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Evaluation of Physicochemical Separation Characteristics of Pig Manure According to the Type of Solid-liquid Separation Process

Soo-Ryang Kim[1], Seung-Hyun Park[2], Su-Chan Lee[2], Joshua Nizel Halder[3], Ji-Won Jung[2], Sang-Hyean Ahn[2], Kwon-Woong Ham[2], Myung-Gyu Lee[4*]

[1]Research Professor, Industry-Academic Cooperation Foundation, Sangji University, Korea
[2]Master's Student, Department of Environmental Engineering, Sangji University, Korea
[3]Post Doc, National Institute of Animal Science (NIAS), 1500 Kongjwipatjwi-ro, Wanju-gun, Jeollabuk-do 55365, Korea
[4]Professor, Department of Smart life science, Sang-ji University, Korea

***Corresponding author:** Myung-Gyu Lee (E-mail: mglee@sangji.ac.kr)

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ABSTRACT

This study evaluated different solid-liquid separation (SLS) methods that are used to treat wastewater and manure originating from pig farms. SLS is crucial for recycling and purification of pig manure. We tested 7 SLS processes at 13 farms: centrifuge, centrifuge with a coagulation agent, belt press with a coagulation agent, drum screen, inclined screen, vibration screen, and screw press. We collected manure samples both before and after the SLS separation process, including the separated liquid and solid manure, and analyzed them for pH, electrical conductivity, moisture, chemical oxygen demand (COD_{Mn}), five-day biological oxygen demand (BOD_5), total nitrogen (TN), total phosphate (TP), K, total solids (TS), suspended solids (SS), sodium chloride, and heavy metals. Belt presses with coagulation agents showed the highest TS and SS reductions (78.8% and 96.9%). Belt press and centrifugation with coagulation agents achieved 41.0% and 94.2% TN and TP removal, respectively. A belt press with a coagulation agent reduced 59.4% and 66.0% BOD_5 and COD_{Mn}, respectively. A centrifuge with a coagulation agent removed 100% Zn and 98.6% Cu. Drum screens, inclined screens, vibration screens, screw presses, and centrifuges without coagulation had lower removal efficiencies for nutrients, solids, Zn, and Cu compared with that of centrifugal and belt presses with coagulation. Centrifugal and belt presses with coagulation exhibited higher efficiencies for removing nutrients, solids, and metals. Further studies are clarify the effects of SLS on the biological and chemical processes.

Keywords: Livestock, Pig manure, Solid-liquid separations

Introduction

Livestock manure is a valuable nutrient source for both plants and crops. However, livestock manure only contributes positively and replaces mineral and chemical fertilizers when used properly, with minimal loss of nutrients such as nitrogen (N), phosphorus (P), and potassium (K) (Bouwman and Booij, 1998; Le, 1998). The P and K contents of livestock manure are similar to those of commercial fertilizers, but the N content is much lower than that in commercial fertilizers (Hjorth et al., 2010). Excessive application of livestock manure as a fertilizer and untreated and/or poorly treated manure causes nutrient leaching and runoff, ultimately polluting the surface and groundwater and salinizing semi-arid regions, resulting in toxic concentrations of heavy metals and decreased soil aeration (Bernal et al., 1992; 1993; Burton and Turner, 2003; Steinfeld et al., 2006). Before utilizing manure as a fertilizer, it should be properly treated to ensure environmental safety with high fertilizer values. However, recovering energy and nutrients from liquid manure is difficult because of the lower concentrations of organic matter and nutrients (Møller et al., 2006; Teira-Esmatges and Flotats, 2003). Therefore, liquid manure separation is a key process in nutrient recovery strategies (Møller et al., 2000). Pig manure is a combination of pig urine, feces, and water spillage, as well as undigested food, antimicrobial drug residues, and pathogenic microorganisms (Vanotti et al., 2018). It is commonly characterized by a high content of suspended solids, organic matter, phosphorus, and nitrogen (Steinmetz et al., 2009), which results in high density and viscosity. Unlike cow and chicken manure, pig manure is more than 90% liquid, therefore, it has limited options for treatment by composting.

Solid-liquid separation (SLS) is a part of the organic and inorganic solid removal processes from manure slurry and most commonly separates manure into two streams, known as the liquid and solid fractions. The SLS process accelerates manure treatment and reduces environmental impacts (Aguirre-Villegas et al., 2019). According to Hjorth et al. (2010), the efficiency of an SLS system depends on (1) the chemical and physical properties of the slurry, (2) the desired end products, and (3) potential separation techniques, including pre-and post-treatments and combinations of different techniques. Typically, the separation efficiencies of mechanical SLS processes range between 34% and 68% (Chastain et al., 2001; Riaño and García-González, 2014). Owing to its operational and environmental benefits, the SLS system is often accompanied by multistep advanced manure treatment processes to improve the subsequent treatment steps and achieve environmental standards and nutrient recovery targets for livestock manure (Cantrell et al., 2008; Vanotti et al., 2018). For pig manure, SLS is a pre-treatment option that helps separate N-rich liquids from P-rich solids and allows the separated liquid to be used as a source of N for crops without oversupplying P (Kumaragamage et al., 2013). Consequently, SLS in the manure pretreatment process creates high processing efficiency by mobilizing biological processes due to particulate solids. A high concentration of pig manure in the slurry can reduce the processing load when solids are effectively removed (separated) by SLS. SLS processes are mainly mechanical pretreatment processes; however, not all are designed to perform in the same fashion. The most common mechanical SLS systems are screen separators (inclined screens, vibrating screens, and rotating screens), centrifuges (vertical and horizontal centrifuges), and presses (roller press, belt press, and screw press).

Because landfilling and ocean dumping of livestock manure and food waste have been prohibited in South Korea since 2005 and 2012, respectively (KMOE, 2008), several manure treatment technologies have been adopted at the farm and public levels, and often consist of several coupled treatment processes (SLS, composting, aeration, anaerobic digestion, liquid fertilization, and purification discharge). In addition, proper SLS processes at the farm level can remove a substantial amount of organic solids from fresh liquid and nutrients to reach liquid manure, which leads to ease of handling and transport of separated manure and reduces the odor in liquid manure solids. To increase the utilization of liquid manure as a biofertilizer, it is important to extract highly concentrated nutrients from the slurry and reduce odorous substances (Bernet and Béline, 2009).

The aim of this study was to investigate the performance of conventional SLS technologies that can produce liquid manure and liquid manure influent suitable for generating nutrient-rich and environmentally safe liquid manure fertilizers in Korea. To do so, we evaluated the separation efficiency of various SLS processes from different farms based on essential mature properties, such as biological oxygen demand (BOD), chemical oxygen demand (COD), nutrients (N, P, and K), and heavy metals (Cu and Zn).

Materials and Methods

Sampling methods for solid-liquid separation (SLS)

Sampling of the influent, effluent, and solid materials of the SLS was conducted after pre-operation of each device for 5 – 30 min, in accordance with the characteristics of the respective equipment. The sampling method adhered to specific regulations and guidelines regarding turbidity sampling criteria and testing methods for liquid fractions. In the case of liquid samples, such as the influent and effluent, a T-valve was installed at the inlet and outlet points to facilitate sample collection upon request (note that in pig farms where the installation of a T-valve was physically impractical, sampling was conducted directly from the inlet and outlet pipes). Influent and effluent samples were collected at the midpoint of predetermined time intervals. For the collection of solid samples, the sampler designated an arbitrary time frame (ranging from 1 to 30 min) and employed an appropriate container to collect the entire discharge from the solid outlet of the SLS. The weight of the collected sample was measured on-site, followed by the extraction of a portion of the solid sample from the collection container.

Solid-liquid separation techniques

Samples were collected from 13 pig farms that used seven different kinds of SLS processes. Table 1 shows the sampling sites, pig populations (heads), and technologies used while this study was being conducted.

The average livestock population was 3,233 heads in the surveyed farms and finishing pig slurry was used in this study. Six of the 12 farms in this study paired screw pressing with other SLS processes, and three farms used coagulation agents. Samples were collected 5 – 30 min after pre-operation based on the characteristics of each solid-liquid separator from individual pig farms. The separated solids were sampled from the solid containers after 30 min of solid-liquid separator operation, and the collected solids were mixed uniformly and weighed on-site. The influent and separated liquids were collected by installing T-shaped valves at the inlet and outlet. On farms without valves, influents and treated liquids were collected from the inlet and discharge pipes. The influents and separated liquids were collected when the treated solids were past their half-time.

The potential of hydrogen (pH), electrical conductivity (EC), total nitrogen (TN), total phosphate (TP),

Table 1. List of the sampling sites and the solid-liquid separation (SLS) techniques used by them

Sampling site	Number of Pigs ($\times 10^x$)	Solid-liquid separation (SLS)	Abbreviations
Pig farm A (Nonsan)	2.0×10^3	Drum screen (+Screw Press)	D/S
Pig farm B (Yeoju)	2.2×10^3		
Pig farm C (Gongju)	1.0×10^3	Inclined screen (+Screw Press)	I/S
Pig farm D (Jincheon)	6.0×10^3		
Pig farm E (Yeongcheon)	1.0×10^4		
Pig farm F (Icheon)	1.6×10^3	Vibration screen (+Screw Press)	V/S
Pig farm G (Gumi)	3.0×10^3	Screw Press	S/P
Pig farm H (Boeun)	1.0×10^3		
Pig farm I (Hapcheon)	2.0×10^3	Centrifuge	Cf
Pig farm J (Yeongju)	3.8×10^3		
Pig farm I (Hapcheon)	2.0×10^3	Centrifuge (+coagulation agent)	Cf (+Cog)
Pig farm J (Yeongju)	3.8×10^3		
Pig farm K (Changwon)	4.2×10^3	Belt Press (+coagulation agent)	B/P (+Cog)

potassium (K), total solids (TS), suspended solids (SS), salt (NaCl), and heavy metals were analyzed for the influents and separated liquids and solids. The pH and EC were immediately measured in the field using a multi-item measuring instrument YSI meter (Multilab IDS 4010-2, Xylem Inc., USA). The salt concentration was calculated by quantifying it with ICP (Spectro Blue, SPECTRO Analytical Instruments, Germany) and converting it into NaCl. Total nitrogen (TN), Total phosphorus (TP), potassium (K), Chemical oxygen demand (COD), and Biochemical Oxygen Demand (BOD) were analyzed after storing and transferred to the laboratory by following the standard method (APHA, 2005). In addition, CODMn, and BOD5 were measured by sulfuric acid, manganese, and distillation methods in compliance with the 「Fertilizer Quality Inspection Method and Sampling Standards」. The heavy metal content (Cu and Zn) were acid-pyrolyzed with microwaves (QWave1000, Questron Technologies, USA) and measured with ICP (Spectro Blue, SPECTRO Analytical Instruments, Germany) based on the US EPA method 200.7 and 200.8 (US EPA, 1994).

All sampling processes were repeated thrice (n = 3), the collected physical and chemical data were analyzed using Microsoft Excel, and the reduction efficiency rates were calculated according to Equation 1.

$$\eta = \left\{1 - \left(\frac{B}{A}\right)\right\} \times 100 \quad (1)$$

Where, η : removal rate (%), A: Concentration before treatment, B: Concentration after treatment.

Results and Discussion

Tables 2 and 3 and Figs. 1 − 3 summarize the changes in the physical, chemical, and nutrient parameters caused by the different SLS processes.

Changes in pH, EC, and NaCl content

Different screen mesh sizes in different SLS methods create differences between the operational and removal efficiencies of SLS systems and manure characteristics (Kunz et al., 2008). pH and EC are two important characteristics of manure, especially when it is used as a liquid or compost fertilizer. pH, EC, salinity, and NaCl are indicators of the applicability of liquid manure fertilizers for plant growth and crop production (Zhao et al., 2009). In addition, plants obtain most nutrients from dissolved ions; thus, high salinity or high EC prevents efficient nutrient absorption by the plants (Abdulkareem et al., 2018).

The changes of pH and EC by SLS processes show similarities with the finding of Jørgensen and Jensen (2009), where separated liquids from the influents showed stable pH changes but variable EC changes. Our values show that the pH units remained at 6.61 − 8.63, which were near neutral, for 44 samples, while EC varied from 2.57 to 4.47 mS/cm. They also showed that centrifugation (+coagulation agent) resulted in the greatest reduction in EC. The near-neutral pH (6.7 − 7.2) and widely varied EC (4.9 − 17.0 mS/cm) were also reflected in studies by Kumaragamage et al. (2016) and Vanotti et al. (2018). However, the samples that used coagulation agents showed a slight increase in pH because of the chemical composition of the coagulant agents, but remained near neutral (Aguirre-Villegas et al., 2019; Jørgensen and Jensen, 2009; Vanotti et al., 2018). In this study, the pH ranges of the influents and separated liquids did not change significantly with any SLS process (Table 2). The pH changed from 6.90 ± 0.22 to 6.65 ± 0.27, 7.08 ± 0.50 to 7.23 ± 0.43, 7.20 ± 0.54 to 7.23 ± 0.75, 7.00 ± 0.94 to 6.88 ± 1.02, 7.28 ± 0.45 to 7.25 ± 0.26, 7.40 ± 0.41 to 7.53 ± 0.68, and 7.15 ± 0.63 to 7.20 ± 0.65 units for the V/S, D/S, I/S, screw press (S/P), centrifuge (Cf), Cf (+Cog), and belt press (B/P) (+Cog) processes, respectively. The (EC) reduction by Cf (+Cog) of 40.5% was the highest when the influent EC was 29.9 ± 10.2 mS/cm and the separated liquid had 17.8 ± 6.4 mS/cm EC. For the V/S, the influents had the highest EC value, 50.1 ± 7.4 mS/cm, but it was reduced by 15.0% to 42.6 ± 6.2 mS/cm after the treatment (Table 3). The lowest EC removal was observed for the Cf, where EC reduction was only 1.5%, a reduction from 28.1 ± 6.5 mS/cm to 27.7 ± 5.2 mS/cm. On the contrary, B/P (+Cog) with a coagulant agent did not show much EC reduction (2.3%). The NaCl reduction by Cf (+Cog) and B/P (+Cog) with a coagulation agent showed the highest removal efficiencies of 74.6% and 72.9%, respectively (Tables 2 and 3). Among the three screening separator processes, when V/S added up to 2.3% NaCl, I/S reduced 32.0%, and D/S reduced only 0.5%.

Changes in TS and SS contents

One of the most important parameters of swine manure is the solid content, as it has a major impact on the

Table 2. Changes in pH, electrical conductivity (EC), sodium chloride and moisture content (mean value) after treatment with different solid-liquid separation (SLS) processes (n = 3)

Items	Units	Stages	V/S	D/S	I/S	S/P	Cf	Cf (+Cog)	B/P (+Cog)
pH		Influents	6.90 ± 0.22[1]	7.08 ± 0.50	7.20 ± 0.54	7.00 ± 0.94	7.28 ± 0.45	7.40 ± 0.41	7.15 ± 0.63
		Separated liquid	6.65 ± 0.27	7.23 ± 0.43	7.23 ± 0.75	6.88 ± 1.02	7.25 ± 0.26	7.53 ± 0.68	7.20 ± 0.65
EC	(mS/cm)	Influents	50.10 ± 7.35	34.88 ± 14.12	22.77 ± 31.94	44.63 ± 7.12	28.08 ± 6.52	29.85 ± 10.17	32.65 ± 2.09
		Separated liquid	42.60 ± 6.21	33.70 ± 13.51	21.13 ± 29.25	41.05 ± 6.46	27.65 ± 5.19	17.75 ± 6.44	31.90 ± 1.69
NaCl	(%)	Influents	1.38 ± 1.46	0.68 ± 1.71	0.63 ± 3.21	2.43 ± 3.00	0.72 ± 0.76	0.75 ± 0.81	0.80 ± 0.84
		Separated liquid	1.42 ± 4.50	0.67 ± 1.77	0.43 ± 3.06	2.32 ± 2.87	0.69 ± 0.73	0.19 ± 0.09	0.22 ± 0.19
MC[2]		Influents	-	-	-	-	-	-	-
		Separated solid	73.20 ± 4.53	68.60 ± 4.54	74.70 ± 3.81	65.70 ± 1.89	47.40 ± 29.45	74.00 ± 3.91	76.40 ± 0.46

[1] Values are mean ± SD (n = 3)
[2] MC are moisture content

Table 3. Reduction and addition rate (%) of the physiochemical properties after operating different solid-liquid separation (SLS) processes (n = 3)

Properties	V/S	D/S	I/S	S/P	Cf	Cf (+Cog)	B/P (+Cog)
pH	3.62	(-)2.12	(-)0.42	1.71	0.41	(-)1.76	(-)0.70
EC	14.97	3.38	7.20	8.02	1.53	40.54	2.30
NaCl	(-)2.90[1]	1.47	31.75	4.53	4.17	74.67	72.50
TS	23.07	12.84	19.88	14.42	19.09	67.95	78.76
SS	23.99	13.78	13.91	8.07	32.12	65.42	96.89
TN	13.13	6.21	10.39	2.93	4.67	36.42	41.02
TP	9.42	8.02	27.74	11.14	29.69	94.14	91.45
K	(-)2.38	(-)0.09	3.50	0.39	2.57	25.55	59.40
BOD_5	14.65	7.76	13.05	3.85	4.71	53.89	66.02
COD_{Mn}	13.92	5.25	10.80	12.86	27.81	75.58	77.53
Zn	5.25	7.82	16.17	(-)4.57	12.35	ND[2]	99.08
Cu	0.45	13.85	33.73	(-)1.06	9.05	98.75	98.12

[1] (-) are addition rate
[2] ND are not detected

performance of solid-liquid separation processes, and the solid content indicates the strength of the separated liquid (González-Fernández et al., 2008; Riaño and García-González, 2014). Fig. 1 shows the changes in TS and SS with the different SLS processes. The B/P (+Cog) and the Cf (+Cog) had 78.76% and 67.94% TS removal efficiency, respectively. Except these two-coagulation agent-supported SLS processes, the rest of the SLS processes showed 12.8-23.0% TS removal efficiency (Table 3). The coagulant supported SLS processes showed the highest SS reductions: 96.9% and 67.94% for B/P (+Cog) and Cf (+Cog), respectively. The Cf process had an SS removal efficiency of 32.2%. The rest of the SLS processes showed 8.1-24.1% TS removal efficiencies. Meanwhile, the

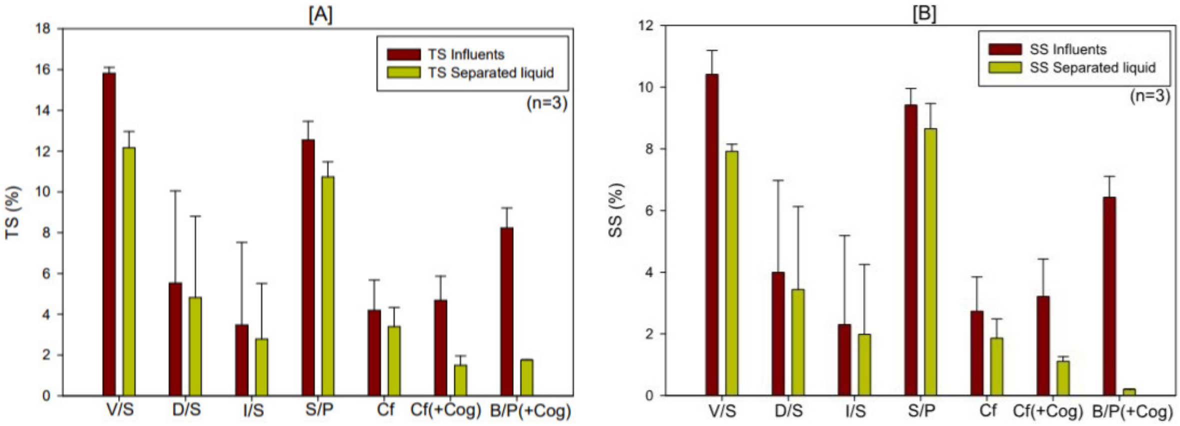

Fig. 1. Changes in solid contents (A) total solids (TS) and (b) suspended solids (SS) after treatment with different solid-liquid separation (SLS) processes.

moisture in the separated solids were 73.2%, 68.6%, 74.7%, 65.7%, 74.0%, and 76.4% for the V/S, D/S, I/S, S/P, Cf (+Cog), and B/P (+Cog) processes, respectively. The results also indicated that the process contained the lowest moisture content at 47.41% (Table 3).

Changes in nutrient content (TN, TP, and K), BOD_5, and COD_{Mn}

By comparing the S/P with a Cf, several authors have found that the centrifuge achieves higher performance (Gooch et al., 2005; Møller et al., 2006; 2000). According to Aguirre-Villegas et al. (2019), Cf processes are more effective for the removal of TS, SS, TN, TP, K, BOD5, and CODMn than S/P processes. This finding was also reflected in this study (Table 3). Fig. 2 shows the changes in nutrient content (TN, TP, and K), BOD5, and CODMn caused by the different SLS processes. When comparing the Cf process with the V/S and D/S processes, the V/S process showed better removal of TS, TN, and BOD5. The Cf (+Cog) process exhibited higher EC, NaCl, TS, and TP removal efficiencies than the B/P process. In contrast, the B/P (+Cog) process had a comparatively better performance for TN, K, BOD5, and CODMn removal than the Cf (+Cog) process. The relatively low removal efficiencies of TN, TP, and K in liquids separated by mechanical processes without coagulation agents could be due to their more suitable or dissolved forms (Aguirre-Villegas et al., 2019; Bernet and Béline, 2009; Riaño and García-González, 2014; Saeys et al., 2005). The higher TP concentrations in the separated liquids and the removal efficiency for B/P (+Cog) were similar to those reported by Møller et al. (2002). However, the higher removal efficiencies of TN, TP, and TK by Cf (+Cog) and B/P (+Cog) were due to the chemical treatment coupled with mechanical (centrifuge and belt press) treatment, which screens out smaller-sized particles (Jørgensen and Jensen, 2009; Vanotti et al., 2002). The B/P (+Cog) showed the highest TN reduction of 41.0%, where the influents contained 7,857 ± 1,029 mg/L and the separated liquid contained 4,631 ± 342 mg/L of TN. The Cf (+Cog) had the second highest TN removal of 36.4%, where the TN decreased from 5,197 ± 1,058 to 3,304 ± 361 mg/L. However, V/S, D/S, I/S, S/P, and Cf showed 2.9-13.1% TN removal efficiency (Table 3). The TP removal was similar to that of TN. The Cf (+Cog) and B/P (+Cog) processes showed 94.2% and 91.5% TP removal efficiency, respectively, in

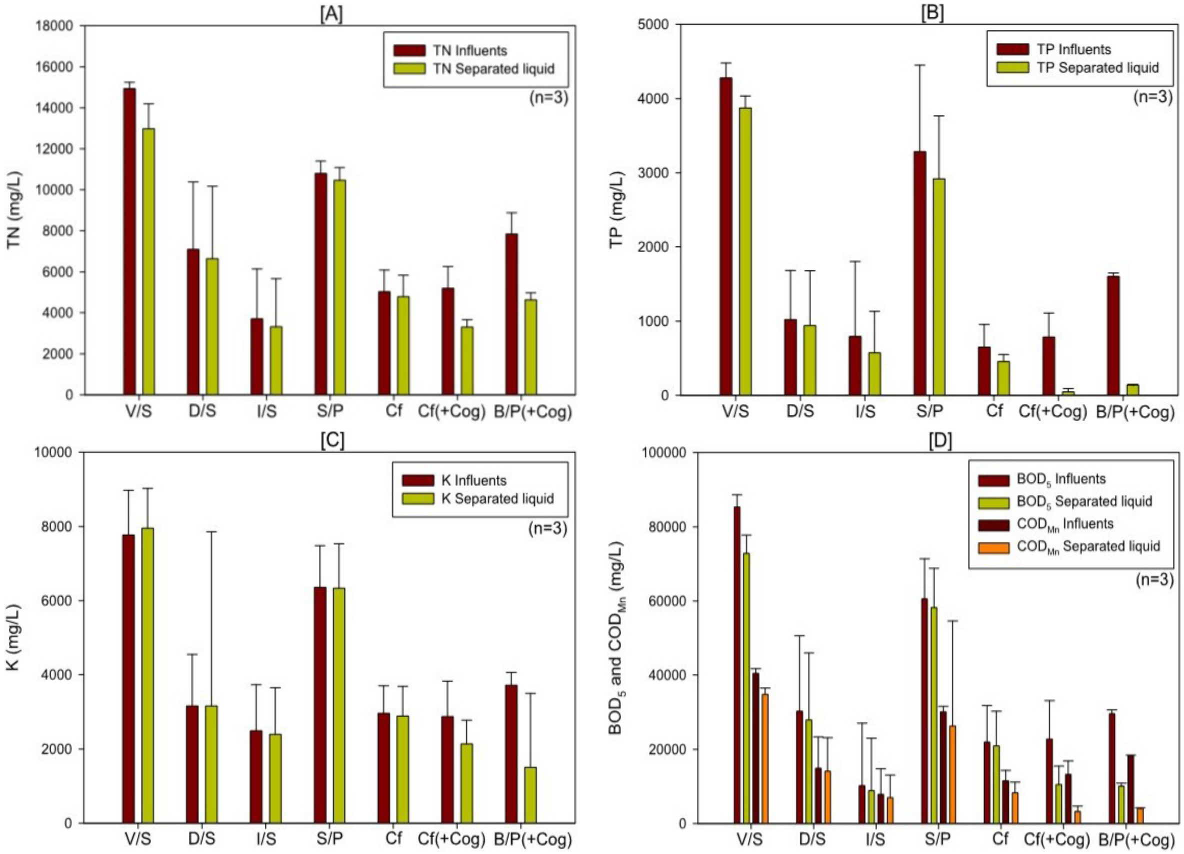

Fig. 2. Changes in (A) total nitrogen (TN), (B) total phosphate (TP), (C) K, and (D) five-day biological oxygen demand (BOD_5), and chemical oxygen demand (COD_{Mn}) after treatment with different solid-liquid separation (SLS) processes.

separated liquids. However, V/S, D/S, I/S, S/P, and Cf showed 8.0-29.8% TN removal efficiencies. The B/P (+Cog) and Cf (+Cog) showed 59.4% and 25.6% K removal efficiency, respectively. The I/S, S/P, and Cf had only 0.4-3.5% removal efficiency for K. Moreover, in the case of V/S and D/S, the concentration of K somewhat increased in separated liquids. The B/P (+Cog) and Cf (+Cog) showed 59.4% and 25.6% K removal efficiency, respectively. The I/S, S/P, and Cf had only 0.4−3.5% removal efficiency for K. Moreover, in the case of V/S and D/S, the concentration of K somewhat increased in separated liquids. The concentrations of CODMn and BOD5 indicate the presence of oxygen-demanding substances in wastewater and are often used as indicators of pollution. In this study, the chemical coagulant agent-supported centrifugal and belt press SLS removed the highest amounts of BOD5 and CODMn. The B/P (+Cog) reduced 66.0% of BOD5, and the Cf (+Cog) reduced 53.9% of it; and the concentration of BOD5 in influents was 29,580 ± 1,078 mg/L and 22,825 ± 10,353 mg/L, and after treatment in separated liquid, it reduced to 10,050 ± 857 mg/L and 10,525 ± 4,948 mg/L, respectively. The removal of CODMn was similar to that of BOD5.

The Cf (+Cog) and B/P (+Cog) processes showed 75.6% and 77.5% of CODMn removal efficiency, respectively, in separated liquids. However, other SLS processes showed low removal efficiency for BOD5 (4.7−14.6%) and CODMn (5.3−27.8%) (Table 3). Approximately 40% of BOD5 was found in the solid fraction of manure;

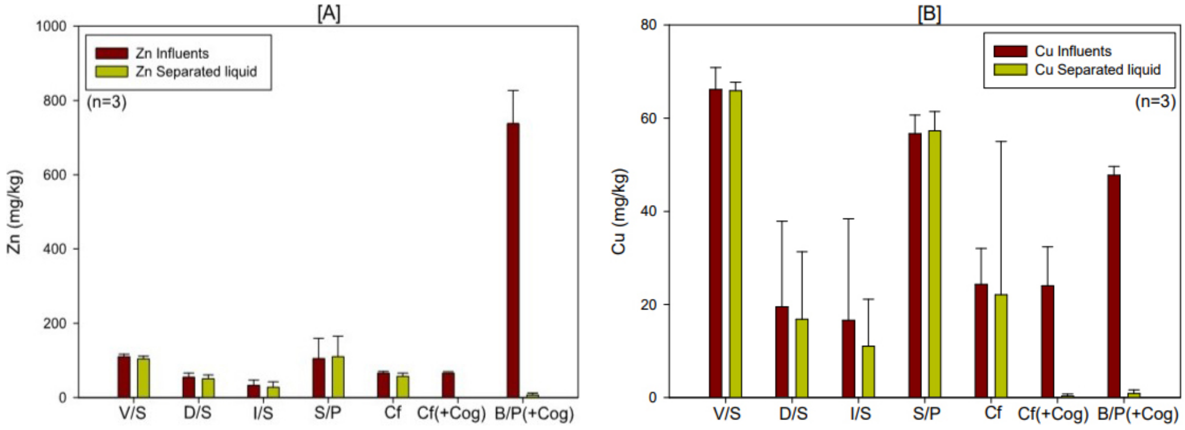

Fig. 3. Changes in (A) Zn, and (B) Cu after treatment with different solid-liquid separation (SLS) processes.

therefore, after performing SLS, about 60% of the BOD5 was supposed to remain in the separated liquid (Zhu et al., 2001) Therefore, the TS and BOD5 concentrations in separated liquids remained in the same sequential order of V/S, S/P, D/S, Cf, and I/S. For the coagulation agent-assisted SLS processes, the TS and BOD5 removal was 67.9% and 53.9% for Cf (+Cog) and 78.8% and 66.0% for B/P (+Cog), respectivey (Table 3). Similar properties were observed for changes in CODMn. Each sample that contained higher TS concentrations in both the influent and separated liquids also showed higher CODMn concentrations as (Chastain and Vanotti, 2003).

Changes in Zn and Cu

Separating heavy metals, such as Zn and Cu, from liquid manure before land application reduces the risk of soil contamination (Bolan et al., 2014; Riaño and García-González, 2014). Among all the analyzed heavy metals, Zn and Cu were found at the highest concentrations in the influents. The probable reason for this is that pigs receive Zn and Cu from their feeding operations (Zhang et al., 2012). Fig. 3 shows the changes in the nutrient contents of Zn and Cu caused by the different SLS processes. The coagulant assist centrifuge (Cf (+Cog)) and belt press (B/P (+Cog)) were very effective at reducing the heavy metals such as Zn (100% and 98.6%) and Cu (99.1% and 98.1%). These findings are similar to those of Vanotti et al. (2018), who found that a PAM-based mechanical pressing SLS system could remove 88% of Zn and Cu. However, the other SLS processes exhibited low Cu and Zn removal efficiencies. The V/S, D/S, I/S, and Cf showed 5.2 – 12.4% Zn removal efficiency and 0.4 – 33.7% Cu removal efficiency (Table 3), respectively. Moreover, for the I/P process, the concentrations of Zn and Cu slightly increased in the separated liquids.

Conclusions

In this study, we assessed the separation and/or reduction efficiencies of various SLS technologies used on pig farms. The centrifugal and belt press processes that used chemical coagulation showed much greater removal of nutrients, solids, and metals such as Zn and Cu. Among all the SLS processes studied, the Cf (+Cog) process showed a 40.5% EC reduction, the highest among all SLS processes. The NaCl was reduced in the Cf (+Cog) and B/P (+Cog) by 74.6% and 72.9%, respectively. The B/P (+Cog) process exhibited the highest TS and SS reductions of 78.8% and 96.9%, respectively. The highest TN and TP removals were 41.0% and 94.2% for B/P (+Cog) and Cf (+Cog), respectively. The B/P (+Cog) removed 59.4% and 66.0% of BOD_5 and COD_{Mn}, respectively. The Zn and Cu were reduced by 100% and 98.6% by Cf (+Cog), respectively. However, V/S, D/S, I/S, S/P, and Cf showed lower removal efficiencies for nutrients, solids, Zn, and Cu than the centrifugal and belt press processes that used chemical coagulation. In this study, we found that chemical coagulants made a notable difference in the SLS performance for the removal of, or changes to, different physicochemical parameters of pig manure. Although SLS is an effective pretreatment process for liquid manure treatment, and using chemical coagulants helps remove excess fine solids, nutrients, and heavy metals, further studies are needed to determine how coagulation agents react with other SLS and liquid manure treatment processes.

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