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The impact of dry mass content in pig liquid manure on its treatment with a filtration method

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The present study examines the impacts of dry mass content in pig liquid manure on its treatment with a filtration method. Samples of liquid manure with variable dry mass content were subjected to treatment using phosphoric acid, sulfuric acid, lime milk and superphosphate, as well as to thermal treatment, while in the last phase of pressure filtration. Increased dilution of the manure resulted in a reduced raw materials consumption ratio and improved filtration process efficiency, which ranged from 408 to 3765 $kg/m^2/h$. The highest filtration efficiency was achieved using manure containing 3% dry mass, while the lowest efficiency was observed in manure at 10% dry mass. The increase in liquid manure dilution also reduced chemical oxygen demand in the filtrate, which ranged from 15 062 to 3656 mg/l. An appropriate manure dilution level, under the constant parameters of the treatment process, reduced phosphorus content in the filtrate to < 10 mg/kg while simultaneously enriching the post-filtration sediment with this precious fertilizing component.

Keywords: pig manure treatment, filtration method, dry mass, filtrate.

INTRODUCTION

Liquid manure is an agricultural waste product generated under the dry swine raising method. The chemical composition of the manure depends on many factors, including the type and age of the animals, the methods of their feeding and care, the volume of water used for sanitary and cleaning purposes, and the storage method, duration, and dilution of the manure[1, 2]. Unmanaged liquid manure is a threat to the natural environment. The waste contains high volumes of nitrogen (1500–9200 mg/l) and phosphorus compounds (220–2500 mg/l), excesses of which cause soil and water contamination, along with volatile organic and inorganic substances that result in air pollution with odorants[3].

To reduce odor emissions and the costs of manure warehousing and transport, as well as to appropriately prepare it for further processing, manure must be separated into solid and liquid fractions[4, 5]. The process we developed for processing pig manure, using a filtration method, into mineral-organic fertilizers creates an opportunity for managing the manure and reducing its unfavorable impact on the natural environment[3, 6].

EXPERIMENTAL

Apparatus

The mineralization of the samples allocated for COD determination was accomplished using an M-9 mineralizer by WSL. For the Kjeldahl nitrogen determination method, a DK6 mineralizer and a steam distillation apparatus, both by VELP, were employed. For analysis of Ca, K, Mg, P, and S, an OPTIMA 7300 DV inductively coupled plasma emission spectrometer, by Perkin Elmer, was used. The determination of C, H and N in the sediment was conducted using a PE 2400 type apparatus by Perkin Elmer. The qualitative and quantitative phase composition of the sediment was determined using a Bruker AXS D8 Advance X-ray diffractometer. Microscopic photographs of the post-filtration sediments were taken using a Hitachi TM 3000 electron microscope.

Methodology

The study was conducted on pig manure collected from a Polish swine farm. The chemical composition of pig manure containing 11.5% dry mass was as follows: Kjeldahl nitrogen 8650 mg/l; biochemical oxygen demand (BOD5) 52 850 mg/l; chemical oxygen demand (COD) 117250 mg/l; phosphorus 2420 mg/l; potassium 4.26%; calcium 4.74%[6].

For each measurement, a fixed volume of manure was weighed and then treated with phosphoric acid to achieve pH ~5.5, followed by treatment with sulfuric acid to reach pH ~3.0. The mineral acids (phosphoric and sulfuric acid) were added to transform the macro- and micro-components of the fertilizer into bioavailable forms, to bind nitrogen-containing volatile inorganic and organic compounds (thereby reducing nitrogen losses during storage and application), and to hydrolysis and mineralization of the organic matter. The acids also improved the sanitary-epidemiological safety of the manure through the destruction of pathogenic bacteria and parasite eggs (hygienization). After the acids were added to the suspension, a 10% solution of lime milk was added to achieve a pH of approx. 10.5. To balance nitrogen and phosphorus contents, superphosphate was then added at a level of 4% of the initial weight of the manure, and the resulting product was again neutralized using lime milk (10% solution). This suspension was heated for approximately 35 minutes, and after cooling to approx. 75°C, it was filtrated on a pressure filter by Sartorius, with a capacity of 2 dm^3. Above mentioned parameters of mineralization were constant in the tests performed. The independent variable was the dry mass content in the output suspension of pig manure. In the tests performed, the original input content of 11.5% dry mass was diluted to 2, 3, 4, 5, 6, 7, 8, 9 or 10% dry mass[6].

In the filtrate, COD content was determined using the dichromate titer method[7], Kjeldahl nitrogen content using distillation[8], pH, and P, Ca, K, Mg and S levels using the ICP-AES method. In the post-filtration sediment, qualitative and quantitative phase composition was determined, along with moisture content and levels of the following elements: P, K, N, Ca, Mg, S, C and H. Photos of the sediment were also taken using an electron microscope.

RESULTS

The volumes of raw materials used during the manure treatment are presented in Table 1, while the ratios of the pig manure suspension filtration process are presented in Table 2. The analysis of raw material consumption ratios (Table 1) shows that the volume of raw materials needed to maintain a fixed pH over the mineralization process increased proportionately with dry mass content in the manure[3, 6]. Dry mass content also had a significant effect on the quantities of filtration products obtained, particularly sediment and filtrate (Table 2). The greatest amount of sediment (approximately 157 g) was obtained using undiluted manure (11.5% dry mass), while the greatest amount of filtrate (184.5 g) was obtained from manure containing 2% dry mass.

The efficiency of the suspension filtration process varied from 408 to 3765 kg/m^2/h (Table 2). Increases in the dry mass content led to longer filtration times and affected the quality of the products. The color of the filtrate changed from dark tea to light yellow (straw) with the degree of manure dilution. The results of the filtrate analyses are presented in Tables 3 and 4, while the phase composition of the post-filtration sediments is presented in Figure 1. Images of the sediments obtained from manure containing 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11.5% dry mass, respectively, are presented in Figure 2.

Table 3 indicates that, under the fixed parameters of the manure mineralization process, selection of dry mass content can significantly impact the pH value of the filtrate, its elemental composition, and its color. It is possible to manage the manure treatment process in this way to ensure the retention of the greatest volume of phosphorus in the solid phase, which may then be used for the production of mineral-organic fertilizer containing nitrogen, phosphorus, potassium and calcium compounds, as well as sulfur and useful microelements.

As the dry mass content of input manure increased, the phosphorus content of the filtrate decreased, in contrast to levels of potassium and sulfur (Table 3). The content of nitrogen also increased from 1023–4462 mg/l as dry mass increased. Dilution of the manure significantly reduced the chemical oxygen demand, which indicates the amount of organic compounds undergoing biological decomposition. Chemical oxygen demand in the filtrate varied from 15 062 to 3656 mg/l It was a reduction of 87–97% to input manure.

Moisture content in the post-filtration sediment remained at a relatively fixed level, ranging between 62 and 70% (Table 4). Sulfur, potassium, nitrogen and magnesium contents all decreased as dilution increased, in contrast to the pattern observed for calcium. The processing performed in this study also accomplished the practical elimination of odor emissions from the filtration products. The post-filtration sediment contained approx. 15–50% amorphous phase products, while the main crystalline component was hydroxyapatite, the volume of which ranged between 48 and 80%.

Results of X-ray and SEM analyses of the after filtrate sediments confirmed that the worked out process of the pig manure mineralization allowed to incorporate into solid phase of slurry over 50% of crystalline phase

Table 1. Figures of raw material consumption in the pig slurry treatment process

Dry mass content [% by weight]	Raw materials [g]				
	Pig slurry	H_3PO_4 (75%)	H_2SO_4 (techn. 95%)	Lime milk (10%)	Super-phosphate
2	230.85	1.97	0.70	27.33	9.24
3	230.55	2.86	1.14	34.10	9.22
4	230.24	3.71	1.46	43.22	9.21
5	230.99	4.44	1.90	56.28	9.24
6	230.54	5.42	2.31	62.54	9.23
7	230.22	5.81	2.83	72.02	9.21
8	230.20	6.98	3.27	80.40	9.21
9	230.35	7.56	3.66	89.11	9.21
10	230.35	8.09	4.21	90.74	9.21
11.5	230.48	9.00	4.83	95.98	9.22

Table 2. Figures of the pig slurry filtration process

Dry mass content [% by weight]	Parameter				
	Weight of treated slurry filtrated [g]	Sediment mass [g]	Filtrate mass [g]	Filtration time [h]	Filtration efficiency [kg/m^2/h]
2	234.09	41.01	184.50	0.004	3658
3	240.97	56.78	176.13	0.004	3765
4	253.21	66.03	177.54	0.007	2261
5	249.87	75.73	165.61	0.015	1041
6	271.27	80.90	180.02	0.014	1211
7	284.03	102.8	170.55	0.019	934
8	279.04	119.98	149.19	0.026	671
9	287.75	128.55	148.99	0.029	620
10	300.64	131.83	155.32	0.046	408
11.5	309.66	156.67	135.18	0.044	440

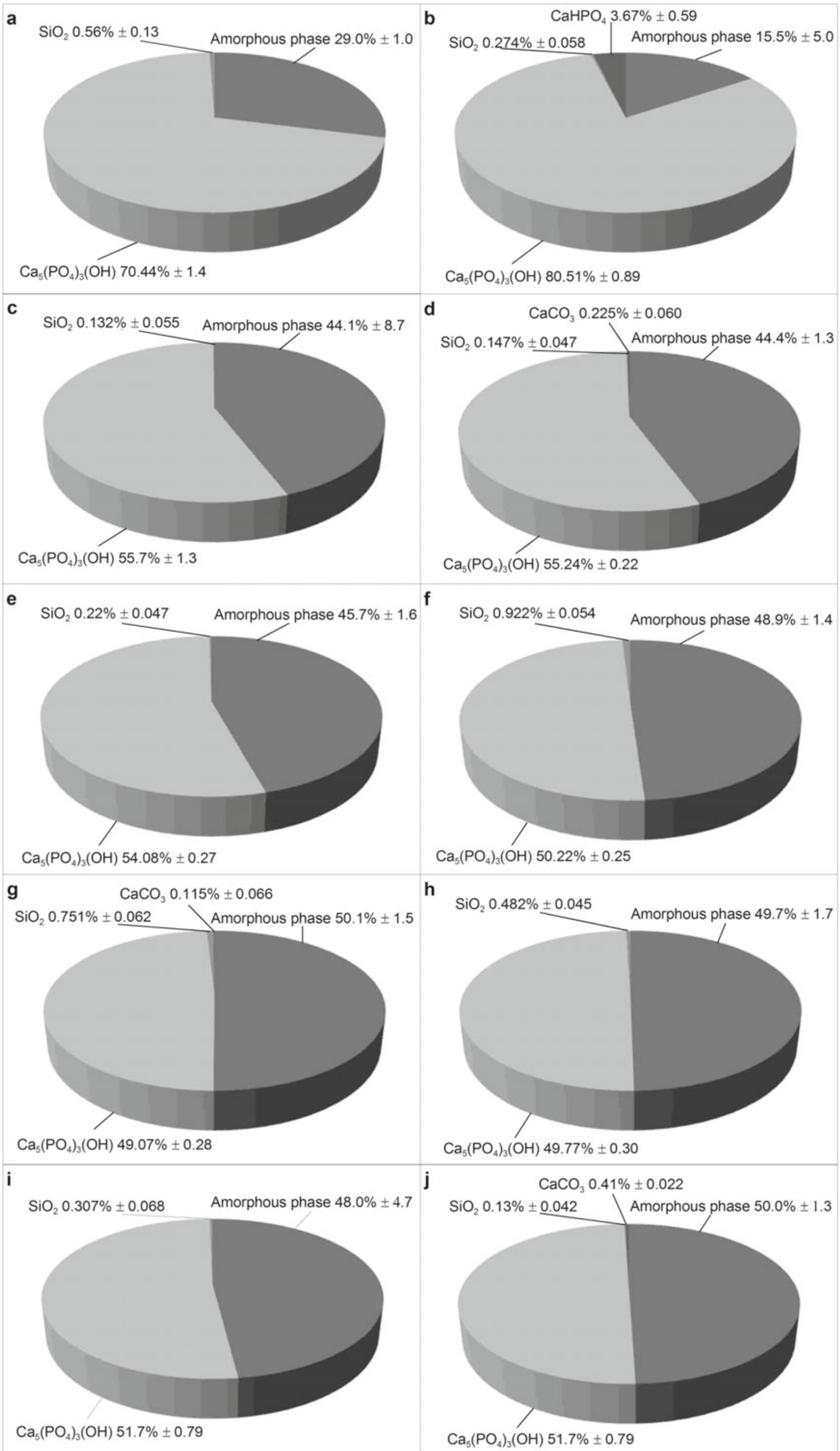

Figure 1. Phase composition of post-filtration sediments contained (% of dry mass): a – 2, b – 3, c – 4, d – 5, e – 6, f – 7, g – 8, h – 9, i – 10, j – 11.5

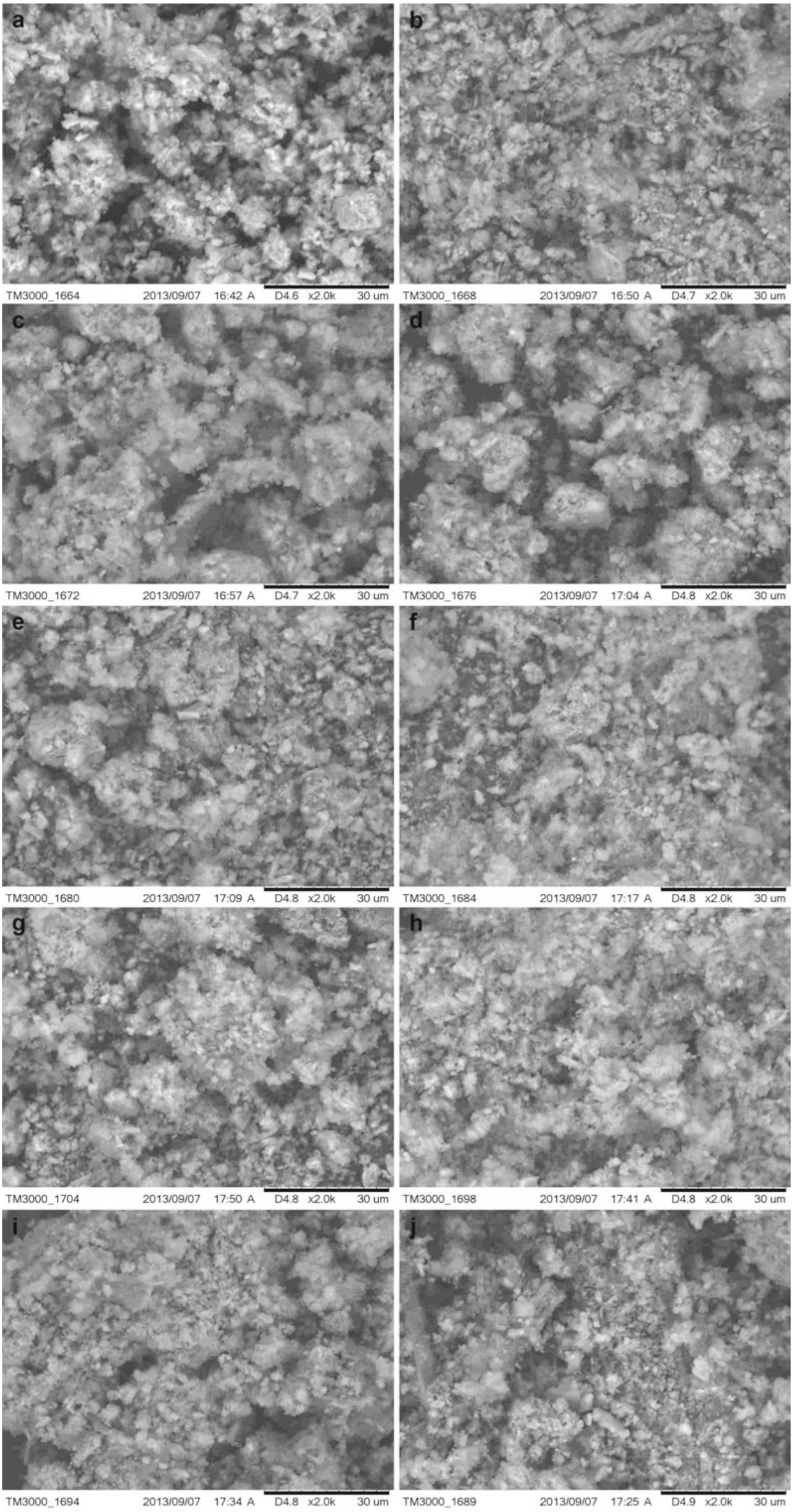

Figure 2. Microscopic images of sediments contained (% of dry mass): a – 2, b – 3, c – 4, d – 5, e – 6, f – 7, g – 8, h – 9, i – 10, j – 11.5

Table 3. Results of filtrate analyses

Dry mass content [% by weight]	Parameter							
	pH	COD [mg/l]	N [mg/l]	P [mg/kg]	Ca [mg/kg]	K [mg/kg]	Mg [mg/kg]	S [mg/kg]
2	4.70	3656	1023	356.00	362.40	597.80	161.60	1408.00
3	5.01	5502	1527	168.80	282.80	854.70	160.90	1745.00
4	5.70	6625	1807	40.90	191.50	1047.00	139.20	1863.00
5	7.16	8470	2200	6.23	168.00	1243.00	144.20	1982.00
6	7.65	9133	2627	7.46	103.10	1373.00	101.50	2107.00
7	8.99	9417	3082	6.07	159.90	1495.00	137.00	1938.00
8	8.23	10658	3405	11.10	151.30	1782.00	162.80	2876.00
9	8.46	12684	3867	7.98	123.10	1629.00	126.30	2267.00
10	8.51	14313	3978	9.12	158.70	1900.00	167.00	2520.00
11.5	8.30	15062	4462	10.21	151.70	2054.00	167.80	2908.00

Table 4. Results of sediment analyses

Dry mass content [% by weight]	Parameter								
	Moisture	N	P	Ca	K	Mg	S	C	H
	[% by weight]								
2	62.54	0.86	8.77	22.89	0.17	0.34	1.07	12.57	1.78
3	65.22	1.01	8.22	22.16	0.26	0.40	1.27	13.99	1.99
4	64.51	1.06	7.82	20.75	0.29	0.46	1.31	15.68	2.31
5	69.91	1.14	7.37	20.30	0.35	0.47	1.53	17.09	2.46
6	62.91	1.19	7.35	19.87	0.36	0.52	1.56	15.87	2.33
7	66.71	1.14	6.80	19.52	0.42	0.50	1.89	17.00	2.54
8	68.18	1.53	5.85	17.20	0.50	0.48	1.85	19.31	2.83
9	68.15	1.51	6.47	17.77	0.51	0.53	1.83	19.12	2.90
10	65.97	1.41	6.43	18.61	0.57	0.55	2.14	19.38	2.85
11.5	68.33	1.24	6.46	17.94	0.72	0.60	2.34	20.95	3.04

(contained mostly calcium phosphates), that constituted some type of filtration aid, enabled achieving the high effectiveness of the filtration process.

CONCLUSION

The present results demonstrate that increasing the dilution degree of the manure caused a reduction in the raw materials consumption ratio and improved the efficiency of the filtration process. The degree of filtration efficiency can be controlled by the appropriate selection of solid phase volume in the manure to be processed. The highest filtration efficiency was achieved for manure containing 3% dry mass. Manure can be separated into solid and liquid fractions, using pressure filtration, with an efficiency of up to 3765 $kg/m^2/h$. Reduction of the chemical oxygen demand (COD) of the filtrate, depending on manure dilution, amounted to 87–97% of the original manure. These results show that it is possible to control the mineralization and filtration process to leave the greatest amount of phosphorus in the solid phase, which may then be used to produce mineral-organic fertilizer. The phosphorus content of the filtrate was $<$ 10 mg/l.

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