

Dewatering Sludge in Geotextile Closed Systems: Brazilian Experiences

M.G.A. Guimarães, D.C. Urashima

Abstract. The use of geotextile closed systems for the dewatering of sludge is a new technology that has been used in recent years in Brazil and globally. This technology has relevant technical and environmental advantages. The variables that influence the operation and evaluation of the efficacy are under constant investigation by the scientific community. This paper presents a state-of-the-art analysis of the use of geotextile closed systems for the dewatering of sludge with high water content, contributing to a better understanding of the fundamentals involved in the technical and scientific application of this technology. This paper also presents the Brazilian experiences with the dewatering of sludge generated in different sectors. This subject has significant relevance; it is a new method to reduce the volume of sludge produced on a large scale and enable final disposal with low environmental impacts.

Keywords: : dewatering, geotextile closed systems, sludges.

1. Introduction

In Brazil and globally, a current major problem is the increasing production of residuals with high pollution potential, such as byproducts from processes for obtaining goods, materials and services. Therefore, studies on proper residual disposal and handling are of great importance.

The sludge dewatering technique for high liquid content waste using a geotextile closed system has recently proven to be an efficient and viable solution for the reduction of liquid content and consequent reduction in final volume for disposal from a technical, economic and environmental perspective. This technique enables the retention and containment of solid mass, provides one response to questions about the disposal of waste generated by human activities in different segments, and even allows the re-use of dewatering waste in different industries (Fowler *et al.*, 2002; Moo-Young *et al.*, 2002; Moo-Young & Tucker, 2002; Muthukumaran & Ilamparuthi, 2006; Lawson, 2008; Satyamurthy & Bhatia, 2009a).

Since the 1960s, tubes constructed of geotextiles have been used as a containment technology in geotechnical works. In Brazil, in the 1980s, geotextile containment booms were executed within the city of Cubatão-SP (Bogossian *et al.*, 1982).

To better understand the phenomenon of sludge dewatering in geotextiles, several laboratory and field studies have been performed in recent years (Moo-Young *et al.*, 2002; Moo-Young & Tucker, 2002; Koerner & Koerner, 2006; Muthukumaram & Ilamparuthi, 2006; Lawson, 2008; Liao & Bathia, 2008; Satyamurthy & Bathia, 2009a; Cantré & Saathoff, 2011). Models have also been developed. For example, the model proposed by Leshchinsky &

Leshchinsky (2002) assessed the mechanical stresses in the filling of a geotextile closed system and the Urashima (2002) assessed the simulation of filtration in suspension model.

Recent studies have demonstrated numerous advantages in the use of geotextile closed systems for dewatering sludge. These systems have proven effective for treating sludge generated from Water Treatment Plants (WTP), domestic sewage, industrial processes and the processing of ore (mining), among others.

This paper presents a state-of-the-art technology solution for the dewatering of sludge in geotextiles closed systems, contributing to a better understanding of the technical-scientific methodologies used recently and demonstrating the importance and relevance to the environmental segment. This paper also presents examples of laboratory studies and field applications performed in Brazil.

2. Dewatering in Geotextile Closed Systems

2.1. Initial considerations

A geosynthetic is “a product at least one of whose components is made from a synthetic or natural polymer, in the form of a sheet, a strip or a three-dimensional structure, used in contact with soil and/or other materials in geotechnical and civil engineering applications” (NBR ISO 10318, 2013).

The first applications of geosynthetics date back to the 1950s, with fabrics manufactured for use as a separation and filter layer between granular soil and soil of low resistance and for critical filtration applications in coastal pro-

M.G.A. Guimarães, PhD. Student, Departamento de Engenharia de Infraestrutura Aeronáutica, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil. e-mail: maggeisielly@yahoo.com.br.

C. Urashima, Associate Professor, Departamento de Engenharia Civil, Centro Federal de Educação Tecnológica de Minas Gerais, Belo Horizonte, MG, Brazil. e-mail: urashima@civil.cefetmg.br.

Submitted on January 21, 2013; Final Acceptance on August 2, 2013; Discussion open until April 30, 2014.

jects in the Netherlands and the United States (Shukla & Yin, 2006).

The geosynthetics commonly studied for the dewatering of fine waste are the woven and nonwoven geotextiles and the geocomposites formed by woven and nonwoven geotextiles. These materials must demonstrate good filtration performance, which corresponds to the retention capacity of the solid, while allowing the free passage of fluid.

The introduction of geotextile closed systems for the dewatering of sludge was recorded in the 1990s with sewage sludge (a cohesive material with high moisture content and high resistance to filtration), providing the first analysis of dewatering sludge (Fowler *et al.*, 1996; Lawson, 2008). Figure 1 illustrates the application of a geotextile closed system in the dewatering of sludge, commonly referred to as geotextile bags or geotextile tubes, depending on geometrical shape and volume.

The dewatering of sludge in geotextiles is expanding, with increasing use in new applications (Lawson, 2008). The granular soil filters are being replaced by geotextile filters in many environmental projects, which is the oldest application of geosynthetics in civil engineering projects (Christopher *et al.*, 1993).

One of the advantages of using geotextiles for dewatering sludge is that they can be customized for specific project dimensions, depending, for example, on the space available for installation. They can also be stacked on one another (Koerner & Koerner, 2006; Lawson, 2008). Furthermore, geotextiles provide for the rapid disposal of large volumes of sludge, ease of construction and installation, high efficiency, low costs, minimal environmental impacts (Fowler *et al.*, 2002; Lawson, 2008) and reduced dependence on weather conditions for the realization of dewatering (Mendes *et al.*, 2001).

In the design of dewatering systems with geotextiles, it is essential to match the functional properties of the geotextile with the properties required in the project (Vidal

et al., 1999). The properties of the geotextile must be adapted to the functions and mechanical stresses that they will be subjected (Trentini *et al.*, 2006). The mechanical resistance of the geotextile can be affected by seam performance, potential damage during installation and operation, an accidental increase in pressure pumping of the sludge on the tube, and degradation of the polymer chain by physical, chemical and/or biological agents, among others.

One of the consequences arising from the non-compatibility of seams is the disruption of the geotextile tube by sewing, resulting in leakage of sludge (Leshchinsky & Leshchinsky, 2002), as illustrated in Fig. 2. Studies must be



Figure 2 - Failure of a seam on a geotextile tube (Leshchinsky & Leshchinsky, 2002).

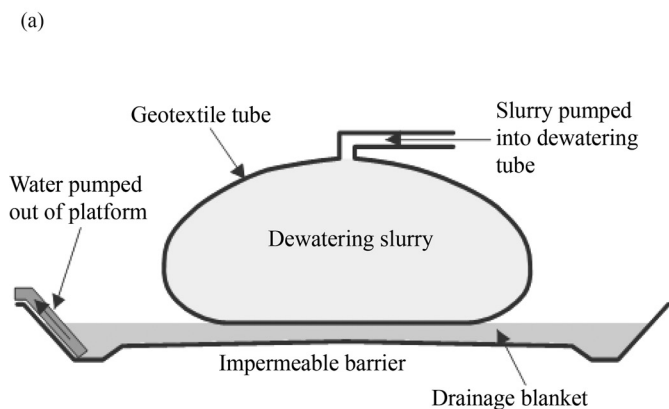


Figure 1 - Geotextile tube dewatering: (a) Details of dewatering; (b) Geotextile tubes used to dewater slurry waste volumes (Lawson, 2008).

conducted on the efficiency of the seams to verify compatibility with the project requirements and on the factors that may affect the seam resistance, line type and number points, type of sewing and equipment used for its preparation (Ten Cate, 2010).

During dewatering, it is possible to consider two basic types of filtration mechanisms within the geotextile: initially the filtration of suspension particles and then, depending on the type of sludge to be dewatered, the filtration situation under porous conditions.

The filtration of suspension particles is a critical problem because of the hydraulic load loss that occurs when the particle finds the filter and tends to be deposited on surface of the geotextile. This occurs even for particles much smaller than the opening size of the filter element.

The behavior of a filtration system with suspension particles may vary according to the type of material. In the case of granular soil, the retained particles form a trapped material layer that remains permeable in a phenomenon equivalent to the increased thickness of the filter. In the case of cohesive soil, the problem of clogging becomes important. Usually, the clogging is caused by the deposition of a layer of low permeability soil upstream of the filter, as in the dewatering of sludge composed of fine particles (Urashima, 2002).

Depending on the size distribution of the sludge, there may be a tendency to form a pre-filter called a filter cake (Vidal & Urashima, 1999; Pilarczyk, 2000; Koerner & Koerner, 2006; Liao & Bhatia, 2008), which is a mass adhered to the internal structure of the geotextile. This greater concentration of solids relative to the initial state of the sludge in dewatering can function as a low permeability hydraulic barrier.

During filtration under porous conditions, smaller particles of the soil adjacent to the filter may be transported through the geotextile, resulting in a soil structure rearrangement. This can function as a natural filter (pre-filter) according to the size distribution of the base material; the retention of larger particles contributes to the blocking of smaller particles reaching the geotextile (Urashima, 2002).

The filtration of suspension particles has been reported to be more critical to filtration in relation to porous conditions because they tend to deposit on the surface of the geotextile, creating a layer of low permeability (Urashima, 2002). This behavior may cause, in many cases, physical clogging, which can obstruct the passage of fluid through the geotextile, compromising the dewatering of the sludge (Leshchinsky *et al.*, 1996; Vidal & Urashima, 1999).

Koerner (2005) presents different design methods that ensure the retention of different particle size materials relative to the geotextile filtering openings, considering also a porous-low permeability condition.

Because of the complexity of the composition of the material being dewatered, which often contains very fine particles or organic components, the following condition

requirements may influence the behavior of the dewatering systems:

- System compression and traction requirements;
- Intensity and velocity of flow inserted;
- Ambient condition requirements, including fluid characteristics, risks of system degradation, chemical alterations to be dewatered in the middle of the process, and possible physical, chemical or biological clogging.

2.2. Factors influencing the process of dewatering

There is a consensus in related literature on the importance of chemical conditioning. It is a 'key point' in the dewatering operations on sludge that presents a high resistance to filtration. The chemical conditioning can be performed with cationic, anionic or non-ionic polymers, depending on the physicochemical characteristics of the sludge. The chemical conditioning causes the solid-liquid separation of the sludge through the coagulation of the solids and the liberation of the adsorbed water, controlling the interaction between suspension, speed and degree of dewatering of the solid mass (Lawson, 2008; Castro *et al.*, 2009; Guanaes, 2009; Satyamurthy & Bhatia, 2009b). Therefore, an evaluation is necessary to select the most effective conditioning chemical for each type of sludge.

Visual observations of the characteristics of the floc formed (stability) and of the solid-liquid separation are a means to evaluate the polymer and its optimal dosage. However, an inadequate observation of the behavior of the sludge conditioning can result in an inaccurate determination of dosage as well as the indiscriminate use of flocculant polymers (Satyamurthy & Bhatia, 2009b). It may even lead to changes in the chemical composition of the sludges (Tominaga, 2010).

Pressure and velocity are important in pumping the sludge to dewatering; high force values may result in the breaking of chemical conditioning, which compromises its functionality (Guanaes, 2009).

A parameter that greatly influences the dewatering process is the initial percent of solids in the sludge. At the beginning of filtration, there is a considerable removal of water retained in the solid mass as well as a small passage of suspended particles; the "filter cake" is formed after a period of dewatering. As the filter cake grows during filtration, the filtrate volume is reduced with the decrease in turbidity (Moo-Young *et al.*, 2002; Moo-Young & Tucker, 2002; Muthukumaran & Ilamparuthi, 2006; Lawson, 2008).

The sludge dewatering causes a concentration of the solid mass within the geotextile closed systems and a decrease in volume, with a concentration of physical, chemical and biological parameters, when compared with the initial sludge values (Guanaes, 2009).

For materials that have a high liquid content and a low permeability, Umezaki *et al.* (2007, apud Tominaga, 2010) proposed the vacuum dewatering of high liquid content ma-

terials in a geotextile closed system, based on the initial conception of Umezaki and Kawamura (2002, apud Tominaga, 2010). This dewatering method involves applying a vacuum pressure in the geotextile closed system, creating a suction effect that accelerates the dewatering.

Umezaki *et al.* (2007, apud Tominaga, 2010) then performed laboratory tests to compare the conventional dewatering method with vacuum dewatering. The geotextile closed system consisted of a double-layer bag and internal plate drainage. The authors noted a further reduction in the height of the geotextile closed system and achieved lower water contents in shorter periods of dewatering compared to the conventional method.

2.3. Parameters for performance analysis

The performance of dewatering systems can be evaluated through the following parameters: filtration efficiency (FE), dewatering efficiency (DE), infiltration efficiency (IE), piping (PP) and solids passing (SP).

The filtration efficiency is the relation between the total solids in the sludge before dewatering and the total solids in the filtrate after filtration (Moo-Young & Tucker, 2002) and expressed as:

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

where FE is the filtration efficiency (%), TS_{initial} is the initial total solids in the sludge (mg.L^{-1}), and TS_{final} is the final total solids in the filtrate (mg.L^{-1}).

Satyamurthy & Bathia (2009b) stated that successful dewatering in geotextiles requires maximizing filtration efficiency and minimizing dewatering time (the time required to dehydrate a known volume of sludge).

The dewatering efficiency is defined as the change in the solids percentage before and after dewatering (Moo-Young *et al.*, 2002), given by:

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

where DE is the dewatering efficiency (%), PS_{initial} is the initial percent solids (%), and PS_{final} is the final percent of solids (%).

The infiltration efficiency is defined as the relation between the water content of the sludge before and after dewatering (Muthukumaran & Ilamparuthi, 2006), as described:

$$IE = \frac{W_i - W_f}{W_i} \times 100\% \quad (3)$$

where IE is infiltration efficiency (%), W_i is the initial water content of the sludge (%), and W_f is the final water content of the sludge (%).

Urashima *et al.* (2010) demonstrated that the term infiltration efficiency is not the most appropriate for a

dewatering process that uses a geotextile closed system. However, this equation is representative of the dewatering process.

The piping is a parameter that reflects the retention capability of a geotextile by weight of suspended solids passing through the geotextile during dewatering (Satyamurthy & Bhatia, 2009a) and it is expressed as:

$$PP = \frac{TSS_{\text{final}}}{A} \quad (4)$$

where PP is piping (g.m^{-2}), TSS_{final} is the final total suspended solids (g), and A is the effective area of the geotextile in dewatering (m^2).

However, the use of the suspended solids concentration in the evaluation of piping is not accurate because the solids present in the filtrate are, in fact, the total solids, which are the suspended solids plus the dissolved solids. Thus, Tominaga (2010) proposes the substitution of suspended solids with total solids.

The solids passing reflects the dewatering performance by comparing the suspended solids in the filtrate with the initial total solids of the sludge in accordance with the formulation proposed by Satyamurthy (2008, apud Satyamurthy & Bhatia, 2009a). It is given by:

$$SP = \frac{TSS_{\text{final}}}{TS_{\text{initial}}} \times 100\% \quad (5)$$

where SP is the solids passing (%), TSS_{final} is the total suspended solids in the filtrate (mg.L^{-1}) and TS_{initial} is the total initial solids of the sludge (mg.L^{-1}).

Among the parameters used in the quantification of a geotextile for dewatering, the solids passing is a simple and accurate measure of the dewatering system performance (Satyamurthy & Bhatia, 2009a). Finally, Tominaga (2010) reported that the suspended solids in the solids passing (SP) formula should be replaced by the total solids in the filtrate, as also used in the piping (PP).

3. Proposed of Standardization for Dewatering Tests

3.1. Cone tests

The cone test is a methodology described by Lawson (2008) that evaluates the need to use a chemical conditioning agent to assist in the dewatering of sludges in geotextiles (Castro, 2005; Martins, 2006; Castro *et al.*, 2009; Guanaes, 2009). This test also allows for the evaluation of the best dosage and concentration of polymeric additives to be added to the sludge under study, without the provision of behavior parameters.

As described previously, the use of a polymeric additive for solid-liquid separation has a great influence on the dewatering of fine sludges that have a high water content relative to solids, allowing the removal of adsorbed water in the solids. As a result, they enable a significant reduction in

the volume of sludge for disposal or recycling and, in some cases, the recirculation of water to treatment or for re-use in the system.

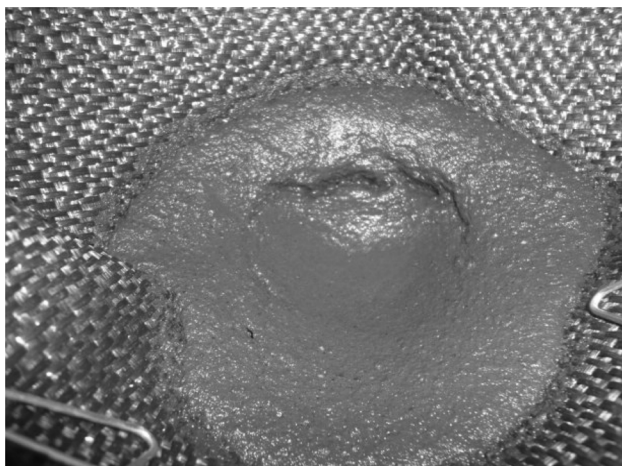
It is important to determine the cost of each polymeric additive and the impact of increasing the dosage because there may be a high daily consumption of a polymeric additive depending on the volume and type of sludge.

As an example, the results of a cone test are presented to evaluate 6 (six) different polymeric additives for the solid-liquid separation of sludge used in the water purifiers of City Eloi Mendes (Minas Gerais, Brazil). The sludge used is shown in Fig. 3.

The polymeric additives were evaluated at a concentration of 0.004 g.L^{-1} . The dosages tested were 10 mL and 15 mL per 500 mL of sludge. The parameters evaluated in each cone test were the filtrate turbidity (NTU), the final water content of the sludge dewatering (Fig. 4a) and the final volume of filtrate (Fig. 4b) 10 minutes after the beginning of the test. Figure 5 shows the results obtained for the 10 mL dosage of polymeric additive. Figure 6 displays the results for the 15 mL dosage.



Figure 3 - Sludge utilized in cone tests.



(a)

It is possible to verify that the turbidity (NTU), the volume of filtrate collected (mL) and the final water content (%) differ for each type of chemical conditioning and even between the dosages used (10 mL and 15 mL). In general, low values of turbidity indicate a lower passage of small particles through the geotextile concomitantly with the passage of liquid present in the sludge. In addition, lower liquid contents indicate a greater removal of sludge liquid, which indicates better dewatering.

For the 10 mL dosage (Fig. 5), better results were obtained for the Polymer 934 because of the lower value of turbidity (NTU) and the good reduction of liquid present in the sludge. Additionally, 213.5 mL of filtrate was obtained, greater than the average amount of filtrate obtained among the other polymers tested (204.0 mL).

For the 15 mL dosage (Fig. 6), the Polymer 934 also excelled in terms of turbidity and volume of filtrate obtained. However, there was an increase in the final water content of the sludge (916.2%). Even after increasing the polymer dosage to 15 mL, there was no improvement in the

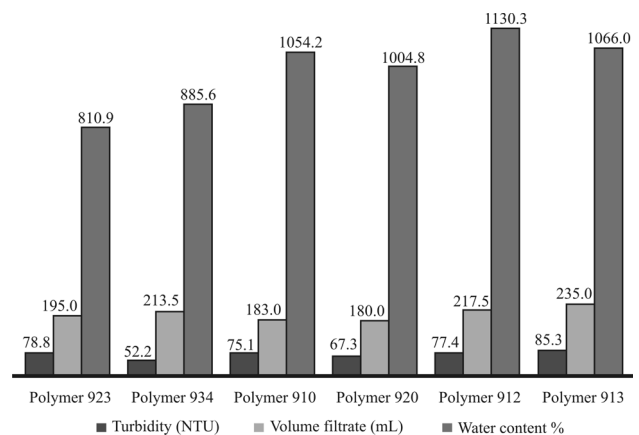


Figure 5 - Cone tests with 10 mL polymer dosage at a concentration of 0.004 g.L^{-1} .



(b)

Figure 4 - Cone tests: (a) Sludge dewatering; (b) Filtrate obtained.

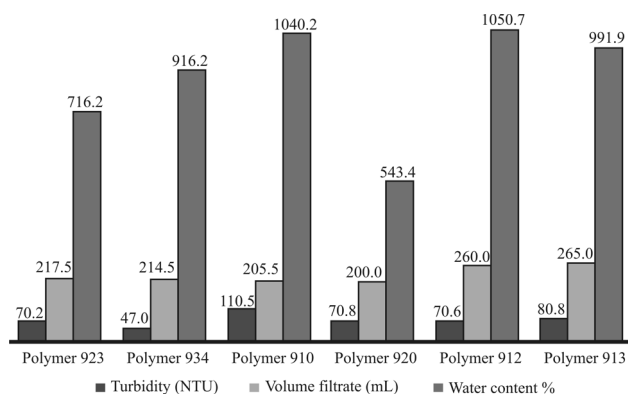


Figure 6 - Cone tests with 15 mL polymer dosage at a concentration of 0.004 g.L^{-1} .

measured parameters (reduction of turbidity and water content, increase of volume of filtrate) for all of the tested polymers. Therefore, increasing the dosage does not necessarily result in better chemical conditioning, which emphasizes the importance of obtaining an optimum dosage, as also discussed in studies by Tominaga (2010).

3.2. Dewatering tests in geotextile bags

The ASTM International published a standard method to determine the flow rate of water and suspended solids in a geosynthetic permeable bag containing high water content sludges (ASTM D 7701, 2011). This methodology describes two test methods. One test involves using a geotextile bag with a 114 cm inner circumference, a length of 165 cm and a volumetric test capacity of 150 to 190 L. The other test uses a geotextile bag with a 1.52 m circumference, a depth of 0.92 m, with a volumetric test capacity of 19 L.

The Geosynthetic Research Institute (GRI) has also proposed methodologies to analyze the behaviors of materials in dewatering, such as GRI-GT14 (2004) and GRI-GT15 (2009). The first method is for field dewatering of solids in a hanging bag test (HBT), as shown in Fig. 7, with one of the faces open and a linear length between 0.3 and 7.0 m.

The GRI-GT15 (2009) serves an identical purpose as the GRI-GT14 (2004); however, it uses geotextile bags with approximate dimensions of 50 to 65 cm in length, 38 to 65 cm in width and a volumetric capacity of 20 to 30 L. These bags contain an adapter flange to guide the sludge with polymeric additives into the bags (Fig. 8). Another difference between the methods is that the GRI-GT15 (2009) allows for the monitoring of the dewatering performance over time by observing the dehydrated material column (cm) by test time (min).

Castro *et al.* (2009) conducted a comparative study of both methods described above. This study showed that the GRI-GT15 (2009) method produces results very close the actual application of dewatering in geotextile bags; the



Figure 7 - Hanging bag test (Lawson, 2008).



Figure 8 - Tests in geotextile closed according to GRI-GT15 (Geosynthetic Research Institute, 2009).

sludge remains confined within the geotextile bags, which allows for better dewatering and prevents rehydration of the dry sludge. There is also a low breakdown of chemical conditioning with the introduction of sludge within the geotex-

tile bags compared to the methodology proposed by GT14-GRI (2004) because it occurs at less critical conditions.

Tominaga (2010) conducted laboratory studies to evaluate the performance of geotextile closed systems for sludge dewatering, which included cone tests for the evaluation of chemical conditioning and tests of small dimensions as proposed by GRI-GT15 (2009). In their studies, Tominaga (2010) used three materials with high water contents (kaolinite, powder-rock and sludge from WTP) for dewatering.

Tominaga (2010) demonstrated some inaccuracies in the methodology proposed by GT15-GRI (2009), such as the reading of the descent level of the sludge in the transparent tube installed above the geotextile bag. There is no specification of important readings to measure the quality of filtrate and of sludge dewatering and also the dewatering performance. Thus, Tominaga (2010) suggested some changes in the methodology proposed by the GRI-GT15 (2009) to provide a better assessment of dewatering using geotextile closed systems, such as fixing a reservoir at the top of the standpipe with a valve to control the filling of the bags; suspending the standpipe from a tripod and brace; and replacing the nozzle in the flange of the geotextile bag with the nozzle in the sleeve formed by the geotextile in the lateral position of the bag.

4. Brazilian Laboratory Study and Field Applications Experiences

4.1. Sludge dewatering at water treatment plants (WTPs)

The residues generated in WTPs, called wash water and sludge decanter, are produced in large quantities that may equal 5% of the volume of water treated in the process (Fontana & Cordeiro, 2005). These residues consist of fluids with high water contents, generally greater than 95% (Reali *et al.*, 1999), and solid sludge.

Thus, the reduction in its volume minimizes the risk of contamination of water and environmental resources. This also reduces the volume of residues to be properly disposed of, with a reduction in transport and disposal costs (Fontana & Cordeiro, 2005).

The legal aspects of environmental protection in Brazil have prompted studies of the treatment and final disposal of WTP residues (Fontana & Cordeiro, 2005). The inadequate disposal of these residues in the environment leads to damaging impacts, such as siltation of water-courses, soil contamination (Reali *et al.*, 1999; Andreoli *et al.*, 2001) and water source contamination (Hoppen *et al.*, 2003), and can aggravate water shortages for supply and purifiers (Mendes *et al.*, 2001).

Urashima *et al.* (2010) conducted studies of WTP sludge dewatering using geotextile bags with dimensions 60 cm x 50 cm and constructed of three types of geotextiles

(GT1, GT2 and GT3) with different filtration openings and tensile strength.

Cone tests were performed to verify the concentration and dosage of the polymer for sludge chemical conditioning.

Finally, a prototype was constructed (Fig. 9) that simulated the conditions of WTP pressure pumping. This prototype contains a reservoir for 75 L of residue, an inverter frequency to fix the average flow of pumping residue, a pressure transmitter and mixer screens for performing the chemical conditioning.

The dewatering system was assessed based on the filtration efficiency (FE), efficiency dewatering (DE) and infiltration efficiency (IE) parameters and on a verification of the decrease in filtrate turbidity during dewatering. This analysis is important because it is an indirect measure of the presence of solids or other particulate in the filtrate suspension.

Urashima *et al.* (2010) obtained average values of 98.1% for FE, 300.9% DE and 70.3% of IE for the three geotextiles tested (GT1, GT2 and GT3). This study showed that the geotextile bag has a good solid particle retention capacity, concomitant with free passage of liquid present in the sludge, thus enabling dewatering and reduction of large volumes for correct disposal or use in other industries as discussed in literature (Tsutuya & Hirata, 2001; Hoppen *et al.*, 2003; Oliveira *et al.*, 2004; Hoppen *et al.*, 2005).

Guimarães *et al.* (2012) conducted dewatering studies with successive pumping of sludge into the same geotextile bag, called dewatering with refills. The same equipment constructed by Urashima *et al.* (2010), after some adjustments to the structure, was used, as shown in Fig. 10.

There were three successive dewaterings conducted in the same geotextile closed system with dimensions of 60 cm x 60 cm. The time between the first and second dewatering was 72 h, and the time between the second and third dewatering was 24 hours. The polymeric additive

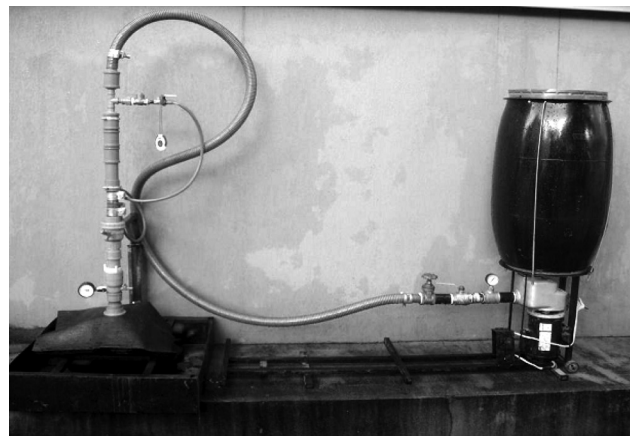


Figure 9 - Equipment for pressurized filling and dewatering (Urashima *et al.*, 2010).

used was identical to that used by Urashima *et al.* (2010), but in different concentrations. Each dewatering was performed with 75 L of sludge at an average sludge pumping flow of 0.75 L.s^{-1} .



Figure 10 - Prototype for the dewatering of sludge from a WTP in a geotextile bag (Guimarães *et al.*, 2012).

The dewatering system was assessed based on FE, PP and SP. The last two parameters were measured according to Tominaga (2010). The average results obtained were FE 97.2%, 2.8% SP and PP 0.6 g.m^{-2} . There was an increase in FE after each dewatering and a decrease in SP and PP. This result indicates an increase in the retention of solid particles after successive recharges of sludge into the same geotextile bag.

4.2. Sludge dewatering in mining

Mining sludges are produced in the processing of raw ore (iron, bauxite, kaolin, graphite, gold, phosphate, etc.). They are generated in large volumes, and the granular characteristics depend directly on the beneficiation process used in mining.

Because of the increase in mining activities in Brazil, there has been an increase in sludge generation. This situation has been aggravated by the absence of final disposal sites, technical and environmental storage constraints and the costs associated with transportation to the storage location. This has become one of the greatest chal-

lenges of modern geotechnical engineering (Bittar *et al.*, 2010).

The dewatering of mining sludges in geotextile closed systems thus provides a viable solution to the technical, economic and environmental concerns cited (Martins, 2006). In addition, the dewatering in geotextiles enables recirculation and recuperation of water inserted into the process, directly impacting the costs associated with beneficiation and producing smaller volumes of sludge for final disposal (Barbosa, 2011).

Gomes (2007) demonstrated some of the principles and potential applications of geotextile tubes for dewatering of mining sludges in pulp, highlighting the operational and economic advantages compared to conventional processes, such as the storage of sludge in dams with the risk of catastrophic rupture.

Martins (2006) used suspended geotextile bags (Fig. 11a) to conduct laboratory and field studies of the dewatering of sludges from the beneficiation of phosphate rock with two different particle sizes: fine-grained (called sludge), 100% of the particles with diameters of less than 0.074 mm (Fig. 11b); and granular sludge with sandy characteristics, 34% of the particles in the silt fraction (Fig. 11c).

Martins (2006) evaluated the effect of filtration efficiency (FE) during the dewatering period, obtaining the final results in approximately 100% of the fine-grained (sludge) and granular sludge.

Barbosa (2011) conducted studies of dewatering of sludge produced from the beneficiation of phosphate rock with a high content of fine particles with silt characteristics. Geotextile bags were used (Fig. 12), with a size of 60 cm x 60 cm and constructed of three geotextiles with different filtration openings and hydraulic permeability.

Dewatering tests conducted by Barbosa (2011) were performed by pumping the sludge that was chemically conditioned with anionic polymer. A prototype that simulated the conditions of pressure pumping of sludge building was used by Urashima *et al.* (2010).

Barbosa (2011) obtained average values of 99.1% for FE, 686% for DE, 0.9% for SP and 0.8 g.m^{-2} for PP for the three geotextile bags.

Bittar *et al.* (2010) performed studies on the dewatering of phosphate fine sludge from ore treatment processes (90% of the particle sizes below 325 mesh) using geotextile bags of small dimension second GRI-GT15 (2009) and Castro *et al.* (2009) and sludge collected directly from the discharge point. The objective of this study was to evaluate the quality of the filtrate collected and to determine the time required to obtain the desired solids content during the dewatering in geotextile bags (Fig. 13).

Bittar *et al.* (2010) performed preliminary cone tests with different polymeric additives, reaching a concentration of 10 ppm (Fig. 14).

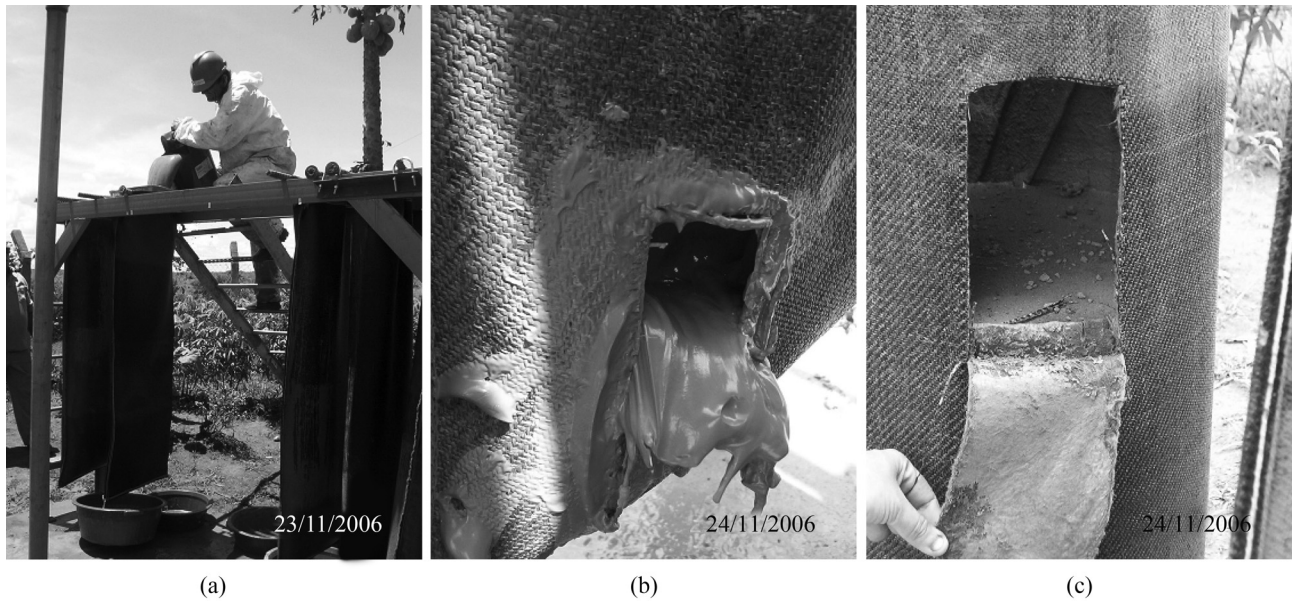


Figure 11 - Dewatering mining sludges in suspended geotextile bags: (a) Detail of bags used; (b) reject fine-grained (sludge); (c) granular sludge (Martins, 2006).

Bittar *et al.* (2010) obtained P_2O_5 and MgO concentrations similar to the initial mine deposit values, approximately 5% and 4%, respectively. A total solids concentration of 74.70% was reached after 10 days of dewatering, with an initial value of total solids in the sludge of 12.60%. Furthermore, the water content ranged from 87.40% (initially) to 25.3% during this period.

4.3. Sludge dewatering of septic tank sludge

Castro *et al.* (2008) performed a field implementation of four geotextile tubes for the dewatering of sewage sludge collected from septic tanks using vacuum trucks and from landfill leachate in the Rio das Ostras City (RJ, Brazil). Two geotextile tubes 30 m in length and 13.7 m in circumference and two geotextile tubes 60 m in length and 13.7 m in circumference (Fig. 15) were installed.

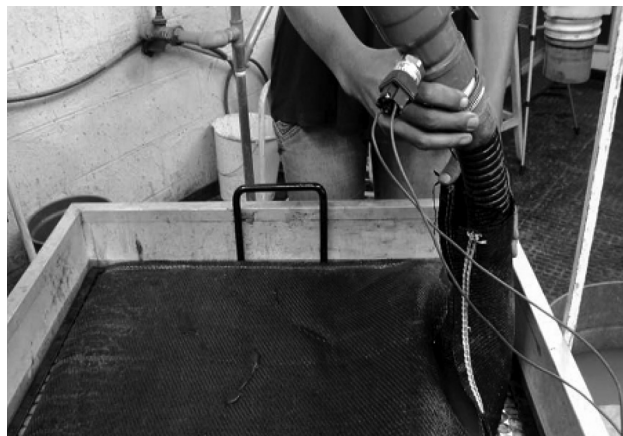


Figure 12 - Geotextile bag for dewatering sludge from beneficiation of phosphate rock (Barbosa, 2011).

The project was developed to reduce and dispose of large volumes of sludge generated in the city, which had no capacity to meet the high demands of sludge generation because of the large annual population increase. The project



Figure 13 - Small scale geotextile tube (Bittar *et al.*, 2010).



Figure 14 - Phosphate tailings passed, before and after the cone test (Bittar *et al.*, 2010).



Figure 15 - Geotextile tubes for dewatering effluent in the Rio das Ostras City, RJ, Brazil (Castro *et al.*, 2008).

met the demand of 34.000 cubic meters of sludge containing an average total suspended solids (TSS) of 1%.

The sludge from the septic tanks and landfill leachate were mixed in an equalization tank, and a cationic polymer was added for flocculation. The sludge mixture was then pumped into the geotextile tubes to dehydrate the sludge, retaining the solid portion and removing the liquid (filtrate). Each geotextile tube was constructed with a drainage system to collect the liquid extracted from the sludge.

Castro *et al.* (2008) obtained satisfactory results, achieving a significant reduction in biochemical oxygen demand (BOD) and chemical oxygen demand (COD) as well as increased total suspended solids (TSS) after sludge dewatering. Furthermore, the filtrate collected was monitored periodically for chemical parameter acceptability for subsequent discharge and/or return to the sludge treatment system. A portion of the filtrate collected from the last

geotextile tube was used for gardening in the Rio das Ostras City (RJ), and a portion was used for compacting landfill.

4.4. Sludge dewatering of industrial effluent

Escobar *et al.* (2010) presented a case study using geotextile tubes for the sludge dewatering of industrial effluent with a high moisture content contaminated with hydrocarbons, salts and other chemical compounds.

The sludge for dewatering originated from the cleaning of the cooling towers of the Brazilian Petrochemical Company Braskem - Petrochemical Basics Unit, which generated a total volume of 2200 m³.

The cooling towers were emptied, and a pump was used to remove and clean the sludge from the towers. The total volume of sludge was removed by six vacuum trucks, which transferred the sludge with a high moisture content and chemical contamination to two equalization tanks, with subsequent pumping into two geotextile tubes with a capacity of 400 m³ each. Polymer additives were added for flocculation of the sludges. Figure 16 illustrates the process steps and the location of the geotextile tubes used for sludge dewatering.

Escobar *et al.* (2010) reported promising results from the project: a 95% reduction in the volume of dewatering sludges after two months, in addition to the recovery and subsequent use of the entire filtrate drained from the geotextile tubes. Finally, the dewatering sludges were removed for disposal by CETREL, a Brazilian Waste Management and , providing a safe destination, from an environmental perspective, for the wastes generated during the cleaning of cooling towers.

5. Discussion and Conclusion

Geotextile closed systems have great application versatility, as exemplified by the Brazilian applications cited

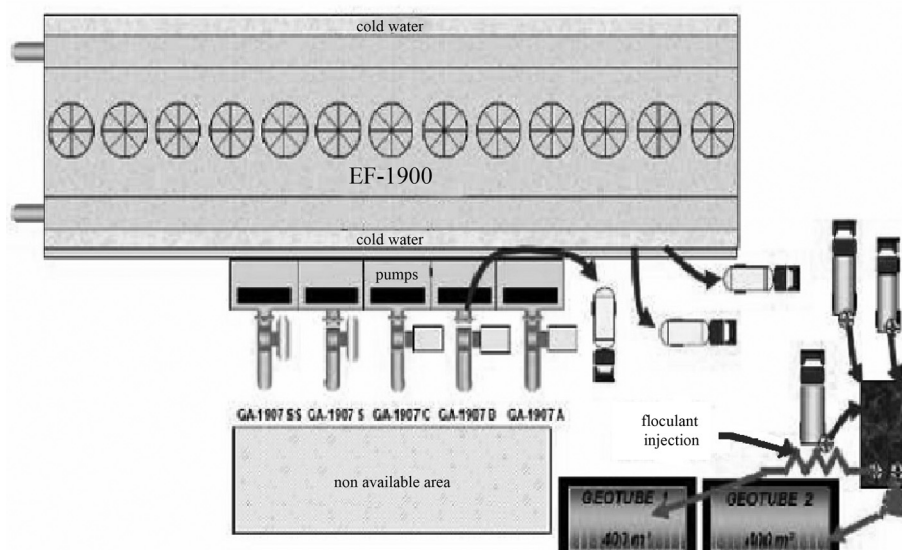


Figure 16 - Dewatering of Braskem Company mining sludges in geotextile tubes (Escobar *et al.*, 2010).

in this paper, such as the single dewatering system or when used together with other techniques. They have also demonstrated easy adaptability to different installation sites.

The efficiency parameters for the performance analysis of the dewatering systems are important in the evaluation of their behavior. These parameters can be affected by several factors, such as water content relative to solids, formation of filter cake, particle size and composition of sludge, opening size and hydraulic conductivity characteristics of the geotextile, and chemical conditioning requirements, among others.

For the good performance of the system under study, it is necessary to evaluate and observe the following aspects:

- The behavior of the seams in light of the field demands, along with the set of elements responsible for the life time of the geotextile closed system, and the mechanical strength and durability of the geotextiles considering physical, chemical and biological agents;
- The characterization of the materials to be dewatered because the efficiency of the method depends on the type of sludge to be dewatered and the filtering characteristics of the geotextile, which may be considered together or separately;
- The possible occurrence of physical, chemical and biological clogging. The physical clogging is an inherent factor. Tests should be conducted with the sludge and the geotextile to evaluate the clogging evolution and its acceptability.

Currently, there are several methodologies for the performance evaluation of geotextiles as a filter material to estimate possible results at a laboratory-scale. From these results, it is possible to optimize the geotextile closed system by improving the parameters that may improve its functioning.

In particular, the cone tests have been used successfully in several studies to preliminarily evaluate the need for chemical conditioning and dosage determination.

In the last decade, studies and field applications of the dewatering of residues and sludges in geotextile closed systems have been conducted in Brazil. These studies have shown promising results that indicate the feasibility of geotextile use in dewatering systems.

The dewatering of sludges in geotextile closed systems is of significant current technical and environmental relevance. It is an alternative technique to reduce the volume of sludge produced on a large scale, allowing its correct disposal and minimizing the environmental impacts resulting from improper disposal in the environment.

Acknowledgments

The authors wish to thank the Federal Center of Technological Education of Minas Gerais, CEFET-MG, Research Foundation of the State of Minas Gerais,

FAPEMIG, and the National Counsel of Technological and Scientific Development, CNPq, for the financial support.

References

- Andreoli, C.V. (coordenador) (2001) *Resíduos Sólidos do Saneamento: Processamento, Reciclagem e Disposição Final*. Projeto PROSAB/ABES/RiMa, Rio de Janeiro, 282 pp.
- ABNT (2013) *Geossintéticos: Termos e Definições – NBR ISO 10318*. Associação Brasileira de Normas Técnicas, Rio de Janeiro, Brasil, 22 pp.
- ASTM (2011) *Standard Test Method for Determining the Flow Rate of Water and Suspended Solids from a Geotextile Bag - D 7701*. ASTM International, West Conshohocken, Pennsylvania, USA, 7 pp.
- Barbosa, J.A. (2011) *Análise laboratorial da eficiência de sistemas fechados de geotêxteis no desaguamento de lama de rocha fosfática*, Dissertação de Mestrado, Departamento de Engenharia Civil, Centro Federal de Educação Tecnológica de Minas Gerais, Belo Horizonte, 115 pp.
- Bittar, R.J.; Gomes, R.C.; Melo, L.C.Q.C. & Martins, P.M. (2010) Feasibility studies for phosphate fine tailing disposal in geotêxtil tubes. *Proc. 9th International Conference on Geosynthetics, Geosynthetics for a Challenging World*, Guarujá, v. 3. pp. 1111-1114.
- Bogossian, F.; Smith, R.T.; Vertematti, J.C. & Yabek, O. (1982) Continuous retaining dikes by means of geotextiles. *Proc. 2nd Conference on Geotextiles, Las Vegas*, pp. 211-216.
- Cantré, S. & Saathoff, F. (2011) Design parameters for geosynthetic dewatering tubes derived from pressure filtration tests. *Geosynthetics International*, v. 18:3, p. 90-103.
- Castro, N.P.B. (2005) *Tubular Sistemas Tubulares para Contenção de Lodo e Sedimentos Contaminados*. Dissertação de Mestrado, Departamento de Engenharia Civil, Instituto Tecnológico de Aeronáutica, São José dos Campos, 103 pp.
- Castro, N.P.B.; Melo, L.C.Q.C. & Escobar, L.G.B (2008) Environmental integrated solution for septic tank sludge and landfill leachate using geotextile tubes dewatering technology. *Proc. The First Pan American Geosynthetics Conference and Exhibition, Cancun*, pp. 419-424.
- Castro, N.P.B.; Martins, P.M.; Stephens, T. & Melo, L.C.Q.C. (2009) Tests to Evaluate Dewatering and Filtration Efficiency for Geotextile Tubes Design. *Proc. Geosynthetics 2009, Salt Lake City, Utah*, 9 pp.
- Christopher, B.R.; Holtz, R.D. & Fischer, G.R. (1993) Research needs in geotextile filter design. In: Brauns, J.; Heibbaum, M. & Schuler, U. (eds) *Filters in geotechnical and hydraulic engineering*. *Proc. First International Conference Geofilters, Karlsruhe*, p. 19-26.

- Escobar, L.G.B.; Ribeiro, J.A.M.; Castro, N.P.B. & Melo, L.C.Q. (2010) Dewatering of contaminated materials with high moisture content in a short period of time using geotextile tubes in Camaçari, Brazil. *Proc. 9th International Conference on Geosynthetics, Geosynthetics for a Challenging World*, Guarujá, v. 3. p. 1309-1312.
- Fontana, A.O. & Cordeiro, J.S. (2005) Gestão Integrada como Busca de Solução para Rejeitos de ETA's - O Caso de Cardoso - SP. *Proc. 23º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, CD-ROM, Campo Grande, Mato Grosso do Sul, 10 pp.
- Fowler, J.; Bagby, R.M. & Trainer, E. (1996) Dewatering sewage sludge with geotextile tubes. *Proc. 49th Canadian Geotechnical Conference*, St. John's New Foundland, 30 pp.
- Fowler, J.; Duke, M.; Schimidt, C.B.; Bagby, R.M. & Trainer, E. (2002) Dewatering sewage sludge and hazardous with geotextile tubes. *Proc. 7th International Conference on Geosynthetics*, Nice, p. 1007-1012.
- GRI (2004) Standard Test Method for the Hanging Bag Test for Field Assessment of Fabrics Used for Geotextile Tubes and Containers – GRI-GT14. Geosynthetics Research Institute, Folsom, PA, United States of America, 9 pp.
- GRI (2009) Standard Test Method for the Pillow Test for Field Assessment of Fabrics/Additives Used for Geotextile Bags, Containers, and Tubes – GRI-GT15. Geosynthetics Research Institute, Folsom, PA, United States of America, 9 pp.
- Giroud, J.P.; Delmas, P. & Artieres, O. (1998) Theoretical basis for development of a twolayer geotextile filter. *Proc. 6th International Conference on Geosynthetics*, Atlanta, p. 1037-1044.
- Gomes, R.C. (2007) Sistemas de disposição de rejeitos de mineração utilizando geotubos como estruturas de desaguamento e/ou de contenção. *Proc. 5º Simpósio Brasileiro de Geossintéticos/REGEO*, CD-ROM, Recife, 8 pp.
- Guaanes, E.A. (2009) Análise Laboratorial do Desaguamento do Lodo Residual de Estação de Tratamento de Água por Meio de Geossintéticos. *Dissertação de Mestrado*, Departamento de Engenharia Civil, Centro Federal de Educação Tecnológica de Minas Gerais, Belo Horizonte, 129 pp.
- Guimarães, M.G.A.; Urashima, D.C. & Vidal, D. (2012) Evaluation the performance of closed geotextiles system for the waste dewatering of water treatment plant (WTP) – The efficacy dewatering. *Proc. Second Pan American Geosynthetics Conference & Exhibition/GeoAmericas 2012*, Lima, 8 pp.
- Hoppen, C.; Andreoli, C.V.; Portella, K.F.; Sales, A. & Joukoski, A. (2003) Estudo da incorporação do lodo centrifugado da estação de tratamento de Água Passaúna em matriz de concreto, com dosagem de 3%. *Proc. 22º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, CD-ROM, Joinville, Santa Catarina, 10 pp.
- Hoppen, C.; Portella, K.F.; Joukoski, A.; Baron, O.; Franck, R.; Sales, A.; Andreoli, C.V. & Paulon, V.A. (2005) Co-disposição de lodo centrifugado de Estação de Tratamento de Água (ETA) em matriz de concreto: método alternativo de preservação ambiental. *Cerâmica*, n. 51, p. 85-95.
- Koerner, R.M. (2005) *Design with Geosynthetics*. Fifty Edition. Prentice Hall, Upper Saddle River, 818 pp.
- Koerner, G.R. & Koerner, M.R. (2006) Geotextile tube assessment using a hanging bag test. *Geotextiles and Geomembranes*, v. 24:2, p. 129-137.
- Lawson, C.R. (2008) Geotextile containment for hydraulic and environmental engineering. *Geosynthetics International*, v. 15:6, p. 384-427.
- Leshchinsky, D. & Leshchinsky, O. (2002) GeoCoPS (2.0): Supplemental Notes. ADAMA Engineering, Inc, Newark, 24 pp.
- Leshchinsky, D.; Leshchinsky, O.; Ling, H.I. & Gilbert, P.A. (1996) Geosynthetic Tubes for Confining Pressurized Slurry: Some Design Aspects. *Journal of Geotechnical Engineering*, p. 682-690.
- Liao, K. & Bathia, S.K. (2008) Geotextile tube dewatering: filtration criteria. *Proc. The First Pan American Geosynthetics Conference & Exhibition*, Cancun, pp. 506-513.
- Martins, P.M. (2006) Utilização de Tubos Geotêxteis para Desaguamento de Rejeitos de Mineração. *Dissertação de Mestrado*, Departamento de Engenharia Civil, Instituto Tecnológico de Aeronáutica, São José dos Campos, 161 p.
- Mendes, R.L.; Ferreira Filho, S.S.; & Scian, J.B. (2001) Desaguamento Mecânico por Filtro Prensa de Lodos Gerados em Estações de Tratamento de Água. *Proc. 21º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, CD-ROM, João Pessoa, Paraíba, Brasil, 10 pp.
- Moo-Young, H.K.; Gaffney, D.A. & Mo, X. (2002) Testing Procedures to assess the viability of dewatering with geotextiles tubes. *Geotextiles and Geomembranes*, v. 20, p. 289-303.
- Moo-Young, H.K. & Tucker, W.R. (2002) Evaluation of vacuum filtration testing for geotextile tubes. *Geotextiles and Geomembranes*, v. 20, p. 191-212.
- Muñoz, C.S. (2005) Desempenho de Geotêxteis na Filtração de Solos Internamente Instáveis. *Dissertação de Mestrado*, Departamento de Engenharia Civil, Instituto Tecnológico de Aeronáutica, São José dos Campos, 119 pp.
- Muthukumaran, A.E. & Ilamparuthi, K. (2006) Laboratory studies on geotextile filters as used in geotextile tube dewatering. *Geotextiles and Geomembranes*, v. 24, p. 210-219.
- Oliveira, E.M.S.; Machado, S.Q. & Holanda, J.N.F. (2004) Caracterização de resíduo (lodo) proveniente de estação

- de tratamento de águas visando sua utilização em cerâmica vermelha. *Cerâmica*, v. 50, p. 324-330.
- Pilarczyk, K.W. (2000) *Geosynthetics and Geosystems in Hydraulic and Coastal Engineering*. A.A. Balkema, Rotterdam, Netherlands, 936 pp.
- Reali, M.A.P. (coordenador) (1999) *Noções Gerais de Tratamento e Disposição Final de Lodos de Estações de Tratamento de Água*. Rede Corporativa de Pesquisas, Projeto PROSAB, ABES, Rio de Janeiro, 240 pp.
- Satyamurthy, R. (2008) *Experimental Investigations of Geotextile Tube Dewatering*. PhD Dissertation, Syracuse University, Syracuse, Nova York, 233 pp.
- Satyamurthy, R. & Bhatia, S.K. (2009a) Experimental evaluation of geotextile dewatering performance. *Proc. Geosynthetics 2009*, Utah, p. 464-473.
- Satyamurthy, R. & Bhatia, S.K. (2009b) Effect of polymer conditioning on dewatering characteristics of fine sediment slurry using geotextiles. *Geosynthetics International*, v. 16:2, p. 83-96.
- Shukla, S.K. & Yin, J.H. (2006) *Fundamentals of Geosynthetic Engineering*. Taylor & Francis Group, Balkema, The Netherlands, 428 pp.
- Ten Cate (2010) *Seaming of Geosynthetics*. Technical Note, Ten Cate Geosynthetics North America, Pendergrass, GA, 12 p.
- Tominaga, E. (2010) *Análise dos Procedimentos para Avaliação de Desempenho de Sistemas Fechados com Geotêxtil para Desaguamento*. Master Dissertation. Departamento de Engenharia Civil, Instituto Tecnológico de Aeronáutica, São José dos Campos, 126 pp.
- Trentini, R.S., Vidal, D.M. & Martins, P.M. (2006) Chemical ageing and creep analyses - influence of synergy and test specimen preparation. *Proc. 8th International Conference on Geosynthetics*, Rotterdam, v. 4. p. 1609-1612.
- Tsutuya, M.T. & Hirata, A.Y. (2001) Aproveitamento e disposição final de lodos de estação de tratamento de água do Estado de São Paulo. *Proc. 21º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, CD-ROM, João Pessoa.
- Umezaki, T. & Kawamura, T. (2002) Techniques of dewatering and volume reduction of surplus with high water content using vacuum consolidation method with paper bag. *Proc. Symposium of Ground Improvement*, v. 7, p. 59-64 (in Japanese).
- Urashima, D.C. (2002) *Simulação do Processo de Retenção de Partículas por Filtros Têxteis*. Tese de Doutorado, Instituto Tecnológico de Aeronáutica, São José dos Campos, 199 pp.
- Urashima, D.C.; Guanaes, E.A.; Guimarães, M.G.A.; Pontes, P.P. & Vidal, D.M. (2010) Laboratory studies on geotextiles tubes dewatering by pressure filtration test in reduced model. *Proc. 9th International Conference on Geosynthetics, Geosynthetics for a Challenging World*, Guarujá, v. 2, p. 951-954.
- Vidal, D.M.; Fabrin, T. & Montez, F.T. (1999) O Conceito de Fatores de Redução Aplicados às Propriedades dos Geossintéticos. *Proc. I Simpósio Sul-Americano de Geossintéticos / 3º Simpósio Brasileiro de Geossintéticos*, Rio de Janeiro, v. 1, p. 189-198.
- Vidal, D.M. & Urashima, D.C. (1999) Dimensionamento de filtros e drenos em geossintéticos. *Proc. Simpósio Sul-Americano de Geossintéticos*, CD-ROM, Rio de Janeiro, 16 pp.