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REUSE OF AGROWASTES FOR DEWATERING ENHANCEMENT OF SEWER SEDIMENTS FOR BRICK PRODUCTION

Nguyen Xuan Huan[a], Dang Thi Thanh Huyen[b], Pham Thi Ngoc Lan[c], Tran Thuy Anh[b], Tran Thi Huyen Nga[a], Hoang Duc Quyen[a], Pham Thi Thuy[a], Nguyen Manh Khai[a,*]

[a] *Faculty of Environmental Sciences, University of Science, Vietnam National University, 334 Nguyen Trai street, Thanh Xuan district, Hanoi, Vietnam*

[b] *Faculty of Environmental Engineering, Hanoi University of Civil Engineering, 55 Giai Phong road, Hai Ba Trung district, Hanoi, Vietnam*

[c] *Faculty of Chemistry and Environment, Thuy Loi University, 175 Tay Son street, Dong Da district, Hanoi, Vietnam*

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Abstract

With the increasing wastewater generation from domestic and industrial activities due to the rapid economic development, the generation of sludge, in particular dredged sludge from municipal sewer system, has been an issue in developing countries. This study evaluated the enhancement of sewer's sludge dewatering via mixing the sludge with different agro-wastes, including corn core powder, rice husk powder, bagasse powder and peanut shell powder. The addition of these agro-waste powders helped decrease the sludge's moisture contents up to 17% while increase the organic matters nearly to 40% after mixing with the ratio of agro-wastes and sludge of 1:3. Statistical analysis revealed the impacts of both additive types and mixing ratio on moisture content reduction. Among the four types of agro-waste, rice husk was shown to be the best additive to dredged sludges with highest reduction of heavy metal concentration and moisture content. The addition of agro-waste powders to enhance the dewatering of sludges is promising in the context of promoting waste reuse and energy saving.

Keywords: sewers'dredged sludge; agro-wastes; moisture content; organic matters; heavy metals, waste reuse.

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1. Introduction

One of the big still challenges for developing countries is wastewater and sludge treatment. In most of the countries applying separate drainage and sewerage system, sludge from the sewers is minimal. However, for the combined sewage systems, the sludge or some other papers called "sediment" accumulated within the sewers is relatively significant [1]. For example, with 3360 km^2 area and 8.05 million inhabitants in 2019, Hanoi city (Vietnam) generated approximately 186 thousand tons of the total wet dredged sludge from its combined sewers [2]. In general, the sludge cannot be treated by a single process but a combination of processes to address various contaminant problems [3–5] and the same requirement occurs with dredged sludge from sewers. It involves pretreatment (physical screening and dewatering) and operational treatment (bioremediation, chemical treatment, extraction, thermal treatment) like sewage sludge in the wastewater treatment plants (WWTPs) [6]. In fact, the dredged sludge from sewers is more like the primary sludge in WWTPs. In developing countries, most of the sludge from WWTPs is dried by natural method (i.e., drying beds) or mechanical method (i.e., sludge compression machines) before landfilling. However, there has been no proper treatment for dredged sludges from combined sewers which was only collected and dumped in a contained site.

*Corresponding author. *E-mail address:* nguyenmanhkhai@hus.edu.vn (Khai, N. M.)

Recently, the dredged sludge from sewers was strongly promoted and encouraged to reuse for different purposes including construction materials (i.e., aggregates, cements, calcined and non-calcined bricks) and fertilizers. Several sludge-reuse projects have been implemented in the past ten years in Vietnam with an attempt of transferring sludges to construction materials [7].

Sludge dewatering is one of critical steps in sludge treatment as it reduces significant water from the mixed sludge which creates favorable conditions for next sludge treatment process. Studies on dewatering enhancement have been done a few and mostly with sewage sludges from WWTPs; such as using chemicals [8–11], electrochemical Fenton [12–14], thermal treatment [15] or combination of hydrothermal treatment and $FeSO_4$/ $Ca(ClO)_2$ oxidation [16]. Addition of agro-wastes for dewatering enhancement has also been paid much attention from researchers within the past decade [10, 17, 18]. The reuse of agro-waste approach is considered attractive as it is environmentally friendly, energy saving and has been promoted tremendously recently [19, 20]. Indeed, the waste-blended sludge can be reused as great potential materials for composting, or post-treatment by incineration. It was found that several carbonaceous materials from agro-wastes, acting as skeleton builders and providing water passages, have enhanced sludge dewaterability and cake properties [21]. In another study, different doses of walnut shell (0, 50, 100, 200, 400, and 600 mg/g dry sludge) were added into sewage sludge samples conditioned with $Ca(ClO)_2$ and ferric coagulant to evaluate the dewatering enhancement. The combination of all had reduced the moisture content from 90.8% to 78.6% compared with the raw sludge [10]. Guo et al. (2019) recently tried waste corn core powder, that was pretreated with 2M NaOH and 0.16M cationic surfactant cetyltrimethylammonium bromide (CTMAB), for sludge dewatering. They found more organic matters were released into supernatant, and more bound water turned into free water phase, thus enhancing sludge dewatering [18]. It can be seen that physical conditioners, that are rich in hemicelluloses, lignin and other hemicelluloses, are often modified with chemicals such as alkaline solutions. Alkaline hydrolyzation was proved to breakdown the lignin structure, and increase the internal surface area [22]. The alkaline hydrolysis was also believed to have impact on intermolecular linkage between xylem hemicelluloses and lignin or other hemicelluloses. In particular, the NaOH treatment of ligno-cellulosic material caused swelling, leading to an increase of internal surface area, and separation of structural linkages between lignin and carbohydrates [22]. Since agro-wastes such as rice husk, rice straw, peanut shell, corn cob, etc., normally have high percentages of hemicelluloses (20-40%), lignin (10-20%), and carbohydrates components [20, 23–25], the preconditioning of the agro-waste additives is a critical step. In addition, the agro-waste generation in Vietnam was significant, i.e., over 156.8 million tons, including 88.9 million tons of crops residues and product processing (accounting for 56.7%) according to the General Statistics Office of Vietnam in 2020 [26]. Nevertheless, the reuse of agro-waste in treating sludge from urban drainage system has been very limited, more in wastewater treatment [27–29]. In Vietnam, food waste (not agro-wastes) was more common to reuse to mix with sludge from wastewater treatment plant for composting purpose.

Review from the literature has showed that most of the studies were conducted with sewage sludge from WWTPs [4, 5, 8, 11]. Only a few was done with dredged sludge from sewers (or sewer sediments) [1, 7] or river sediment [30]. Comparison with sewage sludge from WWTPs, the dredged sludge from sewers contains much less organic matters and more impurities (i.e., sand, trash, etc.); thus, the dewatering process shall be different to a certain extent. Additionally, each previous study focused on one type of agro-wastes. Thus, this is the first time, all four types of agro-wastes such as corn core powder, rice husk powder, sugarcane bagasse powder and peanut shell powder shall be assessed as additives to blend with dredged sludge for dewaterability enhancement. Understanding of the impact of agro-wastes on the moisture content and heavy metal reduction shall be rendered as one of the highlight results of this study and for further reuse in brick production.

2. Materials and Methods

2.1. Sludge for testing

The sampling sludges were taken from Yen So Sludge dumping site (Hanoi city, Vietnam). It was mostly sewer sediment from Hanoi sewer and drainage system. The sludges were screened using 2.5-mm sieves to remove gravels, debris, grits, leaves or cloths before being stored at 4 °C for use. Prior to the test, they were analyzed in terms of physical (moisture content-MC, pH, composition) and chemical (heavy metals, thermal energy, organic matters, etc.) characteristics. Sludge samples after dewatering were sent for Scanning Electron Microscope (SEM). The SEM was implemented using the Tabletop Microscope (TM4000plus, Hitachi, Japan) while The total organic matters of sludge samples (thickened sludge) were analyzed using method for soil analysis employing $K_2Cr_2O_7$ solution (national standard TCVN 7376:2004).

2.2. Preparation of agro-waste additives

Four types of agro-wastes (corn core, rice husk, sugarcane bagasse and peanut shell) were collected dry and ground to a size of 100 mesh (i.e., 150 µm). To increase the hydrophilicity of the additives, they were hydrolyzed by soaking individually in 2M NaOH solution > 98% purity (CAS: 1310-73-2, Sigma Aldrich) for 60 min at room temperature, then washed with distilled water until free of foams and put in the oven at 105 °C until completely dry. After that, they were sieved to particle size diameters < 150 µm. Finally, they were stored in sealed bottles and named as CCP, RHP, SBP, and PSP for corn core, rice husk, sugarcane bagasse and peanut shell powders, respectively.

2.3. Sludge dewatering test

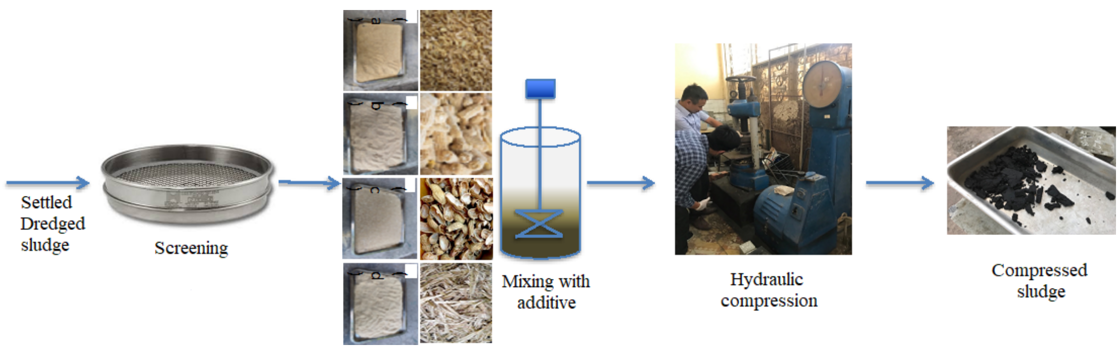


Figure 1. Dewatering procedure in the lab

As mentioned above, the testing sludges were those settled for some time at the Yen So dumping site, so the sludges were slightly thickened. The sludges, after screened, were mixed with individual additives with the additive - sludge ratio of 1:3; 1:5 and 1:7 by weight. Each sample was 100 grams in total. The sludge and additive were mixed for 15 min at 100 rpm. After that, the mixture was compressed by hydraulic compression machine (60T, 267/56/21, Leipzig, Germany) with the compression load of 400 kG. The compression time was 15 min for each sample. The selection of dewatering test's conditions was referred from previous studies with some modification to fit with the dredged sludges [10, 18]. All the tests were conducted in duplicate. The whole process was presented in Fig. 1.

3. Result and Discussion

3.1. Characteristics of testing sludges

The characteristics of testing sludges were given in Table 1. The moisture content was relatively low as 45.5% as they were settled for some time at the dumping site. Initially, its moisture content could be up to 98% when they were dredged and pumped from the sewers into the trucks. They have neutral pH condition as the sewers received mostly domestic wastewater, rainwater and maybe some treated industrial wastewater. Notably, the sand accounts for majority in the composition (corresponding with highest SiO_2 percentage ~ 72.8%) in the dredged sludge from sewers (DSS), while SiO_2 concentration was less than 10% in sewage sludge [3]. It makes sense as the combined system receives lots of runoff water from the road surface during the rain. With this high inorganic composition, it is more logical to reuse the dredged sludges for the production of construction materials than for composting purpose.

Table 1. Characteristic of testing sludges

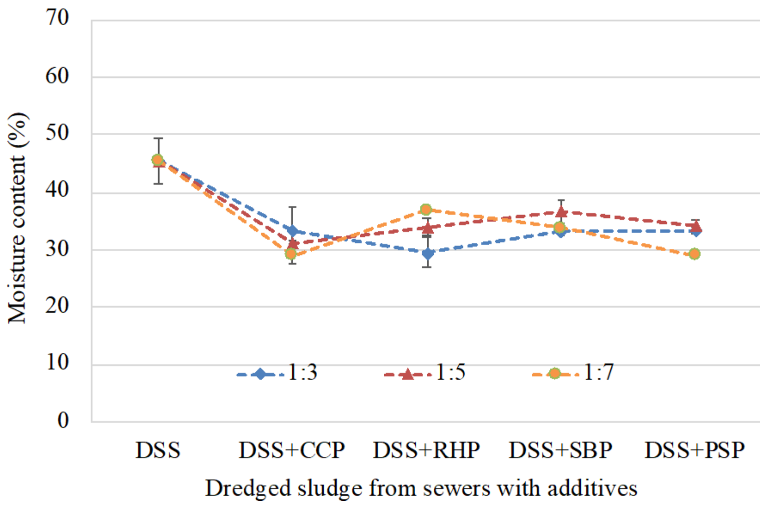
No	Parameters	Unit	Dredged sludge from sewers (DSS)	QCVN 43:2017/BTNMT
1	Moisture content	%	45.5	-
2	pH	-	7.26	-
3	Compositions			-
4	- Sand	%	70.4	-
	- Limon	%	21.9	-
	- Clay	%	7.7	-
	Al_2O_3	%	7.97	-
5	Fe_2O_3	%	5.64	-
6	SiO_2	%	72.86	-
7	CaO	%	6.86	-
8	MgO	%	2.65	-
9	Cl^-	%	0.27	-
10	SO_4^{2-}	%	1.07	-
11	Cu	mg/kg	72.86	197
12	As	mg/kg	50.8	17
13	Zn	mg/kg	1640.8	315
14	Cr	mg/kg	160.5	90
15	Cd	mg/kg	< 2	3.5
16	Pb	mg/kg	108.5	91.3
17	Total organic matters	%	12.3	-
18	Heat value	kCal/kg	1250	-

QCVN 43:2017/BTNMT: National technical regulation on sediment quality.

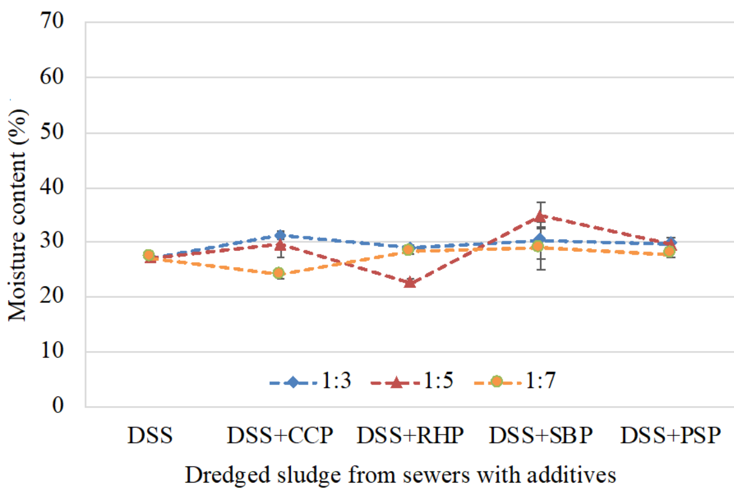
Furthermore, the sewer sediment was contaminated with heavy metals such as Zn, Cr, As and Pb. This could be due to the discharge of improperly-treated industrial wastewater into the sewers. In terms of organic matters, DSS had shown a low concentration of 12.3%. This proved clearly the contrary characteristics of dredged sludge from sewers versus sewage sludge from WWTP. The one from WWTP normally contains higher organic matters (i.e., 20-60%) [31] while the inorganic matters are limited.

3.2. Effect of additive blending on dewaterability

Fig. 2 presents the effect of additive types and additive-sludge mixing ratio on the reduction of moisture contents of the testing sludges.



(a) Before compression



(b) After compression

Figure 2. Moisture contents of testing DSS with additives
(DSS: Dredged sludge from sewers; CCP: corn core powder, RHP: rice husk powder,
SBP: sugarcane bagasse powder, and PSP: peanut shell powders)

It is clearly seen from Fig. 2 that the blending with additives had substantial impacts on dewatering of DSS. The moisture contents (MC) reduced up to 17% and mostly noticeable with corn core powders, followed by rice husk powder (Fig. 2(a)). This result was similar to the findings of previous studies [17, 18] even though they used sewage sludges from wastewater treatment plants. Their previous studies also observed a decrease of about 10%-15% in MC when mixing with these kinds of agro-wastes. The explanation was partly due to particle charge attraction. Normally, sludge particles were negatively charged, which exhibited mutual repulsion, resulted in a negatively charged stable colloid dispersoid. After mixing with NaOH-modified additives, which were positively charged, the additives could play a role of electric neutralization and release of bound water from the dispersoid [18]. They also found that during the reaction process between sludge particles and modified corn core powder, more bound water turned into free water phase, thus enhancing sludge dewatering.

When discussing about the impacts of these additives to sludge dewatering, some research mentioned about their skeleton building ability. Wallnut shell, as an example, was revealed to be a skeleton builder that formed the rigid skeleton and further increased the deep dewatering of the sludge [10]. As explained previously, the selected additives have all rich in hemicelluloses, cellulose and lignin. For instance, rice husk contains 40% cellulose, 30% lignin, and 20% silica [32], peanut shell has 35.7% cellulose, 30.2% lignin, 18.7% hemicelluloses, and 5.9% ash content while the main components of sugarcane bagasse are cellulose (46.0%), hemicellulose (24.5%), lignin (20.0%) [20], and there are 26.5% cellulose, 13.6% lignin and other compounds in corn core [33]. Upon NaOH pretreatment, lignin and hemicelluloses were partly removed, the cellulose content and sample porosity was increased, which was instrumental for the hydrolysis of the additives [34]. Thus, when mixing with the sludges, the additives can absorb water molecules from the dredged sludges more easily.

In comparison of sludges' moisture contents before and after compression, it was revealed that only minimal changes of MC were observed (Fig. 2(b)). This can be expected for sludge samples with high silicate component and low organic matters. In general, sludges with high organic matters tend to hold higher water content and will be more impacted with compression [35]. With the purpose of reducing moisture as much as possible to meet the requirement for reuse as construction bricks, it can be initially concluded that the rice husk with ratio of 1:5 was the best additive for dredged sludge from sewers, i.e., MC decreasing from 45.5±4.1% to 33.9±1.5% after mixing and to 22.7±0.6% after compression.

Regarding to the influence of mixing ratio, there was no obvious impact of the additives on MC, except for rice husk powder (Fig. 2(a)). After compression, the additive blending showed even less influence. While the rice husk powder mixture performed the best at 1:5, the remaining (corn core, sugarcane bagasse and peanut shell) mixtures all worked best with ratio of 1:7. Previous study with sewage sludge mixing with rice husk additive revealed that increasing dosages of rice husk from 50, 100, 200, and 300 mg/g led to the reduction of moisture content from 72.9% to 63.4% [36]. One thing can be concluded that for the dredged sludge from sewers, the agro-waste additives help enhance the dewatering to certain extent, however, the enhancement efficiency is not necessarily proportional to the added quantity.

3.3. *Effect of additive blending on organic matters*

Organic matters were considered in this study as it relates to the potential application for calcined bricks, the sequential target of this research. Should the dredged sludges be reused for materials for calcined bricks, the organic matters as well as the thermal energy/heating values must be put in consideration. It was claimed that the high content of organic matter in raw sludge caused a decrease in mechanical strength and delay in hydration process [37]. However, sludge with high content of organic matters can be considered potential fuel with its high calorific value [38], which would be valued during the incineration for producing calcined bricks.

It is worth noting that the testing sludges were dredged sludges from the combined drainage system, thus, they had some organic matters but at low level (about 12%). The additives employed to enhance the sludge dewatering in this study (corn core, rice husk, sugarcane bagasse and peanut shell) were agro-wastes that are rich in organic matters. As a result, possibly higher organic matters would be expected for the samples [18]. Nevertheless, it was shown in Fig. 3 that the high mixing ratio of 1:3 for additive and sludge would produce significant change in organic content (from 12±0.2% to 39±1.8% after mixing with sugarcane bagasse powder or to 35±6% after mixing with corn core powder). Lower mixing ratio of 1:5 or 1:7 produces no increase in organic content in most cases. A trend of decrease in the organic content was observed when reducing the mixing ratio from 1:3, 1:5 and 1:7. In particular for the case of rice husk additive, the organic matters were about 10%, 20% and 30% for the mixing ratio with additives of 1:7; 1:5 and 1:3, respectively. indicated that the addition of walnut shell biomass significantly promoted the mixed fuel combustion characteristics [10]. Although the presence of organic matters help enhance the combustion capability, they may lead to more µm-scale pores and large macro defects on the surface of brick. Despite these defects, the properties of all brick samples such as compressive strength, water absorption and freeze-thawing resistance still met the standard requirement of brick products [39]. Somehow, the porous and lighter bricks are indeed the development trend of construction bricks nowadays, to impose less impact on the building foundation.

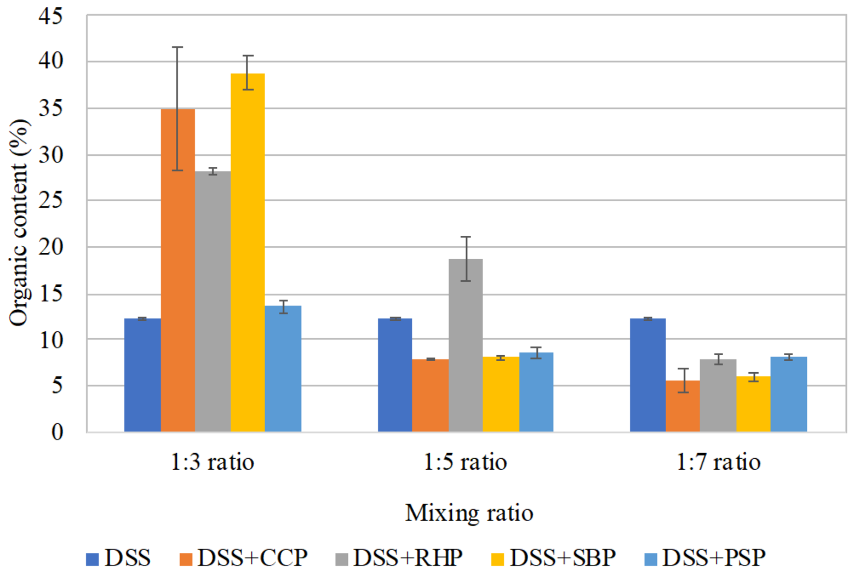


Figure 3. Organic matters in the dredged sludges with and without additives (DSS: Dredged sludge from sewers; CCP: corn core powder, RHP: rice husk powder, SBP: sugarcane bagasse powder, and PSP: peanut shell powders)

3.4. Effect of additive blending on other physical and chemical characteristics

Selected DSS samples (good performance in MC reduction) were sent for physical and chemical examination. This was to evaluate the impact of additives on the sludge characteristics as materials for brick production.

The changes in physical and chemical characteristics can be seen clearly in Table 2. In terms of oxide components, most of them decreased in concentration (%), except for SiO_2. The same trend was observed for the case of heave metals, except for Sr and Cr. Certainly, the decrease varied with different additives. The decreasing trend can be explained in a way that as the additives are mostly organic matters, the inorganic concentrations were reduced within the same volume of samples. This would be better in case the sludge was contaminated with heavy metals. For instance, it helped reduce heavy metal concentrations up to 70%, 58% and 42% for the cases of Zn, Pb and Cu, respectively. It is interesting that the sludge samples blended with rice husk powder (ratio of 1:5) showed consistently the lowest concentration of heavy metals compared with the remaining additives. With the same blending ratio of 1:7, the rice husk and peanut shell powders proved to have more impact than the baggage and corn core powders in term of heavy metals reduction. In addition, the sludge samples blended with rice husk powder (ratio of 1:5) also had the highest moisture reduction (17%) when comparing the

Table 2. Physical and chemical characteristics of samples

No	Index	Unit	M1	M2	M3	M4	M5	M6	Standard
1	Al_2O_3	%	7.97	4.58	4.25	4.2	4.18	4.17	-
2	CaO	%	6.86	7.23	6.78	6.58	6.47	6.66	-
3	Fe_2O_3	%	5.64	2.74	2.97	2.89	2.84	2.9	-
4	K2O	%	1.95	3.33	2.91	1.92	1.88	2.72	-
5	MgO	%	2.65	1.24	1.2	1.07	1.02	1.39	-
6	MnO	%	0.14	0.04	0.04	0.04	0.04	0.04	-
7	P_2O_5	%	1.25	0.87	0.82	0.8	0.93	0.95	-
8	TiO_2	%	0.68	0.38	0.35	0.2	0.29	0.42	-
9	SiO_2	%	72.86	79.59	80.68	82.3	82.35	80.75	-
10	Ag	mg/Kg	< 2	< 2	< 2	< 2	< 2	< 2	-
11	As	mg/Kg	50.8	31.2	34	33.5	32.8	35.1	17
12	B	mg/Kg	62.4	25.2	30	31.1	30.3	40.8	-
13	Ba	mg/Kg	650.5	328	370.5	374.2	369.7	430.9	-
14	Be	mg/Kg	< 5	< 5	< 5	< 5	< 5	< 5	-
15	Bi	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
16	Cd	mg/Kg	< 2	< 2	< 2	< 2	< 2	< 2	3.5
17	Ce	mg/Kg	65.7	35.7	44.4	45.8	44.7	48.2	-
18	Co	mg/Kg	120.8	18.5	22.1	23.2	22.9	32.5	-
19	Cr	mg/Kg	160.5	140.8	171.1	175.2	171.6	180.1	90
20	Cu	mg/Kg	168.2	70.6	83.7	85.7	84.3	90.8	197
21	Ga	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
22	Ge	mg/Kg	< 20	< 20	< 20	< 20	< 20	< 20	-
23	La	mg/Kg	40.4	17.2	23.2	24.3	22.8	27.4	-
24	Li	mg/Kg	52.1	23.4	29	29.8	28	32.7	-
25	Mo	mg/Kg	< 5	< 5	< 5	< 5	< 5	< 5	-
26	Nb	mg/Kg	13.5	5.5	6.2	6.4	6.1	6.5	-
27	Ni	mg/Kg	78.2	60.1	73.4	75	72.7	75.1	-
28	Pb	mg/Kg	108.5	62.4	80.1	82.4	80.6	83.8	91.3
29	Sb	mg/Kg	23.1	14.5	18.1	19.2	18.8	19.2	-
30	Sc	mg/Kg	8.5	6.2	6.9	7.1	6.8	7.2	-
31	Sn	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
32	Sr	mg/Kg	165.2	155.8	210	214.2	210.5	215.2	-
33	Ta	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
34	V	mg/Kg	88.8	48.9	61.8	62.8	60.6	63.6	-
35	W	mg/Kg	50.3	30.7	39.2	41	40.3	40.8	-
36	Y	mg/Kg	25.7	9.4	12.5	13.2	12.7	13.4	-
37	Zn	mg/Kg	1640.8	485.6	630.6	635.7	630	650.1	315

Note: M1: raw DSS; M2: DSS+RHP (1:5); M3: DSS+RHP (1:7); M4: DSS+CCP (1:7); M5: DSS+PSP (1:7); M6: DSS+SBP (1:7); Standard: QCVN 43:2017/BTNMT – National technical regulation in sediment quality; "-": Not applicable.

MC of raw sludge and mixed sludge after compression. Further looking at the composition of rice husk mixed sample, it was found that this sample had the highest content of Al_2O_3 and CaO, which have high potential of water absorption.

In comparison with the national standard for sediment quality, the presence of heavy metals was still higher than the accepted values mostly. Nevertheless, if the modified DSS is reused for making calcined brick, it is recommended to mix maximum 30% by weight of DSS with clay [7]. Thus, the heavy metals would be three times less in concentration in the final brick products, which means their presence in the bricks would be in acceptable range and cause no harm to the environment and human being.

3.5. SEM results of blended sludges

As mentioned above, selected sludge samples (good performance in MC reduction) were sent for SEM examination to see the impact of additives on dewatering.

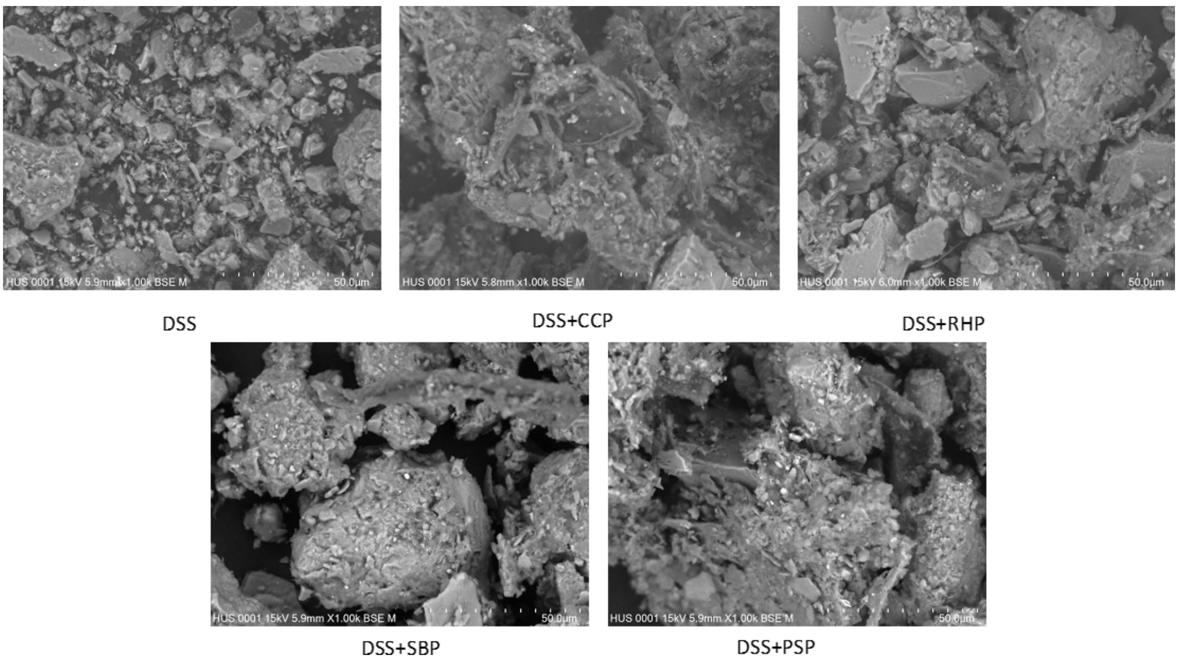


Figure 4. SEM images (magnification of 1000X) of raw and additive-blended dredged sludge from sewers (1:7 mixture ratio). DSS: Dredged sludge from sewers, CCP: Corn core powder, RHP: Rice husk powder, SBP: Sugarcane bagasse powder, PSP: Peanut shell powder

It can be seen from Fig. 4 that with the same magnification of 1000 times, the surface morphology of sludges before and after treatment was completely different. The additives seemed to bind the sludge and make many big aggregates, leaving more pores on the surface. The pores showed clearest for the case of sludge blended with sugarcane bagasse powder, followed by the ones blended with peanut shell powder and corn core powder. The surface of raw sludge was smoother with tiny particles. It was similar to the findings of Guo et al. (2019) and Xiong et al. (2018) [18, 40]. They observed small particles in the raw sludge and those tiny sludge particles became large flocs through re-agglomerate, leaving porous and rough surface with macro pores and voids in the treated sludge. The tiny particles were probably inorganic debris while the big agglomerates were mostly due to organic agro-waste additives [18]. Even though these agro-wastes were claimed to be skeleton builders and made the sludge more porous after mixing, only in this study, they can be seen clearly different performances under the same condition. Although they explained the porous surface formed channels for the outflow of the bound water from sludge, we suggested another possible mechanism, i.e. water absorption ability. Apparently that the additives have absorbed water which made the sludge drier. Bound water from the sludge solids was broken and absorbed by the additives, then released faster after compression.

3.6. Statistical analysis

This section analyzed the impact of both types of additives (corn core, rice husk, peanut shell, and sugarcane bagasse) and the mixing ratio of sludge and additives (1:3, 1:5, and 1:7) in the reduction of moisture contents (MC) after mixing and after compression. The two-way ANOVA from the software StatPlus: mac LE v7.3.31 (AnalystSoft Inc., USA) was employed for this purpose. Table 3 presents the analytical results of two-way ANOVA.

Table 3. Two-way ANOVA results (p-value, n = 26) showing the impact on MC by different additives and mixing ratios

		After mixing	After compression
General interaction			
	Type of additives (A)	0.00003	0.00853
	Mixing ratio (B)	0.26849	0.04167
	A x B	0.0044	0.01323
Detailed interaction according to the Tukey-Kramer method			
Type of additives (A)	Mixing ratio (B)		
Sugarcane bagasse	(1) vs. (2)	0.14379	0.07988
	(1) vs. (3)	0.95277	0.73252
	(2) vs. (3)	0.22817	0.02087
Peanut shell	(1) vs. (2)	0.82725	0.99931
	(1) vs. (3)	0.06475	0.57401
	(2) vs. (3)	0.02277	0.59637
Corn core	(1) vs. (2)	0.45141	0.69127
	(1) vs. (3)	0.06844	0.00669
	(2) vs. (3)	0.45141	0.02952
Rice husk	(1) vs. (2)	0.04961	0.01427
	(1) vs. (3)	0.00255	0.92317
	(2) vs. (3)	0.25190	0.02827

Note: Mixing ratio 1:3 (1); 1:5 (2) and 1:7 (3), $p < 0.05$: significant impact.

It was clearly shown in Table 3 that each factor had a significant impact on the MC either after mixing or after compression. The impact was shown the most for each additive with rice husk powder ($p < 0.05$). Specifically, different mixing ratios of rice husk with DSS would lead to a substantial reduction in MC, which confirms in Fig. 2(a) above.

4. Conclusion

It is the first time dredged sludge from sewers was evaluated in term of dewaterability upon mixing with four different agro-wastes, including rice husk, corn core, sugarcane bagasse and peanut shell. Three mixing ratios of 1:3, 1:5 and 1:7 were tried and it was found that the mixing ratio was statistically significant for the case of adding rice husk powders with MC decreasing from 45.5±4.1% to 33.9±1.5% after mixing and to 22.7±0.6% after compression. For the others, there was no proportional correlation between mixing ratio and the reduction of moisture content or heavy metal concentrations. The incorporation of these agro-waste additives also increased the organic matters in the sludge up to 40%. With the low cost in enhancing dewaterability and heavy metal reduction of the sludge, these agro-wastes, in particular rice husks, were proved to be a promising raw material for reuse as construction materials in the context of sustainable environmental protection.

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