Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879

Advanced Research in Fluid Mechanics and Thermal Sciences

Feasibility of Using Kaolin Suspension as Synthetic Sludge Sample

Open Access

Qabas Marwan Abdulazeez[1], Mohammed Saedi Jami[1,*], Md Zahangir Alam[1]

[1] Bioenvironmental Engineering Research Centre (BERC), Biotechnology Engineering Department, Faculty of Engineering, International Islamic University Malaysia (IIUM), P. O. Box 10, 50728 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 13 June 2018
Received in revised form 9 July 2018
Accepted 5 August 2018
Available online 12 August 2018

Keywords:
Activated sludge, kaolin suspension, sludge dewatering, *Moringa Oleifera*, specific resistance to filtration, sludge volume index

ABSTRACT

In this research, seven coagulants were prepared from *Moringa oleifera* (MO) seeds and tested on kaolin suspension (5% w/v) as a synthetic sludge (SSL) model. The first form was crude MO seeds powder without any treatment, while the second was defatted MO seeds powder. The third form was prepared by mixing the defatted seeds powder with distilled water for the extraction of bioactive compounds. The other coagulant forms were prepared using salts extraction (1 Molar), which were $NaNO_3$, KCl, KNO_3, and NaCl. Dewatering efficiency was evaluated through specific resistance to filtration (SRF) and supernatant turbidity measurements. The most effective coagulant was used for all comparison experiments between kaolin suspension as SSL model and real sludge (RSL) (activated sludge) in terms of flocs shapes, flocs filtration rate, sludge volume index (SVI), SRF, settled sludge volume (SSV) and pH. The results showed that the extractions by $NaNO_3$ and NaCl had the highest dewaterability compared to the other coagulant forms. Due to the availability and high efficiency of NaCl, it was selected as the primary coagulant. The results of SRF for SSL and RSL were close to each other, and both types showed a similar response to the acidic medium by increasing sludge dewaterability at pH 4. On the contrary, the SSV and SVI_{30} values for SSL were lower than RSL under the same process conditions. The filtration rate of the dewatered RSL was about twice faster than the dewatered SSL due to the different flocs sizes of RSL. It can be concluded that kaolin suspension can be used as a SSL model for specific measurements such as SRF, but it is not possible to be used for SVI_{30} or other sedimentation studies.

1. Introduction

Sludge is one of the most harmful wastes and the ultimate challenge for WWTPs due to the daily production in huge amounts. Sewerage sludge consists of various constituents; some of these constituents are pathogenic, others include organic and inorganic matters, such as potassium, nitrogen and phosphorous. Because of the various components and pathogenic content, sludge

* *Corresponding author.*
E-mail address: saedi@iium.edu.my (Mohammed Saedi Jami)

cannot be disposed directly to the environment [1]. The first step in sludge treatment is sludge thickening that increases sludge solids concentration up to 3% by water extracting [2]. The second process is sludge dewatering, which increases solids concentration up to 20% [3]. Sludge can be dewatered using chemical conditioners or mechanical force or both. Many methods have been applied to settle and separate the particles from the liquid mass, including electric field, gravity force, mechanical techniques, chemical and natural conditioners.

1.1 Why Synthetic Sludge Models?

Coagulation and sedimentation studies on sludge are usually sensitive due to the rapid change of the sludge structure during transportation and storage time. The microorganisms can cause sludge bulking and decrease the organic load, whereas total dissolved solids (TDS) and total volatile solids (TVS) can change with time. Synthetic sludge (SSL) can be prepared to simulate the actual sludge and reduce the problems of the fresh sludge. The microbial activity of real sludge (RSL) can change the sludge's characteristics, especially during storage for an extended period. The absence of microbial activities in SSL makes these samples usable for a longer time. The feature of SSL is the homogeneous sludge media that provides a constant particle ratio in sludge samples, while the ratio of the solid particles in RSL changes according to the sampling place and time.

Usually, SSL samples can be prepared in different methods, as shown in Table 1. The most common composition is sulfate polystyrene latex with distilled water as the main sludge particles. Other constituents are alginate, calcium ion ($CaCl_2$), cellulose fibers, and sodium. SSL composition can vary according to the composition of the targeted RSL. For example, Dursun and Dentel [4] and Lau *et al.,* [5] were added yeast to their SSL to simulate the microorganisms, other researchers used cellulose fibres to simulate the filamentous microorganisms. Kaolinite sludge can be prepared by adding a particular amount of kaolin suspension to distilled water [6]. The experimental success of dewatering studies depends on the similarities between the characteristics of SSL and RSL samples. These characteristics must be similar or very close to each other; otherwise, the results obtained will not be reproducible.

1.2 Moringa Oleifera (MO) as a Natural Coagulant

Sludge can be dewatered by chemical coagulants, such as ferric chloride, aluminium sulfate, and polyaluminium chloride (PAC). Some of these chemicals can cause breast cancer, brain distribution, and Alzheimer's disease [18]. The use of polymers as a sludge conditioner has less hazardous effects but expensive. Mechanical dewatering processes can dewater large amounts of sludge without hazardous impacts, but these techniques are costly and consume large amounts of energy.

Jahn *et al*., [19] showed the possible use of MO seed instead of chemical coagulants as an eco-friendly product. The coagulation activity of MO seeds refers to the availability of some cationic proteins and peptides. One of the identified peptides has a significant coagulation activity, which is called MO2.1 [20]. The active compounds of MO seeds neutralize the suspended particles and absorb them together forming settleable large-particles called flocs [21].

In this study, the most effective coagulant-form was conducted and used as a primary coagulant for the comparison study between the kaolinite SSL and the RSL samples. The comparison included flocs shapes, flocs filtration rate, sludge volume index (SVI), specific resistance to filtration (SRF), settled sludge volume (SSV), and the effect of pH variation on flocs sedimentation. The differences between these parameters will determine whether it is suitable to use the kaolinite sludge instead of RSL for sedimentation studies or it is not possible.

Table 1
Synthesis of sludge models and characterization for comparison with real sludge

No	Main sludge particles	Other constituents	Characterizations	Ref.
1	Kaolinites	clay, quartz sand	settling rate	[7]
2	Sulfate polystyrene latex particles	alginate, $CaCl_2$	SRF	[8]
3	Sulfate polystyrene latex particles	alginate, $CaCl_2$	SRF, CST, rheology, polyelectrolyte type, floc strength, average floc diameter, residual turbidity	[9]
4	Sulfate polystyrene latex particles	$CaCl_2$, alginate, cellulose fibers	CST, final interface height, turbidity, viscosity,	[10]
5	Kaolin clay slurry	NaCl, sodium alginate, $CaCl_2$	appearance, dewaterability, floc size, fractal dimensions, floc porosity, sierpinski carpet fractal dimension, fractal dimension of the pore boundaries	[11]
6	Sulfate polystyrene latex particle ($PS\text{-}SO_3H$)	calcium, alginate, fibrous cellulose,	Turbidity, TSS, Flocs size and flocs structure, flocculation dynamics	[12]
7	Sulfate polystyrene latex particles	alginate, $CaCl_2$	CST, final interface height, turbidity, SVI	[13]
8	Sulfate polystyrene latex particles	alginate, Ca (II)	CST, SVI	[14]
9	Sulfate polystyrene latex particles	alginate, Ca (II)	CST	[15]
10	Sulfate polystyrene latex particles	alginate, $CaCl_2$,	polysaccharide concentration in the supernatant	[16]
11	Synthetic gel suspension (final solids content is 10 g/L) Synthetic gel suspension (final solids content is 18 g/L)	alginate, microcrystalline cellulose, fresh yeast, calcium and potassium salts	swelling potential, shear resistance, rheology	[4]
12	Sulfate polystyrene latex particles ($PS\text{-}SO_3H$), carboxyl functional polystyrene latex particles (PS-COOH), albumin functional polystyrene latex particles (PS-Al), EPS-modified polystyrene latex particles (PS-EPS)	alginate, cellulose, $CaCl_2$	flocculation and settling characteristics	[17]
13	Biosolids (gel-like)	sodium alginate, cellulose, yeast, KCl, $CaCl_2$	CST, turbidity, electrical conductivity, zeta potential, cake solids content, particle size	[5]

2. Methodology
2.1 Materials and Equipment

MO seeds were obtained from Mito Masa Sdn. Bhd., Malaysia. The seeds with their pods were put inside small boxes and kept inside a dry room to prevent any changes in the seed characteristics. Activated sludge samples were collected from Bunus sewage treatment plants, Kuala Lumpur, Malaysia. The sludge was directly collected from the digester using a plastic container (30 L capacity). After transportation, the sludge was kept inside a cold room at 4°C and used within three days. Kaolin suspension (R&M Chemicals, UK) was used to prepare the SSL model. Hexane solvent (SYSTEM®) was used to extract the oil from the MO seeds powder, and NaCl (HmbG) was used to extract the bioactive constituents from the defatted MO seeds. Hydrochloric acid (HCl) and sodium hydroxide (NaOH) (HmbG) were used for pH calibration.

2.2 Preparation of SSL Model

The model was prepared by mixing 5 g of kaolin suspension in 1 L distilled water at 200 rpm for 10 min using a jar test apparatus to ensure the homogeneity of the sludge media [22]. The mixture gave a SSL at a solids concentration of 5% w/v. SSL sample at 5% w/v can be considered as a moderate solids concentration, which is between the activated sludge (3% w/v) and the primary sludge (above 5% w/v) [2].

2.3 Characterization of Sludge Samples

SSL and RSL samples were characterized using seven measurements: chemical oxygen demand (COD), biochemical oxygen demand (BOD), total solids (TS), total suspended solids (TSS), TDS, conductivity measurement, and pH measurement. These tests are considered as the prerequisite measurements for the wastewater treatment process. BOD, TS, and TSS were measured according to the APHA standards method [23]. COD was measured according to HACH methods. TDS and conductivity were measured by the HACH meter (sensION 7). Finally, pH readings for all sludge samples were measured using the pH meter (P8-10 SARTORIUS).

2.4 Preparing Different Forms of MO Coagulant

MO seeds were passed through a primary treatment, which included pods removing, grinding, and sieving. The oil was extracted from the shelled MO seeds powder (SMOSP) using hexane solvent by soxhlet extraction apparatus. Each 10 g of SMOSP were defatted with 170 mL of hexane for about 90 min. Then, the defatted powder was dried using an oven at a temperature of less than 50°C. Figure 1 shows the shelled seeds, seeds powder, and defatted seeds powder. The SMOSP and defatted MO seed powder (DMOSP) were used as solid forms.

(a) (b)

Fig. 1. (a) Unshelled and shelled MO seeds, (b) crude seeds powder (light brown color) and defatted seeds powder (white color)

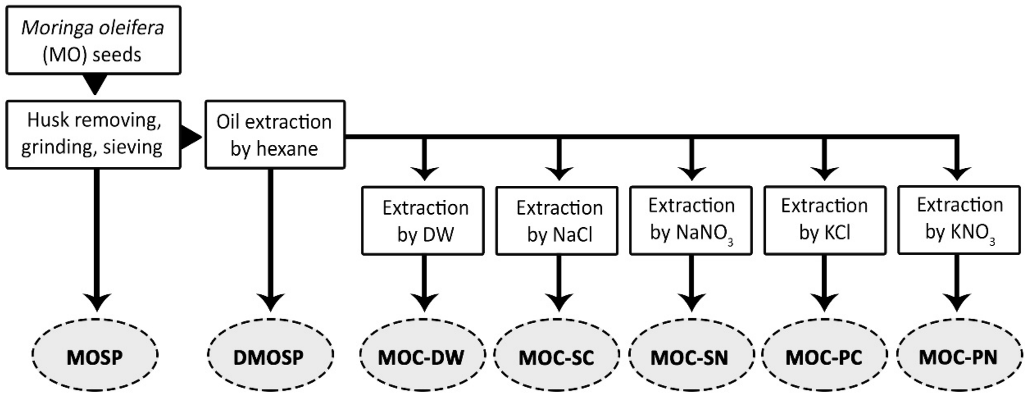


Fig. 2. Preparation of derived MO coagulants

As shown in Figure 2, five liquid coagulants were prepared from DMOSP, which were MO seed extracted by distilled water (MOC-DW), MO seed extracted by sodium chloride (MOC-SC), MO seed extracted by sodium nitrate (MOC-SN), MO seed extracted by potassium chloride (MOC-PC), and MO seed extracted by potassium nitrate (MOC-PN) (1 molar for salt extractions). During active compounds extraction, 5 g of DMOSP was mixed with 1 L of solution for 60 min using a magnetic stirrer to ensure the extraction process [24]. After each extraction process, the mixture was purified from residual MO seeds particles using vacuum filtration apparatus at 300 mmHg by passing the mixture through filtration paper (Whatman #1) [25]. The final products were kept in glass containers and used within five days to prevent the coagulation from being lost from the long storage period [26].

2.5 Determining the Most Effective Coagulant

Each coagulant was experimented using low and high dosages of 200 and 600 mg/L, respectively, and a jar test apparatus was used for mixing the coagulants with sludge for 15 min. Two mixing speeds were used, which were 125 and 40 rpm for fast and slow mixing speeds, respectively. The fast mixing speed was used to spread the coagulant rapidly into the sludge media [22]. The most effective coagulant derived from MO seeds was determined according to turbidity and SRF measurements for the dewatered sludge.

Turbidity was measured by collecting samples from the middle of the supernatant part using a long pipette. Turbidity values were measured after 120 min settling time using a laboratory turbidity meter. Each sample was measured three times, and the average value was calculated to minimize human error. Usually, SRF should be measured after complete sedimentation of the dewatered sludge flocs; therefore, the settling time for SRF measurements was determined in terms of the residual turbidity in supernatant bulk and the volume of the sedimented flocs after the dewatering process. Experiments were run using 200 and 600 mg/L of MOC-SC. The readings were recorded every 15 min, and the suitable settling time for SRF was determined after a complete flocs sedimentation [27].

SRF values were calculated by a derived equation from Darcy's law for liquids flow through porous media. From Equation (1), SRF represents the specific cake resistance (α), and the slope was calculated from plotting filtration time per filtrate volume versus filtrate volume. SRF is proportional to the pressure (ΔP) and filtration area (A), while inversely proportional to the filtrate viscosity (μ) and the mass of dry cake per filtrate volume (r). The pressure of 300 mmHg (40000 N/m^2) was applied using a vacuum filtration apparatus, and the diameter of filter medium was 90 mm [28].

SRF is an indicator for sludge dewaterability [29]. The formula used to calculate SRF was derived from Darcy's law of liquids flow through porous media:

$$\frac{1}{A}\frac{dV}{dt} = \frac{\Delta p}{\mu\, R} \tag{1}$$

where V is the filtrate volume, ΔP is vacuum pressure, and μ is the filtrate viscosity. R is the filtration resistance that consists of the resistance of the filter medium (R_m) and the resistance of the cake solids (R_c).

$$R = R_m + R_c \tag{2}$$

Specific cake resistance (α) can be found from cake resistance (R_c), as follows:

$$R_c = \alpha\, \rho \left(\frac{V}{A}\right) \tag{3}$$

where ρ is the mass of dry cake per filtrate volume, and A is the filter medium area. Substituting Equation (3) and (4) in Equation (2):

$$\frac{1}{A}\frac{dV}{dt} = \frac{\Delta p}{\mu\left[R_m + \alpha\, \rho\left(\frac{V}{A}\right)\right]} \tag{4}$$

Integration of the equation from the time of zero

$$\frac{t}{V/A} = \frac{\mu\, \alpha\, \rho}{2\Delta p}\,(V/A) + \frac{\mu\, R_m}{\Delta p} \tag{5}$$

The resistance of the filter medium R_m is assumed to be negligible [30]. The equation can be arranged as follows:

$$\frac{t}{V^2} = \frac{\mu\, \alpha \rho}{2\Delta p\, A^2} \tag{6}$$

The slope of filtration time per filtrate volume (t/V) versus filtrate volume (V) represents the right term of Equation (6). The slope can be calculated as shown in Figure 3. The specific resistance to filtration (SRF) which represents the specific cake resistance (α) can be calculated from the equation below:

$$SRF = \alpha = \frac{slope\ 2\Delta p\ A^2}{\mu\rho} \tag{7}$$

The value of Δp was fixed at 300 mmHg using vacuum filtration. The filter medium area A is 90 mm^2, and μ values were determined using a viscometer [25].

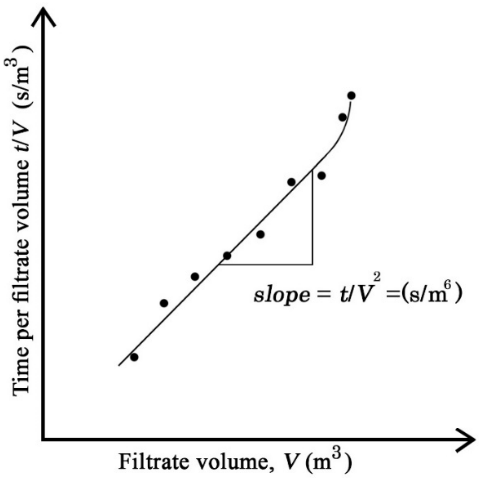


Fig. 3. Plot of filtration time per filtrate volume versus filtrate volume

2.6 Comparison between RSL and SSL Model

SRF values were calculated using Equation 7 for both synthetic and real sludge. Sludge volume index (SVI) is "the volume in milliliters occupied by 1 g of a suspension after 30 min settling" [23]. SVI can be calculated from Equation 8:

$$\text{SVI (mL/g)} = \frac{\text{Settled sludge volume (mL/L)} \times 1000}{\text{Suspended solids (mg/L)}} \quad (8)$$

SRF and SVI values were determined by preparing five samples of SSL and comparing with five RSL samples. Each type was dewatered using MO seed extract at dosages of 200, 400, 600, 800, and 1000 mg/L. SVI values were measured after 30 min of settling process using cylinder beakers of 1 L. The One-Factor-At-a-Time (OFAT) method was used to determine the values of mixing speed, settling time, and mixing time for each type of sludge.

The relationship between flocs size and filtration speed was studied. Two samples of SSL and RSL were prepared and dewatered using 300 mg/L of MO as a conditioner. The filtration rates for both types of sludge were measured by recording the filtrate volume every minute under a vacuum pressure of 300 mmHg. Then, a plot of filtrate volume (mL, y-axis) versus time (min, x-axis) was used to estimate the filtration rate (mL/min) which is the same value of the slope. After filtration rate experiments, the cake on the filter paper (Whatman no.1) was collected and monitored by microscope (Olympus brand) at a 4x objective lens. The images show the differences of the flocs shapes and sizes between RSL and SSL.

The SSV was determined by dewatering sludge with five MO dosages of 200, 400, 600, 800, 1000 mg/L. Settling time was fixed at 4 hrs (according to OFAT results for the RSL) and pH was fixed at 7. Mixing speed and mixing time used were the same values of the previous experiments. The effect of pH on flocs sedimentation was studied using four samples of each type of sludge. The pH values of each sample were 4, 6, 8, and 10, respectively. The pH was calibrated by HCl and NaOH using a laboratory pH meter.

3. Results

The results of sludge characterization are shown in Table 2. Generally, the indicators were different between both types of sludge, and these differences led to different dewatering efficiencies. The BOD value of 566.4 mg/L indicated high amounts of anaerobic bacteria and the huge organic load of RSL sample.

Table 2
Real and Synthetic sludge characterizations

Indicator type	Synthetic sludge	Real sludge
COD (mg/L)	50	1430
BOD (mg/L)	-	566.4
conductivity (ms/cm)	0.269	4.8
pH	8	7.2
TS (mg/L)	4968	3127
TSS (mg/L)	4952	2300
TDS (mg/L)	0.125	1520

3.1 The Most Effective MO-Coagulant Form

The SRF settling time was set to be 120 min for all experiments. As shown in Figure 4 and Figure 5, a settling time less than 120 min would give poor characteristics of sedimented flocs, while a settling time of more than 120 min would not significantly change the sedimented flocs volume. Settling time of SRF measurement is different according to sludge type and wastewater treatment specifications. The long settling time requires a longer detention period in the sedimentation tanks which needs bigger or multiple sedimentation tanks. Guo *et al.*, [27] selected the settling time for SRF measurements to be 120 min, and the experiments were tested on an oily sludge from a flotation process.

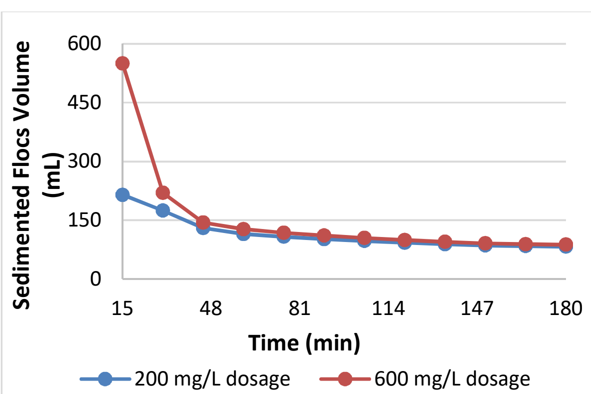


Fig. 4. Sedimented flocs volume during time

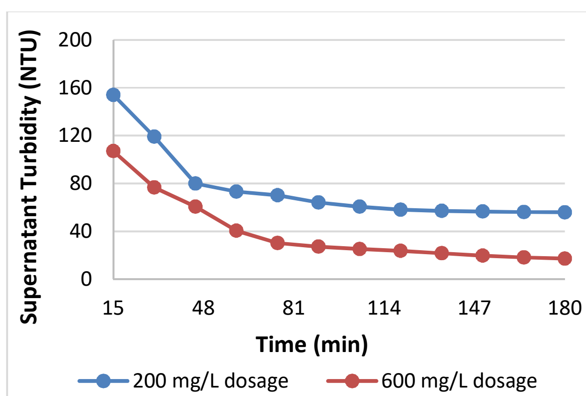


Fig. 5. Supernatant turbidity versus time

The dewatering by MOC-DW did not show any coagulability using both dosages of 200 and 600 mg/L. The use of MO seed powder (MOSP) and DMOSP for kaolinite sludge dewatering were recorded low coagulability, as shown in Table 3. In general, the dewatering by salts extractions showed higher coagulability compared to the previous forms.

Table 3
Supernatant turbidity and SRF for MOSP, DMOSP, and MOC-DW

	Supernatant turbidity (NTU)		SRF x10^{11} (m/kg)	
Dosage (mg/L)	200	600	200	600
MOSP	2900	≈ 950	-	-
DMOSP	2900	150	-	2.54
MOC-DW	2900	2900	-	-

The dewaterability of all MO coagulants was increased with the increase of the dosage. From Figure 6 and Figure 7, the highest dewaterability was recorded using MOC-SN and MOC-SC. MOC-SN recorded supernatant turbidity of 29.3 NTU and SRF of 1.06x10^{11} mg/L at 600 mg/L dosage, same SRF value was obtained with MOC-SC using the same dosage and supernatant turbidity of 31 NTU. Due to the availability and high efficiency of NaCl, MOC-SC was selected as the primary coagulant.

The values of SRF change according to the coagulant dosage and sludge type used in dewatering experiments. The current study recorded SRF of 1.06x10^{11} mg/L at 600 mg/L dosage of MOC-SC. A similar study by Wai *et al.,* [31] compared the dewaterability of MOSP, MOC-DW, and MOC-SC on activated sludge. The researchers found that the optimum dosage of MOC-SC was 7000 mg/L with 2.62x10^{10} m/kg SRF. The sludge type used was activated sludge at total solids (TS) of 7.7 g/L. Comparing the activated sludge with the kaolinite sludge, the first type had higher TS and different solids size. These characteristics can affect the filtration speed and the sedimented flocs density. Although the kaolinite sludge is different from RSL sample, the first type can give constant results due to the fixed solids concentration and the homogeneous medium, therefore, it is more desirable in comparison studies.

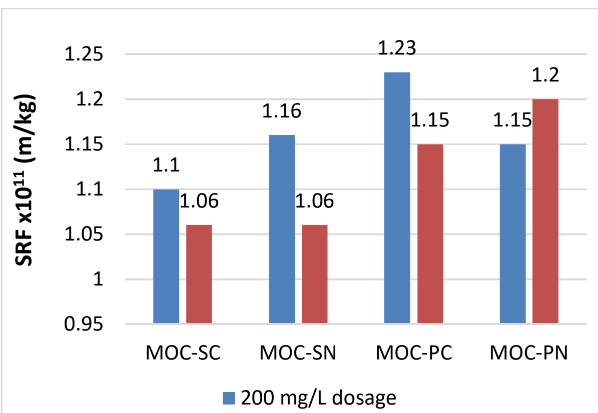


Fig. 6. Effect of coagulant type on SRF

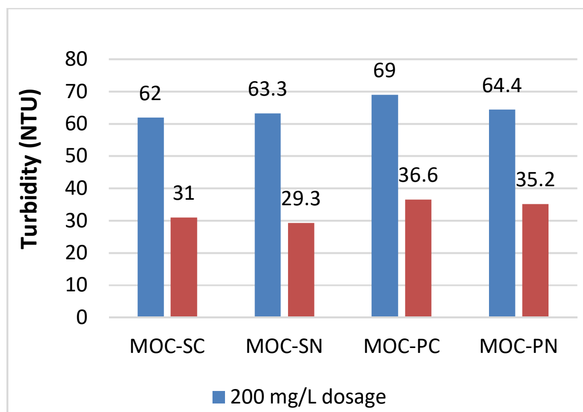


Fig. 7. Effect of coagulant type on supernatant turbidity

3.2 Comparison between RSL and SSL Model
3.2.1 The difference between SVI and SRF

According to OFAT, the values of mixing speed, settling time, and mixing time are 40 rpm, 2 hrs, 15 min, respectively, for SSL, and 140 rpm, 4 hrs, 60 min, respectively, for RSL. SVI_{30} values for RSL were higher than the SVI_{30} for SSL under all MO dosages, as shown in Figure 8. SVI_{30} for RSL decreased from 328.6 mL/g at 200 mg/L of MO dosage down to 274.6 mL/g at 1000 mg/L of MO dosage. The increase of MO dosage can improve the sedimentation and compression of the sedimented flocs process. Contrary to RSL, the SVI_{30} for SSL increased from 38.1 mL/g at 200 mg/L of MO dosage up to

118.5 mL/g at 1000 mg/L of MO dosage. The increase of MO dosage for SSL dewatering can decrease the sedimentation properties of the flocs. To conclude, kaolin suspension cannot be used as a sludge model during SVI_{30} measurements. OFAT results showed that RSL needed sedimentation time of 4 hrs, while in SVI_{30} measurement, the sedimentation time was only 30 min. Inversely, SSL can be settled within 30 min only.

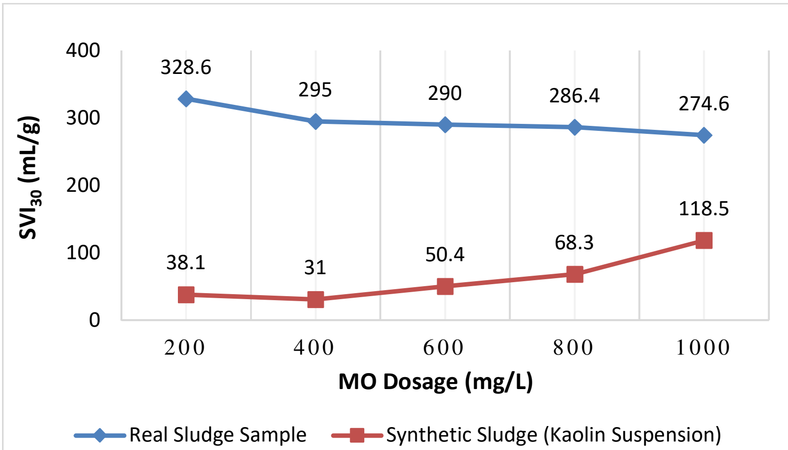


Fig. 8. SVI_{30} for RSL and SSL under different MO dosages

The results showed that SSL can be used successfully as a sludge model through the SRF measurement. The obtained SRF values for SSL and RSL were close to each other, as shown in Figure 9. The nearest SRF values were at 600 mg/L MO dosage, which was 2.2×10^{11} m/kg and 2.1×10^{11} m/kg for SSL and RSL, respectively. SRF for SSL was increased with the increase of MO dosage from 1.6×10^{11} m/kg at 200 mg/L to 3.7×10^{11} m/kg at 1000 mg/L. A study by Abdulazeez *et al.*, [25] also reported the increase of SRF of SSL at high MO dosages. SVI_{30} also increased during the high MO dosage, indicating low dewaterability of SSL at high MO dosages. From the OFAT results, the SRF values were measured after a settling time of 2 hrs for SSL, and 4 hrs for RSL sample which gave a better opportunity for RSL flocs to be settled. Results of SVI and SRF showed that RSL dewaterability increased with the increase of MO dosage.

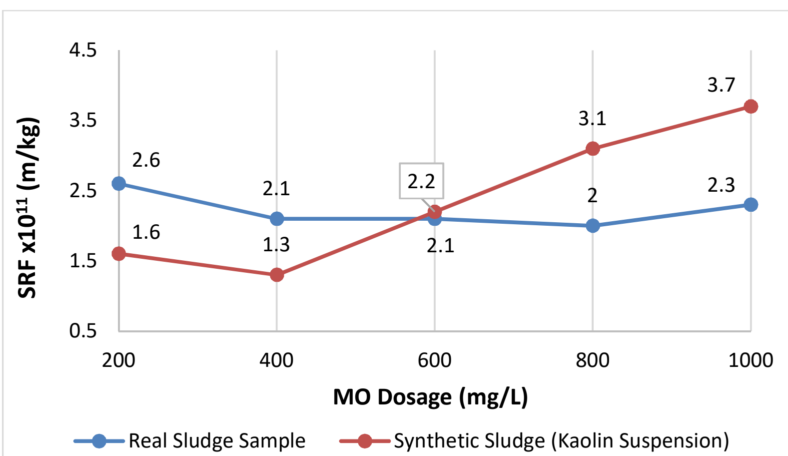


Fig. 9. SRF for RSL and SSL under different MO dosages

A study by Muyibi *et al.*, [32] used MO seeds powder at high dosages for activated sludge dewatering. SRF value was 4.45×10^{12} m/kg for MO dosage of 1000 mg/L, which was much higher than the result of the current study (2.3×10^{12} m/kg at 1000 mg/L dosage). The MO used in the previous study was untreated MO seeds powder, while the current study it is defatted MO seed extract by NaCl. The difference of SRF values between the two studies shows the high dewaterability effect of the defatted MO seed extract.

3.2.2 Flocs shapes and filtration rate

Although the flocs of RSL had lower density and settling velocity compared to SSL, the flocs size of RSL gives a faster filtration rate. Because of the homogeneous particles of SSL medium, the flocculation process will produce similar flocs size. As shown in the proposed mechanism of Figure 10, the small flocs with the same size will limit the filtration rate and quickly block the pores of the filter paper, while the different floc sizes produced from RSL will give a faster filtration rate. Figure 11 shows the flocs of RSL and SSL under the microscope.

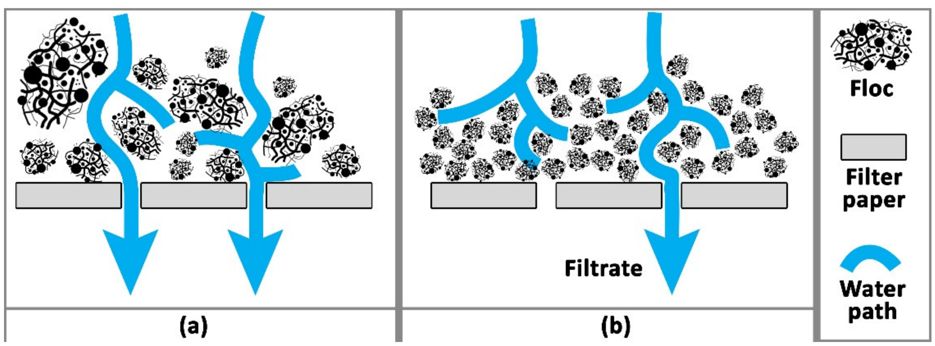
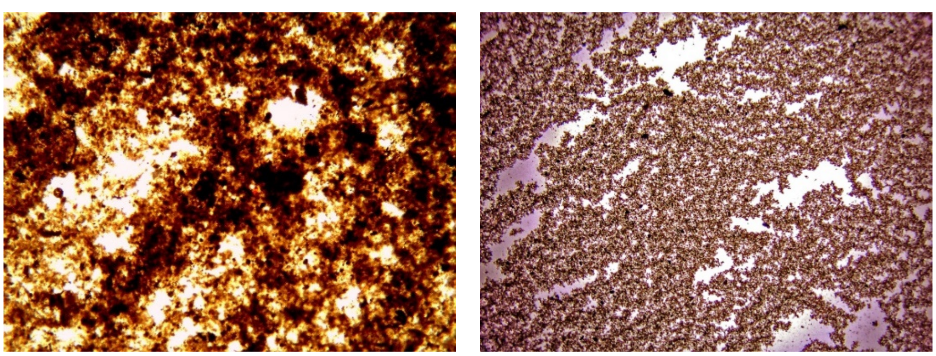


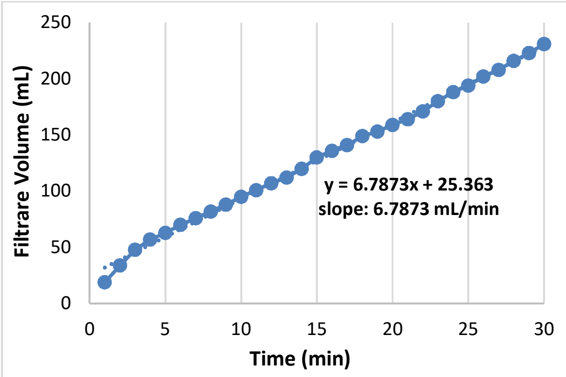
Fig. 10. Proposed mechanism of (a) filtration through different flocs sizes (RSL), (b) filtration through small homogeneous flocs (SSL)



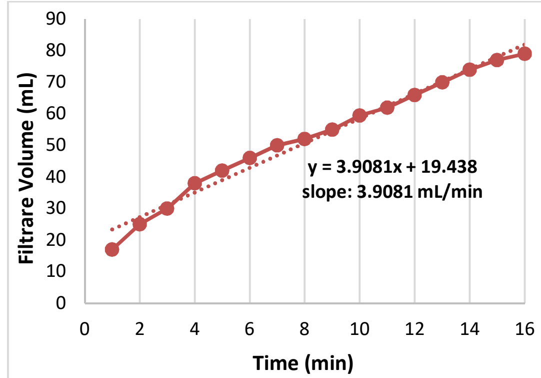
(a) (b)

Fig. 11. Under microscopic (4x): (a) RSL flocs, (b) SSL flocs

The filtration rates of RSL and SSL samples are shown in Figure 12. The slope of the trend line represented the filtration rate measured in mL/min. Comparing the two filtration rates, RSL sample had a filtration rate of 6.7873 mL/min, which was faster than the filtration rate of 3.9081 mL/min for SSL. After flocculation and sedimentation processes, mechanical dewatering will eliminate more water from the sedimented flocs. Flocs with high filterability will minimize the cost of mechanical dewatering and reduce the burning fuel when using the sludge burning technique [33].



(a)



(b)

Fig. 12. Filtration rate for (a) RSL, (b) SSL model

3.2.3 Effect of dose and pH on SSV

SSV is a very important parameter to differentiate between the desirable and undesirable flocs. A good dewatering process with high sedimentation ability can produce a concentrated mass of flocs, thus, the cost of the next step (mechanical dewatering) will be lower. Figure 13 shows that SSL produced a smaller volume of SSV compared to RSL at all MO dosages. The volume of RSL flocs decreased significantly to 262 mL with the increase of MO dosage to 1000 mg/L. The increasing flocs volume indicates that RSL needs higher MO dosages than SSL. Figure 14 shows SSV for RSL and SSL after 3 hrs settling time.

Although the process conditions of the experiments were constant, the change of pH values gave considerable results regarding SSV for both SSL and RSL. When the pH value changed from 10 to 4, SSV decreased from 416 mL to 326 mL for RSL, and from 90 mL to 70 mL for SSL, as shown in Figure 15. The cations released from using HCl for pH calibration contributed in the coagulation process alongside the MO extract [34].

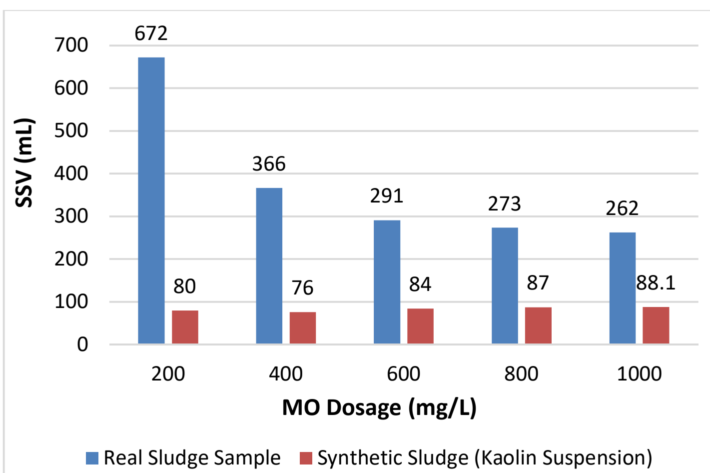


Fig. 13. The effect of MO dosage on SSV


(A) (B) (C)

Fig. 14. SSV of: (a) RSL control, (b) dewatered RSL, (c) dewatered SSL

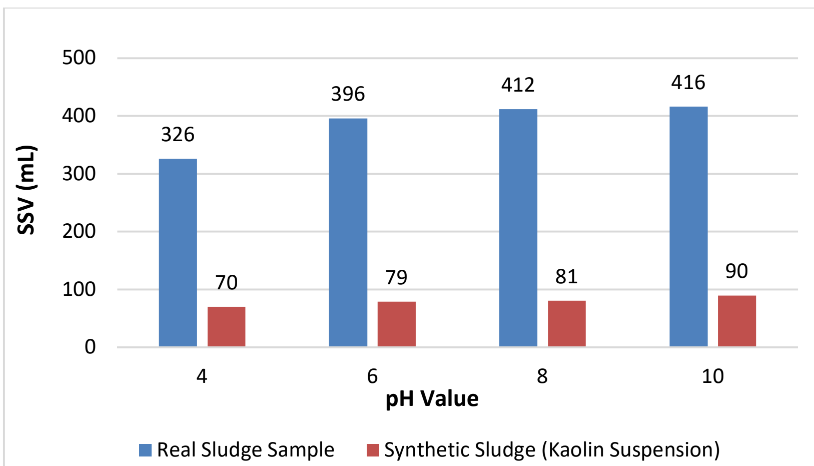


Fig. 15. The effect of pH on SSV

4. Conclusions

The dewaterability of MOC-SC and MOC-SN was higher than MOC-PC and MOC-PN, and all these coagulants were more effective than the un-extracted salts coagulants. The extraction of active compounds by salts led to the salt-in mechanism, which increases protein-protein dissociation and increases the protein solubility due to the ionic strength of the salts. Because of the availability and high efficiency of NaCl, MOC-SC was selected as the primary coagulant for the comparison study. It was obvious that kaolin suspension cannot be used as a sludge model for all measurements. In general, RSL samples required more coagulant dosage, faster-mixing speed, and longer mixing time compared to SSL model. The SSV and SVI_{30} for SSL was much smaller than RSL under the same process conditions. The filtration rate of the dewatered RSL was about twice faster than the dewatered SSL due to the different flocs sizes for the RSL flocs. On the other hand, SRF results showed that SSL can be used as a sludge model because SRF values were similar for both types of sludge. In addition, both sludge types showed the same action by increasing the dewaterability at acidic medium. It is necessary to synthesize the sludge model for coagulation-flocculation and sedimentation studies.

The sludge model should be similar or close enough to RSL in terms of organic and inorganic components, TS, TSS, TDS, conductivity, and pH. Thus, the results obtained from the SSL model can be comparable to the results of RSL.

Acknowledgement
This work was partially supported by International Islamic University Malaysia, (RIGS 16-075-0239) from Ministry of Higher Education of Malaysia.

References

[1] Usman, Khalid, Sarfaraz Khan, Said Ghulam, Muhammad Umar Khan, Niamatullah Khan, Muhammad Anwar Khan, and Shad Khan Khalil. "Sewage sludge: an important biological resource for sustainable agriculture and its environmental implications." *American Journal of Plant Sciences* 3, no. 12 (2012): 1708.
[2] Turovskiy, Izrail S., and P. K. Mathai. *Wastewater sludge processing*. John Wiley & Sons, 2006.
[3] Stefanakis, Alexandros, Christos S. Akratos, and Vassilios A. Tsihrintzis. 2014. "General Aspects of Sludge Management." *In Vertical Flow Constructed Wetlands: Eco-Engineering Systems for Wastewater and Sludge Treatment*, 1st ed., 181–89. Elsevier Inc.
[4] Dursun, Derya, and Steven K. Dentel. "Biosolids as Gels: A New Way of Looking at Conditioning and Dewatering." *Proceedings of the Water Environment Federation* 2008, no. 11 (2008): 4713-4724.
[5] Lau, Shiew Wei, Tushar Kanti Sen, Han Bing Chua, and Ha Ming Ang. "Conditioning of synthetic sludge and anaerobically digested sludge using chitosan, organic polyelectrolytes and inorganic metal cations to enhance sludge dewaterability." *Water, Air, & Soil Pollution* 228, no. 9 (2017): 358.
[6] Jami, Mohammed Saedi, Mohd Arif, Aysha Ralliya, and Qabas Marwan Abdulazeez. "Investigation of bioflocculant as renewable dewatering aid in sludge treatment." (2016): 270-273.
[7] Babchin, A., V. Reitman, and K. Rispler. "Settling Of Synthetic Sludges And Koalinites." In *Annual Technical Meeting*. Petroleum Society of Canada, 1991.
[8] Sanin, F. Dilek, and P. Aarne Vesilind. "Synthetic sludge: a physical/chemical model in understanding bioflocculation." *Water environment research* 68, no. 5 (1996): 927-933.
[9] Sanin, F. Dilek, and P. Aarne Vesilind. "A comparison of physical properties of synthetic sludge with activated sludge." *Water environment research* 71, no. 2 (1999): 191-196.
[10] Örmeci, Banu, and P. Aarne Vesilind. "Development of an improved synthetic sludge: a possible surrogate for studying activated sludge dewatering characteristics." *Water Research*34, no. 4 (2000): 1069-1078.
[11] Chu, C. P., and D. J. Lee. "Comparison of dewaterability and floc structure of synthetic sludge with activated sludge." *Environmental technology* 26, no. 1 (2005): 1-10.
[12] Nguyen, Tan Phong, Nicholas P. Hankins, and Nidal Hilal. "Effect of chemical composition on the flocculation dynamics of latex-based synthetic activated sludge." *Journal of hazardous materials* 139, no. 2 (2007): 265-274.
[13] Nguyen, Tan Phong, Nicholas P. Hankins, and Nidal Hilal. "A comparative study of the flocculation behaviour and final properties of synthetic and activated sludge in wastewater treatment." *Desalination* 204, no. 1-3 (2007): 277-295.
[14] Nguyen, Tan Phong, Nidal Hilal, Nicholas P. Hankins, and John T. Novak. "Characterization of synthetic and activated sludge and conditioning with cationic polyelectrolytes." *Desalination* 227, no. 1-3 (2008): 103-110.
[15] Nguyen, Tan Phong, Nidal Hilal, Nicholas P. Hankins, and John T. Novak. "Determination of the effect of cations and cationic polyelectrolytes on the characteristics and final properties of synthetic and activated sludge." *Desalination*222, no. 1-3 (2008): 307-317.
[16] Nguyen, Tan Phong, Nidal Hilal, Nicholas P. Hankins, and John T. Novak. "The relationship between cation ions and polysaccharide on the floc formation of synthetic and activated sludge." *Desalination* 227, no. 1-3 (2008): 94-102.
[17] Wang, Ling-Ling, Shan Chen, Hai-Ting Zheng, Guo-Qing Sheng, Zhi-Jun Wang, Wen-Wei Li, and Han-Qing Yu. "A new polystyrene-latex-based and EPS-containing synthetic sludge." *Frontiers of Environmental Science & Engineering* 6, no. 1 (2012): 131-139.
[18] Nansubuga, Irene, Noble Banadda, Mohammed Babu, Willy Verstraete, and Tom Van de Wiele. "Effect of polyaluminium chloride water treatment sludge on effluent quality of domestic wastewater treatment." *African Journal of Environmental Science and Technology* 7, no. 4 (2013): 145-152.
[19] Jahn, S. Al A., and H. A. M. I. D. Dirar. "Studies on natural water coagulants in the Sudan, with special reference to Moringa oleifera seeds." *Water Sa* 5, no. 2 (1979): 90-97.
[20] Kansal, Sushil Kumar, and Amit Kumari. "Potential of M. oleifera for the treatment of water and wastewater." *Chemical reviews* 114, no. 9 (2014): 4993-5010.

[21] Mohamed, Radin, Radin Maya Saphira, A. Ibrahim Kutty, Nadira Mariam, Mohd Kassim, and Amir Hashim. "Efficiency of using commercial and natural coagulants in treating car wash wastewater treatment." *Australian Journal of Basic and Applied Sciences* 8, no. 16 (2014): 227-234.

[22] Abdulazeez, Qabas Marwan, Mohammed Saedi Jami, Md Zahangir Alam, and Masashi Iwata. "Analysis of the Efficiency of Sludge Dewatering Using Moringa oleifera as Natural Phytocoagulant." *Int. J. Res. Chem. Metall. Civ. Eng* 2, no. 2 (2015): 111-117.

[23] American Public Health Association (APHA). 1999. “Standard Methods for the Examination of Water and Wastewater.” Washington DC.

[24] Tat, Wai Kien, Azni Idris, Megat Johari Megat Mohd Noor, Thamer A. Mohamed, Abdul Halim Ghazali, and Suleyman A. Muyibi. "Optimization study on sewage sludge conditioning using Moringa oleifera seeds." *Desalination and water treatment* 16, no. 1-3 (2010): 402-410.

[25] Abdulazeez, Qabas Marwan, Mohammed Saedi Jami, and Md Zahangir Alam. "Effective sludge dewatering using Moringa oleifera seed extract combined with aluminium sulfate." (2006).

[26] Katayon, S., M. J Megat Mohd Noor, M. Asma, L. A Abdul Ghani, A. M. Thamer, I. Azni, J. Ahmad, B. C. Khor, and A. M. Suleyman. 2006. “Effects of Storage Conditions of *Moringa oleifera* Seeds on Its Performance in Coagulation.” *Bioresource Technology* 97 (13): 1455–60.

[27] Guo, Shuhai, Gang Li, Jiuhui Qu, and Xilin Liu. "Improvement of acidification on dewaterability of oily sludge from flotation." *Chemical engineering journal* 168, no. 2 (2011): 746-751.

[28] Harrison, Roger G., Paul Todd, Scott R. Rudge, and Demetri P. Petrides. *Bioseparations science and engineering*. Topics in Chemical Engineering, 2015.

[29] Zhou, Jun, Fenwu Liu, and Chengyi Pan. "Effects of cationic polyacrylamide characteristics on sewage sludge dewatering and moisture evaporation." *PloS one* 9, no. 5 (2014): e98159.

[30] Fanun, Monzer, ed. *The role of colloidal systems in environmental protection*. Elsevier, 2014.

[31] Wai, Kien Tat, Azni Idris, Megat Mohd Noor Megat Johari, Thamer A. Mohammad, Abdul Halim Ghazali, and Suleyman A. Muyibi. "Evaluation on different forms of Moringa oleifera seeds dosing on sewage sludge conditioning." *Desalination and Water Treatment* 10, no. 1-3 (2009): 87-94.

[32] Muyibi, Suleyman Aremu, Megat Johari Megat Mohd Noor, Ding Tai Ong, and Khor Woon Kai. "Moringa oleifera seeds as a flocculant in waste sludge treatment." *International journal of environmental studies* 58, no. 2 (2001): 185-195.

[33] Henderson, J P, and J W Heinecke. 2003. “Waste Water Treatment and Reuse in the Mediterranean Region.” In The Handbook of Environmental Chemistry, edited by Damia Barcelo and Mira Petrovic, 3:201–14. Springer.

[34] Martínez-Quiroz, Marisela, Eduardo A. López-Maldonado, Adrián Ochoa-Terán, Mercedes T. Oropeza-Guzman, Georgina E. Pina-Luis, and José Zeferino-Ramírez. "Innovative uses of carbamoyl benzoic acids in coagulation-flocculation’s processes of wastewater." *Chemical Engineering Journal* 307 (2017): 981-988.