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ORIGINAL STUDY

Using Highly Twisted Roving as a Rainwater Purification Medium

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Abstract

This work aims to study engineering aspects of roving wound cartridge water filtration media according to the material of filtration media and their packing densities, number of filtration cycles, and concentrations of suspended solids to investigate the effect of these factors on filtration efficiency (suspended solids removal), and water turbidity. Modified construction of filter cartridges depends on roving as filtration media were produced for water filtration. Filter cartridges were produced with three materials 100% cotton, 50% cotton/50% Polyester (PES) blend, and 100% PES. Filtration processed through one and two filtration stages or cycles and filtration using two levels of suspended solids concentrations 3.6 and 10.8 gm/l. Finally, filtration efficiency and water turbidity tests were carried out to determine the filtration performance of produced cartridges. The results show that the modified filters introduce suspended solids removal efficiencies from 93.1 to 99.1% for the three materials. The 100% PES filter material is the best cartridge in filtration efficiency according to its high packing density compared with other materials in this study. The second filtration cycle improves the suspended solids removal from 0.9 to 1.6%, so most of the suspended solids are removed from filtered water during the first filtration cycle. The second stage or filtration cycle is recommended to improve or reduce the turbidity of filtered water.

Keywords: Cartridge filtration, Filtration efficiency, Rainfall water, Roving filter media and water turbidity

1. Introduction

There is not enough clean water for everyone in the world, and it is causing big problems according to the World Economic Forum. Lots of people are getting sick from drinking contaminated water, and there might not be enough water for us to use in the future. We need to work together to save water and make sure it is clean and hygiene before using or drinking (The World Economic Forum Water Initiative, 2011; Liu et al., 2017; Shabiimam et al., 2018). Water contamination appears in three forms - physically, biologically, and chemically (Niazi et al., 2020). Filters are used to remove any remaining suspended solids (colloidal) and micro-Flocs of water that were not deposited during the clarity stage. The definition of filter medium in The Filtration Dictionary and Glossary is 'any permeable material used in filtration and upon which, or within which, the solids are deposited.' The glossary in their handbook defines filter medium as 'The porous material in a filter that does the actual filtering' (Farzanesh and Mokshapathy, 2016). There are different materials like cotton (CO), wool, and glass fiber that can be used. People are also experimenting with new materials to improve filtration (Eyvaz et al., 2017).

Water treatment processes use physical, chemical, and biological techniques to clean water (Sonune

Abbreviations: μm, Micrometer; ASTM, American Society for Testing and Materials; CO, Cotton; Gm, grams; L, litter; NTU, nephelometric turbidity unit; PES, Polyester; PH, Potential of Hydrogen; TPI, Turns per inch; X1, Experimental design factor: Roving material; X2, Experimental design factor: Suspended solids concentrations; X3, Experimental design factor: Filtration cycles.

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and Ghate, 2004; Eyvaz et al., 2017). The characteristics of raw water determine which treatment method should be chosen. Methods for treating water can be based on less complex physicochemical processes like coagulation or more complex physical processes like sedimentation (Koohestanian et al., 2008). To remove solids, including microorganisms (bacteria, viruses, etc.), filtration is frequently used in the treatment of water, as well as precipitated iron and manganese discovered in surface water (Shivajirao, 2012; Eyvaz et al., 2017). Raw water with a turbidity value less than 10 nephelometric turbidity unit (NTU) can be filtered directly. The low installation and running costs are the result of the lack of need for sedimentation tanks and, in some cases, floatation tanks (Vieira et al., 2013; Maciel et al., 2021). For the removal of suspended solids, such as clay and silt particles, microorganisms, colloid and sediment humic substances, rotten plant particles, and calcium carbonate and magnesium hydroxide precipitates used in water softening, filtration is a fundamental procedure that is frequently used in environmental engineering applications (Crittenden et al., 2012).

One of the earliest uses of filtration is textile fiber-based filtration. The proper selection of filtration media/membrane material is one of the most important factors in filtration such as metals, glass fiber, porous carbon, CO, wool, and rayon, filter media can be categorized. Moreover, their construction is very important also (Amjad, 2022). The hydrolytic nature, oxidative nature, and high biological resistance of the fibers used in this filtration over a wide pH range are crucial characteristics (Geise et al., 2010). The fibers must also be resistant to temperature changes and chemicals used in hard environments (Geise et al., 2010; Eyvaz et al., 2017). One of the basic properties of fibrous materials, which influences filtration performance, is their porosity (Jena and Gupta, 2002). Porosity is defined as the ratio of the total pore void volume to the bulk volume. The pores in textile material are formed by the intersecting fibers and vary in size and shape (Burleigh et al., 1949). Porosity strongly determines important properties of fibrous materials such as liquid management properties, air and liquid permeability, softness, mechanical strength etc.… (Hu et al., 2020). Surface water must be filtered to remove particles and contaminants because it is vulnerable to runoff and does not naturally filter itself (Eyvaz et al., 2017). A sieve or micro-strainer that captures suspended material in the spaces between the grains of filter media is a good analogy for filtration. However, straining is the least significant step in filtration because most suspended particles can readily pass through the gaps between the filter media's grains (Ives and Cleasby, 1972; Chapter 18 Filtration Problem Solving Water Supply and Environmental Engineering, 2023). Adsorption is the most significant of several intricate physical and chemical mechanisms that contribute to filtration. Adsorption is the process by which particles adhere to the surface of the individual filter grains or to the substances that have already been deposited. The forces that attract and hold particles to them are the same as agglomeration or agglomeration. Flocculation and flocculation can occur within the filter bed, especially if flocculation and flocculation are not properly controlled before filtration. Incomplete coagulation can cause serious problems in filter operation (Eyvaz et al., 2017).

There are many factors to consider when designing an end-use filter, including Flow rate, pressure, size, and concentration of particles to be filtered, type and composition of filtered suspension, and fiber selection in the filter system (Droppo, 2006; Cioara and Cioara, 2011). When designing filters from fibrous materials, engineers choose from four types of yarns: monofilament yarns, multifilament yarns, fibrillated tape yarns, and staple yarns (Shah and Rawal, 2016). The first string-wound cartridge entered the US market in the mid-1930s which was made from a woven wire mesh core surrounded by CO yarn to form a depth filtration medium. Yarn was a tightly twisted filtration medium, and filtration occurs at the points of yarns crossing. Typical textile yarns were replaced by roving, a slightly twisted roll, due to lower cost, and improved filter life as more of the liquid could pass through the roving itself. They can remove particles ranging from 0.2 to 100 μm (Kanade and Bhattacharya, 2016). The newly developed filter media was produced using roving instead of ordinary yarns. So, it is very important to produce roving with high turns per inch (TPI) to bear stresses during the processing of filter media. Roving should be rewound on the cone package to be suitable for the creel of subsequent processes (Hakam et al., 2020). Adsorption and filtration are treatments commonly employed for rainwater purification, filter media have adsorbent properties (Morales-Figueroa et al., 2023). The study was conducted based on a simulation for filtering and purifying rainwater, not treating wastewater. The research focused on taking advantage of rainwater to reuse it in some industrial applications, agricultural irrigation, and irrigating landscapes in stadiums and residential areas, and not for drinking, at least until this stage of the research and perhaps in future research. Worldwide, rainwater has not been regulated for human consumption. These environmental regulations provide information on health-based objectives such as microbial factors, taste, odor, water safety plans, chemical issues, and radiological surveillance. The WHO sets maximum permissible limits for various contaminants in drinking water. Each country has its own established regulations (Organization, 2017).

2. Materials and methods

In this study, the major part was how to produce wound filter cartridge by using roving as a main filtration media. So, the first part of this study focused on producing roving with selected parameters on the roving machine. Roving preparations are completely different from ordinary CO system to convert the ordinary package of roving into a suitable package for use in the next stage of this work, filter manufacturing. The second part in this study focused on studying the performance of the filtration efficiency for different types of roving filter media. Roving samples were used as filtration media for the designed cartridge filters.

Modified filter construction is designed depending on roving layers on perforated cylinders. Roving with different materials was produced. Cone winding is very important process to convert roving bobbins into cones to be suitable for laying on filter core or perforated cylinder, directly from roving bobbin to cone. Moreover, roving should have suitable tensile strength to be able for laying process during the manufacturing of filter cartridge. Some cartridge properties, which affect filtration performance were varied in this study. Filter samples with different specifications were designed and manufactured depending on the produced roving as filtration media.

The experimental plan focuses on studying the following aspects as shown in Table 1. This study aims to assess the filtration efficiency for three types of roving materials, Factor X1, as a filter media in the cartridge filter. Three types of roving materials are used as wound cartridge filtration media. The three roving materials are 100% CO, 50 Polyester (PES)/50 CO and 100% PES with the same roving English count of 1.1 Ne and the same level of turns per inch 1.5 TPI. Two types of water were used as an influent rainwater to the produced filter according to their suspended solids concentration, Factor X2. Two types of water were used as a run 1 and run 2 of operation. The suspended solids concentrations were 3.6 and 10.8 gm/l for run 1 and run 2, respectively. Moreover, the effects of using two cycles of filtration, Factor X3. Two levels of number of filtration intervals during water filtration process were selected, one filtration cycle and two filtration cycles. In addition to that, the highly concentration suspended solids, 10.8 gm/l, are selected for two filtration cycles only. So, six samples are selected for one filtration cycles and three samples are selected for two filtration cycles in this research.

Table 2 shows the specifications of produced cartridge filters after preparing materials of filtration media, roving and its processing as mentioned previously, the cartridge filter design and manufacturing is considered by using perforated plastic pipes with 26.5 gm empty weight, 25.4 cm length, and 2.54 cm inner diameter, as shown in Table 2. Net weight of roving material in grams for each cartridge filter,

Table 1. Experimental plan of this study.

Series	Roving material (X_1)	Suspended solids concentrations (X_2)	Filtration cycles (X_3)
1	100% CO	3.6 gm/l	One filtration cycle
2	100% CO	10.8 gm/l	
3	(50%/50%) CO/PES	3.6 gm/l	
4	(50%/50%) CO/PES	10.8 gm/l	
5	100% PES	3.6 gm/l	
6	100% PES	10.8 gm/l	
7	100% CO	10.8 gm/l	Two filtration cycles
8	(50%/50%) CO/PES	10.8 gm/l	
9	100% PES	10.8 gm/l	

Table 2. Specifications of cartridge filters.

Roving material type	100% CO	(50%/50%) CO/PES	100% PES
Net weight of roving material (gm)	265	250	290
Inner diameter of the cartridge (cm)	2.54	2.54	2.54
Outer diameter of the cartridge (cm)	6.35	6.22	5.97
Length of the cartridge (cm)	25.4	25.4	25.4
Calculated packing density of filter cartridges (gm/cm^3)	0.392	0.389	0.498

Fig. 1. Perforated plastic pipe.

Outer diameter of the cartridge in centimeters, and calculated packing density of filter cartridges in (gm/cm^3) are also shown in Table 2.

Filter manufacturing procedures are as follows: First, a perforated pipe was used, as shown in Fig. 1, as a support for winding the roving on it, which is the basic material for the filtration process and the reason for using a perforated pipe to allow water to pass through it during the filtration process. Perforated plastic pipes are 26.5 gm empty weight, 25.4 cm length, and 2.54 cm inner diameter. Moreover, a modification was made in the sliver drawing machine in the laboratory of the Textile Engineering Department, Faculty of Engineering, Alexandria University, as shown in Fig. 2. The modification was done by allowing the feeding of the smaller diameter roving instead of the larger diameter sliver, taking advantage of the drawing cylinders and modifying its task instead of drawing the sliver to be its function in this research, the roving is wound on the filter body, i.e., the perforated pipe, by friction force, and thus obtaining the filter candle as shown in Fig. 3 after adjusting the tension and weight required through the speed of rotating cylinders and length of the roving that was wrapped on the pipe, as well as the number of turns and the outer diameter at the end of the winding process. The roving on the perforated pipe, filter candle as the main filtration medium, which installed in the filter housing through a simulation of a real filtration process and a system that was built in the laboratory of the Textile Engineering Department, Faculty of Engineering, Alexandria University, as shown in Fig. 4. Water used in the filtration process, was prepared in the lab with two desired suspended solids concentrations. Solid particles, which used to prepare the water samples, were prepared in lab from the passing through sieve no 200 (sieve opening 75 micro). The tested water was prepared by adding 3.6 and 10.8 gm of particles to 1 L of water for run 1 and run 2, respectively. The suspended solids concentrations for run 1 and run 2 were 3.6 and 10.8 gm/l, respectively. A movable stirrer was used inside the water tank during filtration process to prevent sedimentation.

Fig. 2. Winding the roving on the perforated pipe.

Fig. 3. The filter cartridge.

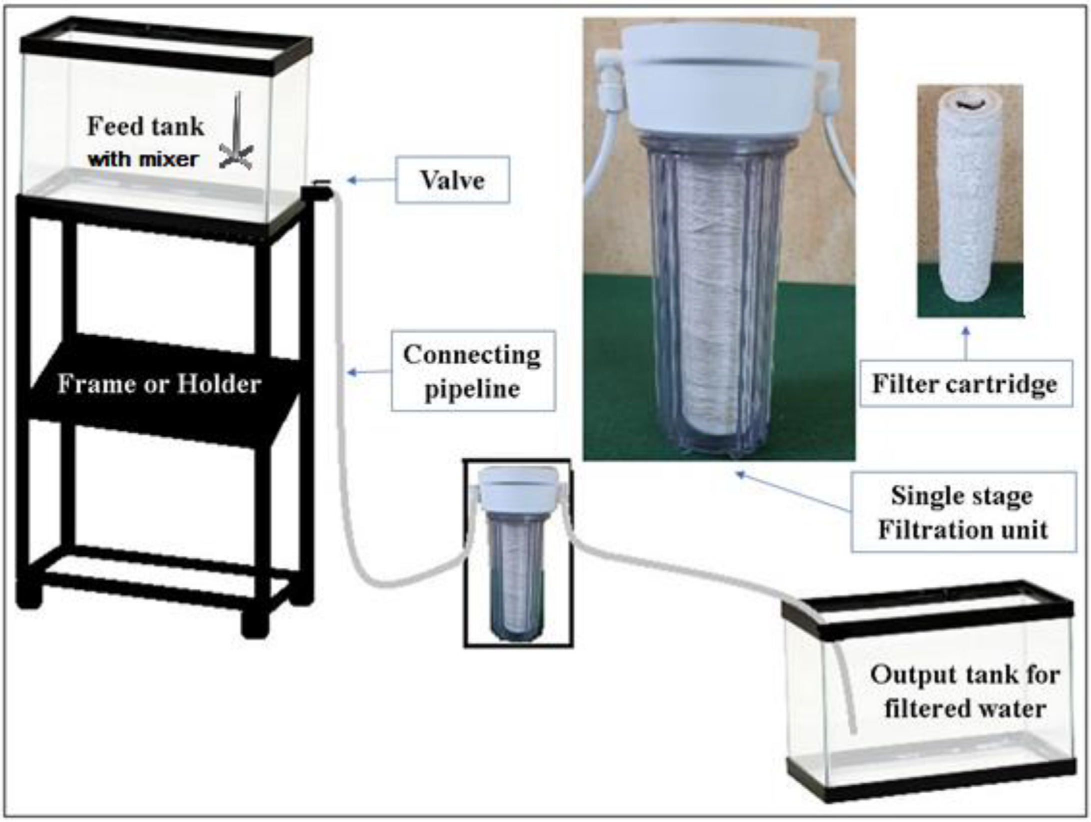

Fig. 4. Single-stage filter unit using roving cartridge filter medium.

All the designed materials were subjected to some important tests according to international standards. Roving count and turns per unit length, and twisting, tests were carried out on the produced roving. The roving count test was carried out according to ASTM standard D 1907-01 and twisting was evaluated according to ASTM standard D-1423. Some filtration media were selected from the produced roving and subjected to water filtration test in the form of an actual water filtration process. Filtration efficiency according to total suspended solid test carried out according to standard method committee of the American public health association and water environment federation, 2540 total suspended solid in standard method for the examination of water and wastewater (Committee, 1976; Clesceri et al., 1989).

Some tools should be used for carrying out water filtration efficiency tests as follows: Filter paper, Glass funnel and Flask, Desiccators, Graduated cylinder, and the following device and tools are used also: Digital balance, Drying oven, Dish tongs, and Glass dishes.

Filtration efficiency test starts by preparing the filter paper for each sample of water. The paper was weighed before and after usage. Bend the filter paper into two halves and then into two halves again to become a quarter of a circle. Then, the bended filter paper is placed in the glass funnel, the funnel is placed in the beaker, and the amount of water prepared is then inserted in the flask, which was 100 ml of water, and it is placed in the funnel with paper filter until all water sample passes through the filter paper to the beaker. After water completely passes through the filter paper, the filter paper is carefully taken and placed in a glass dish and then put in the oven at a temperature of 105 °C for 1 h, the sample is then removed from the oven and placed in the desiccators for 24 h to be left to dry without the filter paper getting a percentage of air moisture. Then the filter paper is weighed, and the weight of the filter paper is compared before the experiment and after the experiment the weights are recorded to determine the weight of solid particles removed by the filter from the total particles prepared in the tested water and finally calculating filtration efficiency.

Water turbidity test was carried out using a turbidity meter as shown in Fig. 5 according to the standard method committee of the American Public

Fig. 5. Turbidity meter.

Health Association and water environment federation, 2130 turbidity in standard method for the examination of water and wastewater (Rice et al., 2012). Turbidity is a measure of water clarity. It describes the amount of light scattered or blocked by particles floating in the water as shown in Fig. 6. These particles cause the water to look cloudy or murky. Turbidity is best measured on site directly in the water but can also be measured in samples sent to the lab. A turbidity sensor shines light into the water and measures how quickly that light is scattered by particles in the water. The results are reported in units called NTU. Tested samples could be compared with standard samples as shown in Fig. 7.

3. Results and discussion

The following results are illustrated in the following tables and figures. Table 3 shows material

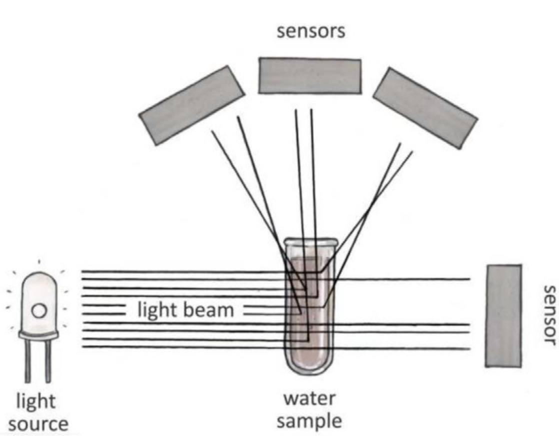

Fig. 6. Principle of water turbidity meter.

Fig. 7. Turbidity of standard samples.

type of cartridge, suspended solids concentration (gm/l) before filtration (flow in), number of filtration cycles, suspended solids concentration (gm/l) after filtration (flow out), suspended solids removal efficiency (%) after filtration, and effluent water turbidity (NTU). The shape of the filter cartridge before and after filtration is shown in Fig. 8. It appears that the color of filter candle tends to be yellow or semi brown color because of capturing solid particle during filtration.

As seen in Table 3 and Fig. 9, it appears that after the filtration process using different materials, the water filtration efficiency varies according to the packing density of filter cartridges used and the contamination level of water. At 100 PES at a contamination level of 3.6 gm/Lit, the filtration efficiency is found to be 95.8% when at a contamination level of 10.8 gm/Lit, the filtration efficiency is found to be 98.2%. In addition to, using 50 PES/50 CO material at contamination level of 3.6 gm/Lit, the filtration efficiency is found to be 95% when at contamination level of 10.8 gm/Lit, filtration efficiency is found to be 97.3%. Moreover, using 100 CO material at a contamination level of 3.6 gm/Lit, the filtration efficiency is found to be 93.1% when at contamination level of 10.8 gm/Lit, the filtration efficiency is found to be 96.2%. As a result of the previous analysis, it can be concluded that the 100 PES cartridge has the best water filtration efficiency compared with others at different contamination levels. In fact, the calculated packing density of 100% CO = 0.392 gm/cm^3, and the packing density of 50/50 CO/PES = 0.389 gm/cm^3, it means that they are almost equal, and the packing density of 100% PES = 0.498 gm/cm^3 which is much higher than both. This is the reason for improving filtration

Table 3. Water filter efficiency and water turbidity for three material types and two contamination levels after one and two filtration cycles.

Material type of cartridge	Suspended solids concentration (gm/l) before filtration (flow in)	Number of filtration cycles	Suspended solids concentration (gm/l) after filtration (flow out)	Suspended solids removal efficiency (%)	Effluent water turbidity (NTU)
100 PES	3.6	1	0.151	95.8	3.32
100 PES	10.8	1	0.194	98.2	10.2
50 PES/50 CO	3.6	1	0.180	95.0	4.35
50 PES/50 CO	10.8	1	0.292	97.3	12.2
100 CO	3.6	1	0.248	93.1	14.2
100 CO	10.8	1	0.410	96.2	20.3
100 PES	10.8	2	0.97	99.1	6.7
50 PES/50 CO	10.8	2	0.183	98.3	8.2
100 CO	10.8	2	0.237	97.8	11.7

Fig. 8. The shape of the filter candle before and after filtration.

efficiency when using 100% polyester. So, in fact 100% polyester is the best, not because it is a PES compared with cotton and cotton blends, but because the packing density of the PES roving is the largest compared with 100% CO and CO/PES blend according to calculated packing densities for filter cartridges as shown previously in Table 2.

As seen in Table 3 and Fig. 10, after the filtration process using different materials, the water turbidity (NTU) varies according to the type of material used and the contamination level or particle concentration of tested water. When using 100 PES at a contamination level of 3.6 gm/Lit, Turbidity is found to be 3.32 NTU. Moreover, at contamination level of 10.8 gm/Lit, Turbidity is found to be 10.2 NTU. For material type 50 PES/50 CO at a contamination level of 3.6 gm/Lit, the Turbidity is found to be 4.35 NTU while at a contamination level of 10.8 gm/Lit, the

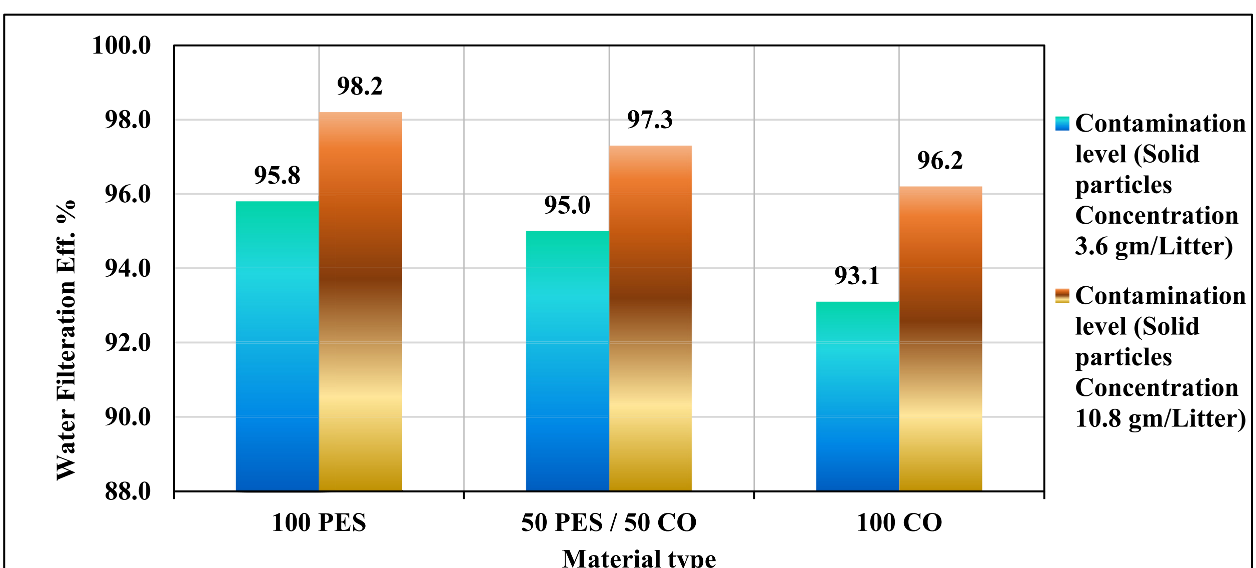

Fig. 9. Effect of material type and contamination level on water filter efficiency at one filtration cycle.

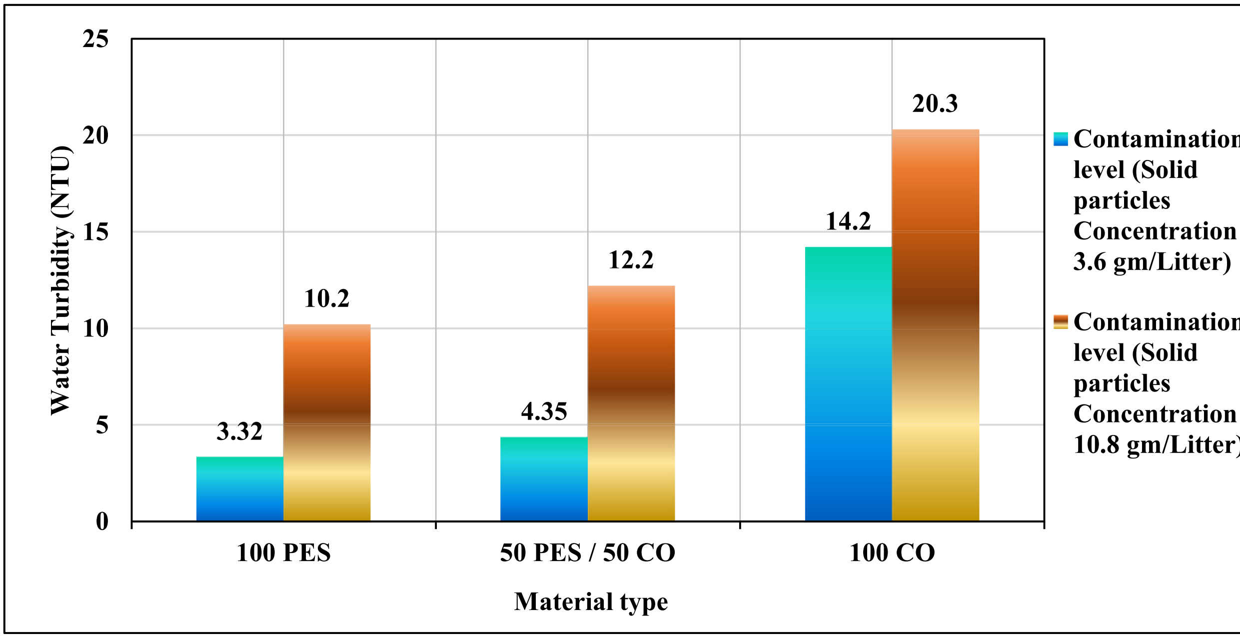

Fig. 10. Effect of material type and contamination level on water turbidity at one filtration cycle.

Turbidity is found to be 12.2 NTU. Among 100 CO at a contamination level of 3.6 gm/Lit, the Turbidity is found to be 14.2 NTU while at a contamination level of 10.8 gm/Lit, Turbidity is found to be 20.3 NTU. As a result of the previous analysis, it can be found that the 100 PES material has the best Water turbidity compared with other materials used in this experiment at different contamination levels as it has the lowest values of water turbidity. Not because it is a PES compared with CO and CO blends, but because the packing density of the PES roving is the largest compared with 100% CO and CO/PES blend according to calculated packing densities for filter cartridges as shown previously in Table 2.

As shown in Table 3 and Fig. 11, water filtration efficiencies vary according to number of filtration cycles, they tend to improve and introduce higher filtration efficiencies after the second filtration cycle

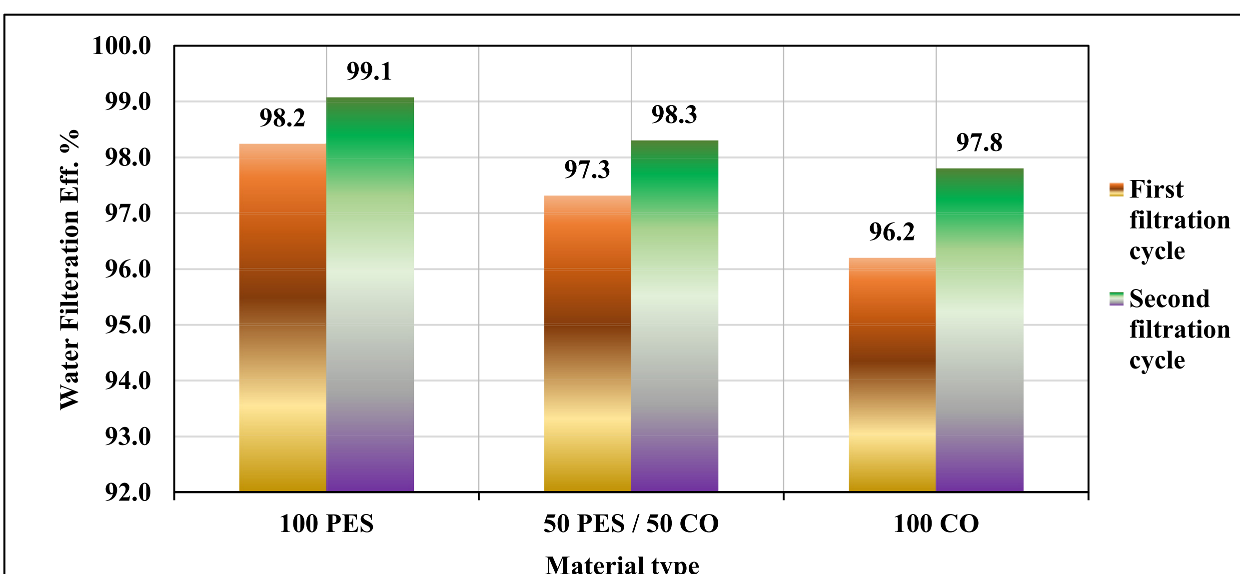

Fig. 11. Effect of material type and number of filtration cycles on water filter efficiency at contamination level (Solid particles concentration 10.8 gm/l).

than that of one filtration cycle. In the case of 100 PES material, it can be noticed that the water filtration efficiency was 98.2% in the first filtration cycle and increased to 99.1% in the second filtration cycle. Moreover, in the case of 50 PES/50 CO material, the water filtration efficiency was 97.3% in the first filtration cycle and increased to 98.3% in the second filtration cycle. In addition to 100 CO material, the water filtration efficiency was 96.2% in the first filtration cycle and increased to 97.8% in the second filtration cycle. As a result of the previous analysis, it can be deduced that 100 PES material has the highest water filtration efficiency in the first and second filtration cycles at 98.2% and 99.1%, respectively, but 100 CO material has the highest increase in efficiency when using a second cycle and the increase was 1.6%. The second filtration cycle for the three types of materials improves the suspended solids removal from 0.9 to 1.6% which means the first stage or filtration cycles is the most important to remove most of suspended solids from filtered water.

As shown in Table 3 and Fig. 12, water turbidity varies according to a number of filtration cycles, they tend to improve and introduce lower values after the second filtration cycle than that of one filtration cycle. For 100 PES material, it can be figured out the water turbidity was 10.2 NTU in the first filtration cycle and decreased to 6.7 NTU in the second filtration cycle. In addition to 50 PES/50 CO material, the water turbidity was 12.2 NTU in the first filtration cycle and decreased to 11.7 NTU in the second filtration cycle. Finally, 100 CO material, the water turbidity was 20.3 NTU in the first filtration cycle and decreased to 8.2 NTU in the second filtration cycle. As a result of the previous investigation, it can be concluded that 100 PES material has the lowest water turbidity 10.2 NTU after the first and 6.7 NTU after the second filtration cycle, but 100 CO material has the maximum drop in water turbidity after the second filtration cycle as it decreased from 20.3 NTU to 8.2 NTU and the decrease was 12.1 NTU. So, it is recommended for 100% CO material to apply two filtration cycles for perfect water treatment according to end-use. The second filtration cycle for the three types of materials improves and reduces water turbidity by 34.3, 32.7, and 42.36% for 100% CO, 50%CO/50%PES, and 100% PES, respectively, which means the second stage or filtration cycles is recommended to improve or reduce turbidity of filtered water.

3.1. Conclusion

Cartridge filters of the three materials are efficient in removing suspended solids, improving water turbidity and could be used efficiently as a pretreatment stage in a highly turbidity water. The suspended solids removal efficiencies are in range 93.1–96.2% for low and high turbidity water, respectively. 100 PES is the best, according to its higher packing density, with filtration efficiency 95.8% and 98.2% for low and high turbidity water, respectively. The second filtration cycle for the three materials improves suspended solids removal from 0.9 to 1.6% which means that the first filtration

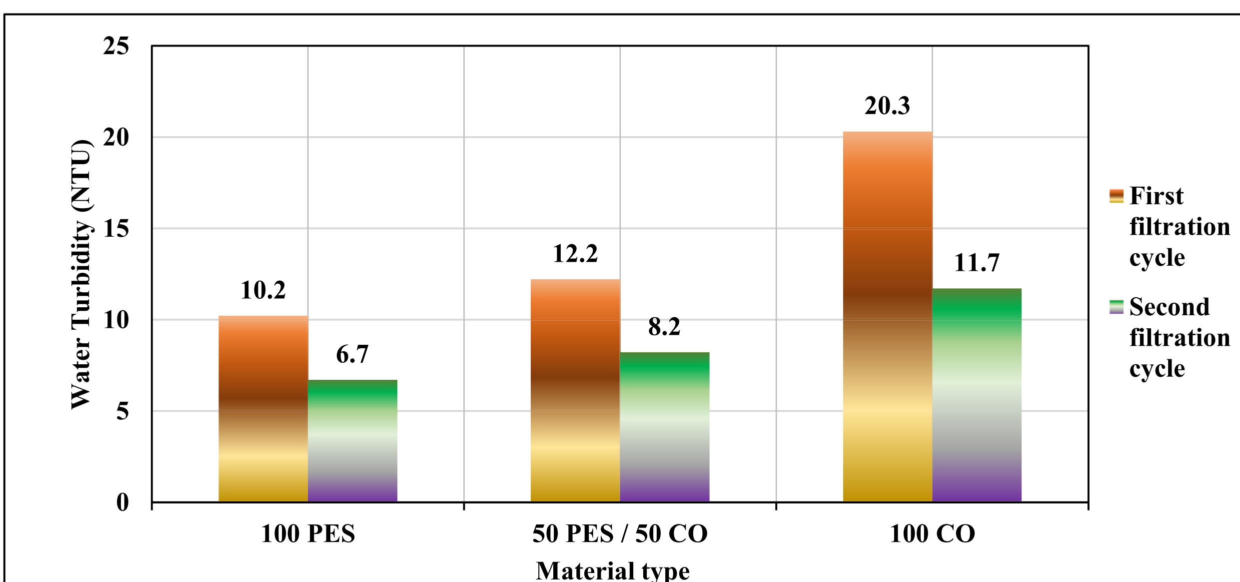

Fig. 12. Effect of material type and number of filtration cycles on water turbidity at contamination level (Solid particles concentration 10.8 gm/l).

cycles is the most important to remove majority of suspended solids from water. The second filtration cycle for the three materials improves and reduces water turbidity by 34.3, 32.7, and 42.36% for 100% CO, 50%CO/50%PES, and 100% PES, respectively, which means the second stage or filtration cycles is recommended to improve or reduce turbidity of filtered water.

3.2. Future work

Some experiments will be conducted regarding the color, smell, taste, percentage of bacteria, viruses, and fungi, and all experiments related to drinking water according to the recommendations of the WHO and the Egyptian code for drinking water to evaluate whatever this filtration system can be used for drinking water or only for industrial, agricultural, and nondrinking applications.

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Author contribution

First and corresponding author's contributions: MH: study conception or design of the work, investigation, methodology, critical revision of the article, final approval of the version to be published. The corresponding author is responsible for ensuring that the descriptions are accurate and agreed by all authors. Second author's contributions: HA: data collection and tools, drafting the article, data analysis and interpretation, investigation, statistical analysis, supervision, final approval of the version to be published. Third author's contributions: AA: study conception or design of the work, visualization, investigation, project administration, resources, final approval of the version to be published. Last author's contributions: WAH: visualization, data collection and tools, project administration, resources, supervision, final approval of the version to be published.

Intellectual property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, concerning intellectual property.

Conflict of interest

There are no conflicts of interest.

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