



Water treatment plant sludge dewatering using geotextile bags: with and without lateral constraints

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Desaguamento de lodo de estação de tratamento de água por meio de bolsas geotêxteis: com e sem restrições laterais

RESUMO

Objetivo – Avaliar o desempenho de bolsas geotêxteis no desaguamento de lodo de Estação de Tratamento de Água (ETA), com e sem restrições físicas laterais, por meio de enchimentos cíclicos.

Metodologia – A pesquisa foi conduzida por meio de ensaios de campo, com a coleta de lodo proveniente dos decantadores de uma Estação de Tratamento de Água (ETA), seguida da avaliação do condicionamento químico desse resíduo por meio de ensaios de cone. Posteriormente, realizou-se o desaguamento do lodo em bolsas geotêxteis, sob duas condições experimentais: com restrições laterais (CR) e sem restrições laterais (SR), ambos executados em réplicas. Os ensaios contemplaram três ciclos sucessivos de enchimento, com monitoramento de turbidez (NTU), massa de filtrado (kg), massa retida nas bolsas (kg), altura de enchimento e teores de sólidos totais no lodo e no filtrado (mg/L). Adicionalmente, foram determinados parâmetros de eficiência, incluindo a eficiência de filtração (EF), eficiência de desaguamento (ED), sólidos passantes (SP) e *piping* (PP).

Originalidade/relevância – A pesquisa responde aos desafios contemporâneos relacionados ao tratamento e à disposição adequada dos resíduos gerados em Estações de Tratamento de Água (ETAs). Ao investigar o desaguamento de lodos em condições com restrições laterais (CR) e sem restrições laterais (SR), o estudo discute a viabilidade técnica do uso de sistemas geotêxteis tanto em ambientes confinados e submetidos a esforços laterais, quanto em situações emergenciais, de forma a ampliar as perspectivas de aplicação dessa tecnologia conforme evidenciado na literatura especializada.

Resultados – Destaca-se a relevância do condicionamento químico para tornar viável o desaguamento de resíduos sólidos com elevado teor líquido e alta resistência à filtração. Nesse contexto, utilizou-se o polímero aniônico A110, na concentração de 0,2% e dosagem de 30 mL/L. Os ensaios realizados com restrições laterais (CR) apresentaram melhores desempenhos de eficiência, com eficiência de filtração (EF) de 99,5%, sólidos passantes (SP) de 0,5% e perda de partículas (*piping* – PP) de 0,8 g/m². Adicionalmente, registraram-se menores valores de turbidez nos filtrados obtidos nas condições de desaguamento com restrições laterais.

Contribuições teóricas/metodológicas – A pesquisa contribui para o avanço do conhecimento sobre os processos de desaguamento de lodos de ETA em sistemas geotêxteis, de forma a oferecer subsídios técnicos para tomadas de decisão relacionadas ao condicionamento químico do lodo, à avaliação das condições de contorno e ao comportamento dos desaguamentos com restrições laterais (CR), com base em parâmetros de eficiência. Dessa forma, o estudo fornece elementos que podem orientar a adoção e o sucesso dessa tecnologia em ETA's, especialmente em cenários com limitações de área disponível para tratamento.

Contribuições sociais e ambientais – A pesquisa destaca a situação emergencial de tratamento e disposição adequada de lodos de ETA e a busca pela sustentabilidade social e ambiental. A tecnologia de desaguamento por sistemas geotêxteis viabiliza a gestão e manejo adequado destes resíduos industriais e seu alinhamento direto aos Objetivos de Desenvolvimento Sustentável, com destaque a ODS 6, 9, 11, 12, 14 e 15.

PALAVRAS-CHAVE: Sustentabilidade social e ambiental. Desaguamento em bolsas geotêxteis. Lodos de Estações de Tratamento de Água.

Water treatment plant sludge dewatering using geotextile bags: with and without lateral constraints

ABSTRACT

Objective – To evaluate the performance of geotextile (GTX) bags in terms of dewatering sludge derived from a Water Treatment Plant (WTP)—with and without lateral constraints (LCs)—through cyclic fillings.

Methodology – The research was conducted through field tests. Sludge was collected from the decanters of a WTP, and this was followed by an evaluation of the chemical conditioning of this waste with cone tests. The sludge was subsequently dewatered in GTX bags under two experimental conditions, namely, with LCs and without LCs, both of which were performed in replicates. The tests included three successive filling cycles, with monitoring of the turbidity

(NTU), filtrate mass (kg), mass retained in the bags (kg), filling height and total solid (TS) content in the sludge and filtrate (mg/L). Additionally, efficiency parameters, including the filtration efficiency (FE), the dewatering efficiency (DE), passing solid (SP) rate and piping (PP), were determined.

Originality/relevance – The study addresses contemporary challenges related to the treatment and proper disposal of waste generated by WTPs. In the context of the dewatering of sludge under conditions with LCs and without LCs, the technical feasibility of the use of GTX systems in confined environments, GTX systems that are subjected to lateral forces, and the use of GTX systems in emergency situations is discussed. The aim is to broaden the application perspectives of this technology, as evidenced in the specialized literature.

Results – Chemical conditioning is relevant to making the dewatering of solid wastes with high liquid contents and high levels of resistances to filtration viable. In this context, the anionic polymer A110 was used at a concentration of 0.2% and dosage of 30 mL/L. The tests performed with LCs showed better efficiency, with a FE of 99.5%, a SP rate of 0.5% and a particles loss (PP) of 0.8 g/m². Additionally, lower turbidity values were recorded in the filtrates obtained under dewatering conditions with LCs.

Theoretical/methodological contributions – The study contributes to the advancement of knowledge concerning WTP sludge dewatering processes implemented in GTX systems to provide technical support for decision-making tasks related to the chemical conditioning of sludge, evaluations of boundary conditions and the behavior of dewatering with LCs, which is based on efficiency parameters. Thus, the study provides elements that can guide the adoption and success of this technology in WTPs, especially in scenarios with limited areas available for treatment.

Social and environmental contributions – This study highlights the emergency situation concerning the treatment and proper disposal of WTP sludge and the search for social and environmental sustainability. Dewatering technology involving GTX systems enables the proper management of these industrial wastes and their direct alignment with sustainable development goals (SDGs), especially SDGs 6, 9, 11, 12, 14 and 15.

KEYWORDS: Social and environmental sustainability. Dewatering in geotextile bags. Sludge from Water Treatment Plants.

Deshidratación de lodos de plantas de tratamiento de aguas mediante bolsas geotextiles: con y sin restricciones laterales

RESUMEN

Objetivo – Evaluar el rendimiento de las bolsas geotextiles en la deshidratación de lodos de una Planta de Tratamiento de Aguas (PTAR), con y sin restricciones físicas laterales, mediante llenado cíclico.

Metodología – La investigación se llevó a cabo mediante pruebas de campo, con la recolección de lodos de los decantadores de una Planta de Tratamiento de Aguas (PTAR), seguida de la evaluación del acondicionamiento químico de este residuo mediante ensayos de cono. Posteriormente, los lodos se deshidrataron en bolsas geotextiles bajo dos condiciones experimentales: con restricciones laterales (CR) y sin restricciones laterales (SR), ambas realizadas por réplica. Las pruebas incluyeron tres ciclos de llenado sucesivos, con monitoreo de turbidez (NTU), masa de filtrado (kg), masa retenida en las bolsas (kg), altura de llenado y contenido total de sólidos en lodos y filtrado (mg/L). Además, se determinaron parámetros de eficiencia, incluyendo eficiencia de filtración (EF), eficiencia de deshidratación (ED), sólidos que pasan (PS) y tuberías (PP).

Originalidad/Relevancia – Esta investigación aborda los desafíos contemporáneos relacionados con el tratamiento y la correcta disposición de los residuos generados en las Plantas de Tratamiento de Agua (PTA). Mediante la investigación de la deshidratación de lodos en condiciones de restricción lateral (CR) y sin restricción (SR), el estudio analiza la viabilidad técnica del uso de sistemas geotextiles tanto en entornos confinados como con tensión lateral, así como en situaciones de emergencia, ampliando así las perspectivas de aplicación de esta tecnología, como se evidencia en la literatura especializada.

Resultados – Se destaca la relevancia del acondicionamiento químico para la deshidratación de residuos sólidos con alto contenido de líquido y alta resistencia a la filtración. En este contexto, se utilizó el polímero aniónico A110 en una concentración del 0,2 % y una dosis de 30 mL/L. Las pruebas realizadas con restricción lateral (CR) mostraron una mejor eficiencia de filtración (EF) del 99,5 %, un paso de sólidos (SP) del 0,5 % y una pérdida de partículas (tuberías – PP) de 0,8 g/m². Además, se registraron valores de turbidez más bajos en los filtrados obtenidos en condiciones de deshidratación con restricciones laterales.

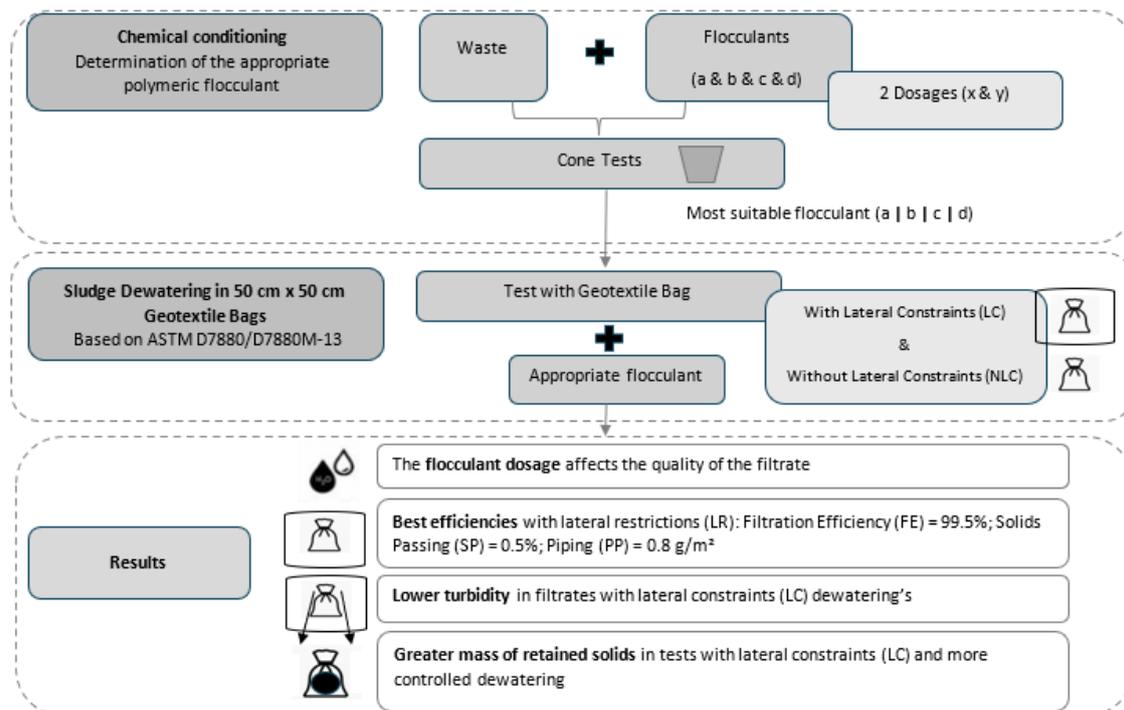
Contribuciones Teóricas/Metodológicas – Esta investigación contribuye al avance del conocimiento sobre los procesos de deshidratación de lodos de plantas de tratamiento de aguas residuales (PTAR) en sistemas geotextiles,

brindando soporte técnico para la toma de decisiones relacionadas con el acondicionamiento químico de los lodos, la evaluación de las condiciones de borde y el comportamiento de la deshidratación con restricciones laterales (CR), con base en parámetros de eficiencia. Por lo tanto, el estudio proporciona elementos que pueden guiar la adopción y el éxito de esta tecnología en plantas de tratamiento de aguas residuales (PTAR), especialmente en escenarios con área disponible limitada para el tratamiento.

Contribuciones Sociales y Ambientales – La investigación destaca la urgente necesidad de un tratamiento y disposición adecuados de los lodos de plantas de tratamiento de aguas residuales (PTAR) y la búsqueda de la sostenibilidad social y ambiental. La tecnología de deshidratación con geotextiles permite la gestión y el manejo adecuados de estos residuos industriales y su alineación directa con los Objetivos de Desarrollo Sostenible (ODS), en particular los ODS 6, 9, 11, 12, 14 y 15.

PALABRAS CLAVE: Sustentabilidade social e ambiental. Desaguamento em bolsas geotêxteis. Lodos de Estações de Tratamento de Água.

GRAPHIC SUMMARY



Source: Authors (2025).

1 INTRODUCTION

The growth of the world population and the consequent increase in the demand for freshwater, which is an essential and limited resource, have accentuated international concern about the environmental impacts of anthropogenic actions (Gomes Néto et al., 2020). This situation is aggravated by the increasingly high consumption patterns that support a production model that is highly dependent on the exploitation of natural resources, as well as water scarcity, especially due to the contamination of water bodies by domestic and industrial waste (Cadore; Tochetto, 2021; Karadoğan et al., 2022).

Faced with such challenges, several global initiatives aim to promote environmental awareness and foster structural changes in models of production and development. The Stockholm Conference (1972), Rio-92 and Rio+10 (2002) stand out as milestones that preceded the formulation of the 2030 Agenda by the United Nations (UN), where 17 Sustainable Development Goals (SDGs) and 169 inseparable goals were proposed (United Nations Brazil, 2015).

In Brazil, this concern began to be addressed by public policy in 1971 with the creation of the National Sanitation Plan (Plano Nacional de Saneamento – PLANASA), which increased the expansion of supply networks and the construction of water treatment plants (WTPs) in several regions of the country. Many of these plants were constructed more than five decades ago in a context that predated environmental legislation aimed at sustainable development; as a result, there is an absence of waste treatment units (WTUs) in water purification systems in Brazil (Borma et al., 2021; Müller et al., 2023).

With the population increase and the consequent increase in the demand for treated water, WTPs began to operate in areas that, over time, became densely urbanized. Even with the significant advancement of environmental norms and legislation, many of these units do not have sufficient physical space for adequate structures for treating and disposing of the waste generated by clarification, sedimentation and filtration (Bellaver; Santos, 2019; Oliveira; Barcelo; Colares, 2013; Pereira; Tsugawa; Boscov, 2018; Silva; Achan; Isaac, 2022).

WTP wastes are known as decanter sludge and filter washing water (Richter, 2021; Richter; Netto Azevedo, 2021). Water treatment plant sludge (WTPS) is a Class II A solid waste; i.e., it is nonhazardous and has the potential for contamination if disposed of incorrectly (ABNT NBR 10004-1:2024; ABNT NBR 10004-2:2024); WTPS is a thixotropic fluid with non-Newtonian behavior, and it has high liquid content relative to solid content, high resistance to filtration and sedimentation, and low biodegradability (Boscov; Tsugawa; Montalvan, 2021; Richter, 2021).

Although the characteristics of WTPS are variable, in general, phosphorus, potassium, fluorine, chlorine and lime; potentially pathogenic microorganisms; solid materials in suspension; and metals such as aluminum, iron, copper, zinc and possibly heavy metals are present, in addition to sand, clay and silt (Andreoli et al., 2001; Pereira; Tsugawa; Boscov, 2018; Reali et al., 1999). They have a specific mass of approximately 1.002 to 1.500 kg/m³ and solid contents of 0.1% to 2.0% (Reali et al., 1999; Richter, 2021). The brown color of the sludge is usually due to the use of aluminum sulfate (Al₂SO₃) or iron salts as coagulants (Di Bernardo; Dantas; Voltan, 2011; Reali et al., 1999).

WTPS cannot be disposed of in water bodies or sewage systems without prior treatment (ABNT NBR 10004-1:2024; ABNT NBR 10004-2:2024; Brazil, 2011). Law no. 9,605 (Brazil, 1998) established that the disposal of WTPS in a manner that violates the recommended requirements constitutes an environmental crime because of its adverse environmental impacts. Silva, Achan and Isaac (2022) reported that in 2017, 56% of WTP sludge in Brazil was discarded in water bodies; 23% was disposed of in sanitary landfills; 13% was disposed of in landfills, dumps or controlled landfills; 7% was destined for reuse processes; and 1% was sent to other destinations. Therefore, the relationships among the integrated management of these wastes, the environment and public health are urgent and of paramount importance (Garcia; Ferreira, 2017).

Data from the National Solid Waste Plan (Planares) indicate that in 2018, Brazil treated approximately 13.11 billion m³ of water and that in 2017, Brazil generated more than 778 million tons of sludge, with the Southeast Region responsible for 43% of this volume. Nevertheless, this value does not fully reflect the amount of waste actually produced by WTPs in the country (Brazil, 2022). These findings highlight the need for sustainable technical solutions that enable the treatment and proper disposal of WTPS to prioritize environmental management and prevent its disposal without prior treatment (Hussein et al., 2021).

In this scenario, the use of geosynthetics (GSY), particularly geotextiles (GTXs), in WTP sludge treatment processes has emerged as an important technique because they are materials with versatile functions and can play an important role in engineering solutions that enable sustainable development (Touze, 2021). GTXs are permeable materials with flat structures that can be used for a variety of functions, such as the filtration of suspended solid particles (ABNT NBR ISO 10318-1, 2021).

For dewatering purposes, GTXs can be structured in the form of bags or tubes or confined in containers, depending on the dimensions of the target system (IGS-BRAZIL, 2016). Dewatering occurs through successive pumping cycles, whose characteristics (the pumped volume, stability and integrity of the system) depend on the specific imposed boundary conditions. Adequate intervals are provided between cycles, with the objective of optimizing the dewatering performance of the system and promoting the consolidation of the solid fraction inside the GTX structure (Guimarães; Urashima; Vidal, 2014; Lawson, 2008).

Flocculants or chemical conditioners are typically added to sludge waste to retain the coagulated solid particles, which are transported to an appropriate disposal site, and to dewater the liquid fraction, which can be used for treatment or recycling (Mattos et al., 2019).

The process of dewatering sludge in GTXs has high adaptability to the physical and operational limitations of many WTPs in Brazil, as previously highlighted, and therefore represents an important engineering solution for the safe disposal of waste with high liquid content relative to its solid content. Guimarães and Urashima (2023) emphasized that the use of GTXs is strongly aligned with at least six SDGs, namely, SDGs 6, 9, 11, 12, 14 and 15, which are related to adequate solid and liquid waste management practices; this alignment highlights the potential for these materials to promote environmental sustainability (United Nations Brazil, 2015).

The use of GTXs for the dewatering of sludge and sediments is promising, as evidenced by the literature (Ardila et al., 2020; Dąbrowska et al., 2023; Pawar et al., 2017; Silveira; Abe; Mendes, 2013; Silveira; Koga; Kuroda, 2013). For example, Guanaes and Sampaio (2012) demonstrated that the dewatering of WTPS in the municipality of Piquete, São Paulo, resulted in a 10% reduction in the volumes of liquids and enabled the treatment of 320 m³ of water per hour. Urashima et al. (2019) reported an increase of 59% in the solid content of WTPS relative to that achieved with the conventional technique of sludge disposal in drainage beds, which resulted in only a 25% increase in solid content.

Research has focused on the analysis of the GTX bags used in terms of dewatering sludge output from WTPs, with two scenarios that involve filling and dewatering, namely, (i) structures without lateral constraints (LCs) and (ii) structures with LCs, according to previous studies by Müller et al. (2023) and Müller (2023). For this purpose, experiments were conducted in the field and in the laboratory with sludge obtained from a WTP located in southern Minas Gerais, Brazil.

The tests with LCs are justified because it is possible to install GTX tubes in containers, in which case they would work under confined conditions and would be subject to lateral forces. These devices have advantages such as “roll-on/roll-off” operations; i.e., the mobile bucket enables transportation via trucks, easy installation in smaller areas, easy replacement of GTX tubes for waste disposal in the solid phase, and application potential in emergency scenarios (Müller, 2023).

2. OBJECTIVES

The general objective was to analyze the efficiency of GTX bags in two scenarios, those with and without lateral constraints (LCs), that were subjected to filling and dewatering cycles for sludge produced by a WTP. The specific objectives were (i) to evaluate the influence of chemical conditioners on determining the optimal dosage; (ii) to determine the initial and final total solid (TS) content, turbidity, and TS content of the material retained in the GTX bags; and (iii) to consider the performance of the GTX bags subjected to cyclic filling and dewatering requests in two scenarios: with and without LCs.

3 ANALYSIS METHODS

3.1 Collection of sludge for testing

A total of 500 L sludge was collected. It was directly acquired from the decanters and was stored in a single reservoir for single and homogeneous sampling processes for each test. The WTP operated with an average flow rate of 70 to 75 L/s and performed the complete treatment cycle. The decanters were cleaned every 5 days and every 30 days during drought periods. The TS content of the sludge, as obtained through oven tests, was 8.38%; i.e., the TS content of the sludge was 74.5 g/L.

3.2 Chemical conditioning

As a preliminary step prior to dewatering, chemical conditioning tests, namely, cone tests, were performed (Figure 1). These tests involved the use of a cone structured with the dewatering GTX material and fixed on a tripod, into which a set volume of sludge was poured. The preliminary addition of a polymeric solution was implemented at the concentration and dosage desired for analysis purposes. Chemical conditioning enabled the coagulation of ultrafine particles (< 10 µm) and reduced the volume of the suspended solids (France; Massarani, 2010; Urashima et al., 2019). In addition, flocculant overdoses could compromise the efficiency of the system (Crittenden et al. 2012).

Cone tests were performed with 4 polymers (Table 1) (2 cationic and 2 anionic polymers) at concentrations of 0.2% and dosages of 30 and 40 mL/L, as measured in graduated syringes. A sludge volume of 1 liter was established, and the filtered volume and turbidity were measured after 5 minutes. Then, the turbidity (NTU) and volume of the dewatered fluid were evaluated (Lawson, 2008).

Figure 1 – Cone test.



Source: Authors (2025).

Table 1 – Polymers used in the preliminary cone tests.

Polymer	Classification	Concentration	Dosages
C492	Cationic		
C498	Cationic	0.2%	30 and 40
A100	Anionic		mL/L
A110	Anionic		

Source: Authors (2025).

3.3 Dewatering in GTX bags

Dewatering tests were performed on GTX bags using a methodology adapted from the standard ASTM D7880/D7880M-13 (2022), which consisted of integrating chemically conditioned sludge into an upper 80-liter reservoir. Then, the sludge–polymer mixture was

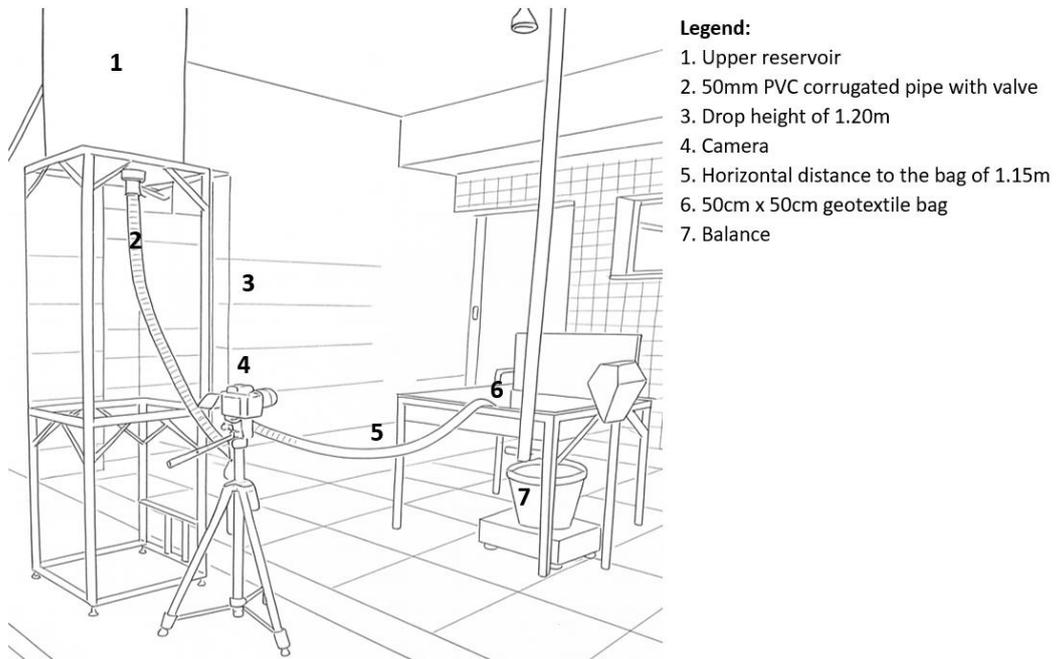


moved by gravity to the GTX bag through a corrugated tube after the valve positioned below the reservoir was opened. The corrugated tube was positioned in circles within the support structure of the upper reservoir to provide an adequate sludge polymerization system.

The filtered volumes were weighed, and turbidity readings were performed at intervals of 5, 10, 15 and 20 minutes; additionally, photographic records were acquired to evaluate the height reached by the bags after dewatering. The configuration of the tests is shown in Figure 2.

The bags employed for dewatering were made of woven geotextile (GTX-W); the properties stated by the manufacturer shown in Table 2. The dimensions were 50 cm × 50 cm, and a lateral nozzle was used to fix the corrugated pipe with a galvanized clamp.

Figure 2 – Dewatering tests.



(a) Diagram with indications of the main components



(b) Test setup



(c) Determination of the filtrate by mass



(d) Geotextile bag during the dewatering process



(e) Records of the filling heights

Source: Authors (2025).

Table 2 – Properties of the GTX-W bags.

Properties	Norms	Nominal values
Mass per unit area	ISO 9864:2005	≥ 440 (g/cm ²)
Opening size	ISO 12956:2019	≤ 0.40 (mm)
Permeability	ISO 11058:2019	≥ 55x10 ⁻³ (m/s)
Nominal tensile strength	ISO 10319:2015	≥ 105 (kN/m)

Source: Prepared by the authors on the basis of the manufacturer’s data (2025).

The tests were performed in bags with and without lateral constraints (LCs), which were imposed by LCs within 5 centimeters from a metal structure (Figure 3). All tests were performed in replicates, which were named as follows: without LCs (NLC1 and NLC2) and with LCs (LC1 and LC2).

Figure 3 – Configurations in the GTX bag tests.



Source: Authors (2025).

The sludge in the bags was pumped through three fillings of previously conditioned sludge, with 30-minute intervals between successive fillings. The first filling was performed with 25 liters of sludge; the second filling was performed with 15 liters; and the third filling was performed with 15 liters. Notably, these cycles were adopted because performing successive sludge pumping in GTX systems for dewatering purposes until the maximum storage capacity is reached under controlled pressures and volumes is realistic in practical applications (Lawson, 2008). A total volume of 55 liters of sludge for each bag was adopted at the expense of the storage and confinement capacity during pumping with LCs. When the sludge density was 1,100 kg/L, each GTX bag received 60.5 kg of sludge.

In addition, the dewatered masses in the bags after the three fillings were determined at intervals of 1 to 55 days to evaluate the internal consolidation processes of the WTPS after dewatering. For this purpose, the bags remained at rest on wooden platforms and were protected from light.

3.4 Efficiency parameters

To evaluate the effectiveness of the use of GTX bags for achieving WTPS dewatering with and without LCs, formulations from the literature were used. The filtration efficiency (FE),

as shown in Equation 1, shows the relationship between the TS content of sludge before dewatering and the TS content in the filtrate after performing filtration (Moo-Young; Tucker, 2002). The dewatering efficiency (DE), described by Equation 2, addresses the parameters in terms of the percentages of initial and final TS content obtained after dewatering (Moo-Young; Gaffney; Mo, 2002).

$$FE = \frac{TSS_{\text{initial}} - TSS_{\text{final}}}{TSS_{\text{initial}}} \times 100\% \quad (1)$$

Given that,

TSS_{initial} : TS content in the sludge before dewatering (mg/L);

TSS_{final} : TS content in the filtrate (mg/L).

$$DE = \frac{PS_{\text{final}} - PS_{\text{initial}}}{PS_{\text{initial}}} \times 100\% \quad (2)$$

Therefore,

PS_{final} : percentage of final TS content (%);

PS_{initial} : percentage of initial TS content (%).

The solids passing (SP) indicator expresses the percentage ratio between the total amount of suspended solids in the filtrate and the initial TS content in the WTPS before dewatering is performed according to Equation 3 (Satyamurthy, 2008; Satyamurthy; Bhatia, 2009). The Piping (PP) reflects the retention capacity of solid particles suspended by the GTX material, according to Equation 4 (Satyamurthy; Bhatia, 2009).

$$SP = \frac{TSS_{\text{final}}}{TSS_{\text{initial}}} \times 100\% \quad (3)$$

Given that,

TSS_{final} : final TS content in the filtrate (mg/L);

TSS_{initial} : initial TS content in the sludge (mg/L).

$$PP = \frac{TSS_{\text{final}}}{A} (g/m^2) \quad (4)$$

Then,

TSS_{final} : TS content in the filtrate (mg/L);

A: effective area of the GTX during dewatering (m^2).

In this study, the total suspended solid parameter (TSS_{final}) was replaced by the final TS content in the filtrate (TS_{final}), which was determined by collecting the filtrate produced after the 3rd filling step.

4 RESULTS AND DISCUSSION

4.1 Chemical conditioning

Table 3 summarizes the results obtained from the cone test. The mean results are shown in Figure 3. Although the cationic polymers (C492 and C498) resulted in lower turbidity values (NTU), smaller dewatered volumes were obtained after their coagulation and passage through the filtering system formed by the GTX cone. Thus, the use of the analyzed cationic polymers was discarded for the sludge under analysis.

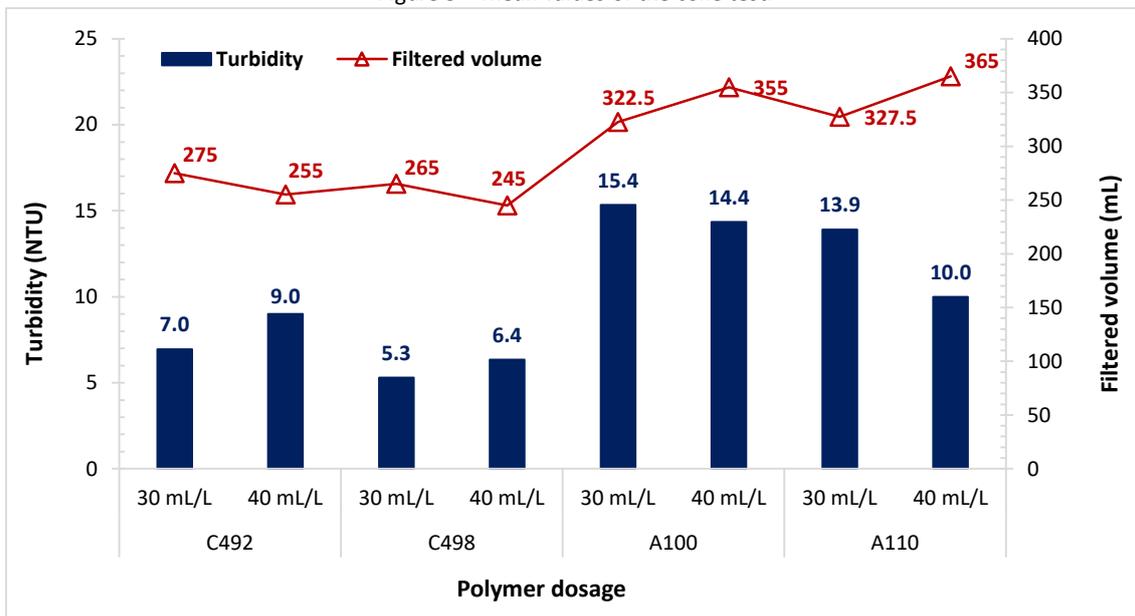
Among the anionic polymers (A100 and A110), lower turbidity and higher filtrate volumes were obtained for A110. The 40 mL/L dosage resulted in better results than the 30 mL/L dosage did, with a mean turbidity difference of 3.9 NTU and a filtrate volume of 37.5 mL (Figure 3). However, when considering the consumption of polymers in practical applications, i.e., chemical conditioning in relation to the volume of sludge being treated, it is necessary to consider the costs involved in this step and to avoid a loss of efficiency. Therefore, for the analyzed conditions, the use of polymer A110 at a concentration of 0.2% and a dosage of 30 mL/L was defined.

Table 3 – Results of chemical conditioning with a single concentration of 0.2%.

Polymer	Replicate	Dosage	Turbidity (NTU)	Filtrate volume (mL)
C492	R1	30 mL/L	6.8	280.0
	R2		7.1	270.0
	R1	40 mL/L	9.4	250.0
	R2		8.6	260.0
C498	R1	30 mL/L	4.9	270.0
	R2		5.7	260.0
	R1	40 mL/L	6.8	250.0
	R2		5.9	240.0
A100	R1	30 mL/L	15.1	320.0
	R2		15.6	325.0
	R1	40 mL/L	14.4	360.0
	R2		14.3	350.0
A110	R1	30 mL/L	13.6	330.0
	R2		14.2	325.0
	R1	40 mL/L	9.7	370.0
	R2		10.3	360.0

Source: Authors (2025).

Figure 3 – Mean values of the cone test.

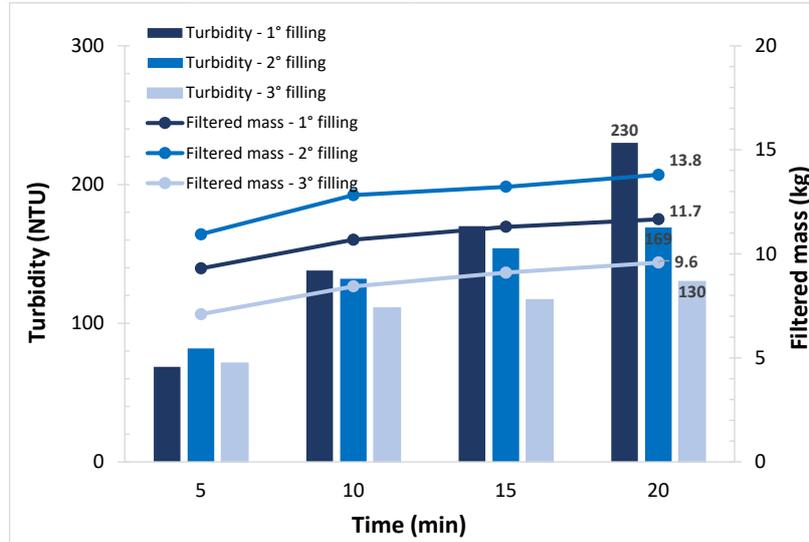


Source: Authors (2025).

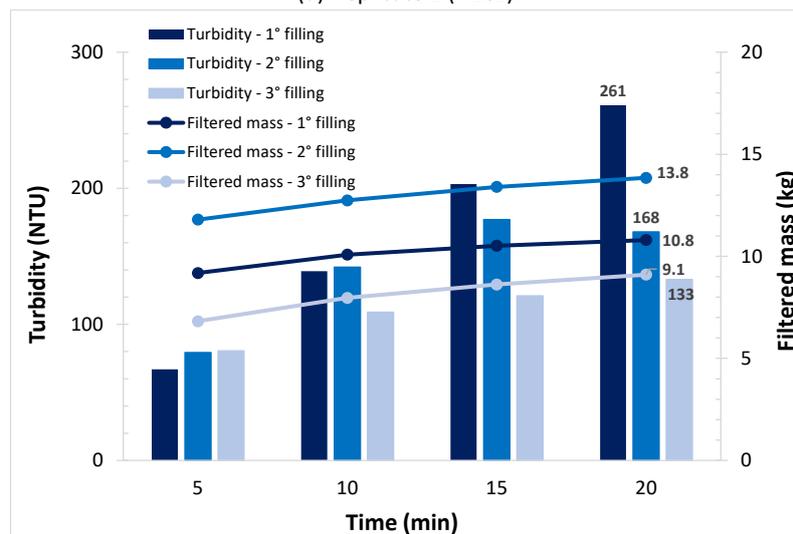
4.2 Dewatering parameters

Figure 4 shows the turbidity values (NTU) of the filtrate mass (kg) recorded between the 1st and 3rd sludge fillings in the bags without LCs (NLC1 and NLC2) for 5, 10, 15 and 20 minutes. The parameters recorded in the bags with LCs (LC1 and LC2) are shown in Figure 5. To provide a better understanding, the cumulative values of the analyzed parameters are indicated for the 20-minute case.

Figure 4 – Dewatering without LCs: turbidity levels and filtrate masses between fillings.



(a) Replicate 1 (NLC1).



(b) Replicate 2 (NLC2).

Source: Authors (2025).

Between the time intervals, there was an apparent increase in the turbidity of the filtrates for the dewatering tests without LCs (NLC1 and NLC2) and with LCs (LC1 and LC2) because of the possible accumulation of particles remaining from the previous filling step. Notably, changes were observed in the color of the filtrates between the collection times and the readings of the turbidimeter, whose filtrates began to show a yellow color, which influenced the turbidity readings (Figure 6).

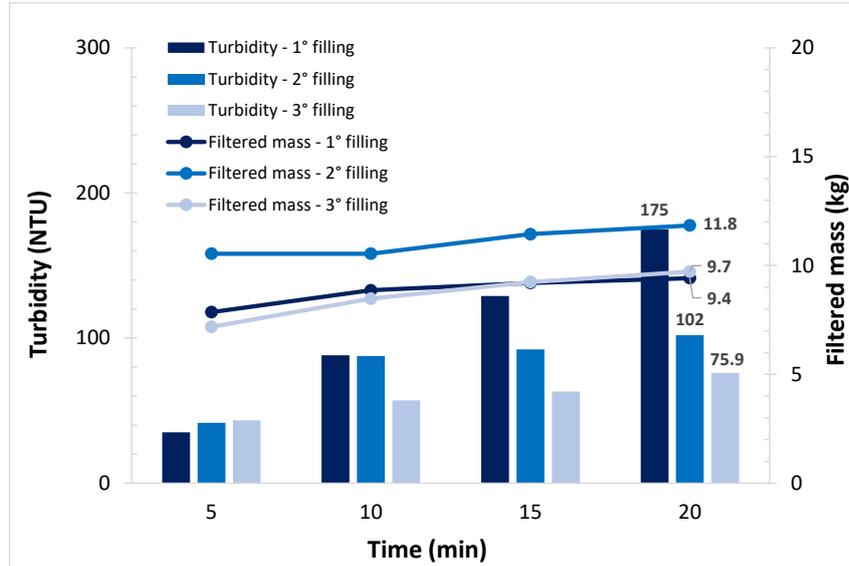
Additionally, regarding the turbidity values (NTU), decreases were observed between the 1st and 3rd fillings because of the formation of an internal filter with dewatered sludge, which is known in the literature as *filter cake* (Moo-Young; Tucker, 2002). For dewatering without LCs, a reduction in turbidity from 230 NTU (1st filling) to 130 NTU (3rd filling) was recorded at 20 minutes for replicate 1 (NLC1). For replicate 2 (NLC2), the values ranged from



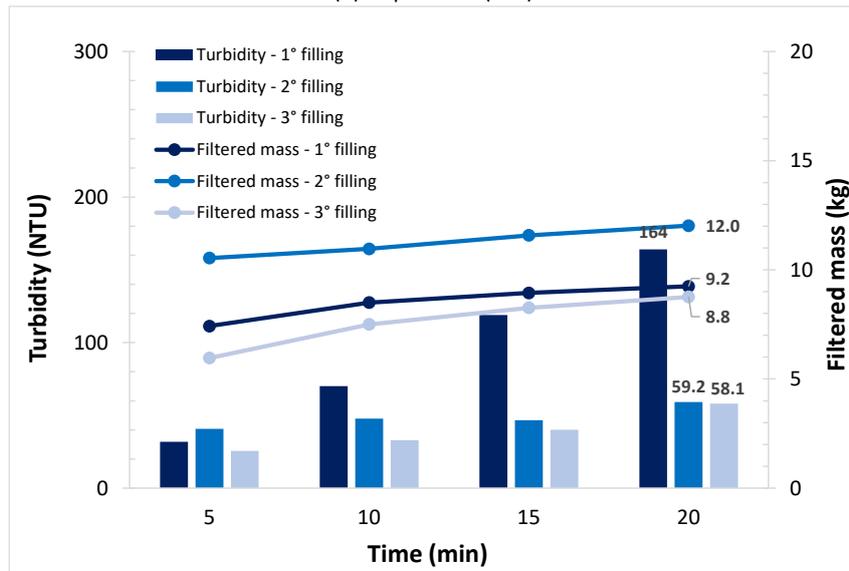
261 NTU (1st filling) to 133 NTU (3rd filling). That is, the percentage turbidity reductions were 43.5% (Figure 4a) and 49.0% (Figure 4b), respectively.

For the dewatering replicates with LCs, the behaviors were similar to those of the tests without LCs in terms of the turbidity reduction induced during dewatering; however, lower turbidity records were observed between the 1st and 3rd fillings. That is, for replicate 1 (LC1), a reduction from 175 NTU (1st filling) to 75.9 NTU (3rd filling) was achieved. In replicate 2 (LC2), the results ranged from 164 NTU (1st filling) to 58.1 NTU (3rd filling). These results indicated turbidity reductions of 56.6% (Figure 4c) and 64.6% (Figure 4d), respectively. Although the reduction percentages were lower in the tests with LCs, notably, the initial and final turbidities were lower than those recorded in the tests without LCs; i.e., implementing dewatering under confined conditions led to a greater retention of solid particles in the filtrate and, therefore, greater efficiency during the process.

Figure 5 – Results of dewatering with LCs: Turbidity levels and filtrate masses between fillings.



(a) Replicate 1 (LC1)



(b) Replicate 2 (LC2)

Source: Authors (2025).

Figure 6 – Changes in the color of the filtrates after dewatering.



(a) Filtering process during the initial part of dewatering.



(b) Filtrate stored in an airtight container.

Source: Authors (2025).

For the recorded filtrate mass (kg) parameter, the same mass increase behavior was observed between the 1st and 2nd fillings and, subsequently, the dewatered mass reduction between the 2nd and 3rd fillings, which were lower than 1° for fillings without LCs (NLC1 and NLC2) and with LCs (LC1 and LC2). This was also due to the formation of an internal filter between the 1st and 2nd fillings, which favored greater solid retention and, consequently, dewatering of the liquid portion of the sludge, as well as greater internal pressure caused by the initial pumping stage. For the first filling, the pumping volume was 25 liters, and that for the 2nd filling was 15 liters. In the dewatering replicates performed without LCs, the filtrate masses ranged from 13.8 kg to 9.6 kg (NLC1) and from 13.8 kg to 9.1 kg (NLC2) at 20 minutes. For the tests with LCs, the values ranged from 11.8 kg to 9.4 kg (LC1) and from 12.0 to 8.8 kg at 20 minutes. That is, compared with the bags without LCs, the bags with LCs had lower dewatered masses at 20 minutes (between the 1st and 3rd fillings). This result was directly due to the effects of LCs, which restricted lateral movements and, therefore, slowed the dewatering processes. However, more solid particles were retained, and this metric is of paramount importance for evaluating for the efficiency of confined dewatering systems.

Table 4 shows the heights reached by the bags during dewatering, and Figure 7 shows the respective photographic records. Notably, the height measurements between the fillings were obtained from the initial positions indicated in the photographic records.

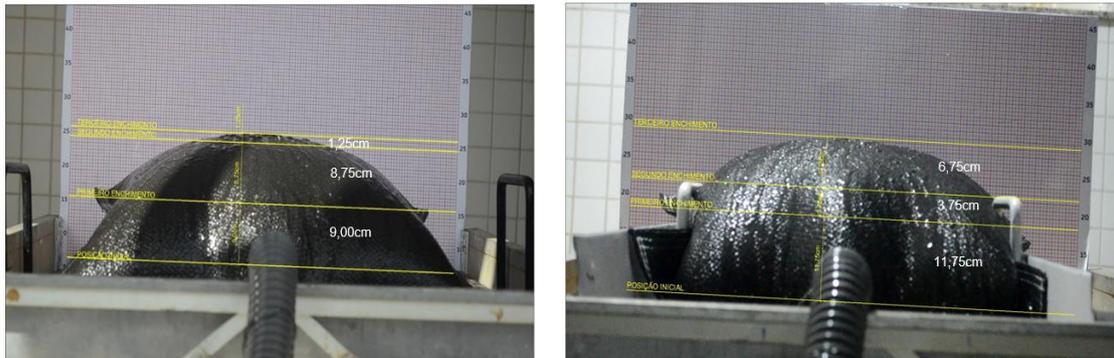
Table 4 – Heights of the pockets based on dewatering effects.

Dewatering cycle	Without LCs	With LCs
1st filling	9 cm	11,75 cm
2nd filling	8.75 cm	3.75 cm
3rd filling	1.25 cm	6.75 cm
Total height*	19.00 cm	22.25 cm

Source: Authors (2025).

The maximum values obtained were 19.00 cm in the tests without LCs and 22.25 cm in the tests with LCs. Thus, a percentage difference of 17% was induced by the LCs, which promoted an increase in the internal stresses during the dewatering processes. Therefore, the LCs (Figure 7b) caused the confined system to reach higher levels of internal and controlled stress and slower dewatering rates over time. This favored better consolidation of the internal filter generated by the dewatered sludge and contributed to greater reductions in turbidity (NTU).

Figure 7 – Bag heights between filling cycles.



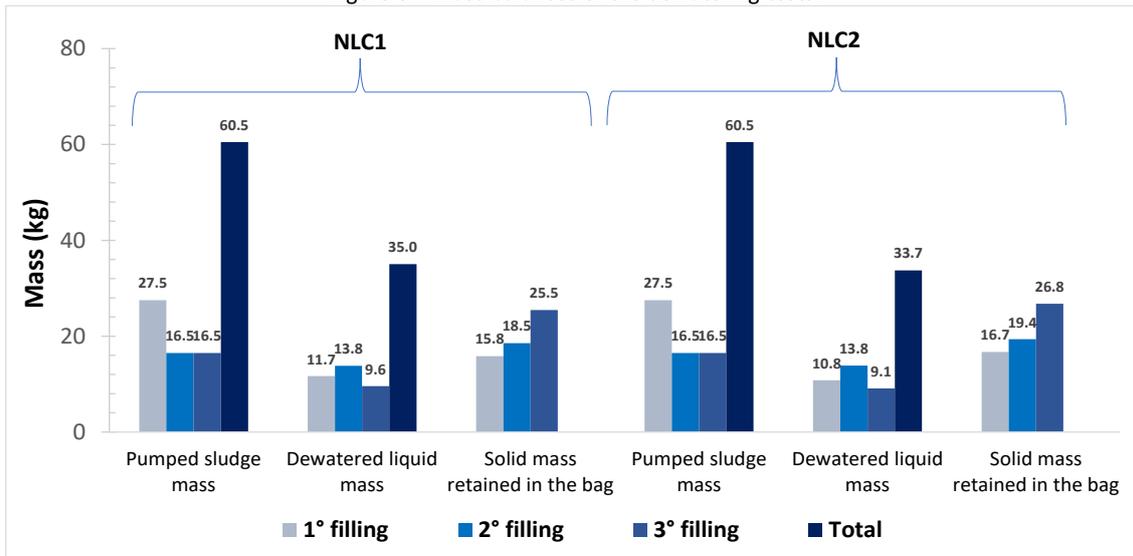
(a) Without LCs.

(b) With LCs.

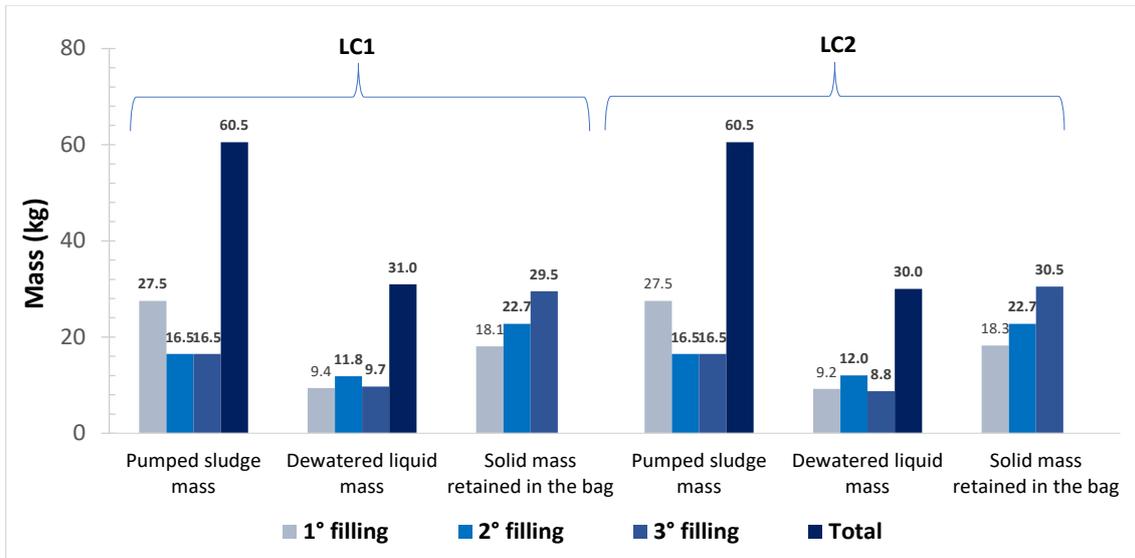
Source: Authors (2025).

Figure 8 shows the mass ratios between the pumped sludge and the liquid portions that were dewatered and retained in the bags, which were recorded after each filling cycle.

Figure 8 – Mass balances of the dewatering tests.



(a) Without LCs.



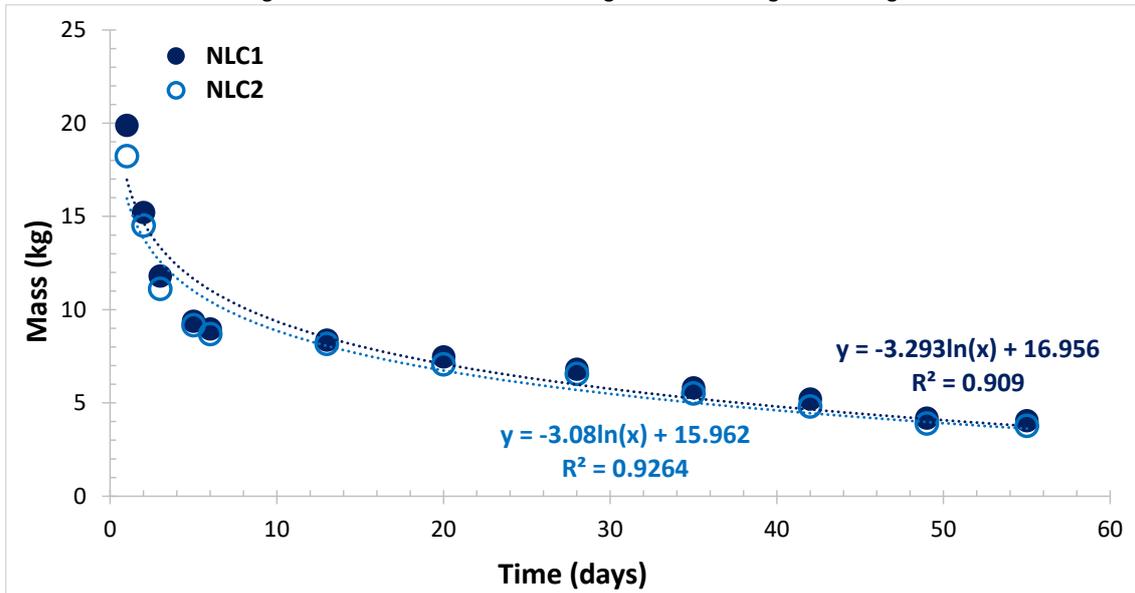
(b) With LCs.

Source: Authors (2025).

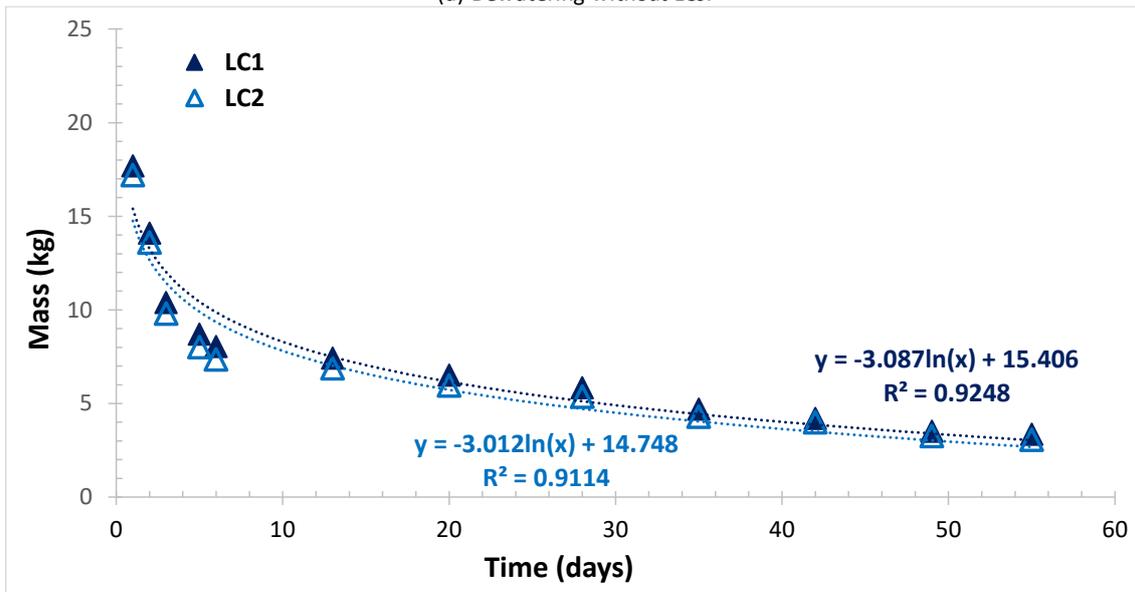
Higher solid masses were observed in the LC1 (29.5 kg) and LC2 (30.5 kg) bags than in the NLC1 (25.5 kg) and NLC2 (26.8 kg) bags. These findings aligned with the findings that the dewatering tests with LCs had lower filtered masses than the tests without LCs. For each comparison, the volumes of pumped sludge were converted into mass values on the basis of a density of 1,100 kg/m³. Thus, the percentages retained in the tests with LCs were 48.8% (LC1) and 50.4% (LC2), and the values obtained in the tests without LCs were 42.1% (NLC1) and 44.2% (NLC2). That is, the masses retained in the condition with LCs were 6.4% greater than those in the condition without LCs after the 3rd filling step.

Regarding the behavior of the retained masses over time, Figure 9 shows more pronounced reductions during the first few days and less significant reductions until the last record (55 days). Thus, the bags exhibited a logarithmic time-to-mass relationship.

Figure 9 – Masses retained in the bags after executing dewatering.



(a) Dewatering without LCs.



(b) Dewatering with LCs.

Source: Authors (2025).

During the evaporation phase, the dewatered CR bags were kept under evaporation conditions without LCs, which explains the similarities in behavior between the bags without LCs (NLC1 and NLC2) and those with LCs (LC1 and LC2). However, notably, the bags that were filled under LC conditions (LC1 and LC2) had a mean retained mass of 3.2 kg, which was slightly lower than the mean of 3.9 kg obtained for the bags without LCs (NLC1 and NLC2). That is, between the 3rd filling and 55 days, the retained masses decreased from 49.6 kg to 3.2 kg (LCs) and from 43.2 kg to 3.9 kg (NLCs).

4.3 Dewatering parameters

Table 5 shows the mean results obtained for the efficiency parameters. A higher FE was observed for the dewatering tests with LCs, whereas it had a lower SP and PP, indicating that it is more efficient than dewatering without LCs in terms of the retention of solid sludge particles and the dewatering of the liquid portion; dewatering without LCs (LC1 and LC2) also had lower turbidity levels (NTU).

In terms of DE, because this parameter was obtained 24 hours after the end of the tests, the bags (LC1 and LC2) remained at rest and without LCs. This result explains the difference of only 1.2% between the results with and without LCs. In addition, the low mean DE values of 32.7% (without LCs) and 33.9% (with LCs) are supported by the fact that the initial solid content in the sludge (8.38%) was considered high.

Table 5 – Mean efficiency parameters of the system.

Parameters	Without LCs	With LCs
Total solid content in the sludge (mg/L)	74500	74500
Total solid content in the filtrate (mg/L)	800	400
Effective area of the geotextile (m ²)*	0.5	0.5
Filtration efficiency – FE (%)	98.9	99.5
Dewatering efficiency – DE (%)**	32.7	33.9
Solids Passing – SP (%)	1.1	0.5
Piping – PP (g/m²)	1.6	0.8

Observations: *Area of the upper and lower surfaces; ** Obtained 24 hours after the 3rd filling cycle. Source: Authors (2025).

4 CONCLUSIONS

The dewatering of sludge in GTX systems has emerged as an efficient technique for reducing the high volumes of sludge that are generated daily, which require integrated management and appropriate final disposal. Most WTPs do not have areas available for the implementation of traditional treatment technologies, such as drying beds and sedimentation ponds, and they face high demand for drinking water; these factors increase the volume of waste generated.

The results of the study show the numerous advantages of treating WTP sludge through dewatering in GTXs and highlight the impacts of LCs. Volume reductions should be implemented to ensure appropriate final disposal, efficiency in the retention of solid masses and dewatering of the liquid portion of sludge with low turbidity levels. This is possible as long as there is compatibility between the preliminary chemical conditioning of the waste, pumping pressures, the quantities and volumes of fillings, the volumetric capacity of the GTX system and its hydraulic and mechanical properties.

The implementation of confined dewatering systems combines the numerous advantages of solid waste treatment with high liquid contents and requires only small management areas. Therefore, the results of this study can inform discussions concerning the alignment of WTP sludge dewatering techniques that involve GTXs with the SDGs to promote environmental sustainability for current and future generations.



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STATEMENTS

CONTRIBUTION OF EACH AUTHOR

When describing the participation of each author in the manuscript, use the following criteria:

- **Conception and Design of the Study:** Denise de Carvalho Urashima.
 - **Data Curator:** Denise de Carvalho Urashima.
 - **Formal Analysis:** Marcus Vinícius Mendes Pereira, Denise de Carvalho Urashima and Mag Geisielly Alves Guimarães.
 - **Financing Acquisition:** Denise de Carvalho Urashima.
 - **Research:** Marcus Vinícius Mendes Pereira, Denise de Carvalho Urashima and Mag Geisielly Alves Guimarães.
 - **Methodology:** Denise de Carvalho Urashima.
 - **Writing – Initial Draft:** Marcus Vinícius Mendes Pereira
 - **Writing – Critical Review:** Denise de Carvalho Urashima and Mag Geisielly Alves Guimarães.
 - **Revision and Final Editing:** Denise de Carvalho Urashima and Mag Geisielly Alves Guimarães.
 - **Supervision:** Denise de Carvalho Urashima.
-

DECLARATION OF CONFLICTS OF INTEREST

We, **Denise de Carvalho Urashima, Marcus Vinicius Mendes Pereira and Mag Geisielly Alves Guimarães**, declare that the manuscript entitled “**Water treatment plant sludge dewatering using geotextile bags: With and without lateral constraints**” satisfies the following:

1. **Financial ties:** The authors have no financial ties that may have influenced the results or interpretation of the study. No institution or funding entity was involved in the development of this study.
 2. **Professional Relationships:** The authors have no professional relationships that may have impacted the analysis, interpretation or presentation of results. No professional relationship relevant to the content of this manuscript was established.
 3. **Personal Conflicts:** The authors have no personal conflicts of interest related to the content of the manuscript. No personal conflicts related to the content were identified.
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