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Case Study: Application of Design of Experiment (DoE) in Wet Sludge Processing

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Abstract
Purpose: The model of full factorial used in the Design of Experiment (DoE) has been used in many applications. However, little research has been conducted on waste treatment and wet sludge processing. The aim is to apply the Design of Experiment (DoE) to optimize Wet Sludge Processing as well as to identify the optimum polymer to the process
Design/methodology/approach: This case study follows the path, in-depth, of statistical methodology to find out the relationship between the main inputs which are polymer type, polymer quantity and duration of mixing against the output of the drying process of wet sludge, which is the water reduction (%). Consequently, a model was built and had demonstrated the positive relationship between the inputs of the process against the output.
Findings: The optimum result for the water reduction found to be 35% when the inputs were as following, polymer D, 200 ml of polymer was added and 6 hours of mixing duration. In addition, the model can predict the results based on the given input with 95% confidence level.
Originality/value: The paper provides a statistical model in Minitab to optimize the process of wet sludge. Moreover, the paper compere four key elements for the aim of getting the optimum results.

Keywords: Design of Experiment, Wastewater, Waste Management, Sludge Treatment

1. Introduction

The use of design of experiment (DOE) has been extended across numerous businesses as a feature of a dynamic interaction either with a new developed product or the process of production side by side the development of those products. (Durakovic, 2017). As part of decision-making procedure in many industries DOE used to develop a new product and enhance manufacturing process. There are different types of DoE such as Comparison, Variable screening, Transfer function identification System Optimization and Robust design. (Guo and Mettas , 2012). The DoE will be applied in wastewater in an industrial area to find the optimum results for processing wet sludge.

2. Literature Review

2.1. Wastewater Treatment

The treatment of wastewater is mainly a separation process. (Peavy, et al., 1986). Sludge partition, treatment and removal acquires a significant capital expense in wastewater treatment. Dewatering costs and costs of removal for a medium-sized can reach to more than 50% of cost as working expenses. (BERKTAY, 1998). The origin of sludge is mixing of heterogeneous of inorganic and organic substances. (KUCHAŘOVÁ, et al., 2014). There are three main types of sewage sludge: primary or raw, secondary and anaerobically digested sludge. (Baroutian, et al., 2013). Different Case Studies in Oman for wastewater conducted in

Oman region such as An Evaluation of Solid Waste and Landfilis in the Muscat Region of Oman (El-Zawahry, et al., 2001), Municipal Solid Waste (MSW) generation and composition in Muscat, Sultanate of Oman (Palanivel and Hameed, 2014) and (Al-Mahrouqi and Victor, 2017).

3. Methodology

3.1.The Process of Dewatering the Sludge

The process of removing the major quantity of water from the wet sludge is called “dewatering”. This treatment must be done before further processing the sludge to other products such as fertilizer. The process of dewatering usually consists of the following major elements, sludge holding tank, aeration, a thickening chemical, and dewatering mechanism. The below schematic (Figure.1) shows the major components:

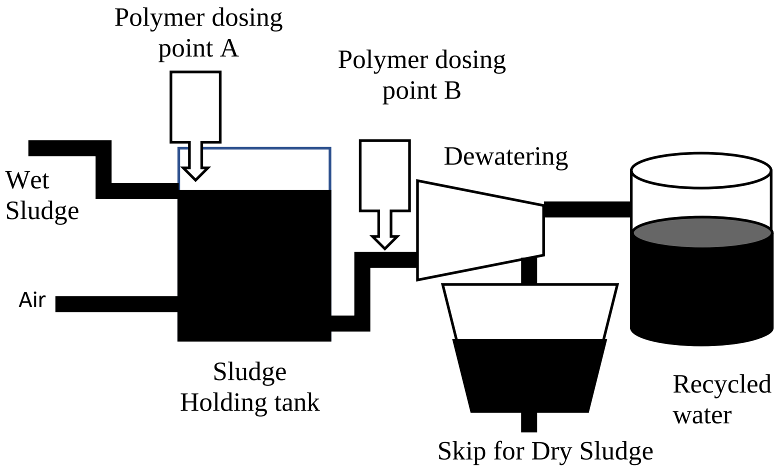

Figure 1: Major components of sludge processing

In this process, the sludge enters in the sludge holding tank where there is a continues supply of air where is plays an important role to maintain the sludge physical condition and characteristics. There are two main theories about the polymer dosing, in one hand the dosing shall be at the tank while the theory suggests that the dosing location to be at the discharge of the sludge dosing tank. In our experiments, the focus will be dosing inside the tank of the sludge holding tank. Once the dosing happens, reaction time must be considered, which is one of the main parameters of experiments. After that, the core of the process take place which is the separating of the water from the sludge. The dewatering machine for our experiments is a centrifuge that contains two rotating elements, the bowl and drum, usually rotates at two different speeds utilizing the centrifugal force for separation of thickened sludge from water. The separation causes the dry sludge to drop down into the skip for further processing while the water goes back for recycling in the process. There are many parameters that effect the dryness of the sludge at the outlet of the dewatering centrifuge such as the initial density of the wet sludge, amount of polymer dosed, reaction time, location of the dosing, flow rate of the centrifuge inlet, flocculants size.

3.2.The Process of Dry Sludge Limitations

During the process of dewatering, there is a challenge of not having the right level of dryness for the sludge and therefore, it defeats the purpose of processing the wet sludge into dry sludge. This encounter was the drive for this experiment to objectively and statistically define the optimum outcome to ensure the desired dryness of the sludge is achieved at any time and every time.

3.3.The Experiment

3.3.1. Setting up the trial

For the experiment's trails, the wet sludge is the input of the process and sludge dryness was measured as an output of the process. The following were the process control parameters (Figure.2) on which the trials will be based on:

- Type of polymer.
- Polymer quantity
- Duration of mixing the polymer

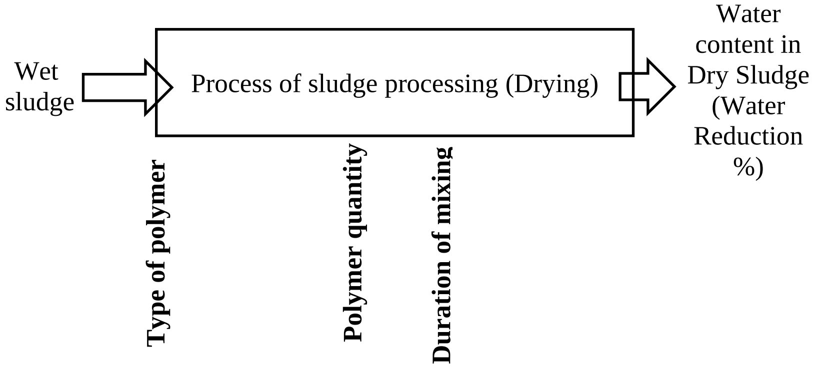

Figure 2: Process of sludge processing parameters

3.3.2. Design of Experiment (DoE)

Design of experiments objective is to target a maximum output of the process which was in study case will be highest percentage of sludge dryness (water reduction %). For the process inputs i.e. controllable factors are shown in the figure above to illustrate the interaction in the process. Below each factor will be explained along with the levels for the experiment. This experiment will be based on full factorial fashion.

I. Polymer Type

For the trials, there will be 4 polymers will be used to get the optimum outcome for the sludge dryness as following Polymer A, Polymer B, Polymer C and Polymer D.

II. Polymer Quantity

In this factor, the quantity limits are predetermined based on a previous experience as following:100 ml in 200 L tank, 200 ml in 200 L tank, 300 ml in 200 L tank and 400 ml in 200 L tank.

III. Duration of Mixing

The duration of mixing the polymer inside the sludge holding tank. The timing is from the moment the full quantity of the polymer has been added to the tank in full. 4 hour, 6 hours, 8 hours and 12 hours.

4. The Result

Here are two cases table 1 shows case A and table 2 shows case B from the experiments for before and after the process (Figure 3 and Figure 4) following the design of experiments. The measurement is done to find out the difference of water content in the dry sludge by 1000ml liquid beaker before and after the dewatering process.

Table 1: Case A

Sr.	Factor	Level
1	Polymer Type	Polymer C
2	Polymer Quantity	200 ml in 200 L tank
3	Duration of Mixing	6 hours

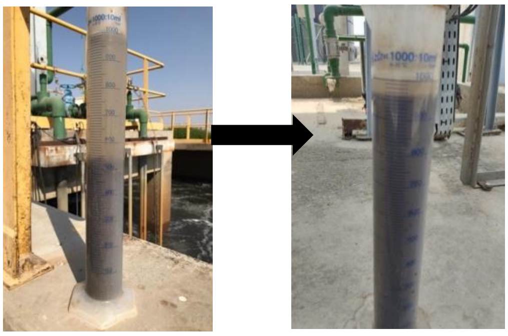

Figure 3: Before and After the dewatering Process for case A

Table 2: Case B

Sr.	Factor	Level
1	Polymer Type	Polymer A
2	Polymer Quantity	300 ml in 200 L tank
3	Duration of Mixing	4 hours

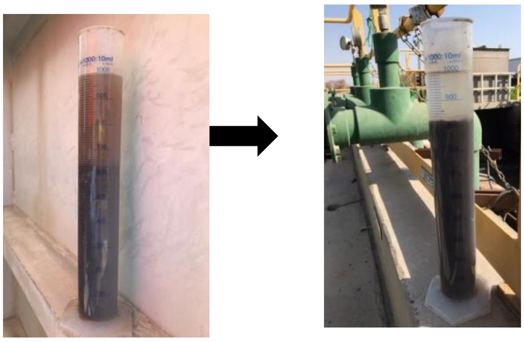

Figure 4: Before and After the dewatering Process for case B

As can be shown in from the pictures from the before and after, the reduction of water in case A was 32%, while in case B, the reduction of water was 19%. The summary of the relationship between the factors and response of the experiments shown in (Figure 5)

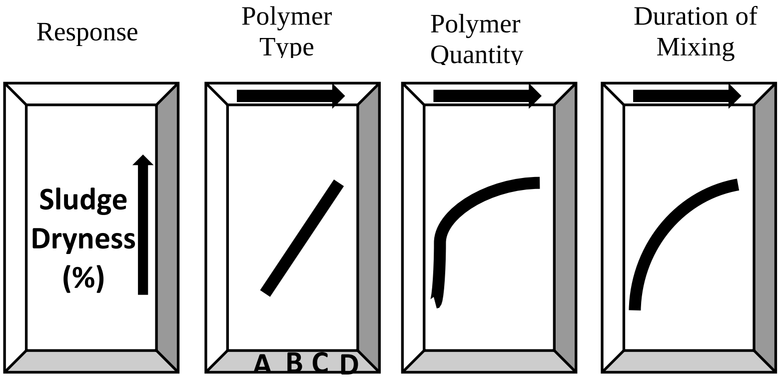

Figure 5: Relationship between the factors and response

Note: The arrow, ➡, shows an increase of the factor while the lines and curves, ➡, shows an response of the sludge dryness.

4.1.Testing the DOE model

The model is tested to find out the maximum result for the given input as following in table 3 and table 4:

Table 3: Settings of parameters

Variable	Setting
Polymer Type	D
Polymer Quantity	200
Duration of Mixing	6

Table 4: Solution by the model

Solution			Polymer Type	Polymer Quantity	Duration of Mixing	Result Fit	Composite Desirability
1	D	200	6	35		1	

The below Figure 6 shows the result of the model to be 35% water reduction based on the selected input.

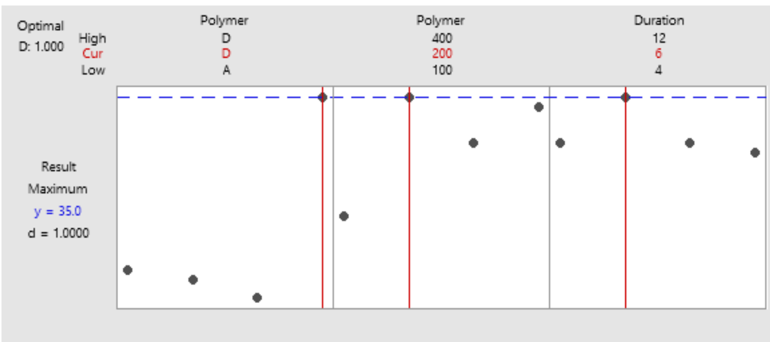

Figure 6: Optimum results from the model

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4.2.Lab Analysis

Lab analysis was done to find out the sludge dryness after each trial to measure the correlation between the input with the output and how big is the relationship aiming to find out optimum results. After getting the results from the model constructed by the software used, the result was tested in lab-controlled environment to verify the results as shown in Table 5.

Table 5: Setting of parameters

Sr.	Factor	Level
1	Polymer Type	Polymer D
2	Polymer Quantity	200 ml in 200 L tank
3	Duration of Mixing	6 hours

This time, the expectation is to have the results matching the model results from the design of experiments methodology (DOE) with +/-5% as chance of error considering the confidence limits to be 95%. As it can be seen from the figure 7, the water reduction is 35%. In the before beaker, there was 55% of water while in the after beaker 20% of water. As a result, 35% water reduction occurred in the process.

Figure 7: Lab results for sludge

5. The Discussion

Considering the study of the problem statement for achieving the optimum results of sludge dryness while controlling the started parameters, the experiment was a clear success. The main objective was to get the desired output by selecting the inputs. In the lab experiment, the information, input, was taken from the mathematical model by the Minitab software which are as following: polymer type D, polymer quantity 200ml and 6 hours of mixing time. After all, the results from the lab experiment matched the result from the model. That being said, this model can be used in the operational settings with 95% level of confidence.

6. The Conclusion

The Process of sludge dewatering could be a tricky and challenging process especially when the aim to minimize the usage of resources while the results. For this experiment, there were 3 main factors that need to be controlled, which are polymer type, polymer quantity and duration of mixing and all the three factors had 4 levels to be considered. The approach taken for this study case is Design of Experiment (DOE) on full factorial fashion where there were 64 trials over the period of 6 months. As a result, the outcome of the experiment was satisfactory based on the fact the model was not only tested by the software, but also was tested in a lab and the results were compared accordingly. For the future studies, other factors will be studies to look at the correlation with the results and its impact to the outcomes.

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