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Agnieszka Makara*, Zygmunt Kowalski, Agnieszka Saeid

Treatment of wastewater from production of meat-bone meal

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Abstract: The paper presents the results of the selection of the flocculent and coagulant types as well as the evaluation of the best parameters of treatment of wastewater deriving from meat-bone meal (MBM) production. The efficiency of purification depends on the composition of the coagulant and flocculent as well as the magnitude of the applied dose. The use of ferrous sulfate PIX 113 coagulant assured the highest reduction of the contamination content in filtrate, resulting in the reduction of color of wastewater by 96.8%, turbidity by 99.2%, and the phosphorus content by 99.9% and nitrogen by 92.4%, with the Chemical Oxygen Demand (COD) being reduced by 62.8%. The X-ray method proved the significant presence of phosphorus salts in the content of sediment. The moisture content in the sediment varied from 45 to 78.5%. The elaborated method of pretreatment of wastewater from meat-bone meal unit was verified on an industrial scale. A very high reduction of the phosphorus content in filtrate (> 99.9%), and a significant reduction of COD as well as nitrogen and suspended solid contents (90–95%) were presented. A high reduction of contamination in filtrate increases the production capacity of the existing biological treatment plant, in the next step of treatment of filtrate in the biological treatment unit.

Keywords: meat-bone meal, wastewater, flocculent, coagulant

***Corresponding author: Agnieszka Makara:** Institute of Chemistry and Inorganic Technology, Cracow University of Technology, Warszawska 24, 31-155 Cracow, Poland; , E-mail: amak@chemia.pk.edu.pl
Zygmunt Kowalski: Institute of Chemistry and Inorganic Technology, Cracow University of Technology, Warszawska 24, 31-155 Cracow, Poland
Agnieszka Saeid: Department of Advanced Material Technologies, Faculty of Chemistry, Wroclaw University of Technology, Gdańska 7/9, 50-344 Wrocław, Poland

1 Introduction

Every year, approximately 18 million tons of waste from meat processing is produced in the European Union that has to be recycled or treated in accordance with respective EU directives. The amount of these wastes produced in Poland is estimated to be 1 million tons/year. In the past, a vast majority of these wastes were processed into meat-and-bone meal used as an additive to livestock feed. However, the appearance of bovine spongiform encephalopathy (BSE) banned the use of these wastes for this purpose, and made the management of wastes coming from meat processing sector problematic, bringing about higher costs for their recycling. In Poland, the annual production of meat-bone meal is estimated at 400,000 t. This material is mainly used as bio-fuel, soil improving agents, and mineral-organic fertilizers (meat-bone meal of 3rd waste category) [1,2]. Animal fat can also be used as bio-fuel [1-3].

Meat wastes that are used to produce meat-bone meal contain approximately 40% of moisture and 60% of dry matter. From 1t of meat waste ~ 400 kg of meat-bone meal and ~ 200 kg of fat are obtained. As the contribution of individual raw materials in the waste varies, the composition of the obtained products varies as well. Pre-treatment of raw material (comprised of removal of metallic parts, grinding and mixing) is followed by sterilization for 30 min. at a temperature of ~ 133°C and a pressure of 0.3 MPa. Next, the obtained material is dried (simultaneous evaporation of humidity occurs), thereby the separation of fat takes place. Dry material is filtered in pressure filtration presses to remove residual fat. The solid fraction obtained in this way forms meat-bone meal (MBM), which is subsequently ground and screened [1,4-7]. Advanced MBM production units in Poland are examples of the utilization of clean technologies [6,8].

The amount of wastewater produced during processing of meat waste into MBM in Poland was estimated at 1 million m^3 per year. Wastewater from meat industry contains a large amount of organic matter (COD > 25,000 mg L^{-1}), as well as nitrogen and phosphorus compounds. The large content of organic matter causes tremendous difficulties in biological treatment of wastewater. Therefore, the methods of filtration as well as precipitation, to reduce COD value are applied as the pre-treated stage prior to the biological treatment of wastewater [4,9].

Screening, settling and dissolved air flotation (DAF) are widely used for removing of suspended solids and fats, oils and greases from slaughterhouse wastewater [10]. Three methods of flotation are used to treat wastewater from meat processing: pressure-free flotation, induced air flotation (IAF) as well as dissolved air flotation (DAF). Flotation processes combined with filtration allows the reduction of BOD in filtrate by 70%, the content of nitrogen and phosphorus compounds by 55% and 70%, respectively, as well as the content of remaining fats by 85% [4,9-10].

The first step of pre-treatment of waste water from MBM production is separation of solids on the bar screen. The efficiency of solid removal by means of the bar screen amounts to 15–30%, with a 15–20% reduction of BOD. The next step is separation of solids on the 3–4 mm mesh size drum screen, which allows for reducing BOD_5 by a further 15–20%. To improve the efficiency of filtration, sedimentation and flotation, coagulants, flocculants and other precipitating agents are used. The following coagulants are the most frequently used in the meat processing sector: $Fe_2(SO_4)_3$, $FeCl_3$, $Al_2(SO_4)_3$, $AlCl_3$, lime milk [4,10-11].

The obtained liquid phase is usually directed to a biological wastewater treatment plant (WWTP) [4,10]. It can be further treated in order to reduce COD, e.g. by the utilization of membrane methods (micro-, ultra- and/or nanofiltration, reverse osmosis). The final product - process water - is biologically safe, and as such may be re-used e.g. to clean farm facilities or to irrigate crops [12-13].

The utilization of coagulants and flocculants results in the formation of sludge that contains metal salts that cannot be used as fertilizers [4,14]. Zueva et al., [15] described the results of (the) experiment(s) and the chemistry of wastewater treatment with coagulants and so called "coagulant aids". Aluminum sulfate was nearly twice as effective in presence of alumina powder. Aggregation and sedimentation speeds could be enhanced [15]. The physicochemical treatment of the wastewater from meat industry was studied using three ferric salts as coagulants in conjunction with four different polymers as coagulation aids by batch column flotation [16,17]. The effluent was characterized in terms of turbidity (1000–12000 NTU), total solids content (2300–7000 mg L^{-1} of TS), and biochemical and chemical oxygen demands (BOD_5 and COD) (1200–1760 and 2800–3230 mg L^{-1}, respectively). The treatments led to the achievement of reductions of total solids (up to 85%), as well as the reduction of BOD_5 and COD (between 62.0–78.8% for the former and 74.6–79.5% for the latter). The research also found that thanks to the use of a column flotation it is possible to achieve high efficiency of organic matter removal. Additionally, the application of column flotation as a primary treatment step did not show a significant influence on the pollutant removal and air flow rate.

In the work by Sena at al., the effectiveness of the wastewater treatment by dissolved air flotation (DAF) followed by advanced oxidation processes (AOPs) using photo-peroxidation (H_2O_2/UV) and photo-Fenton reactions were evaluated on a laboratory scale. The primary treatment was carried out in a DAF system, with the utilization of optimal doses of ferric sulfate and coagulation aids. The results showed that the DAF process followed by an AOP process might be efficient for meat wastewater treatment, intended or not for water reuse purposes. The reduction of BOD_5 and COD varied between 54–67% in the case of the former and 74–82% in the case of the latter. In the case of the reduction of TS as well as VS, the following results were obtained: up to 68% and 84% for TS and VS, respectively.

The paper [12] presents the results of meat industry wastewater treatment with hybrid processes in the following combinations: ultrafiltration-reverse osmosis, coagulation-reverse osmosis, and coagulation-ultrafiltration-reverse osmosis. Neither coagulation, nor ultrafiltration enabled a sufficient removal of pollutants from the wastewater, which, as a result, could not be discharged into receiving water due to elevated pollution indices, however, the introduction of an additional stage of treatment, such as reverse osmosis, made it possible. The obtained wastewater could be reused in the production cycle of the plant.

The wastewater from the meat industry was treated in the system that connects processes such as coagulation and biological treatment using the activated sludge method with simultaneous precipitation of phosphorus and reverse osmosis [13]. The results showed that after the simultaneous precipitation of phosphorus the sewage could be returned to the natural receiving water, since its pollution ratio did not exceed the permissible values for sewage waters which can be returned to natural receiving waters. Wastewater treated in the process of reverse osmosis proved to be capable of being reuse in the technological cycle.

This paper presents the results of laboratory tests on selection of iron-, aluminum- and chlorine-based flocculent and coagulant types and the evaluation of the most advantageous parameters of their use for treating

Table 1: Characteristic of used coagulant.

Parameter	Scanpol 40	Kemira PIX 113	Kemira PAX 18	Ekoflok
Form – liquid	dark brown	dark brown	yellow, pale yellow	brown
Odor	hydrochloric acid -weak	lack	lack	nearly odorless
pH	~ 1.0	< 1.0	1.0	1.7–2.3
Boiling point [°C]	100–105	100–105	100–105	98
Flammability	inflammable	inflammable	inflammable	inflammable
Vapors pressure	non-volatile	non-volatile	non-volatile	non-volatile
Water solubility	total	total	total	total
Relative density at 20°C [g cm^{-3}]	1.40–1.48	1.50–1.58	1.35–1.38	1.10–1.20
Viscosity at 20°C [mPa s]	no data	30	20	no data

wastewater coming from meat-bone meal production by the utilization of precipitation method. The physical and chemical properties of waste water coming from production of meat-bone meal as well as parameters of solid and liquid phases deriving from wastewater treatment were also determined. Moreover, the description of the technology and the results of the test of pre-treated wastewater from the process used in an industrial unit of big MBM producer were also presented [18].

2 Experimental procedures

Physical and chemical properties of wastewater from MBM production were determined and the contents of COD, Kjeldahl's nitrogen, phosphorus, total suspended solids, color, turbidity and pH value were analyzed. Six 5 L samples were taken from averaging discharge tank of the industrial MBM wastewater pre-treatment unit. Each 1 day sampling was made using the same system and source of sample. Samples were representative for the whole volume of MBM wastewater.

Wastewater was treated by various doses of commercially available coagulants: Kemira PIX 113 and PAX 18 (produced by Kemipol) and Scanpol 40 (produced by Scandrill Poland). Ekoflok – a natural liquid coagulant being a tannin derivative obtained from the Brazilian black acacia, (delivered by Technologie Galwaniczne Sp z o.o., Łódź), was also used for wastewater treatment [19]. This coagulant is 100% biodegradable and does not cause secondary waste water contamination. The specifications of the coagulant(s) used are given in Table 1.

Other treatment tests of wastewater from MBM production made use of/were based on/were performed with the utilization of the combination of PIX 113 coagulant applied in doses of 6.0, 5.0 and 4.0 mL per 1 L of effluent, and Kemira's "Superfloc SD-2085" cationic polyacrylamide flocculent in the form of water emulsion containing a 41% active ingredient in doses of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 mL per 1 L of effluent.

A constant volume of effluent (100 mL) was treated with a varying dose of PIX 113: 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0 (~ 0.1–0.8%) mL L^{-1} of effluent. Wastewater with the coagulant added was stirred with the magnetic stirrer for 10 min. with a rotary speed of 500 rpm at a room temperature of 22 ± 1°C. The samples were left for 30 min. to ensure sedimentation; afterwards they were filtrated.

In the tested wastewater, Chemical Oxygen Demand (COD), Kjeldahl's nitrogen, phosphorus, total suspended solids, color, turbidity and pH value were determined. COD was determined according to the Polish Standard for determination of COD [20]. The samples were mineralized in the M9 mineralizer (manufactured by WSL). Biological Oxygen Demand BOD_5 was determined according to the Polish Standard for determination of biological oxide demand BOD_5 [21]. Kjeldahl's nitrogen content in the liquid phase was determined using the method with selenium after mineralizing according to the Polish Standard for determination of Kjeldahl's nitrogen [22], while their content in the sediment sludge was determined according to the Polish Standard for determination of Kjeldahl's nitrogen in sewage sludge [23]. The sample was at first mineralized in the DK6 mineralizer and next it was distilled with steam in the UDK 132 distilling apparatus (both manufactured by VELP). Phosphorus content was determined with Nanocolor UV-VIS spectrophotometer (manufactured by Macherey Nagel) [24]. Color determination was carried out upon filtration of the sample through a membrane filter according to the Polish Standard for color measurement [25]. Turbidity was measured according to the Polish Standard for turbidity measurement [26] with nephelometer built into Nanocolor UV/VIS spectrophotometer. The content of the total suspended solids in wastewater was determined

Table 2: Characteristic of wastewater from MBM production.

No	COD [mg L^{-1}]	Kjeldahl's nitrogen [mg L^{-1}]	P [mg L^{-1}]	Color [mg Pt L^{-1}]	Turbidity [NTU]	pH
1	7939	5290	150	22298	67	6.7
2	8500	3689	105	23128	58	7.2
3	9732	3400	160	18629	72	7.0
4	7500	4700	143	15830	93	7.3
5	8506	5100	97	24902	52	6.7
6	9300	4156	104	18900	63	6.3

according to the Polish Standard for determination of total suspended solids [27]. The content of cadmium, chromium, nickel, lead, zinc and mercury in the sludge were determined according to the Polish Standard for determination of cadmium, chromium, nickel, lead, zinc, mercury with the FAAS method [28], while the contents of organic matter, nitrogen, phosphorus and potassium in the sludge were determined according to the Polish Standard for determination of pH, organic matter, organic carbon, nitrogen, phosphorus and potassium [29].

The Inductively Coupled Plasma Atomic Emission (ICP-AE) spectrometer (OPTIMA 7300 DV type, manufactured by Perkin Elmer) was used in order to determine Ca, K, Mg, P and S contents in filtered sludge. Phase composition of the sediment was determined with the use of Philips X'Pert diffractometer with PW W 1752/00 graphite monochromator.

The morphology of sediment surface was examined by the Hitachi TM 3000 scanning electron microscope equipped with the Secondary and Backscattered Electron (SE and BSE) Detectors and Energy Dispersive X-Ray Spectrometer (EDS) (manufactured by Bruker Quantax 70).

3 Results and Discussion

Table 2 gives physical and chemical properties of wastewater from the MBM production process. Wastewater upon removal of solids on stationary and drum screens, sampled from the intermediate tank located in an industrial MBM production unit was tested. The test results (effluent 6 in Table 2) are shown in Table 3.

Wastewater treatment with the utilization of commercial coagulant showed that the best quality of treated filtrate was obtained when iron-sulfate-based PIX 113 coagulant was used. The application of the most advantageous dose of 3.0 mL per 1 L of effluent (~ 0,3%) allowed for the reduction of color and turbidity by 99.2% and 96.8% respectively. This dose proved to be also the best for the removal of phosphorus (the phosphorus concentration was reduced by 99.9%) as well as for the reduction of Kjeldahl's nitrogen content whose concentration was reduced by 92.4%. The use of PIX 113 dose of 6.0 mL per 1 L of effluent (~ 0,6%) resulted in the highest reduction of COD, by 72.9%; other tested doses also showed a significant reduction in COD and reached 60%.

Treatment of wastewater with iron(III)-chloride-based Scanpol 40 coagulant resulted in a considerable reduction of the pollutant content in filtrate, but the results of tests showed that the treatment process in this case was by a few to a dozen percent less efficient. The use of aluminum-polychloride-based PAX 18 coagulant yielded similar results.

The analysis of the filtrate subjected to the treatment by MBM wastewater using Ekoflok coagulant revealed a relatively low level of color and turbidity reduction in comparison with the efficiency demonstrated by coagulant based on iron sulfate. On the other hand, the reduction in COD was comparable to that obtained when PIX 113 or PAX 18 and Scanpol 40 coagulants were applied, whereas phosphorus reduction wasn't observed, therefore any data available of phosphorus content is in Table 3.

The analyses of filtrate from wastewater treated with PIX113 coagulant and Superfloc SD-2085 flocculent are given in Table 4. Input wastewater to be treated had turbidity: 87 NTU, color: 18752 mL Pt per 1 L, COD: 9200 mg per 1 L and pH 7.2.

The application of PIX 113 coagulant in the amount of 5.0 mL per 1 L effluent (~ 0,5%) and Superfloc SD-2085 flocculent in various doses (~ 0,02%) in the treatment process caused a reduction in turbidity and color by 96.6% and 98.9% respectively. On the other hand, the reduction in COD was relatively low: 18% only.

Figs. 1 and 2 show SEM images (magnitude: 500× and 2500×) of sediment obtained after wastewater treatment with PIX 113 coagulant in various doses. The sediment

Table 3: Results of purification of wastewater from MBM production after coagulant dosage (SD - standard deviation for triplicate test).

Parameter Average ± SD	**Coagulant dose [mL L^{-1} of effluent]**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	**MBM wastewater (sample 6, Table 2)**
COD [mg L^{-1}]	Scanpol 40	3153 ± 145	3099 ± 140	2944 ± 130	2962 ± 135	2844 ± 132	2826 ± 133	2583 ± 131	2673 ± 135	9300 ± 520
	Kemira PIX 113	3050 ± 140	2876 ± 135	2848 ± 134	2775 ± 130	2720 ± 129	***2519*** ± 120	2718 ± 130	2835 ± 133	
	Kemira PAX18	2974 ± 135	2800 ± 130	2811 ± 131	2856 ± 133	2684 ± 135	2675 ± 134	2709 ± 135	2700 ± 135	
	Ekoflok	2814 ± 130	2805 ± 130	2573 ± 125	2733 ± 128	2787 ± 520	2760 ± 130			
Kjeldahl's nitrogen [mg L^{-1}]	Scanpol 40	415 ± 25	405 ± 25	397 ± 24	403 ± 25	412 ± 24	417 ± 25	414 ± 25	421 ± 26	4156 ± 250
	Kemira PIX 113	363 ± 23	344 ± 24	***315*** ± 22	335 ± 24	355 ± 23	361 ± 23	354 ± 23	371 ± 23	
	Kemira PAX18	369 ± 23	351 ± 24	321 ± 22	333 ± 24	362 ± 23	367 ± 23	389 ± 24	384 ± 23	
	Ekoflok	371 ± 23	364 ± 25	349 ± 23	346 ± 24	359 ± 23	365 ± 23	379 ± 24	381 ± 23	
P [mg L^{-1}]	Scanpol 40	33.02 ± 1.9	21.37 ± 1.1	8.27 ± 0.4	1.25 ± 0.05	5.45 ± 0.25	0.82 ± 0.04	1.61 ± 0.06	12.16 ± 0.6	104 ± 5
	Kemira PIX 113	1.57 ± 0.06	0.31 ± 0.02	***0.04*** ± 0.003	0.35 ± 0.02	1.33 ± 0.05	0.51 ± 0.03	1.18 ± 0.05	1.96 ± 0.08	
	Kemira PAX18	5.03 ± 0.25	1.10 ± 0.05	0.86 ± 0.04	0.16 ± 0.01	6.59 ± 0.30	4.63 ± 0.22	26.87 ± 1.3	30.59 ± 1.5	
Color [mg Pt L^{-1}]	Scanpol 40	921 ± 20	2667 ± 60	1813 ± 40	1583 ± 36	902 ± 20	436 ± 11	1162 ± 25	3784 ± 80	18900 ± 400
	Kemira PIX 113	1995 ± 40	193 ± 9	***156*** ± 5	188 ± 5	247 ± 6	1032 ± 21	4622 ± 95	8110 ± 200	
	Kemira PAX18	1065 ± 25	633 ± 15	210 ± 6	255 ± 7	212 ± 6	326 ± 8	460 ± 9	451 ± 9	
	Ekoflok	1143 ± 30	1280 ± 32	1366 ± 35	1116 ± 30	1044 ± 27	978 ± 22			
Turbidity [NTU]	Scanpol 40	31 ± 1	82 ± 2	95 ± 2	47 ± 2	25 ± 1	11 ± 0.5	8 ± 0.3	8 ± 0.3	63 ± 2
	Kemira PIX 113	97 ± 3	3 ± 0.1	***2*** ± 0.1	4 ± 0.1	8 ± 0.3	44 ± 1.5	20 ± 0.8	54 ± 2	
	Kemira PAX18	60 ± 2	55 ± 2	9 ± 0.4	11 ± 0.5	6 ± 0.2	10 ± 0.4	13 ± 0.5	12 ± 0.5	
	Ekoflok	39 ± 1.5	57 ± 2	90 ± 3	72 ± 2.5	59 ± 2	64 ± 0.2			
pH	Scanpol 40	7.5 ± 0.1	7.6 ± 0.1	7.0 ± 0.1	6.5 ± 0.1	6.2 ± 0.1	5.9 ± 0.1	4.3 ± 0.1	3.7 ± 0.1	6.3 ± 0.1
	Kemira PIX 113	6.4 ± 0.1	5.6 ± 0.1	5.1 ± 0.1	4.6 ± 0.1	4.0 ± 0.1	3.4 ± 0.1	2,8 ± 0.1	2,6 ± 0.1	
	Kemira PAX18	7.1 ± 0.1	6.8 ± 0.1	5.9 ± 0.1	5.9 ± 0.1	5.6 ± 0.1	5.3 ± 0.1	4,5 ± 0.1	4,4 ± 0.1	
	Ekoflok	7.9 ± 0.1	7.8 ± 0.1	7.7 ± 0.1	7.7 ± 0.1	7.7 ± 0.1	7.7 ± 0.1			

Table 4: Results of purification of wastewater from MBM production after adding of coagulant PIX 113 and flocculent Superfloc SD-2085(SD – standard deviation for duplicate test).

Dose / determined parameter Average ± SD	**Coagulant PIX 113 dose 6 [mL L^{-1} of effluents]** **Flocculent Superfloc SD-2085 dose [mL L^{-1} of effluents]**					
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
Color [mg Pt L^{-1}]	455 ± 12	820 ± 22	1282 ± 35	980 ± 24	957 ± 24	813 ± 20
Turbidity [NTU]	11 ± 0.5	26 ± 1.2	45 ± 2	41 ± 2	45 ± 2	48 ± 2
COD [mg L^{-1}]	8188 ± 500	8609 ± 520	8372 ± 510	8324 ± 510	8456 ± 510	8353 ± 510
pH	4.3 ± 0.1	4.2 ± 0.1	4.2 ± 0.1	4.2 ± 0.1	4.2 ± 0.1	4.2 ± /0.1
Dose / determined parameter	Coagulant PIX 113 dose 5 [mL L^{-1} of effluents] Flocculent Superfloc SD-2085 dose [mL L^{-1} of effluents]					
	0.1	0.2	0.3	0.4	0.5	0.6
Color [mg Pt L^{-1}]	567 ± 14	209 ± 6	532 ± 14	487 ± 12	558 ± 14	741 ± 19
Turbidity [NTU]	17 ± 0.9	3 ± 0.12	15 ± 0.8	28 ± 1.3	31 ± 1.4	46 ± 2
COD [mg L^{-1}]	7566 ± 450	7418 ± 440	7305 ± 430	7545 ± 450	8407 ± 510	8198 ± 500
pH	4.5 ± 0.1	4.4 ± 0.1	4.4 ± 0.1	4.5 ± 0.1	4.5 ± 0.1	4.5 ± 0.1
Dose / determined parameter	Coagulant PIX 113 dose 4 [mL L^{-1} of effluents] Flocculent Superfloc SD-2085 dose [mL L^{-1} of effluents]					
	0.1	0.2	0.3	0.4	0.5	0.6
Color [mg Pt L^{-1}]	201 ± 6	269 ± 8	336 ± 10	244 ± 7	348 ± 11	418 ± 12
Turbidity [NTU]	5 ± 0.20	12 ± 0.7	19 ± 1.0	11 ± 0.7	24 ± 1.2	32 ± 1.4
COD [mg L^{-1}]	8412 ± 510	8427 ± 510	8153 ± 500	8372 ± 510	8381 ± 510	8359 ± 510
pH	4.8 ± 0.1	4.8 ± 0.1	4.8 ± 0.1	4.8 ± 0.1	4.7 ± 0.1	4.8 ± 0.1

contains crystalline structures. No impact of applied coagulant dose on the size of crystallites present in the sediment was found.

The results of sludge EDS quantitative analysis obtained while using PIX 113 coagulant in various doses are shown in Figs. 3 and 4.

The results of quantitative analysis of the sediment show the highest content of such elements as carbon, oxygen, iron, sulfur, phosphorus and calcium. EDS analysis detected also some other elements of the content < 1% present in the sediment: aluminum, chlorine, and silicon.

The results of the tests carried out with the use of coagulants and flocculants demonstrate that the efficiency of treatment of wastewater coming from the production of meat-bone meal depends on the preparation composition and the doses that were actually used. The best results of wastewater treatment in terms of efficiency of phosphorus removal and reduction in turbidity and COD value were obtained when PIX 113 coagulant based on iron sulfate was used. The use of PIX 113 dose of 6.0 mL per 1 L of effluent (~ 0,6%) resulted in the highest reduction of COD, by 72.9%. The application of the most advantageous dose of 3.0 mL per 1 L of effluent (~ 0,3%) allowed for the reduction of color and turbidity by 99.2% and 96.8% respectively. This dose proved to be also the best for the removal of phosphorus (the phosphorus concentration was reduced by 99.9%) as well as for the reduction of Kjeldahl's nitrogen content whose concentration was reduced by 92.4%. The application of PIX 113 coagulant in the amount of 5.0 mL per 1 L effluent (~ 0,5%) and Superfloc SD-2085 flocculent in various doses (~ 0,02%) in the treatment process caused a reduction in turbidity and color by 96.6% and 98.9% respectively, but the reduction in COD was relatively low: 18% only.

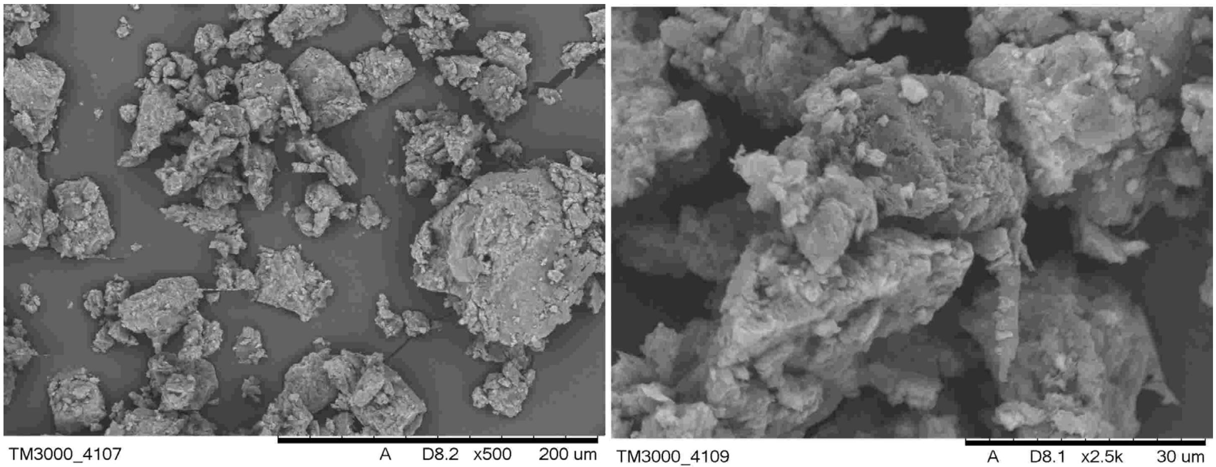

Figure 1: Sediment obtained after wastewater treatment with dose 3.0 mL PIX 113 per 1 L.

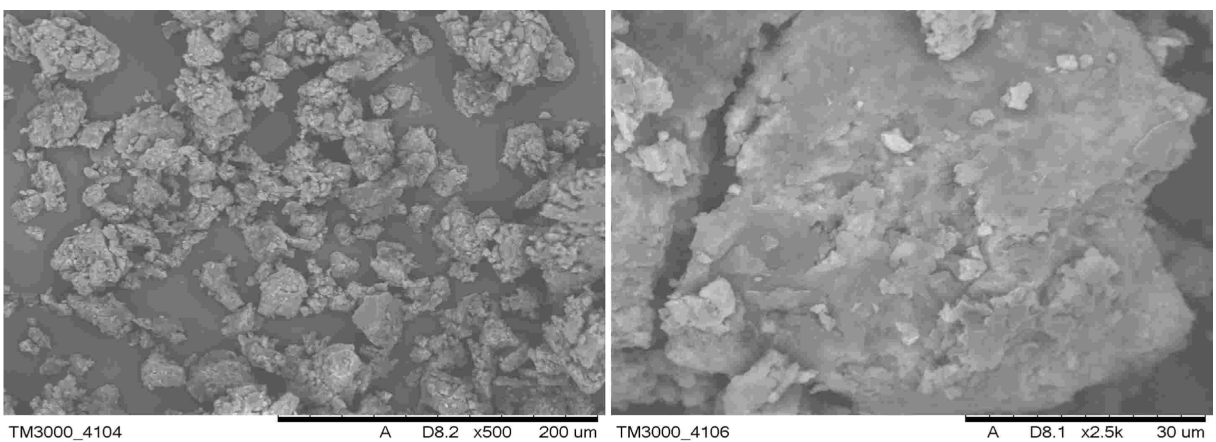

Figure 2: Sediment obtained after wastewater treatment with dose 6.0 mL PIX 113 per 1 L.

Description of technology of pre-treatment of wastewater from the production of meat-bone meal used in industrial MBM production unit

Wastewaters that came from the meat waste collection facility and were obtained during storage and transport of these wastes were disintegrated in a breaker with screw conveyors equipped with draining systems. The industrial pre-treatment unit flow-sheet was presented in Fig. 5. At first, the wastewater flows through the stationary screen from which larger solid waste particles are removed. Next, the wastewater is delivered to the drum screen, where smaller solid waste particles are separated. Pre-treated suspension is pumped to the homogenization tank, where the effluents are mixed and aerated to make them homogenic and prevent putrescibility. Subsequently, the wastewater is pumped to the flocculetor tube, to which coagulant and flocculent are added. PIX 113 coagulant is added in an amount of 0.50–0.70 L per 1 m^3 of effluents (~ 0.06%), and, subsequently, a solution of NaOH is added until pH ~6 is reached (0.05–0.10 L per 1 m^3 of effluents). SUPERFLOC 8298 flocculent is added using a metering pump with manual dose setting (0.015–0.020 L per 1m^3 of effluents - i.e. ~ 0.002%). The homogenized wastewater in the flocculent unit flows up to the dissolved air flotation DAF unit, where hardly wettable impurities carried at the effluent surface as foam are removed. The floatation machine is equipped with a plough skimmer to skim floated foam. Post-flotation concentrate is skimmed to a discharge hopper, from where it gravitationally flows down to a sludge tank.

Some part of the flotate from the clarifying area is recycled into the flotation machine and mixed at a higher pressure with the supplied compressed air (dissolved air flotation DAF). Air-saturated recycled material enters the working space of the apparatus, where small air bubbles with a diameter of ~ 50 μm are removed. Heavy contamination particles, which do not undergo the action of buoyant force, precipitate at the bottom of the device

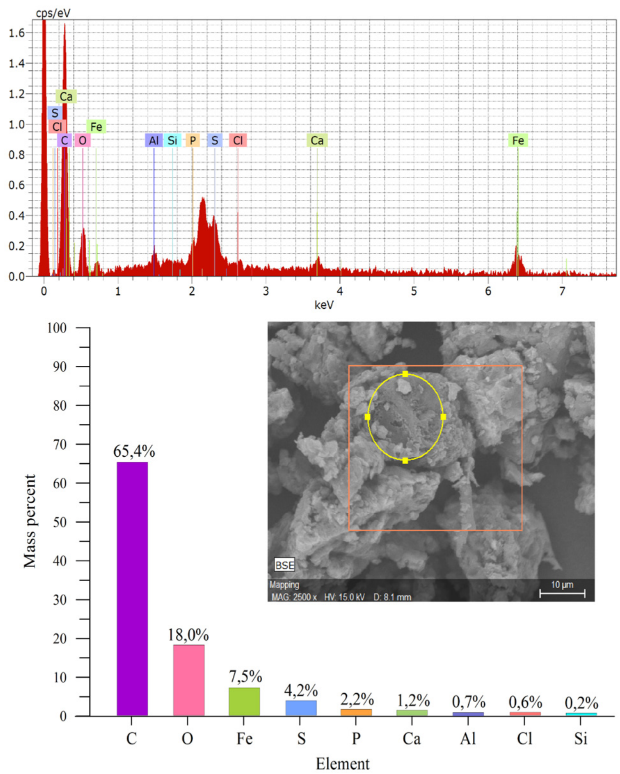

Figure 3: Quantitative analysis of sediment obtained after wastewater treatment with dose 3.0 mL PIX 113 per 1 L.

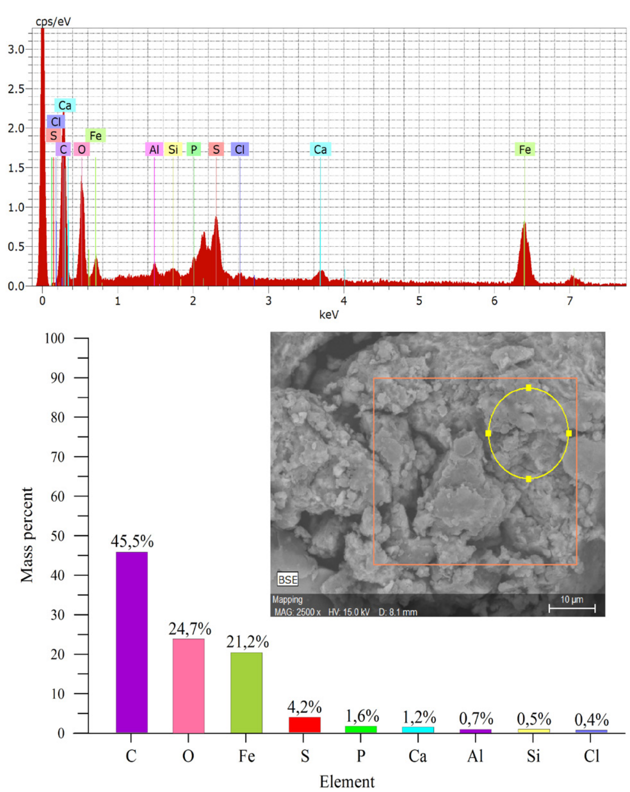

Figure 4: Quantitative analysis of sediment obtained after wastewater treatment with dose 6.0 mL PIX 113 per 1 L.

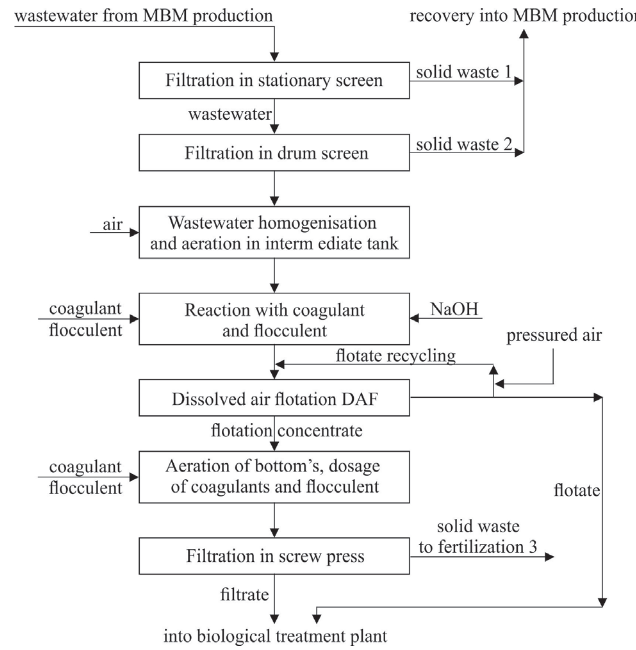

Figure 5: Flow-sheet of industrial pre-treatment unit of wastewater from MBM production.

Table 5: Analyses of industrial wastewater from meat waste collection unit.

No	Content [mg L^{-1}]				
	Kjeldahl's nitrogen	BOD_5	COD	P	Suspended matter
1	1285	8200	22380	194	3940
2	4400	9350	30310	11,4	264
3	4990		84900	231	2556
4	3510	10540	32570	222	6972
5	4600		33240	195	
6			35800		
7			33740		
11			21690		3570
12			39880		7437
13	2840		29810	200	9123
14	2520		28680	114	6270

and accumulate in discharge hoppers. Bottom sludge is periodically skimmed to a sludge tank. Post-flotation liquid is delivered to the biological WWTP for further treatment.

In order to be conditioned the sludge kept in the tank is aerated and treated again with PIX-133 coagulant (max.

3.0 L per 1 m^3 sludge, i.e. ~ 0.3%). The product obtained in this manner is mixed with SUPERFLOC 8294 flocculent (0.1–0.13 L per 1m^3 of sludge, i.e. ~ 0.01%) and filtered in the screw press. Post-filtration sludge may be used for agricultural purposes.

Table 5 presents the analysis of wastewater coming from a meat waste collection facility, and Table 6 – the results of the analysis of the filtrate obtained after the screw press (which is subsequently delivered to a biological WWTP). Table 7 shows the test results of post-filtration sediment coming from the screw press.

Filtrate analyses show a very high reduction of the phosphorus content in effluents (by > 99.9%), and a significant reduction of COD, BOD_5, Kjeldahl's nitrogen and total suspended solid contents (by 90–95%). A very high reduction of the pollutant load in wastewater delivered to the biological WWTP means that much more effluents may be biologically treated at/in the existing unit. Thus, the MBM production capacity may be increased without a need to enlarge the biological WWTP, which would require expensive investment.

Filtrated sediment from the screw press (solid waste 3 – Fig. 5) contains 9–22% dry matter and its output is approximately 40–90 kg/1 t of wastewater. The sediment contained organic matter and sulfur, is used as fertilizer, but its fertilizing value is not high, because iron phosphates present in the sediment are not bioavailable to plants [30-32], and the iron content in the sludge may reach even 20% of dry mass. However applying of this sediment resulted in increasing the content of the organic carbon, biomass and the activity of microbiological transformations in the fertilized soil [30-32].

Sludge from stationary and drum screens (sludge 1 and 2 – Fig. 5) contains 25–45% dry matter, and its output is approx. 50-80 kg/1 t wastewater. This sludge may be recovered into MBM production process.

Table 6: Composition of industrial filtrate after pre-treatment.

No	Content [mg L^{-1}]					
	Kjeldahl's nitrogen	BOD_5	COD	P	Suspended matter	Total organic carbon
1	320	690	2141	0.06	50.2	185
2	389	766	1434	0.01	50.0	
3	333		1850	0.06	55.0	200
4	350	724	1930	0.08		
5	363		2050	0.07	53.0	195

4 Conclusions

The wastewater from meat-bone meal MBM production contains a very large load of organic compounds, up to 25,000 mg L^{-1} COD. It creates many difficulties in their biological treatment, and should be pre-treated for example by the application of precipitation methods.

The results of the laboratory tests with the use of a coagulants and a flocculent show that the efficiency of treatment of wastewater coming from MBM production

Table 7: Composition of industrial post-filtration sediment.

No	Content [% in dry mass]							
	Dry mass [%]		Nitrogen		P	Ca	Mg	K
	Content	Ignition losses	Kjeldahl's	ammonium				
1	9.2	79.5	0.80	0.64	2.02	2.21	0.26	0.40
2	9.4	77.5	7.60	0.49	2.36	1.31	0.21	0.46
3	21.9	90.5	7.17	0.84	1.11	1.11	0.11	0.20
4	11.1	80.3	6.98	0.73	2.10	1.54	0.15	0.30
5	12.3	81.4	73.4	0.62	2.25	1.39	0.17	0.35
No	Content [mg kg^{-1} of dry mass]							
	pH	Cd	Cr	Cu	Ni	Pb	Zn	Hg
1	7	1.2	67.9	75.9	20.2	< 5.0	584	0.93
2	6.2	< 5.0	< 25.0	87.1	15.7	< 5.0	688	1.33
3	6.2	< 5.0	< 25.0	39.4	5.6	< 5.0	611	0.08
4	6.3	< 5.0	< 25.0	43.5	12.3	< 5.0	597	0.07
5	6.2	< 5.0	< 25.0	56.3	14.7	< 5.0	610	0.09

depends on the type of precipitation agent and the dose applied. The highest reduction of contamination content in the filtrate was obtained when PIX 113 was used, a ferrous-sulfate-based coagulant in an amount of ~ 0.3%. It caused a reduction in effluent color and turbidity by 96.8% and 99.2%, respectively. Moreover, phosphorus and Kjeldahl's nitrogen contents were reduced by 99.9% and 92.4%, respectively. The reduction in COD amounted to 72.9% when PIX 113 in the amount of ~ 0.6% was applied. Nevertheless, when applying this coagulant in other tested doses the reduction in COD was also significant and reached 60%.

The results of the quantitative analysis of filtered sediment show the highest content of such elements as carbon, oxygen, iron, sulfur, phosphorus and calcium. X-ray analysis proved the predominating presence of phosphorus salts. Moisture content in the sludge varied from 45 to 78.5%, and pH value from 5.4 to 6.4.

Analyses of the results of pre-treatment of wastewater from meat-bone meal in industrial unit demonstrate a very high reduction in phosphorus content by > 99.9 % and COD, BOD_5, Kjeldahl's nitrogen and total suspended solid contents by 90–95% in the filtrate. A very high reduction in the pollutant load in wastewater delivered to the biological WWTP means that more effluents may be biologically treated at this unit.

The sludge from stationary and drum screens obtained during the waste water treatment containing 25–45% dry matter and produced in the amount of 50–80 kg/1 t effluent may be recovered to MBM production process. Filtered sediment from the screw press containing 9–22% of dry matter and produced in the amount of 40–90 kg/1 t wastewater can be used to fertilize soil; however, its fertilizing value is not high.

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