Feasibility Study to Retrofit Existing Rotary Drum into A Chemical Sludge Thermal Dewatering System Through Lab-Scale Experimental Investigations

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Abstract. The adoption of the landfill method for chemical sludge management is an issue of concern as landfill leachates can cause negative impacts on the environment. Furthermore, the high moisture content in chemical sludge has resulted in higher disposal costs due to its heavyweight. This research study is conducted to determine the optimum thermal dewatering condition for chemical sludge through experimental testing and thereafter deduce a recommendation to retrofit an existing rotary drum for chemical sludge dewatering. The water removal rate from chemical sludge was evaluated through thermal dewatering experiments using a lab-scale furnace. Referring to results obtained, increased dewatering temperature and dewatering time, and decreased volume of chemical sludge has improved the water removal rate. The highest water removal rate is 82% when 1.0 cm³ chemical sludge sample is dewatered under a temperature of 250°C for 90.0 min. Based on the economic evaluation between current chemical sludge handling and newly installed rotary drum dewatering methods, an estimate of one hundred and fifty-four thousand Malaysian Ringgit in annual net-saving is expected to be achieved through dewatering of chemical sludge in retrofitted equipment. The finding has justified the feasibility of retrofitting the current rotary drum for chemical sludge dewatering.

1. Introduction

In the oleochemical industry, the significant amounts of chemical sludges generated from wastewater treatment plant (WWTP) have drawn attention in recent years. The sludge handling, transportation, and disposal costs have resulted in economic and environmental issues. Based on a study from Rajkumar et al. [1], approximately 1200 tons of chemical sludges were generated from 19 oleochemical plants in a month in Malaysia. Therefore, it can be deduced that an average of 63 tons of
chemical sludges was generated from one oleochemical plant in a month. Generally, filter press equipment was introduced in the final sludge treatment process to reduce the moisture content of the chemical sludge due to low energy consumption and simple operation [2]. However, an estimate of 70% of moisture content in wet basis (MCwb) have remained in the chemical sludge [3]. The costs for disposal of sludge in a secured landfill are estimated at five hundred Malaysian Ringgit per tonne of chemical sludge according to the scheduled waste management company in Malaysia [4]. The higher MCwb in the chemical sludge has resulted in higher sludge disposal costs as the calculation is based on the weight of the chemical sludge. Other relevant factors such as operating expenditure (OPEX), amount of vapor emission, and dewatering rates are taken into consideration when determining the best practice of the sludge dewatering process. In this research paper, a lab-scale furnace is adopted for the dewatering of chemical sludge. Despite the OPEX and energy consumption in thermal dewatering of chemical sludge is relatively high as compared to other dewatering methods, thermal dewatering is still favorable as it could be achieved with a value which is lesser than 10% in MCwb and thus minimize the sludge handling and disposal costs. Precedent studies have demonstrated the impact of the thermal dewatering method in sludge pre-treatment after mechanical dewatering from filter press equipment.

Aside from achieving low MCwb in sludge, the thermal dewatering method has significantly reduced the costs for sludge handling, transportation, and disposal. The disposal costs are reduced due to a reduction in weight and volume of chemical sludge through the evaporation of water. Besides, the elimination of MCwb has enhanced the calorific value and combustibility of sludge. Thus, the dewatered sludge could be utilized as an alternative fuel in a coal-fired power plant. Despite the thermal dewatering method was well employed in chemical sludge dewatering, factors such as physicochemical properties of chemical sludge and operating conditions are the main concern as it could strongly affect the thermal dewatering efficiency. There are two different types of sludges generated from WWTP, which are biological sludge and chemical sludge. The type of sludge generated was depending on the type of wastewater treatment process used in WWTP. For instance, the biological sludge and chemical sludge are generated from activated sludge process and chemical coagulation treatment process respectively. The biological sludge is declared as a non-schedule waste by Department of Environment (DOE) Malaysia [5]. Thus, it could be utilised as alternative fertilizer for agricultural used [6]. For the chemical sludge disposal, a pre-treatment and the landfill methods are currently adopted by schedule waste management company Malaysia.

An industrial collaborator has an idling rotary drum waste treatment system that was previously used to treat liquid residuals from oleochemical processes. The rotary drum was operated at vacuum to slightly positive pressure and temperature of 400°C to 600°C with a capacity of 2 tonnes per day. The rotary drum is heated externally. Since the rotary drum can perform thermal treatment with such temperature conditions, the industrial collaborator has proposed to retrofit existing unit operation for thermal dewatering of chemical sludge. They provided the chemical sludge samples and analysis.

The research aims to determine the optimum thermal dewatering condition for chemical sludge dewatering using rotary drum thermal dewatering system. Moreover, this research was also conducted to investigate the effect of different dewatering temperatures (T), different dewatering retention times (t), and different volume of chemical sludge (V) on thermal dewatering efficiency of chemical sludge in a lab-scale furnace. The MCwb equation in wet basis was introduced to illustrate the dewatering effects of chemical sludge.

2. Methodology

2.1. Material

The chemical sludge samples were collected from oleochemical manufacturing plant in Klang (2°58'41.9"N 101°20'00.1"E, Pulau Indah, Selangor, Malaysia). These chemical sludges consist approximately 70% of MCwb.
2.2. Determination of weight loss
Furnace (Carbolite, ELF 11/6, UK) was adopted to dewater chemical sludge. The initial and final mass of the chemical sludge were measured using a Mettler Toledo electronic balance (Model ME203, Germany). Equation (1) was used to calculate the percentage of weight loss in chemical sludge.

\[ W_l = \frac{(W_i - W_f)}{W_i} \times 100\% \] (1)

where \( W_l \) = Percentage of weight loss in chemical sludge, \( W_i \) = Initial weight of chemical sludge, \( W_f \) = final weight of chemical sludge.

2.3. Experimental design (Lab-Scale)
Chemical sludge samples with different volumes were prepared by cutting into several dimension such as 1.0 cm x 1.0 cm x 1.0 cm, 2.0 cm x 2.0 cm x 1.0 cm, and 3.0 cm x 3.0 cm x 1.0 cm with a stainless steel knife and the dimension is measured with a ruler. The dimension of the chemical sludge samples are presented as Length x Width x Height. These chemical sludge samples were then placed on a white tile and dewatered in the furnace with temperatures of 150°C, 200°C, and 250°C. During thermal dewatering, the samples were removed at intervals of 30.0 min and weighed before returned into the furnace. The weight differences of chemical sludge samples after dewatering for 90.0 min in the furnace was recorded using the electronic balance. Parameters such as volume of chemical sludges, dewatering temperature, and dewatering time were evaluated in this experiment as such parameters could strongly affect the water evaporation rates and thermal dewatering efficiency. All the lab experiments were performed in triplicated. The initial and final characteristics of the chemical sludge were captured using an Iphone camera (Model XR, China).

2.4. Experimental optimisation
Process optimisation for thermal dewatering of chemical sludge in rotary drum thermal dewatering system was performed using Minitab Software (Version 18). Response Surface Methodology (RSM) was applied to determine the optimum thermal dewatering condition for chemical sludge dewatering using rotary drum thermal dewatering system. The experiment was conducted by altering different conditions for thermal dewatering of chemical sludge in lab scale furnace. The developed models were validated through triplicating the experiments under optimised parameters where a total of 81 sets experiments were conducted. The average experimental results were presented as mean. This procedure is vital to enhance the accuracy of the optimised parameters. Parameters such as capital expenditure required to retrofit existing unit operation, annual pay for chemical sludge disposal, annual utilities cost, annual gross-saving, and annual net-saving that could be achieved from this project were calculated during economic evaluation. Ultimately, the return on investment (ROI) and the breakeven point of this project were calculated to justify the feasibility of this project.

3. Results and Discussions

3.1. Effect of dewatering temperature on thermal dewatering efficiency of chemical sludge
Table 1 demonstrates the percentage of weight loss in a 9.0 cm³ chemical sludge sample when dewatering at different temperatures. In this experiment, the dewatering temperature was set at 150°C, 200°C, and 250°C. Referring to table 1, it can be seen that dewatering temperature has an important effect on the percentage of weight loss in chemical sludge. The highest percentage of weight loss found in the chemical sludge sample with a volume of 9.0 cm³ was 13% when dewatered under a dewatering temperature of 150°C for 30 min. When the dewatering time has prolonged from 30 min to 90 min, 46% of the total weight of the chemical sludge sample was reduced. When the dewatering temperature further increased to 200°C and 250°C, the percentage of weight loss increased to 65% and 76% respectively to thermal dewatering time of 90 min. The results have shown a relationship where
the percentage of weight loss in chemical sludge is directly proportional to higher dewatering temperature. This relationship was due to the large temperature differences between the hot gas and chemical sludge sample. Therefore, such a phenomenon has enhanced the heat transfer between the hot gas and chemical sludge samples and thus increasing the percentage of weight loss in the chemical sludge sample. The results obtained in this experiment were shown to be similar to Han et al. [7] and the relationship between dewatering temperature and thermal dewatering efficiency was justified.

**Table 1.** Percentage of weight loss in 9.0 cm³ chemical sludge sample when thermal dewatered under different furnace dewatering condition.

| Temperature, (°C) | Time, (min) | Percentage of weight loss, (%) |
|-------------------|-------------|--------------------------------|
| 150               | 30.0        | 13.48                          |
|                   | 60.0        | 32.59                          |
|                   | 90.0        | 46.11                          |
| 200               | 30.0        | 35.87                          |
|                   | 60.0        | 58.95                          |
|                   | 90.0        | 65.09                          |
| 250               | 30.0        | 47.08                          |
|                   | 60.0        | 68.88                          |
|                   | 90.0        | 76.14                          |

3.2. **Effect of thermal dewatering on physical properties of chemical sludge**

The effect of thermal dewatering on the physical properties of chemical sludge is observed and demonstrated in table 2 when a chemical sludge sample with a volume of 9.0 cm³ was dewatered with a dewatering temperature of 250°C for 90 min. The changes in the physical appearance of 9.0 cm³ chemical sludge samples in every 30 min were captured using the iPhone camera (Model XR, China).

Referring to table 2, the volume of the chemical sludge sample was reduced and shrunk heterogeneously with respect to longer dewatering time. The effect of shrinking in the volume of chemical sludge samples during thermal dewatering has demonstrated a reduction in the overall weight of chemical sludge. Moreover, the physical appearance of the chemical sludge sample has turned from light brown color into black when dewatered with longer dewatering time. This phenomenon has demonstrated that the chemical sludge sample has encountered the first falling rate and carbonized during thermal dewatering. During the first falling rate, it can be deduced that the vicinal water which adsorbs tightly on the surface of the chemical sludge sample was further eliminated with respect to longer dewatering time. The findings were agreed with Font et al. [8]. Further to this, the carbonized chemical sludge sample has implied that the remaining weight of the chemical sludge sample was filled with intracellular moisture where heavy metals such as aluminum, sulphate, and arsenic remained. The inference on the remaining of heavy metals within the chemical sludge sample was deduced from the experimental results obtained where it demonstrated only with characteristics of the first falling rate. The drying characteristics of chemical sludges observed in this experiment were justified with the trend of the drying curve demonstrated by Deng et al. [9]. In addition, the shrinking in the volume of the chemical sludge sample has promoted the cracking effect. Referring to figures shown in table 2, the cracking effect was observed more significantly as the chemical sludge sample was dewatered with a longer time. The creation in a bigger size of cracking
within the chemical sludge sample has significantly enhanced the thermal dewatering efficiency as the specific surface of the chemical sludge was enlarged. The experiment conducted by Hsu et al. [10] has demonstrated a similar observation.

**Table 2. Observation on effect of thermal dewatering on physical properties of chemical sludge sample.**

| Dewatering duration | 0 min (Initial) | 30.0 min | 60.0 min |
|---------------------|-----------------|----------|----------|

3.3. **Optimisation of process parameters**

The optimum thermal dewatering condition for chemical sludge dewatering using a rotary drum thermal dewatering system was determined using an optimization plot generated from Minitab Software. The optimum operating condition for each process parameters is evaluated and shown in figure 1.

![Optimisation plot](image)

*Figure 1. Optimisation plot of different process parameters.*

Referring to figure 1, an operating condition with a chemical sludge input volume of 2.0 cm³, a dewatering temperature of 246°C, and a dewatering time of 80.3 min were determined as the optimum operating condition for thermal dewatering of chemical sludge using retrofitted rotary drum thermal dewatering system. Approximately 80% of the percentage of weight loss in chemical sludge was expected to be achieved if the retrofitted rotary drum thermal dewatering system has adopted such a condition for thermal dewatering of chemical sludge. This assumption was supported through interpolation of results obtained from a laboratory experiment where the percentage of weight loss in a chemical sludge sample with a volume of 4.0 cm³ was 81% when dewatered under the dewatering temperature of 250°C for 90 min long. Subsequently, the results obtained from the laboratory experiment and the Minitab Software is served as a basis for performing the economic evaluation.

If the retrofitted rotary drum thermal dewatering system has to adopt the optimum operating condition generated from the optimization plot for chemical sludge thermal dewatering, approximately 80% in the percentage of weight loss in chemical sludge will be achieved. Therefore, it can be deduced that the value calculated for annual gross-saving was 80% from the annual pay for chemical
sludge disposal as 80% in the total weight of chemical sludge has been reduced through thermal dewatering in retrofitted rotary drum thermal dewatering system. Ultimately, an estimate of one hundred and fifty-four thousand Malaysian Ringgit is calculated as annual net-saving through the differences between annual utility costs and annual gross-saving. The positive value calculated in annual net-saving has justified the feasibility of chemical sludge dewatering through retrofitted rotary drum thermal dewatering system. Further to this, a value of 30% is calculated in ROI when the retrofitted rotary drum thermal dewatering system is adopted for thermal dewatering of chemical sludge over 20 years of the operating period. The detailed calculation of economic evaluation is demonstrated in table 3.

Table 3. Cash flow for method of chemical sludge dewatering using retrofitted rotary drum thermal dewatering system.

| Item                             | Value               |
|----------------------------------|---------------------|
| Annual pay for chemical sludge disposal | MYR 380k/year     |
| Capital expenditure for retrofitting existing unit operation | MYR 300k         |
| Annual utilities costs           | MYR 150k/year       |
| Annual gross-saving              | MYR 304k/year       |
| Annual net-saving                | MYR 154k/year       |
| Return On Investment (ROI)       | 30%                 |
| Breakeven point                  | 3 Years             |

4. Conclusions
The experimental results obtained using lab-scale furnace demonstrated that the percentage of weight loss in chemical sludge is directly proportional to the smaller volume of chemical sludge, higher dewatering temperature, and longer dewatering time. The highest percentage of weight loss in the chemical sludge sample with a volume of 9.0 cm³ was 46% when dewatered using a lab-scale furnace for 90.0 min. When the dewatering temperature was increased from 150°C to 250°C, 76% in the total weight of the chemical sludge sample is reduced. As the volume of chemical sludge sample was reduced to 1.0 cm³, the percentage of weight loss in the chemical sludge sample was further increased to 70% and 82% when the chemical sludge sample was dewatered at a temperature of 150°C and 250°C respectively for 90.0 min. Despite that dewatering temperature and dewatering, time was identified as the dominant parameters which affecting the most on the percentage of weight loss in chemical sludge, higher dewatering temperature and longer dewatering time will result in higher annual utility costs. Therefore, optimization tool was essential to be adopted in determining the optimum thermal dewatering condition for chemical sludge dewatering using a retrofitted rotary drum thermal dewatering system. Further to this, the positive value of one hundred and fifty-four thousand Malaysian Ringgit calculated in annual net-saving has justified the feasibility of the sludge dewatering method using retrofitted rotary drum thermal dewatering system with an achievable breakeven point of 3 operating years and ROI of 30%. Ultimately, the industrial collaborator has proceeded to retrofit existing unit operation by installing a set of the industrial hopper at feeding section of rotary drum thermal dewatering system for crushing chemical sludge into smaller volumes and thus maximize the thermal dewatering efficiency.
References

[1] K Rajkumar, M Muthukumar and R Sivakumar 2010 Resour. Conserv. Recycl. 54 752 – 8
[2] B Q Rao, Y J Wan and X F Liang 2017 Eng. Des. 24 34 – 9
[3] G Chen, P L Yue and A S Mujumdar 2002 Dry. Technol. 20 883 – 916
[4] M Z Alam, S A Muyibi and R Wahid 2008 Bioresour. Technol. 99 4709 – 16
[5] Department of Environment 2020 Guidelines For The Application Of Special Management Of Scheduled Waste [online] Available at: <https://www.doe.gov.my/portalv1/wp-content/uploads/2016/02/AS-WM.1-2005-App-For-Special-Mgmt-Of-Scheduled-Waste-1.pdf> [Accessed 10 April 2020]
[6] S N Roslan, S S Ghazali and N M Asli 2013 Int. Jour. Of. Environ. And. Ecolo. Eng. 7 647
[7] R Han, J Liu, Y Zhang, X Fan, W Lu and H Wang 2012 Bioresour. Technol. 107 429 – 36
[8] R Font, M F Gomez-Rico and A Fullana 2011 Sep. Puri. Technol. 77 146 – 61
[9] W Deng, X Li, J Yan, F Wang, Y Chi and K Cen 2011 Jour. Of. Environ. Sci. 23 875 – 80
[10] J P Hsu, T Tao and A Su 2010 Dry. Technol. 28 922 – 26