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Water penetration resistance of geotextiles: current state of knowledge

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ABSTRACT

Soil-geotextile systems are often subject to water infiltration due to natural weather variations. When the water penetration resistance of the geotextile leads to the accumulation of water at the soil-geotextile interface, a serious problem of instability in the geotechnical structure may occur, especially in thin layers of soil such as landfill covers. Most nonwoven geotextiles have a water penetration resistance greater than 5 mm when completely cleaned and composed only of hydrophobic filaments/yarns. The evaluation of the resistance offered by the geotextile to water penetration can be useful to understand the interaction between water and geotextiles under unsaturated conditions. The purpose of the present article is to discuss the different test procedures found in the literature for the determination of water penetration resistance of geotextiles. Experimental data are presented to illustrate the affinity of geotextiles with water under different conditions. This paper also presents an evaluation of the current state of knowledge regarding the hydrophobic/hydrophilic properties of geotextiles under unsaturated conditions. Often, geotextiles are used as filters, separators, or drains without proper verification of some of the basic principles for selecting and installing the product, and thus some minimum and important requirements may be ignored. Although in most cases there are no serious problems, sometimes the accumulation of a few centimeters of water over drainage systems may compromise the stability of geotechnical structures if this condition is not considered in the design. It has been observed that some of the test procedures reviewed do not take into account the hydrophobic/hydrophilic characteristics of the geotextiles.

1. INTRODUCTION

The inherent property of a material that allows a liquid to spread or not on its surface is known as wettability. This property is related to the surface water contact angle, which in turn determines its hydrophobic or hydrophilic characteristics. Geotextiles under unsaturated conditions often exhibit resistance to water penetration at initial wetting. This phenomenon is known as 'water penetration resistance' or 'water head support'. But does the geotextile wettability significantly influences the water penetration resistance?

Geotextiles porous structure is of great complexity and a series of factors involving the hydraulic properties of the geotextile, as well as some microscopic-scale phenomena, such as the effects of capillarity, must be considered. The migration of water from the soil to the geotextile is also affected by the type of polymer that composes the fibers of the geotextile. Polyester and polypropylene are the most common polymers used in the manufacture of nonwoven geotextiles and they are both hydrophobic materials. In addition to the differences inherent to the polymer itself and to the manufacturing process, the surfaces of the fibers and filaments may be covered by additives such as lubricating oils, surface-active and antistatic materials during the manufacturing process that alters the geotextile-water angle of contact and imparts hydrophobic or hydrophilic characteristics to the material, and this feature is often ignored in projects.

The surface of polymers has characteristics that interfere with their relationship with other substances. Chemical inertia, for example, is a characteristic present in polymeric materials that make them resistant to interact with other substances. In addition to chemical inertia, polymers generally have a chemically inert surface with relatively low free energy, therefore, they are materials that have a surface that is not receptive to the adhesion of other substances (Garbassi et al. 1996). Geotextiles have hydrophobic characteristics because they are made of polymers, that is, water molecules are not attracted by the nonpolar groups of the polymer (Atkins and Jones 2012).

Wetting problems involving geotextiles used as drain envelope materials were observed in France back in 1981. Lennoz-Gratin (1987) reports that the outflow of some wrapped drains became very low even after a storm, a few months after installation. After digging up, stagnation of water was noticed and, in some cases, could exceed 50 cm. The geotextile was then cut up and water flew quickly into the pipe, samples were then visually inspected and presented no trace of contamination or degradation. These field investigations gave evidence of the geotextile wetting problem, and it was also encountered larger risks with polyester fine-textured nonwoven geotextiles than with PVC products. At the time, it was suggested that the solution for this kind of problem could be to treat the fibers with a wetting agent.

A wettability problem was also stated in a sports ground application as 10 cm of standing water was found on a geotextile after heavy rainfall during the execution of earthworks. Therefore, the effect of wettability deficiency was evaluated under laboratory circumstances in a sand tank model study. It was concluded through the results that some geotextiles reached substantially high water heads before the water starts to flow through the geotextile and that this resistance to water penetration influences the performance of geotextile drainage systems (Dierickx 1996).

The water infiltration in the soil is related to the pore size and to the capillarity phenomenon. Because soil is a hydrophilic material, it does not present any resistance to water penetration. However, the water penetration in the geotextile pores is affected by the hydrophobic behavior of the fibers/filaments that implies penetration resistance. This work intends to discuss the phenomena involved in this situation and the proposed procedures to measure the water penetration resistance of geotextiles.

2. HYDROPHOBIC VS. HYDROPHILIC BEHAVIOR

2.1 Angle of contact

According to AATCC 127: 2017, water penetration resistance of textile products depends on the repellency of the fibers and yarns, as well as the manufacturing process of the product. The surface of textile products is often chemically modified since chemicals such as finish oil are used as a lubricant and anti-static coating, thus influencing the wettability of the surface.

This happens because the shape that a drop of water presents when spread on a surface depends on the interactions between water and the surface of the material. At the macroscopic scale, the surface wettability can be determined by measuring the angle of contact between the solid surface and the liquid, which indicates the degree of wetting when an interaction between them occurs. The measurement of contact angles of solid surfaces is useful in wettability studies. Contact angles smaller than 90° correspond to high wettability, while contact angles larger than 90° correspond to low wettability, as can be seen in Figure 1.

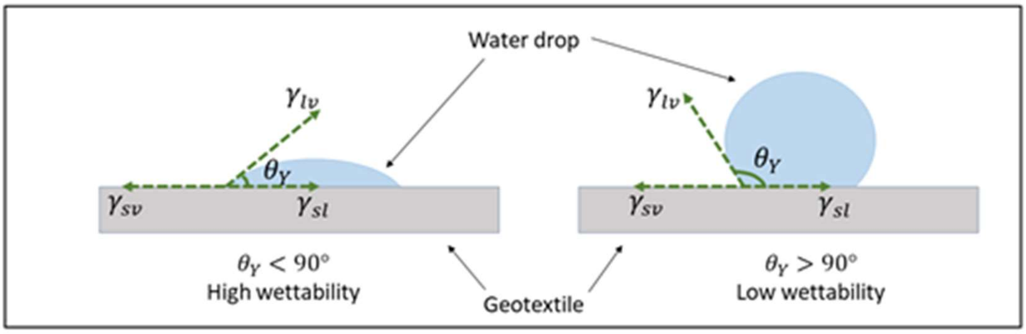

Figure 1. Angle of contact between water and two geotextiles with different affinity with water.

The contact angle of a drop on an ideal solid surface was first defined by Thomas Young in 1805 (Young 1805). The mechanical equilibrium of a drop under the action of three interfacial tensions can be described by Young's equation:

$$\gamma_{lv} \cos \theta_Y = \gamma_{sv} - \gamma_{sl} \quad [1]$$

where γ_{lv}, γ_{sv}, and γ_{sl} represent the liquid-vapor, solid-vapor, and solid-liquid interfacial tensions, respectively, and θ_Y represents the contact angle, usually referred to as Young's contact angle (Yuan and Lee 2013).

The wettability of a surface can also change over time, like when a hydrophobic material is exposed to water for a long time. This happens because small adsorption events of water on the surface can alter its water content, making it less hydrophobic, like if it “got used” to the water (Gondim 2016). When it comes to geotextiles, wettability may also be altered by removing the chemicals used in the manufacturing process, for example in case of exposure to various rain events.

The contact angle of water on the fibers of two different geotextiles specimens, before and after being washed to remove residues of additives used during the manufacturing process, was measured by Henry & Patton (1998). A significant reduction of the contact angle was observed in one of the specimens that were submitted to superficial washing.

In addition, to demonstrate the influence of the manufacturing process additives, Vidal et al. (2014) compared the behavior of a needle punched geotextile composed of polypropylene staple fibers, before and after specimens of the sample immersed in water with a neutral detergent to wash the fibers. Figure 2a shows the hydrophilic behavior of the product as received, and Figure 2b shows the hydrophobic behavior when water is poured over the dried specimen, after being washed. Thus, this possible alteration of behavior, if not foreseen in the design stage, can yield the risk of project failures.

a) As received. b) After being washed.

Figure 2. Affinity with water of a nonwoven geotextile, before and after being washed (Vidal et al. 2014).

Thus, because the resistance to water penetration is influenced by surface wettability, hydrophobic surfaces will have greater resistance to water penetration than hydrophilic surfaces.

Bachurova and Wiener (2012) discuss some of the aspects that influence the contact angle, as the volume of the drop, the advancing or receding drop volume, and the surface characteristics. Table 1 resumes some of the values obtained by these authors to the contact angle measured in a smooth plate and in textile products at an advancing volume of 5 nm^3.

Table 1. Example of contact angle values measured by Bachurova and Wiener (2012)

Polymer	Smooth plate	Textile
Polyamide 6.6	56.7	95.5
Polyester	80.0	105.2
Polypropylene	95.3	126.1

2.2 Capillarity phenomenon

Fredlund and Rahardjo (1993) presented a detailed discussion of the capillarity phenomenon focusing on the soil particles and water. Figure 3 shows the physical model employed by the authors. In this case, the capillary tube is composed of a hydrophilic material (glass) and the contact angle is lower than 90°, being 0° in the case of clean glass and pure water.

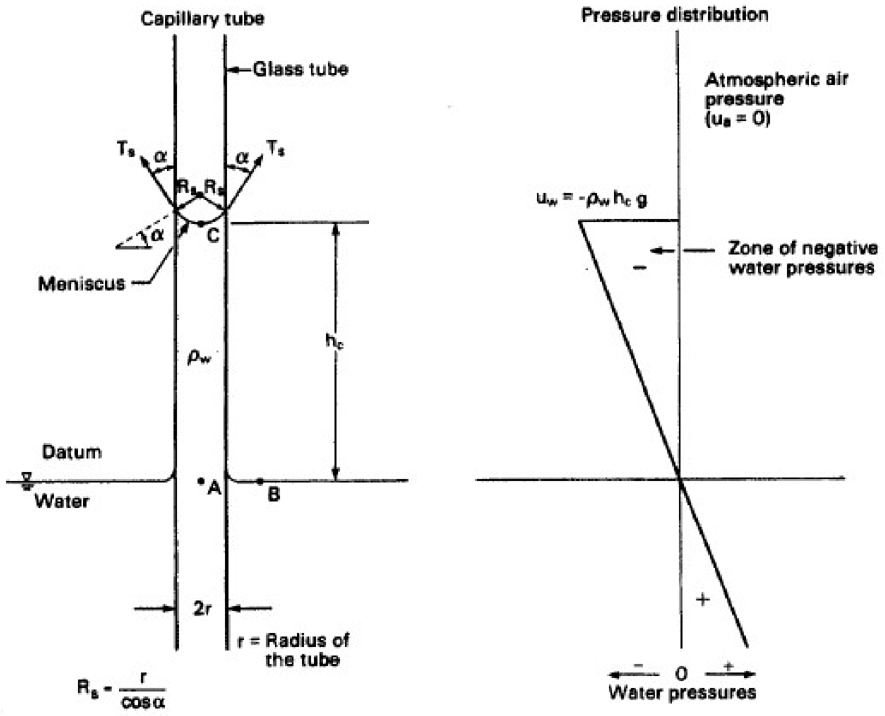

Figure 3. Physical model and phenomenon related to the capillarity (Fredlund and Rahardjo 1993).

In Figure 3, r is the radius of the capillary tube, T_s is the surface tension of water, α is the contact angle, h_c is the capillary height, g is the gravitational acceleration, and ρ_w is the density of water.

In the case illustrated in Figure 3, the capillary height can be calculated by (Fredlund and Rahardjo 1993):

$$h_c = 2\, T_s \cos\alpha \;/\; (\rho_w\, g\, r) \qquad [2]$$

According to Equation 2, if a tube composed of a material with a contact angle greater than 90° was immersed in water, the water into the tube would be repelled to a level below the surface because h_c would be negative.

3. WATER RETENTION CURVES IN GEOSYNTHETICS

In this section, it is discussed if water fraction in geosynthetics is controlled by suction or by positive water pressure. In order to achieve that, it is important to bear in mind the concepts of hydrophilic and hydrophobic materials.

Most soils are a hydrophilic porous media, and therefore prone to retain water by capillary forces in such a way that water volumetric fraction in sands decreases with suction raising: as suction raises, smaller pores have their voids filled by air (see Figure 4).

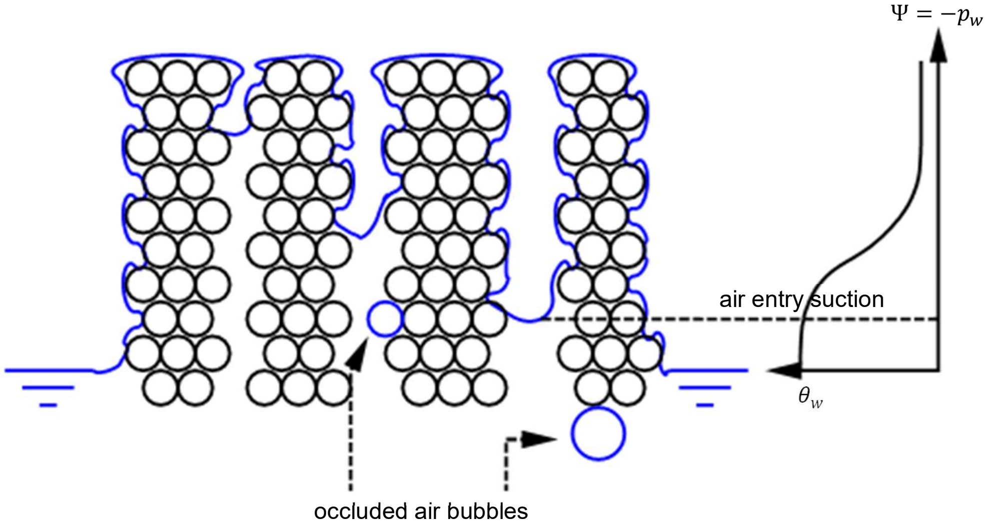

Figure 4. Water retention in hydrophilic porous media.

During the wetting process of a hydrophilic material, larger voids eventually may still retain occluded air bubbles. These bubbles should not be under atmospheric pressure, because this air phase is discontinuous and the law of communicating vessels does not hold there. Therefore, air pressure p_a in these occluded bubbles will depend on the water pressure p_w in their surroundings, on the bubble radius r, and on the surface tension T_s between water and air:

$$p_a = p_w + \frac{T_s}{r} \qquad [3]$$

These air bubbles may persist even when suction does not take place, that is, when water pressure is positive and the theoretical water retention curve should indicate that the soil is totally saturated by water. In this case, it may not be possible to move these air bubbles via pressure gradients and the only way to remove it is by raising water pressure in order to dissolve the air in water. This is the saturation process carried in triaxial sampling preparation, which is controlled by Skemton's b-bar parameter.

By analogy to hydrophilic media, hydrophobic porous media like geosynthetics are prone to retain air due to capillary forces, such that the air volumetric fraction in some geotextiles usually increases as air pressure raises: as water pressure increases, smaller pores have their voids filled by water (see Figure 5).

p_w

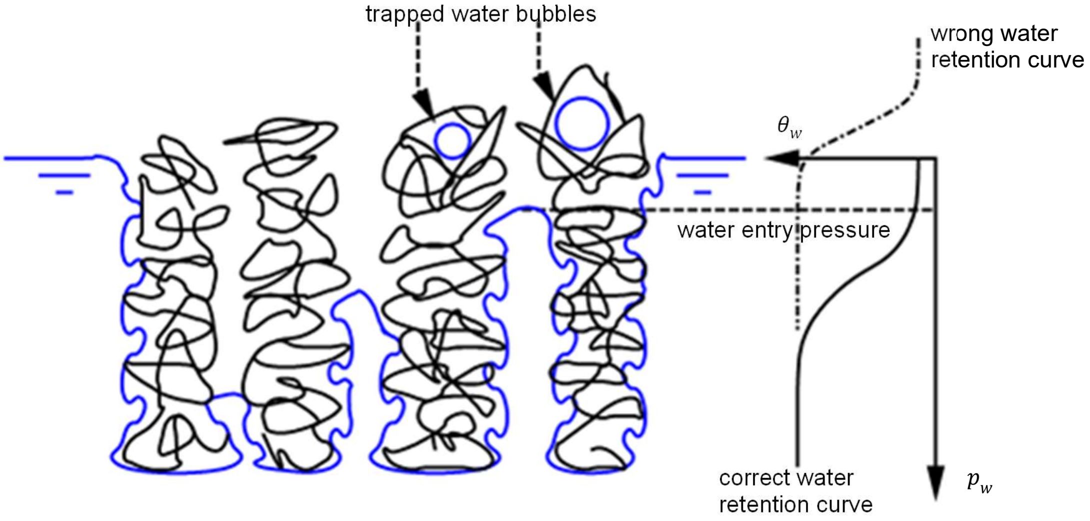

Figure 5. Water retention in hydrophobic porous media.

During the process of drying a hydrophobic material, larger voids may still retain residual water in isolated suspended (trapped) bubbles. Although these bubbles may get stuck far above the free water level, they will not be under negative water pressure (suction), as the water phase is discontinuous and the law of communicating vessels does not hold there. The water pressure within these bubbles will depend on the air pressure in their surroundings, on the bubble radius, and on the surface tension between water and air:

$$p_w = p_a + \frac{T_s}{r} \quad [4]$$

These water bubbles may persist even when positive water pressure does not take place, that is, when suction takes place and the theoretical water retention curve should indicate that the soil is totally saturated by air. A misinterpretation of this situation is very common, as some authors suppose that these water bubbles are subject to suction and determine water content based on these entrapped bubbles. These authors fit water retention curves for water in geotextiles as a function of the water suction calculated by the height above free water or by suction measured in free water, which is not in contact with these bubbles. Nonwoven geotextiles have openings usually larger than soils, which may result in some easiness to remove some of these bubbles by pressure gradients. Nevertheless, some bubbles entrapped into smaller openings may be removed only by evaporation, either by vacuum application or by heating.

4. WATER PENETRATION RESISTANCE MEASUREMENT

4.1 Technical standards

Nowadays, the only technical standard related to the measurement of the water penetration resistance directed to geotextiles is EN 13562, published in 2000, that substitutes AFNOR NF G 38-020, the first standard proposed for these products. This standard presents a method to evaluate the geotextile water penetration resistance using geotextile dry specimens and is a hydrostatic pressure tester. The procedure proposed is easily applied and allows obtaining fast information about hydrophobic behavior (Vidal et al. 2014).

The procedure proposed by EN 13562 consists on submitting specimen of a geotextile sample to a steadily increasing water pressure of (10 ± 0,5) cm/min, on the bottom or on the top of the specimens, until the formation of continuous droplets on the surface of the specimen, observing and recording the hydrostatic pressure at which the breakthrough occurs at the third position of each textile specimen. The exposed area of the specimen is 100 cm^2 and the specimen is clamped to the apparatus in the horizontal orientation. At least five specimens of each face are tested, and the water must be distilled or deionized at a temperature of either (20 ± 2) °C. Figure 6 shows the test setup.

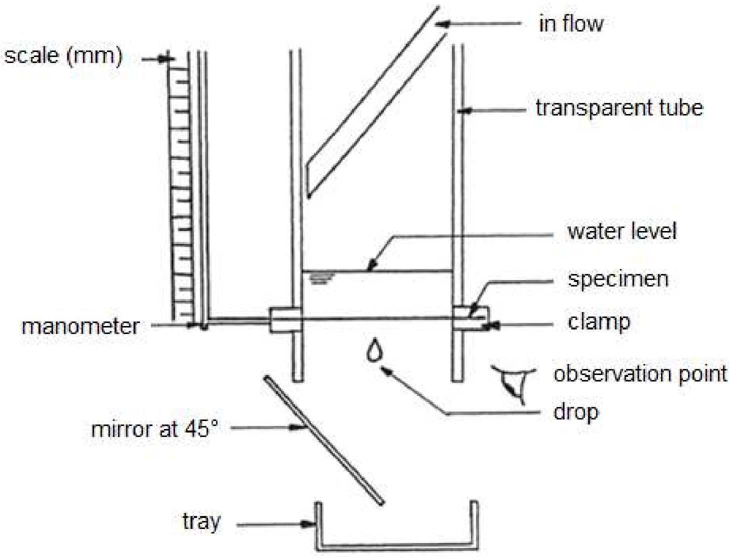

Figure 6. Apparatus suggested in EN 13562.

Considering the standards proposed for textiles, the most recent is ISO 811, published in 2019. The test consists on submitting at least five 100 cm^2 specimens of a textile sample clamped to the apparatus in horizontal orientation, to a steadily increasing water pressure of either (10 ± 0,5) cm/min or (60 ± 3) cm/min, on the bottom or on the top of the specimens, until water percolates in at least three different places, observing and recording the hydrostatic pressure at which the breakthrough occurs at the third position of each textile specimen. The water used in the tests must be distilled or deionized and at a temperature of either (20 ± 2) °C or (27 ± 2) °C. The test method also requires that the specimen should be monitored continuously, and it is suggested that fine droplets or subsequent drops in the same position should be disregarded, which could leave some room for the subjectivity of results.

The main difference between EN 13562 and ISO 811 is the criterion to determine the geotextile hydrostatic resistance quantitatively. While the first considers the formation of continuous droplets on the surface of the specimen to be the turning point, the second suggests that the test should end when three separate water penetration points appear.

The AATCC 127, published in 2017, presents a test method very similar, also measuring the resistance of the fabric to the penetration of water under hydrostatic pressure, but it suggests that the textile specimen should be at least 200 x 200 mm and that water should be introduced from above or below the specimen at a rate of 10 mm/s of hydrostatic head.

AATCC 127 requires that a minimum of three specimens, taken diagonally across the width of the fabric, should be tested to be representative of the material, instead of the five specimens demanded by ISO 811. The temperature of water in contact with the test specimen suggested is (21 ± 2) °C. Water droplets that appear within approximately 3 mm adjacent to the edge of the clamping ring should be disregarded and lateral water leakage can be minimized by sealing the textile with paraffin at the clamping area.

The AATCC 127 also emphasizes that it is important to specify the surface of the textile to be exposed to water, as different results may be obtained on the face and on the back. The surface tested should be identified on a corner of each specimen tested. Also, the specimens should be handled as little as possible and folding or contaminating the area to be tested must be avoided. Nevertheless, it is important to note that AATCC 127 provides an indiscriminate spatial analysis that includes all penetration events at the fabric perimeter, regardless of whether or not the apparatus induced the failures.

4.2 Previous Works

Dierickx (1996) performed tests to investigate whether the wetting problem is only an initial problem and whether geotextiles behave in the same way in contact with soil. To this end, drain tubes were wrapped with geotextiles and installed in a sand model under various soil/geotextile moisture conditions, and an apparatus adapted from AFNOR NF G 38-020, to evaluate the geotextiles initial resistance to water penetration was also utilized.

The apparatus described by Dierickx (1996) was placed on a mirror to improve the visual observation of water flowing through the geotextile, and it consisted of two concentric cylinders made of plexiglass. The space between the walls of both cylinders was meant to create a peripheral outer reservoir for the inflow of water. The inner cylinder was fixed at a distance of 2 cm above the geotextile by means of spacers. The diameter of the inner column was slightly greater than 10cm, so that the exposed diameter of the geotextile clamped between two flanges at the bottom of the apparatus was 10cm, and the height of the apparatus was 20 cm. The water head required for water to start flowing through the geotextile was recorded. For heads larger than 5 mm also the percentage of the wetted area was determined. If a head of 100 cm was reached, the test was ceased after recording the time required for passing the geotextile or after 1 h when no water passes.

According to Dierickx (1996), the results revealed that, although most of the investigated geotextiles did not exhibit a wettability resistance larger than 2 mm, for some geotextiles significantly high water heads were reached before the water started to flow through the geotextile, and this resistance to water penetration can influence the performance of the geotextile and might be disadvantageous compared with geotextiles which do not possess this resistance in some cases. Moreover, the products with a wettability resistance larger than 5 mm exhibited a large variability.

It was also concluded from the results that the wetted area is the subject of large variabilities and that it is not easy to determine. Furthermore, the knowledge of the wetted area was not found to be directly related to the water penetration resistance and so, it does not give any additional information. Thus, it was suggested that the determination of the wetted area can be omitted (Dierickx 1996).

Rodrigues (2020) carried out experiments based on the procedure suggested by EN 13562. Tests were performed with a water pressure increase rate of 100 mm/min and of 10 mm/min, applied to woven and nonwoven geotextile specimens. Moreover, tests were performed adding a layer of soil below the geotextile. According to Rodrigues (2020), the results showed that the water penetration resistance is influenced by the geotextile structure, by the rate of increase in water pressure, and by the flow behavior in the soil/geotextile system.

Table 2 summarises some results of the water penetration resistance obtained in the literature.

Table 2. Some results of water penetration resistance tests.

Author	Method	Geotextile	Average value(mm)
Dierickx (1996)	AFNOR NF G 38-020 (at 10 mm/min)	Nonwoven needle-punched (Tg=1.6 mm)	24
		Nonwoven needle-punched (Tg=3.2 mm)	26
		Woven tape/monofilaments (Tg=0.8 mm)	18
Vidal et al. (2014)	EN 13652:2000 (at 10 mm/min)	Nonwoven needle-punched PET filaments (Tg=2.7 mm)	22
		Nonwoven needle-punched PP fibers (Tg=2.9 mm)	0
		Nonwoven needle-punched PP fibers (Tg=2.9 mm) washed	6
Rodrigues (2020)	EN 13652:2000 (at 100 mm/min)	Nonwoven needle-punched PET filaments (Tg=2.5 mm)	30
		Woven monofilaments PP (Tg=1.0 mm)	57
	EN 13652:2000 (at 10 mm/min)	Nonwoven needle-punched PET filaments (Tg=2.5 mm)	25
		Woven monofilaments PP (Tg=1.0 mm)	24

According to the French Geosynthetics Committee, to be accepted as a filter element, a geotextile must present water penetration resistance lower than 5 mm (CFG 2014). However, it is important to note that most nonwoven geotextiles have a resistance to water penetration greater than 5mm, when composed of hydrophobic fibers or filaments (Avancini & Vidal 2019). Vidal et al. (2014) carried out tests to verify the water penetration resistance of nonwoven geotextiles that had approximately the same thickness (2.8 mm). It was observed 22 mm of water penetration resistance for a nonwoven geotextile composed of polyester continuous filaments, and 6 mm for a polypropylene short fibers geotextile superficially washed.

Moreover, the resistance to water penetration in filtration and drainage designs using geotextiles is often not even considered, and it is not uncommon to specify the product due to availability in the market (brand), sometimes ignoring the products hydraulic characteristics and its interaction with the soil at the soil-geotextile interface (Palmeira et al. 2005).

5. CONCLUSIONS

This paper presented different test procedures found in the literature to assess the water penetration resistance of geotextiles. Some experimental data was also presented to illustrate that most nonwoven geotextiles have a resistance to water penetration greater than 5mm under unsaturated conditions. Some of the experimental results showed indicate that the water penetration resistance obtained in the tests is influenced by the geotextile structure and by the rate of increase in water pressure.

It was pointed out that water penetration resistance of geotextiles depends on its hydrophobia, as well as on the manufacturing process of the product since the surface of textile products is often chemically modified, thus altering the interaction between water and the surface of the material. So, the resistance to water penetration is influenced by the polymer that composes the geotextile fibers or yarns, since different polymers present different contact angles. A zero or low water penetration resistance is generally due to the additives used in the manufacturing process, that can impart hydrophilic characteristics to the product. However, this behavior can be temporary if the additive could be lixiviated. The subject addressed in this paper is often overlooked and can lead to misinterpretations of the hydraulic behavior of geotextiles, so it deserves a broader discussion. t

It was mentioned that during the wetting process, hydrophobic porous media like geotextiles are likely to retain air due to capillary forces, such that the air volumetric fraction in some geotextiles usually increases as air pressure raises. When drying, water bubbles may be entrapped into smaller openings and could only be removed by evaporation, either by vacuum application or by heating.

Finally, it was mentioned that geotextiles that are used as filters, separators, or drains, in applications where drying and wetting cycles may occur, should be submitted to proper verification of its resistance to water penetration so that minimum and important requirements are attended.

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