Statistical analysis in Geotextile Tube semi-performance Test for sludge dewatering generated in Water Treatment Plants

M. A. A. Ardila, São Carlos School of Engineering, University of São Paulo, São Carlos, Brazil
S. T. de Souza, São Carlos School of Engineering, University of São Paulo, São Carlos, Brazil
C.A. Valentin, São Carlos School of Engineering, University of São Paulo, São Carlos, Brazil
J. Lins da Silva, São Carlos School of Engineering, University of São Paulo, São Carlos, Brazil

ABSTRACT

Nowadays there is a concern related to the dewatering and final disposal of sludge generated at the water treatment plant (WTP). In this context, the geotextile tube appears as a solution, standing out for offering a series of technical and economic advantages, due to its ease of operation. The main objective of this work is to analyze sludge dewatering from a Water Treatment Plant (WTP), using 0.5x0.5m geotextile tubes made in woven geotextile. The statistical analysis was performed using the response surface methodology through a central composite design, where the independent variables analyzed were the initial concentration of Total Solids (TS) of the sludge and the polymer dosing. The dependent variables (or responses) obtained were the performance indices of dewatering (turbidity of the effluent, the final concentration of solids within the geotextile tube and percent dewatered (PD)). Graphs of response surfaces and polynomial models that establish the relationship between the dependent and independent variables are presented. A maximum final solids content of 47.9% was observed in the combination of 1.7 mgPol/gTS and initial TS of 12.1 g/L.

RESUMEN

En la actualidad, existe preocupación relacionada con el tratamiento de deshidratación y disposición final de los residuos generados en las estaciones de tratamiento de agua (ETA). En este contexto, aparece el tubo geotextil como una solución, destacándose por ofrecer una serie de ventajas técnicas y económicas, debido a su facilidad de operación. El principal objetivo de este trabajo fue analizar estadísticamente la deshidratación de los residuos de ETA, por medio de ensayos en tubos de geotextil de 0,5x0,5 m elaborados en geotextil del tipo tejido. El análisis estadístico fue realizado empleando la metodología de superficie de respuesta por medio de un diseño central compuesto, donde las variables independientes analizadas fueron la concentración inicial de Sólidos Totales (ST) del residuo y la dosis de polímero. Fue observada una concentración de sólidos máxima de 47,9% en la combinación de 1,7 mgPol/gST y ST inicial de 12,1 g/L.

1. INTRODUCTION

The waste from industrial processes remains an environmental problem, where the waste generated takes the form of slurry or sludge with high water content. Between these types of materials appear the sludge generated on a WTP, which is characterized by the composition of fine solid particles. In this backdrop, geotextile tubes are a solution applicable for the dewatering of sludge from WTP, as long as the WTP has a large area available for the installation of the tubes. In this application, retention of solids is not a problem, whereas the turbidity of effluent does not exceed applicable environmental standards, like the recirculation of the effluent in the plant and the release into water bodies.

Besides, geotextile filter criteria have limited applicability in the geotextile tube application, due to sludge properties be the dominant control factors, and the formation of a filter cake influence in the filtration process. For this reason, semi-performance testing of the sludge is often recommended before full-scale use in the field (Moo-young *et al*. 2002). The most common semi-performance tests are the hanging bag test and the geotextile tube test (pillow test). Both are standardized, the hanging bag test in 2004 (GRI-GT14) and the geotextile tube test in 2009 (GRI-GT15) and 2013 (ASTM D7880). Due to the ease of execution of the test and the recommendations made by authors such as Koerner *et al.* (2016), the geotextile tube test was selected for evaluating the sludge dewatering of WTP in the present work.

There are, however, distinctions between performance interpretations, due to information are published using dissimilar performance criteria. Many of these performance measures are difficult to interpret (like dewatering efficiency) and depend upon material conditions (use of polymer flocculants) and experimental methods. For this reason, this paper will study statistically the dewatering of WTP sludge in geotextile tubes, using performance criteria easier to interpret, adopting the indices proposed by Bhatia *et al*. (2013) for performance evaluation.

2. MATERIALS AND METHODS

2.1 Sludge and geotextile properties

The sludge used for this research comes from the Jardim Bela Vista WTP decanters, located in the city of Nova Odessa, Brazil, where all the tests were carried out. The WTP is of the conventional type and uses Aluminum Chloride (PAC 10) for the coagulation process. The sludge presented specific gravity of the grains of 2.4 g/cm³. The grain size distribution consists of 0.5% of sand, 16.5% of silt and 83.0% of clay.

The woven polypropylene (PP) geotextile represents the geotextile typically used in dewatering applications (Figure 1) and Table 1 describes the relevant geotextile properties as provided by the manufacturer or measured by the authors.

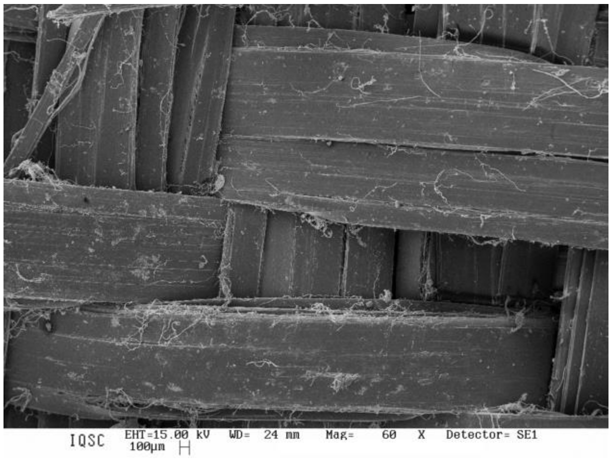

Figure 1. Polypropylene geotextile used in this study, SEM 60 X

Table 1. Geotextile properties.

Properties	Test Method	GTX
Wide-width tensile test (kN/m)¹	ABNT NBR ISO 10319	106 x 109
Permeability (m/s)¹	ASTM D4491	$2.4x10^{-3}$
Apparent opening size (µm)	ABNT NBR ISO 12956	200
Mass per unit area (g/m²)¹	ABNT NBR ISO 9864	414
Thickness (mm)¹	ABNT NBR ISO 9863-1	2.81

¹ measured by authors

2.2 Performance Index

The most common index for evaluating the performance is filtration efficiency (FE) and dewatering efficiency (DE), retention and a dewatering index, respectively. Moo-Young and Tucker (2002) expressed FE as the relation between the final TS of the sludge filtrate TS_{final} (g/L), to the initial TS of the sludge $TS_{initial}$ (g/L) (Equation 1):

$$FE = \frac{TS_{initial} - TS_{final}}{TS_{initial}} x\ 100\ (\%) \qquad [1]$$

Where determinate the final TS of the sludge filtrate is difficult if the turbidity of the filtrate is low (indicate low content of solids present in the filtrate). Another index, DE (Equation 2) measures how effectively fluid is drained from the sludge and is defined as:

$$DE = \frac{PS_{final} - PS_{initial}}{PS_{initial}} x\ 100\ (\%) \qquad [2]$$

Where DE is the dewatering efficiency (%), $PS_{initial}$ is the initial percent solids of the sludge, and PS_{final} is the final percent solids of the sludge retained inside the tube. Equation 2, shows that DE has an inverse correlation with the initial percent solids content, indicating that DE can exceed 100%, hampering the interpretation. Bhatia *et al*. (2013) recommend the adoption of the index percent dewatered (PD) that can be more easier to interpret as it ranges from 0-100% regardless of initial sludge concentration (Equation 3).

$$PD = \frac{W_{initial} - W_{final}}{W_{initial}} x\ 100\ (\%) \qquad [3]$$

Where PD is percent dewatered, $W_{initial}$ is the initial water content of the sludge, and W_{final} is the final water content of the sludge retained inside the tube. The performance index utilized in this paper is the PD.

2.3 Central composite design

Experimental planning called a Central Composite Design (CCD) 2^2 was carried out aiming to evaluate the dewatering, in the function of the variable's initial Total Solids (TS) of the sludge and the polymer dosing. The selection of the polymer flocculant had been raised by cone dewatering tests, where was selected a cationic polymer (Superfloc 8396). Table 2 shows the Levels of factors used in the experimental planning.

Table 2. Levels of factors used in experimental design CCD 2^2.

Factors	Code	Level		
		-1	0	1
Initial TS of the sludge (g/L)	x_1	0.25	10.13	20.00
Polymer dosing (mgPol/gST)	x_2	0.80	1.70	2.60

For the initial TS variable (x_1), the levels assessed by Guimarães (2019) were adopted, where the maximum (20 g/L), medium (10.13 g/L) and minimum (0.25 g/L) were established as characteristic values for the discharge from the decanters, the mixing tank (filter washing water and the decanter discharge) and the filter washing discharge water, respectively. The levels for polymer dosing (x_2) were defined based on the literature.

Table 3 shows the results of the test matrix (scenarios) with the coded values and the real values (between parentheses) of the studied variables, according to Rodrigues and Iemma (2014). Moreover, 11 tests were carried out on each type of geotextile studied, whereby three of the tests were repeated at the central point (Tests Nº. 9, 10 and 11).

Table 3. Design matrix tests (scenarios).

Test (Nº)	1	2	3	4	5	6	7	8	9	10	11
initial TS (g/L)	-1 (0,25)	1 (20)	-1 (0.25)	1 (20)	-1 (0.25)	1 (20)	0 (10.13)	0 (10.13)	0 (10.13)	0 (10.13)	0 (10.13)
Polymer dosing (mgPol/gST)	-1 (0.8)	-1 (0.8)	1 (2.6)	1 (2.6)	0 (1.7)	0 (1.7)	-1 (0.8)	1 (2.6)	0 (1.7)	0 (1.7)	0 (1.7)

The geotextile tube dewatering tests were analyzed using the results of turbidity at 5 minutes, turbidity at 25 min, final solids content, and percentage of dewatering PD.

2.4 Test procedure

For the preparation of dewatering tests in geotextile tubes, a single sample of sludge was collected in a reservoir with a capacity of 1000 liters. The test methodology was adapted from ASTM D7880 (2013) with 0.5x0.5m tubes. The tubes were filled manually, with a 50 mm diameter and 1.10 m long tube. The tube was connected to a system consisting of an elevated reservoir with a capacity of 100 liters, which allowed us to control the volume of sludge inserted (30 liters) in each prototype using a butterfly valve (Figure 2). Dewatering was observed for 1 week. In the first 24 hours, the volume and turbidity of the effluent were monitored, and samples of the sludge cake were collected within 24 to 168 hours to calculate the solids content.

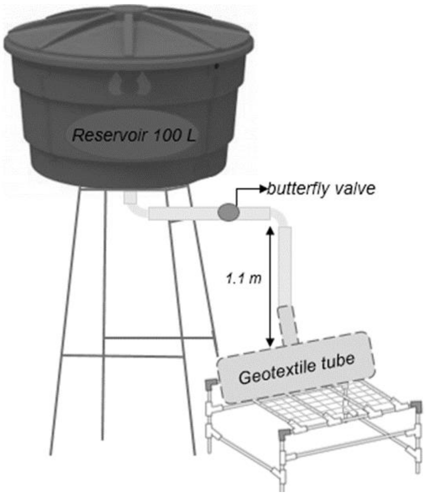

Figure 2. Geotextile tube dewatering test scheme.

3. RESULTS AND DISCUSSIONS

Table 4 shows the results obtained in the 11 geotextile tube tests. The statistical analysis was performed with a 90% confidence level, resulting in mathematical models that express the correlation between the dependent and independent variables. Equations 4, 5, 6 and 7 are the polynomial models for turbidity at 5 minutes, turbidity at 25 minutes, solids content and percentage of dewatering PD, respectively. The models were evaluated using analysis of variance (ANOVA). Figures 3 and 4 show the response surfaces obtained.

Table 4. Results from the geotextile tube dewatering test.

Test	Factors		Results			
Nº	initial TS (g/L)	Polymer dosing (mgPol/gST)	Turbidity at 5 minutes (NTU)	Turbidity at 25 minutes (NTU)	Final solids content (%)	PD (%)
1	-1 (0,25)	-1 (0.8)	141.0	7.4	0.0	0.0
2	1 (20)	-1 (0.8)	612.0	84.2	31.2	95.5
3	-1 (0.25)	1 (2.6)	215.3	3.6	0.0	0.0
4	1 (20)	1 (2.6)	39.3	17.1	30.8	95.4
5	-1 (0.25)	0 (1.7)	64.7	5.8	0.0	0.0
6	1 (20)	0 (1.7)	153.0	55.3	28.4	94.9
7	0 (10.13)	-1 (0.8)	415.7	23.1	48.0	98.9
8	0 (10.13)	1 (2.6)	132.7	19.9	28.6	97.5
9	0 (10.13)	0 (1.7)	68.4	30.4	37.6	98.3
10	0 (10.13)	0 (1.7)	124.3	20.5	80.7	99.8
11	0 (10.13)	0 (1.7)	162.0	13.0	35.6	98.1

$$\text{Turbidity at 5 minutes (NTU)} = 114.49 + 53.55\, x_1 - 119.89\, x_2 + 134.51\, x_2^2 - 146.26\, x_1 x_2 \quad [4]$$

$$\text{Turbidity at 25 minutes (NTU)} = 25.48 + 23.31\, x_1 - 12.36\, x_2 - 15.82\, x_1 x_2 \quad [5]$$

$$\text{Final solids content (\%)} = 46.11 + 15.06\,x_1 - 31.04\,x_1^2 \qquad [6]$$

$$\text{PD (\%)} = 98.51 + 47.63\,x_1 - 50.88\,x_1^2 \qquad [7]$$

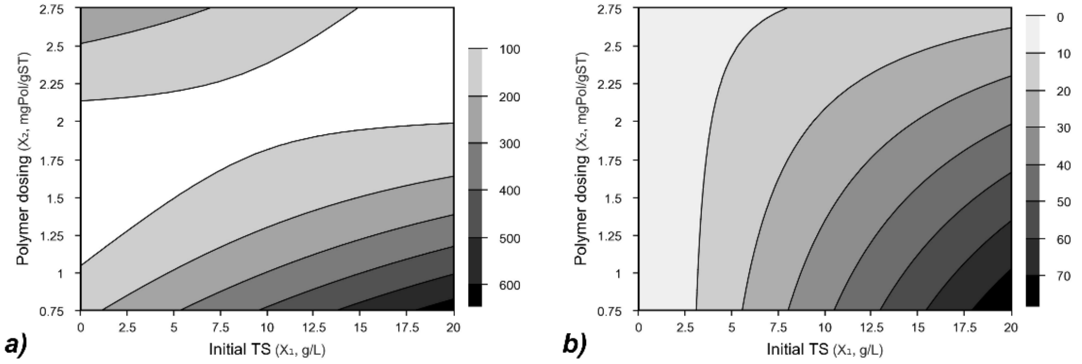

Figure 3. Response surface for geotextile tube dewatering test. (a) Turbidity at 5 minutes and (b) Turbidity at 25 minutes.

It was observed that turbidity is a dependent variable of the two independent variables (initial Total Solids (TS) of the sludge and the polymer dosing), contrary to was observed in the final solids content and PD, who are solely dependent of the initial ST. It was observed that the effluent turbidity value decreases with the test time, where in the first 5 minutes the region with minimum turbidity value had 100 NTU, after 25 minutes of test a region with minimum turbidity value had 10 NTU.

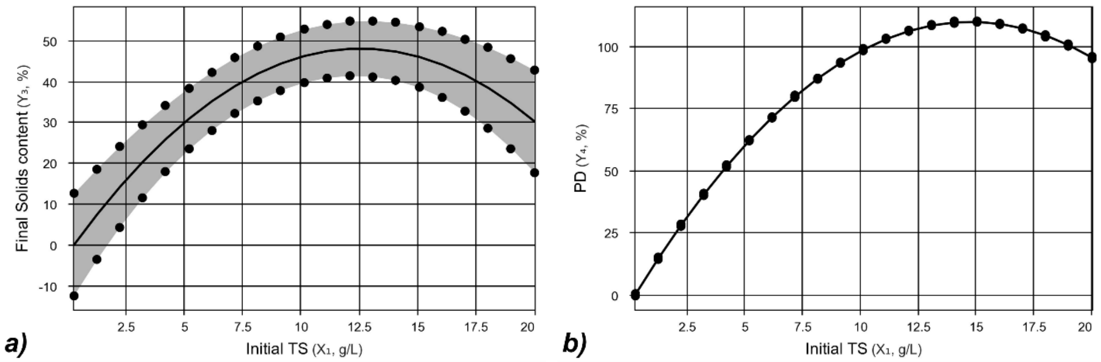

Figure 4. Response surface for geotextile tube dewatering test. (a) Final solids content and (b) PD.

A maximum final solid content of 47.9% was observed in the combination of 1.7 mgPol/gTS and initial TS of 12.1 g/L and a maximum PD of 98.5% was observed in the combination of 1.7 mgPol/gTS and initial TS of 10.13 g/L.

4. CONCLUSIONS

The work evaluated the dewatering of woven geotextile tubes, under different scenarios of initial TS and polymer dosing. After statistical analysis using the response surface methodology, we observed that:

Turbidity is dependent on the variable's initial Total Solids (TS) of the sludge and the polymer dosing. The turbidity value of the effluent decreases with the test time, a fact that could be related to the filter cake formation.

The maximum final solid content and percentage of dewatering PD (determined in function of final solid content) are dependent on the variable initial Total Solids (TS). It was observed that for the maximum values, the optimal dosing of the polymer was close to 1.7 mgPol / gTS.

Although woven geotextiles are usually used for dewatering tubes, a larger number of tests with another type of geotextiles are needed to evaluate the advantages and disadvantages to use this type of material in the field.

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