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NONWOVEN DEVELOPMENT AND CHARACTERIZATION PRODUCED FROM CIGARETTE BUTTS

*** Ana Silvia de Lima Vielmo** [1]
Ailton Borges Rodrigues [1]
Fabíola Tomassoni [1]
Maria Eliza Nagel Hassemer [1]

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Abstract

The aim of this study was to develop and evaluate the performance of a nonwoven (NT) with cellulosic material from cigarette butts. The NT used as a filtering medium had a diameter of 7 cm, height of 24 cm, a surface area of 528 cm^2 and a total volume of 692 cm^3. The NT was applied for the filtration of water from a pond. To evaluate NT performance, NT characterization, grammage, absorption capacity and permeability analyzes were performed. The results showed that NT was characterized as a microporous material and presented a good absorption performance (values in the order of 4.01 g g^{-1} to 4.99 g g^{-1}), weight of 115 g m^{-2}, permeability between 3.787 L m^{-2} h^{-1} and 3.422 L m^{-2} h^{-1}. The NT developed showed potential for use as a filtering medium for the surface water pre-treatment. In addition to helping to reduce the negative environmental impacts caused by the residues of cigarette butts present in the environment.

Keywords: cigarette butt waste, filtration system, surface water.

[1] Universidade Federal de Santa Catarina (UFSC), Brasil.
* *Autor correspondiente*: Laboratório de Reuso de Águas (LaRA), Universidade Federal de Santa Catarina.
Email: ana.vielmo@ifc.edu.br

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Introduction

The way of life of contemporary society contributes significantly to the generation of solid waste in the environment. Cigarette butts are the most common residue found in the environment (Rahman and Mohajerani, 2021). Cigarette butts are responsible for 25% of the frequent rural and urban fires that occur in periods of low rainfall, in addition to leaching toxic substances that contaminate the soil and surface and underground waters (Souza and Conegero, 2009). This residue is composed of a polymeric structure based on cellulose acetate, which, due to the high degree of acetate substitution, makes the cellulose inaccessible to microorganisms, making this residue take around ten years to biodegrade (Puls *et al.*, 2011; Rahman and Mohajerani, 2021). Moreover, during the butt manufacturing process, the fibers receive high compaction, in addition to the addition of plasticizers, making the disintegration process even more difficult. The most common final destinations for this waste after being collected are landfills and incineration. However, these processes are not considered environmentally adequate and economically viable due to the emission of CO_2 from incinerators is higher than for plants powered by coal, oil, or gas (Rahman, 2021). Thus, technological developments are extremely necessary to recover the cellulosic material present in the butts, as well as to providing a correct destination for this waste.

In this way, a promising possibility is the development of a nonwoven (NT) fabric based on cellulose acetate textile fiber present in the butts. For the use of butts in the production of NT, it is necessary to remove the paper, as well as the ash and tobacco residues. In addition to cleaning through two stages of cooking using sodium bicarbonate, hydrogen peroxide and sodium hypochlorite. Cellulose acetate fiber is widely used for the production of membranes, due to high mechanical strength, biodegradability, high filtration capacity and porosity, ease of processing, and film formation, high flux, absence of toxicity and biocompatibility, in addition to being a material low cost (Edgar *et al.*, 2001). In addition, the development of NT is a very relevant trend, due to the wide field of application, especially in the control of air pollution and water treatment, as they are versatile and flexible structures to be designed in different ways (Hutten, 2007). The application of NT is a very comprehensive technology, especially in the areas of filtration, automotive, healthcare, geotextiles, civil construction, battery separator, thermal and acoustic insulator, hygienic products and composites development (Kellie, 2016).

In the NT segment, the portion that expands the most is the use of material for filtration, especially in air, dust, liquid, and gas filters in the automotive, industrial and other sectors (Abit, 2017). This fact linked to NT have advantages associated with large and adjustable surface area, filtration characteristics, ease of forming composite structures with another material, thick cross-section, and volume, high permeability (Strader, 2015). In this way, until today, the field of research using non-woven fabric is multidisciplinary and quite broad. Hu *et al.* (2015) developed a NT for coalescence filtration of four types of oil-in-water emulsions and achieved separation efficiencies of up to 99.61% in a single-pass stream. Mulligan *et al.* (2009) studied the use of

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nonwovens for surface water treatment reporting removal rates above 93% turbidity, 98.9% for suspended solids, in addition to heavy metals. Moreover, Inoue *et al.* (2009) showed suspended solids, chemical oxygen demand and total phosphorus removal of 88.5%, 56.5% and 64.2% respectively for NT.

Based on the growth in the use of NT aimed mainly at water filtration and the need for strategies for environmentally appropriate disposal of butts, the aim of this study was the development of an NT from cellulose acetate fiber from cigarette butts for use in the pre-treatment system of surface water.

Materials and Methods

The process for obtaining a cellulosic material (CM) was conducted in three steps. The first stage consisted of collecting cigarette butts and manually cleaning waste paper and carbon. The second stage counted on removing the fused fibers followed by a treatment process in an alkaline medium, under heating, then left to rest in a sodium hypochlorite solution and promptly centrifuged and taken to drying. The third step consisted of the carding was performed to open the fibers and later moistened them with the resin, and taken to drying to consolidate the NT.

Cellulose acetate sanitation

For cleaning the cigarette butts, the methodology proposed by Salem (2010) adapted from the textile treatment of the cotton fiber was applied. Different cigarette butts were used, regardless of source and brand. After collection, manual cleaning was performed in order to remove paper residues, melted acetate ends, and carbon. After this step, cigarette butts, drinking water, sodium bicarbonate, and hydrogen peroxide were added to a stainless steel container (6%) (500 g cigarette butts, 160 g sodium bicarbonate, 100 mL hydrogen peroxide). This solution was brought to the boiling point, remaining for 30 min, thus characterizing the cooking step, which was repeated twice at the same temperature and time. Subsequently, the material was washed with water and left to rest in a sodium hypochlorite solution (2.5%), centrifuged (1.000 RPM) and dried at room temperature for approximately 48 h.

Carding, preparation and consolidation process of the nonwoven

With the cellulose acetate sanitized and dried, the carding step was carried out, with the purpose of untangling and aggregating the fibers, in order to produce a continuous ribbon prepared for the consolidation operation. After production, the tapes were placed on a metallic surface to form a layer, which was moistened with an aqueous solution of acrylic resin (styrene acrylic copolymer 5-chloro-2-methyl-2H-isothiazol-3-one;2-methyl-2H-isothiazol-3-one). The solution used resulted from the dilution of the resin in water, resulting in a 10% concentration of solids content. The layer was placed on a metallic surface and dried in an oven at 70 °C for 3 hours, giving rise to NT.

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Characterization of resin, cellulosic material and nonwoven

The NT was characterized by different analyzes linked to functional groups, morphological structure, grammage, absorption capacity, permeability, as well as to porosity, and surface area. Meanwhile, resin and CM were characterized using functional groups.

The chemical composition of the resin, CM and NT were identified through the Fourier-transform infrared spectrometer (FTIR) (Cary 600 Series, USA), (640 - 4.000 cm^{-1} wavelength range, at a spectral range of 4 cm^{-1} was used). The morphological structure was analysed by scanning electron microscopy (JEOL JSM-6390LV, USA) and the grammage of NT was evaluated following the recommendations of NBR ISO 139 and NBR 12984 (ABNT, 2008; 2009). In order to examine the use of NT as a filtering element, the water retention capacity was analysed by the absorption analysis. This analysis was performed in triplicate and followed the recommendations of (Kakonke *et al.*, 2020). The samples were weighed and subsequently submerged in two types of aqueous environments separately. The samples were weighed on an electronic balance and subsequently submerged in two types of aqueous environments separately, being one potable water and the other water from a surface water body. After 60 minutes of submersion of the samples, they were suspended for 15 minutes, in order to drain off the excess liquid. After the flow process, the samples were weighed again and the weights from before (W1) and after (W2) were recorded and used in Equation 1 to calculate the absorption capacity of NT.

$$Absorption\ capacity\ \left(\frac{g\ of\ liquid\ absorved}{g\ of\ NW}\right) = \frac{W_2 - W_1}{W_1} \qquad \textbf{Equation (1)}$$

Where: W1: Dry nonwoven weight (g); W2: Nonwoven weight after the absorption process (g).

The permeability of NT was tested using a filtration system at room temperature. The system consisted of a raw water tank, a pump (¼ CV), a pipe that connected the elements, a support structure containing the filter element of the system, and the filtered water tank. To make the filtering element, a commercial filter tube was used, measuring 24 cm in height, 3 cm in diameter, and 3 blankets of NT. The blanket was wrapped in a commercial filter tube and taken to a drying and sterilization oven, where it remained in the drying process at 70 °C for 12 h. After drying, the filter material had a diameter of 7 cm, a height of 24 cm, a surface area of 528 cm^2, and a total volume of 692 cm^3. The samples were collected in triplicate after 10 minutes of activation of the filtration system in order to ensure total NT humidity and the stabilization of the equipment pressure. Permeability was determined by Equation 2.

$$J = (V/A \cdot t) \qquad \textbf{Equation (2)}$$

Where:
J= Membrane flux (L m^{-2} h^{-1});
V= Permeate volume;
A = Effective membrane area (m^2);
t = t: Time needed to obtain the volume permeated through the membrane (h).

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The evaluation of the textural analysis of the NT was performed by nitrogen adsorption/desorption isotherms at -196 °C, recorded using Quanta Chrome Instruments NOVA 2200e. Samples were degassed at 175°C for 12 hours under vacuum prior to analysis. Each point of the isotherm had a thermal equilibrium time of 600 seconds. The specific areas (S) were calculated from the analysis of the relative pressure range (p/p0 from 0.05 to 0.30) using the Brünauer-Emmett-Teller (BET) method. Pore size (PS) distribution and mean pore diameter were evaluated by the Barrett-Joyner-Halenda (BJH) method. Pore volume (PV) was measured from a single point at the maximum adsorption/desorption point (p/p0 = 0.98).

Results and discussions

Sanitization of cellulosic material

After the first stage of cooking the cigarette butts, an effluent resulting from the MC cleaning process was identified called as dark liquor (Fig. 1a). In the second stage of cooking, the bleached CM was obtained (Fig. 1b). In this sense, the importance of the third stage of cooking is noted, where the alkaline process causes the breakdown of the cellulose acetate molecule, releasing the cellulose (d'Heni Teixeira *et al.*, 2017).

Figure 1. Steps in the process of cooking cigarette butts. a) First step of cooking; b) second stage of cooking; c) rest in sodium hypochlorite solution.

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The alkalinity of the solution was also responsible for the dissolution of lignin, hemicellulose, and also toxic agents, in addition to providing absorption to the material (Fig 1c) (Mehta *et al.*, 2006). The removal of toxic agents varied in the order of 72.26 %, 9.61 %, and 2.12 % for cadmium, iron, and copper, respectively.

Based on the dissolution process occurred by the applied methodology, an increase of 50% of cellulose was identified in relation to the initial mass of used cigarette butt.

Characterization of cellulosic material, resin and nonwoven

Functional groups and morphology analysis

Analyzing the spectra identified in the three samples (Fig 2), changes were observed in the region from 1000 to 1500 cm^{-1} can be noted, indicating changes in lignin, hemicellulose, and other impurities and also in the acetate, acetylated and cellulosic groups (Cai *et al.*, 2013). Moreover, was notable in all samples, the presence of the peak 3360 cm^{-1}, which is associated with the stretching vibrations of the O-H bonds, attributed to water absorption. The 2940 cm^{-1} peak was also identified, and is characteristic of the stretch vibrations of the aliphatic C-H bonds. The carbonyl group presents in the 1730 cm^{-1} peak characterized by the stretch vibration of the C=O bond coming from the ester group present both in the cellulose structure and in the resin structure. (Brum *et al.*, 2012).

In the CM sample the appearance of three peaks (1038, 1226 and 1371 cm^{-1}) was identified, characterized as acetylated groups, acetate, and cellulose respectively (Fig. 2). This fact showed that the sample is characterized as cellulose acetate (Cai *et al.*, 2013). At the same time, peak 1138 cm^{-1} and 1455 cm^{-1} were characteristic for the resin sample (Fig. 2). These peaks are related to ether and styrene (Tavares, 2009). On the other hand, NT was characterized as a material derived from cellulose acetate and styrene acrylic resin (Fig. 2). This happened because 5 peaks were identified during the monitoring. The first peak (1038 cm^{-1}) appeared due to acetylation, the second peak (1226 cm^{-1}) revealed itself due to the presence of acetate. The third peak (1371 cm^{-1}) and the fourth peak (1165 cm^{-1}) was characterizing groups related to ether, and finally the fifth peak (1455 cm^{-1}) which is related to the styrene present in the resin.

Fig. 3 showed the morphological images of the NT. The formation of a film on the fibers by the addition of resin can be observed, thus presenting a smooth and homogeneous surface resulting from the uniformity and cohesion of the fibers due to resin viscosity. Moreover, another important factor for the uniformity of the fiber layer is linked to the regularity of the fibers (Fig 3c). This fact linked to considering regenerated fiber, that is, filaments that have a defined length, diameter, and cross-section. Also was notable that the fiber encapsulation filled the fiber intersections, providing greater strength and also smaller pore size. Due to arrangement of the fibers, the formation of a lamellar NT was identified (Fig. 3c). Thus, the filtration process took

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place through the material structure. As the textile fiber is characterized by having length by less 100 times greater than the diameter or thickness, that is, very fine fibers that favor the lamellar formation, thus facilitating the filtering process (ASTM, 2013).

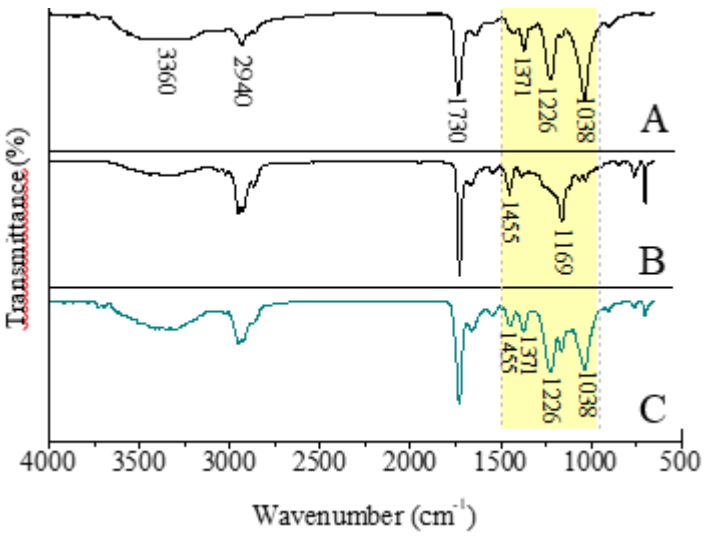

Figure 2. FTIR spectrum. a) Cellulosic material; b) Resin; c) Nonwoven.

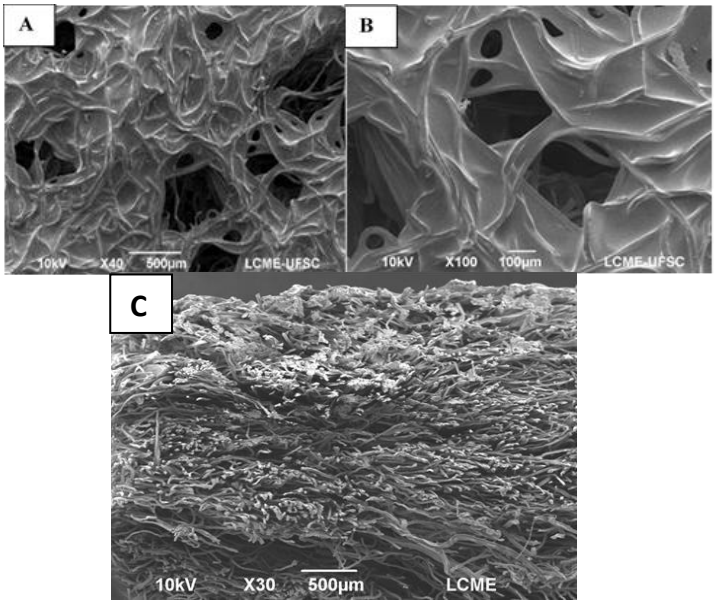

Figure 3. Images of electron microscope images. a) Nonwoven (magnification 40 x); b) Nonwoven (magnification 100 x); c) cross view of nonwoven.

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Nonwoven absorption capacity

Due to the non-hygroscopic characteristic of the resin, it was necessary to evaluate the absorption NT capacity. The NT absorption value ranged between 4.01 g g^{-1} for potable water and 4.99 g g^{-1} for raw water (Fig. 4).

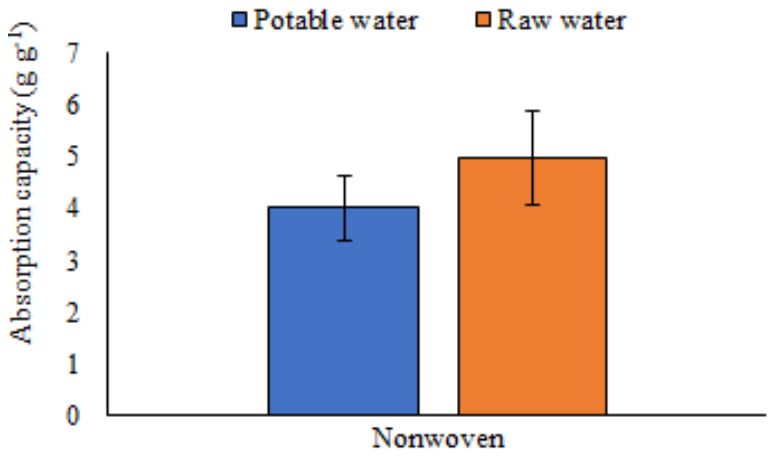

Figure 4. Nonwoven absorptive capacity.

A good absorption performance was identified. This fact was already expected due to the consolidation of the fibers and the formation of a uniform, flexible layer, in addition to this presenting a thin film formed by the resin. Moreover, it is noteworthy that the constituent fiber of NT is classified as regenerated derived from cellulose. In this way, cellulose is characterized by its high moisture absorption power (Khulbe *et al.*, 2004).

Weight, permeability, porosity and surface area of the nonwoven

The weight of an NT is considered one of the important properties in evaluating its performance. The NT presented 115 g m^{-2}. In this way, the NT characterized as heavy (ABINT, 2019). The identified weight was already expected, considering that an average of 65 g of CM was used, and every 0.4 g of a cigarette butt is formed by 12.000 filaments which were separated by the carding process, resulting in a layer which was soaked with 150 ml of resin solution.

The permeability of the NT ranged from 3.787 L m^{-2} h^{-1} to 3.422 L m^{-2} h^{-1} (Fig. 5). The permeability between 2.000 and 16.000 Lm^{-2} h^{-1} is characterized as good water permeability in the microfiltration/ultrafiltration range (Ursino *et al.*, 2021). In this way, permeability performance was considered satisfactory. Despite this, a 6% decrease in permeability occurred in the first 5 days (Fig. 5). This behavior may have been influenced by the characteristics of raw water, due to

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the occurrence of rain in this period, resulting in increased values for color, turbidity and solids content. After this period the permeability continued to decrease over time. This fact may be linked to the deposit of particles inside the NT. The decrease in permeability in NT has been reported in other studies. Ceron (2015) in a study carried out with NT with polyester and polyacrylonitrile fibers found that the permeability decay occurred due to the ease of initial deposition of fine particles inside the NT, as the greater distance between the fibers (larger pores) facilitates the accumulation.

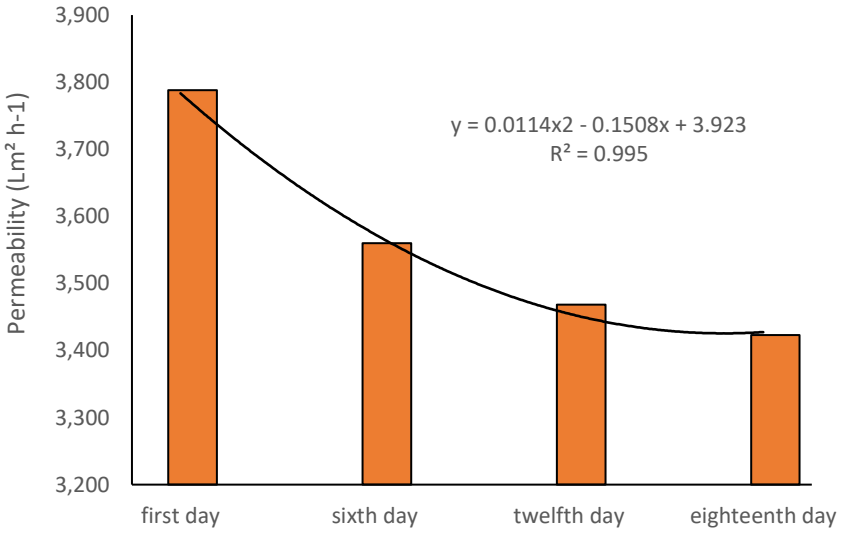

Figure 5. Nonwoven permeability.

The average pore diameter of NT was 3.296 nm, a surface area of 4.748 $m^2\ g^{-1}$ and a total pore volume of 0.00711 $cm^3\ g^{-1}$. Based on physical characteristics related to pore size and volume, surface area, NT is characterized as a mesopore material (IUPAC, 1994). Permeability and pore size are considered conventional criteria for filter media selection. However, these properties do not directly relate to NT performance due to the porous structure are not defined (Cumbi, 2013). For NT, the retention capacity is commonly indicated, establishing the correlation of pore size based on the opening of the interweaving (Cumbi, 2013). On the other hand, Fluet *et al.* (1985) showed that these factors do not apply to all NT, as there is no standardization in the orientation of fibers or filaments. Moreover, Di Bernardo and Dantas (2005), reports that the porosity of fibrous media cannot be related to the permeability coefficient, having to be detected experimentally.

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Due to the arrangement of the fibers, the formation of a lamellar NT was identified (Fig. 3c). In this way, the filtration process took place through the structure of the material. The textile fiber is characterized by having a length at least 100 times greater than the diameter or thickness, that is, very fine fibers that favor lamellar formation, thus facilitating the filtering process (ASTM, 2013). In addition, considering the adsorption process the best fit considering the isotherm, type II with type H2 hysteresis (Fig. 6). The type II isotherm occurs in monolayer and multilayer. The H2-type hysteresis is a typical curve of materials that present open cylindrical pores with "throat pore" type strangulations (SCHMITT, 2009). This means that inside the pore, there are areas much smaller than the diameter of the pore itself.

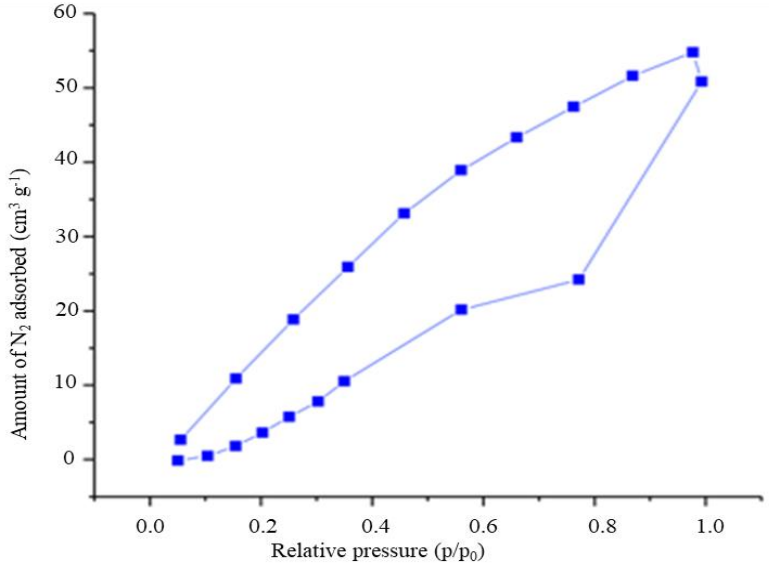

Figure 6. adsorption isotherms of nonwoven.

Conclusions

Based on the development of an NT with cellulose acetate from cigarette butts it is concluded that:

- The NT made with resin containing 10% solids content presented good encapsulation and cohesion between the fibers, in addition to good absorption capacity (4.99 g g^{-1} for raw water and 4.01 g g^{-1} for potable water) for the production of the filtering element;
- The permeability of NT varied between 3.787 L m^{-2} h^{-1} and 3.422 L m^{-2} h^{-1} indicating good water permeability in the microfiltration/ultrafiltration range;
- NT was characterized as a mesoporous material with lamellar arrangement of fibers favoring the filtration process;
- NT showed potential for being employed in the surface water pre-filtration process.

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