wastewater treatment plants followed by lower water consumption and frequent effluent monitoring by national authorities are indispensable to provide and secure the recommended criteria prescribed by the European and the national legislations. Knowing and recognizing how to deal with this issue in the best way, how to measure the implications and to understand their impact is crucial for the overall improvement of the quality of the effluents derived from meat-processing industry in order to keep the environment as clean as possible for better life of humans and wildlife.

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