Chapter 11

Textile Materials in Liquid Filtration Practices: Current Status and Perspectives in Water and Wastewater Treatment

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.69462

Abstract

Filtration is considered the keystone of water and wastewater treatment and is used for various purposes, such as sludge dewatering and concentrating any solution. Moreover, as an advanced filtration technology, membranes can remove materials ranging from large visible particles to molecular and ionic chemical species. Proper selection of filter media/membrane material in filtration processes is often the most important consideration for assuring efficient separation. Filter media can be classified by their materials of construction, such as cotton, wool, linen, glass fiber, porous carbon, metals, and rayons. Recently, new polymeric materials have been used both individually and/or blended in filtration processes for the treatment of waters and wastewaters. The purpose of this chapter is to bring an overview on the textile-originated filter materials in filtration applications from conventional filtration to advanced membrane processes. Although many researches on filter media are available, very few researches have been carried out on the cutting-edge technologies about using filter materials on filtration processes from classical to advanced membrane processes. Therefore, in this part of the book, following major and minor titles are stated truly on the aforementioned new technologies and linked with conventional methods in water and wastewater treatment applications.

Keywords: filtration, membrane, textiles, woven, nonwoven, fibers, nanofibers, electrospinning, water treatment, wastewater treatment

1. Introduction

Physical, chemical, and biological methods are used in water treatment to convert raw water to potable water. The selection of the treatment method depends on the properties of the raw water. Water treatment methods can be based on simple physical processes, such as sedimentation processes or more complex physicochemical processes, such as coagulation. Among these purification methods, filtration is the process of removing solid substances from a fluid/liquid (water/wastewater) by passing them through a porous medium (filtration). Filtration is commonly used in water treatment to remove solids, including microorganisms (bacteria, viruses, etc.) and precipitated iron and manganese found in surface waters [1]. In addition to conventional filtration, direct filtration, which is a simple and economically attractive process in which the sedimentation phase is lifted, is often used. Direct filtration is suitable for raw waters with a turbidity value lower than 10 NTU. It does not require sedimentation tanks and, in some cases, floatation tanks, which leads to low installation and operating costs [2]. Filtration is a basic procedure widely used in environmental engineering applications 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 [3]. Filtration is used in the treatment of drinking water, especially in high-quality surface water. For the treatment of wastewater, different kinds of filtration processes can be used at different stages of the process [4, 5]. In addition to solid-liquid separation, the filtration process is used for dewatering. A classification based on the operating mode of the filtration and the filtration unit used is shown in **Figure 1**.

Filters are selected in different qualities depending on the characteristics of the industries in which they are used. For example, the reverse osmosis process used to desalinate water and

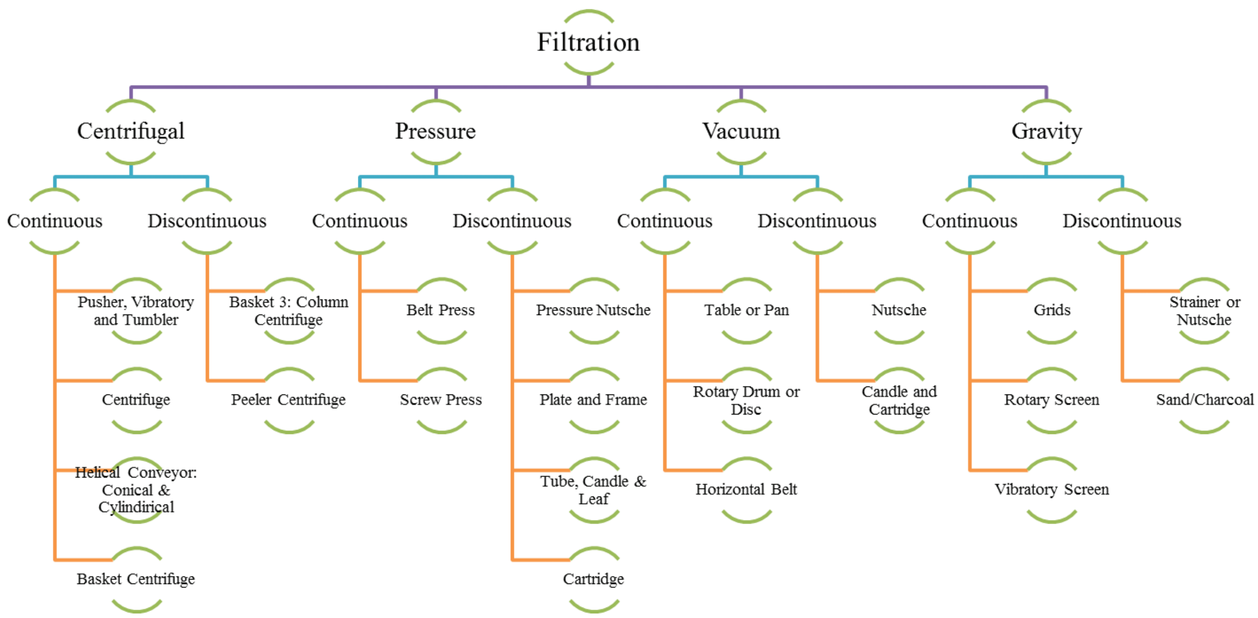

Figure 1. Operational modes of filtration (adopted from [6]).

the cellulose acetate and aramid hollow fiber membranes used are among the first applications of fiber-based filtration. The important properties of the fibers used in such a filtration are their hydrolytic nature, oxidative nature, and high biological resistance over a wide pH range. In addition, the fibers need to be resistant to temperature changes and chemicals used in different industries. Poly (phenylene sulfide), polysulfone, aramids, polyimide, PEEK (Victrex), fluorocarbon, and related fibers are examples of high-performance fibers effective for liquid filtration under extreme and rapid changing environmental conditions [7].

Proper selection of filter media/membrane material in filtration processes is often the most important consideration for assuring efficient separation. Filter media can be classified by their materials of construction, such as cotton, wool, linen, glass fiber, porous carbon, metals, and rayons. Recently, new polymeric materials have been used both individually and/or blended in filtration processes for the treatment of waters and wastewaters. The purpose of this chapter is to bring an overview on the textile-originated filter materials in filtration applications from conventional filtration to advanced membrane processes. Although many researches on filter media are available, very few researches have been carried out on the cutting-edge technologies about using filter materials on filtration processes from classical to advanced membrane processes. Therefore, in this part of the book, following major and minor titles are stated truly on the aforementioned new technologies and linked with conventional methods in water and wastewater treatment applications.

2. Principles of filtration

2.1. Filtration mechanisms

Filtration is based on the principle that water is passed through a porous medium at a certain rate. The filter does not allow particles to pass while allowing water to pass through. Particles (0.01–5 mm) retained in the filter medium are smaller than the size of the filter material (5–20 mm), and such retention takes the place in trapping in unfiltered extraneous materials, which strikes and adheres to the filter material due to the rapid flow of the fluid. Although the flow in the porous media was announced by Darcy in 1856, the first filters were designed by trial and error until the publication of the Carman-Cozeny equation (1937), which describes the flow in the filter bed. As research continues on the design of granule filters, the earlier empirical equations used in design are still widely used [8].

The trapping of particles in the filter bed consists of two phases, collision and attachment. In the first stage, the particles in the fluid approach the surface of the densities of the porous filter media by mechanisms, such as sedimentation, impaction, diffusion, and interception, and become accessible to hold. In the second step, the retention of particles in the filter depends on the balance between the superficial forces between the particles and the filter medium. These steps and the mechanisms that play a role in each step are explained elsewhere (**Figure 2**) [9, 10].

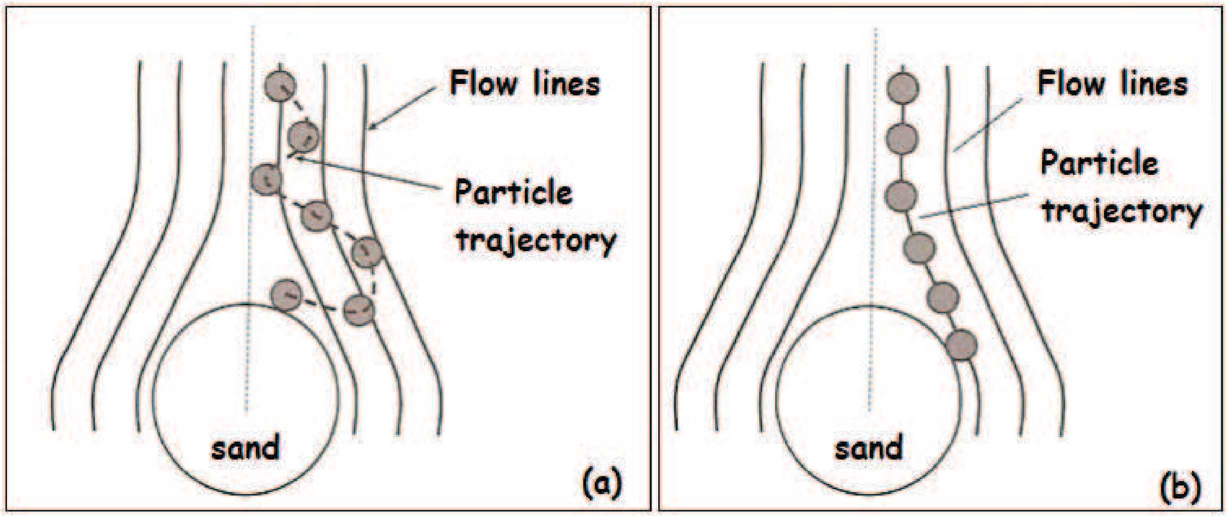

Figure 2. Filtration mechanisms in deep-bed filter, (a) diffusion, (b) interception [9, 10].

2.2. Types of filtration processes

2.2.1. Surface (membrane) filtration

Membrane filtration is the process of separating a material from a medium through which it can pass more easily than other materials in the same environment. In water and wastewater treatment, membranes are used to remove unwanted suspended or dissolved substances. However, in some cases, the membrane may move to remove contaminants from the wastewater or to transfer special components (such as oxygen) into the liquid medium. Extraction processes currently used include electrodialysis (ED), dialysis, pervaporation (PV), and gas transfer (GT). In such cases, the membrane is used to allow selective penetration of specific components dissolved in water. However, filtration processes such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) are of much more industrial significance. In these processes, it is the bulk water that passes through the membrane under an applied pressure, leaving the pollutants in a concentrated form on the unpermeated side of the membrane [10, 11]. Membrane classification based on filtration is shown in **Figure 3**.

2.2.2. Depth filtration

Deep-bed filters are more than a century-old and are widely used in water and wastewater treatment applications. The theory of deep-bed filtration is the same as the formation of wells or springs in nature, which are drained from porous media, such as rocks and sand. In practice, deep-bed filters are obtained by placing the material to be filtered in a closed tank (pressurized) or in an open concrete pond. The filter tank is designed according to the properties of the liquid to be filtered or filtration method (pressure or gravity operation). Particles in the liquid are trapped in the filter bed by the abovementioned filtration mechanisms. During

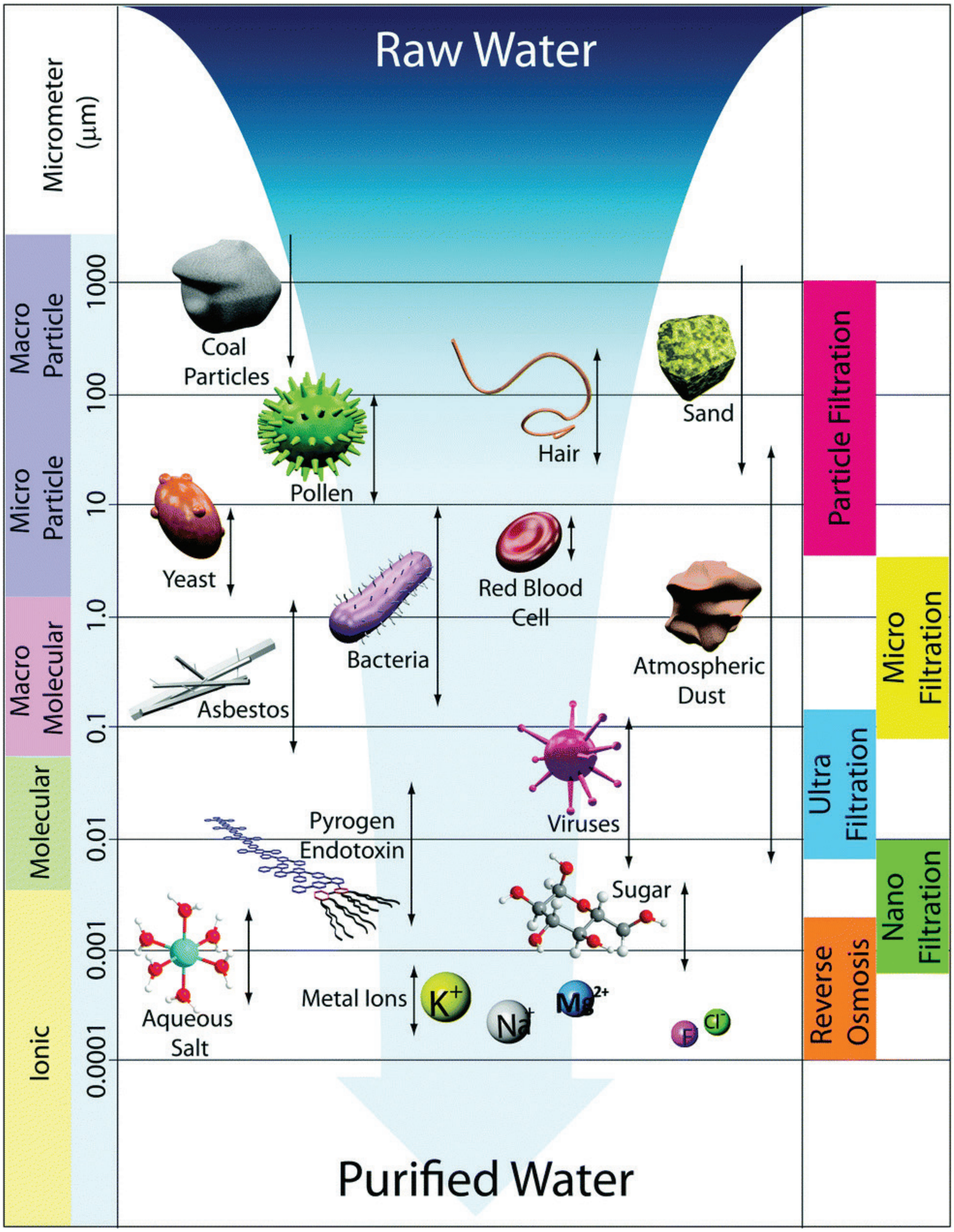

Figure 3. Schematic illustration of membrane filtration spectrum [11].

filtration, the particles that accumulate in the filter bed begin to clog the filter and reduce the fluid pressure. For this reason, solids are not required at high concentrations. Filtration is generally applied for concentrations lower than 0.5 g/L. Alternative or pretreatment systems should be considered as the solids concentration increases. Precoagulation and/or flocculation systems have to be applied before the filtration of submicron particles that are too small to be filtered or settled readily. The common types of deep-bed filtrations are slow sand filtration, rapid filtration, and direct filtration, which are explained in detail elsewhere [6]. Both surface and depth filtration are shown schematically in **Figure 4**.

2.3. Operating parameters of filtration

The filter medium is evaluated as the heart of any filtration process. Ideally, while the solids to be retained are concentrated on the feed side of the membrane, the liquid portion is forced to pass through the membrane and is transported to its other side. A filter medium, by its nature, is not homogeneous, and its dimensions and geometries come from irregular pores. These pores may also exhibit an irregular distribution over the membrane surface. Since the flow in the environment only takes place through the pores, the microfluidic velocity therein can cause large differences on the filter surface. This indicates that the top layers of the filter cake produced on the membrane surface are not homogeneous and are also formed based on the nature and properties of the filter medium. Since the number of passages in the filter cake is larger than the number in the filter media, the primary structure of the cake is strongly attached to the structure of the first layers. This means that the filter crayon and filter material are influenced by each other.

The pores containing passages extending along the filter medium can catch solid particles smaller than the narrowest cross section of the passageway. Such retention of the particles is

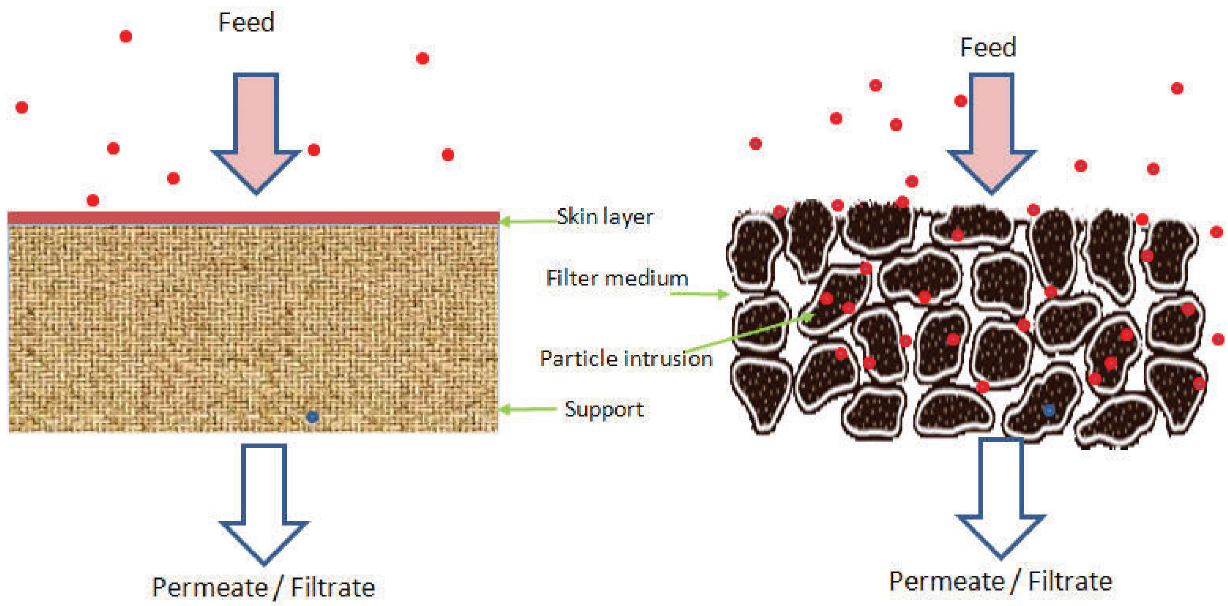

Figure 4. Schematic representation of surface filtration (on the left side) and depth filtration (on the right side) [12].

generally explained by particle bridging or, in some cases, physical adsorption. Depending on the intended use, different filter media are used. The commonly used filter media are sand, diatomite, coal, cotton or wool fabrics, metal wire cloth, porous quartz plates, chamotte, sintered glass, metal dust, and powdered ebonite. The average pore size and configuration of the filter material (including tortuosity and connectivity) is due to the size and form of each element from which the material is produced. The manufacturing method of the filter material also influences the average pore size and shape. For example, pore characteristics vary when the fibrous media is first pressed. Pore properties also depend on the properties of the fibers in the woven fabric or on the methods of sintering glass and metal powders. In addition to all these, some filter media, especially fibrous layers, are subject to significant compression when subjected to typical pressures used in industrial filtration processes. Other filter materials, such as sintered plates of ceramics, glass, and metal powders, are stable under the same operating conditions.

The filtration/separation process also influences pore properties. Because as filtering continues, effective pore size decreases and flow resistance increases. This is because the particles penetrate into the pores of the filter media. The separation of solid particles from the liquid by filtration is a complex process. In practice, it is desirable that the filter pores are larger than the average size of the particles to be filtered. However, the selected filter medium must have the ability to retain solids by adsorption, and cohesive forces between the particles must be large enough to induce particle agglomeration around the pore openings [13].

2.4. Application of filtration

2.4.1. In drinking water treatment

The filtration process discussed in this section is used to remove particulate material from the water. Filtration is one of the unit processes used in drinking water treatment. The particles retained in the filter may be particles present in the spring water, or may come into play during the purification process. Particulate materials include clay and silt particles; microorganisms, such as bacteria, viruses, and protozoa cysts; humic substances and other natural organic particles; calcium carbonate and magnesium hydroxide precipitates used in softening processes; or alumina or iron precipitation used in coagulation processes [14]. High-quality drinking water production and filtration units are shown schematically in **Figure 5**.

About 30–40 years ago, lead was considered among the dangerous harmful pollutants in drinking water. Today, along with lead, pesticides, bacteria, viruses, coliphages, nitrates, chlorine, chlororganic substances, and aluminum have been added to the list of health threats, and the pollutant list is renewing day by day [15]. The contaminants typically found in water are shown in **Table 1**.

2.4.2. In wastewater treatment

The treatment of wastewater is a big deal when considering the volume of the water to be treated. Most of the water used for domestic, commercial, institutional, and industrial purposes is returned to the environment as waste. For this reason, a suitable treatment for a safe discharge is needed, which can manage wastewater treatment, from collection of waters to treatment, from

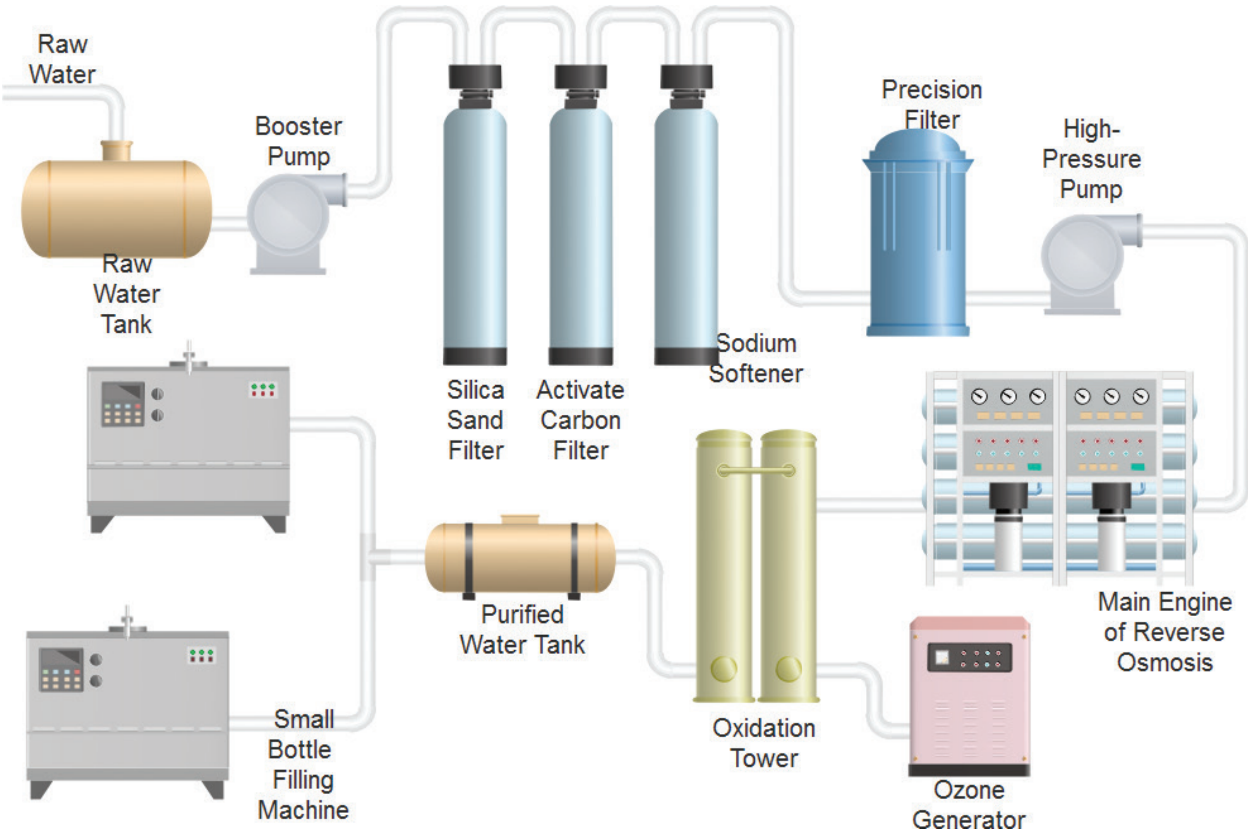

Figure 5. Drinking water production units.

Contaminants	Effects
Chlorine	• Reacts with organics and forms trihalomethanes
Bacterial diseases	• Cause cholera, the most widespread infection
The parasitic protozoan *Cryptosporidium*	• Get into the water supply from animal excrement
	• Can survive for long periods in water
	• Self-limiting gastroenteritis to life-threatening situations
Cryptosporidium	• Resist chlorine
	• Cause disease
	• Treatable with antibiotics
Giardia lamblia	• Cause disease
	• Treatable with antibiotics
Bacteria and viruses	• Can be removed by ultrafiltration and activated carbon

Table 1. Typical contaminants found in water (adopted from [15]).

equipment selection to process design. In most of the developed areas, wastewaters are collected by a municipality or a private operator and are directed to the treatment plant for collection by the sewerage system and surface runoff. The purpose of wastewater treatment is to convert these mixed wastes into a liquid stream, which will not harm the environment. Wastewater discharged without treatment threatens the life of plants and animals by consuming oxygen in the receiving environment. The contaminated receiving environment waters can be transported to the surface waters to be used for water supply and can adversely affect human health. Although most of the industrial wastewater treatment process is the same as domestic wastewater treatment, the characteristics of the industrial wastewater source should be taken into account.

Granular filtration is generally used for the treatment of water and wastewater containing suspended solids. The filter medium is composed of materials, such as sand and anthracite, which contain granular particles. The filter medium is contained in a basin, and underneath the material there is a layer that serves both as a support and as a drain. As the water or wastewater passes through the filter bed, the particles are trapped in and on the bed. When the filter is clogged, backwash is performed at high speed. The backwash water contains solids at high concentration and is recycled to another treatment step or plant inlet. Filtration is typically used for liquids with a solids content of 100–200 mg/L. As the concentration of suspended solids in the water-wastewater to be treated increases, the filter blockage accelerates and the frequency of backwash increases. Sudden and continuous flow changes in the filtration are another factor affecting the filtrate quality. Sedimentation is generally applied before filtration to reduce the suspended solids load. Filtration can also be applied to reduce suspended solids before biological treatment or before activated carbon process. The particles that can be removed by the granular filtration process are usually in colloidal size or may be in larger sizes such as floc. Although the floc is more likely to remain in the filter, it clogs the filter faster. Sometimes, however, flocculation of the particles may not be possible (as in many oil and water emulsions). In this case, some other equipment such as ultrafiltration may be needed. In a typical physical/chemical treatment plant, there are three parallel filters having three filter media layers (sand and anthracite) connected in parallel.

2.4.2.1. In municipal wastewater treatment

In most municipal wastewater treatment plants, the wastewater delivered to the treatment is not continuously characterized. For this reason, considering that other pollutants may also be transported to the plant wastewater inlet, the design of the treatment plant should be designed to cope with the pollutant in a wide range. These contaminants may be suspended or dissolved, organic or inorganic, or toxic or not. The treatment plant should be able to reduce the total amount of these pollutants below the limit values set by national and local regulators. These limits are regulated according to the structure of the receiving water environment. The units of a conventional municipal wastewater treatment plant are shown in **Figure 6**.

2.4.2.2. In industrial wastewater treatment

Industrial wastes differ from domestic wastes in three main ways:

(i) They contain more inorganic or biodegradable contaminants,

(ii) They generally have low or high pH, and

(iii) They often contain high amounts of toxic substances.

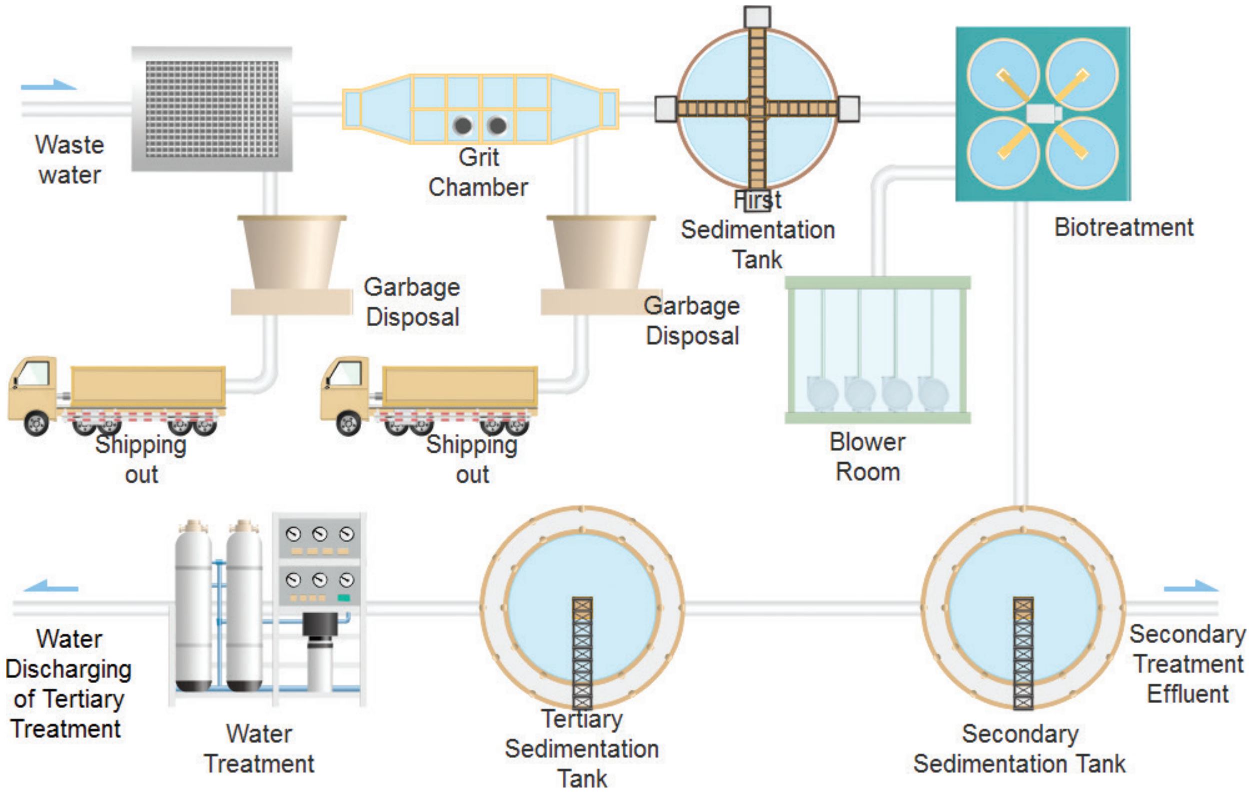

Figure 6. Conventional municipal wastewater treatment plant.

The oil compounds are also a problem for the treatment process. Although the waste amount of a plant that applies a certain production standard is generally constant in terms of compound and content, the purification cost is also very high since large volumes of wastewater and high amounts of sludge are formed. Although most industrialized countries have comprehensive legislation on industrial wastewater, this is not sufficient in wastewater management alone. It is also important that the industry owner knows the regulations and that the audits are carried out in sufficient frequency and extent. For this reason, wastewater treatment is a complex process in environmental management. In the majority of industrial wastewater treatment plants, there are two main parts: (i) to dispose of special wastes that are initially dependent on the raw material of the industry and (ii) to remove other general wastes. In the first part, the main function is to minimize the loss of any product material carried with the waste. If it is possible, the main thing is to recover the products in the waste [15].

2.4.2.3. Treatment of hazardous wastes

Membrane processes are used in many water and wastewater treatment applications. Most of these applications involve the separation and concentration of organic and inorganic substances. Wastewater can originate from industrial processes, contaminated ground or surface waters, or byproducts of other treatment processes. Membrane and filtration processes are used in water and wastewater treatment from visible particles to ionic species in many pollutant removal methods. Membrane processes are also preferred for the separation of hazardous wastes. In the organic pollutant removal, the separation takes place depending on the size (molecular weights) and polarities of the pollutants. For this, a suitable membrane having a different pore diameter is selected and used. The smaller the pores of the membrane, the higher the removal of small molecular weight compounds. However, as the pore size of the membrane decreases, the flux will also decrease. This will adversely affect the amount of product water obtained.

The polarity of an organic component is a measure of the ability of ionization in solution. Polar molecules include, for example, water, alcohols, and compounds having hydroxyl groups (e.g., phenols) and carboxyl groups (e.g., organic acids). Aliphatic hydrocarbons and polynuclear aromatic hydrocarbons are examples of nonpolar organic molecules. The chemical properties of the membrane can be used to separate nonpolar components from polar components in a waste stream. For example, a membrane that is surface hydrophilic will allow the passage of polar components while retaining nonpolar components. These membranes can be used to separate dissolved and emulsified oils from aqueous waste streams. Inorganic contaminants, such as salts and heavy metals, can be removed and concentrated by membrane processes from waste streams. Suspended inorganic materials can be easily removed using microfiltration membranes. These membranes have pore sizes ranging from 0.01 to several microns. Dissolved inorganics can be removed by reverse osmosis membranes or by precipitation followed by microfiltration. Only when reverse osmosis is used, a pretreatment is absolutely necessary, or it is used in the treatment of relatively clean waters. Chemical precipitation, on the other hand, provides higher flux with microfiltration membranes that are less sensitive to fouling [15].

3. Textile materials for filtration

3.1. Properties of filter media

There are a number of materials available for use in the filter medium that can be used to meet the needs of the user (**Table 2**). The material to be used must be easy to place on the filter tank/module. For this purpose, wool and nonwoven fabrics, natural or synthetic fibers may be preferred. In some cases, the weaving medium may be equipped with metal glands. The same material may be incorporated into the hard porous media (porous ceramic, sintered metal, woven wire, etc.), cartridge, and wax filter.

The proper selection of filter material is the most important factor in achieving efficient filtration. A good filter medium/filter should have the following characteristics: the filter medium should be able to retain the particles contained in the suspension in a wide size distribution; in order to obtain a high amount of filtrate in the desired quality, the filter must exhibit minimum resistance to flow; the cake deposited in the filter should be suitable for easy removal; it must be resistant to chemicals that can be transported to the filter medium and should not be a soluble material; during the filtration or backwashing process, the filter material should not swell; it must be sufficiently resistant to temperature changes in the fluid or environment; it must be resistant to the pressure applied in the filter and mechanical abrasion that may occur during the flow; and the filter material must be capable of preventing particles from being wedged in the pores [6]. The parameters to be considered in the filter selection are schematized in **Figure 7**.

Basic media format	Types of media
Loose granules	Deep bed
Loose fibers	Pads, felts
Structured granules	Bonded, sintered
Structured fiber	Needlefelts, spun
Sheet	Perforated, microporous
Woven/knitted	Spun yarn, monofilament
Tubular	Hollow fiber
Block	Rigid
Wound on core	Spun yarn, monofilament
Structured array	Ribbon, rods, bars
Extruded mesh	Netlon

Table 2. Filter media types [15].

Figure 7. Parameters in filter selection.

3.1.1. Classical filtration media

The filter medium is described as a porous (or at least semipermeable) barrier used to hold part or all of a suspension. When the pores of this barrier are much smaller than the diameter of the smallest particle to be filtered, the entire filtration process will take place on the surface,

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not the depth of the filter medium. If there is any particle smaller than the pore diameter, it will point toward the pores. Larger particles will clog the pores while smaller particles will clog the surface, thereby reducing the filtrate flow. At a certain point, the filtration process should be stopped and cleaned.

The mechanism by which the relationship between the particle size of the filtration process and the filter pore size depends strongly is called surface straining. As long as the particles are not deformed, the surface of the filter is separated by pore size with the help of tension. A second mechanism, referred to as deep stretching, occurs when a particle moves along the pore and is retained completely at a narrower point of the eye due to particle size. At this point, the clogged pore should be cleaned with backwash. The fine particles move on a tortuous path in filter bed and are trapped in the filter pores through a direct or inertial retention/diffusion mechanisms. This process is known as depth filtration. Congestion in the filter bed also occurs with these mechanisms. Particles retained in the filter material are compressed and do not completely cover the pores. Thus, the flow continues until the filter is completely clogged. In this case, the filter should be backwashed.

During the filtration process, particles in the pores are held together, and after a while they begin to function like filter material and assume the responsibility of trapping the particles that come after it in the fluid. A similar mechanism is also seen in the cake layer formed by the separated particles held on the filter media, and this separation is called cake filtration. More complicated mechanisms can occur in cake filtration. Because the cake compressed less or more by water pressure.

3.1.2. Membrane filtration media

Membranes are classified according to the size of the particles they separate. Macrofiltration is used to separate the intrinsic particles in the range of about 1 mm to 5 μm (screening is used for particles above 1 mm). Microfiltration is applied for particles from about 5 μm to about 0.1 μm, while ultrafiltration is used for lower dimensions. While ultrafiltration separates finer particles such as colloids, the lower limit of the particle size is usually determined by the term molecular weight, measured in Dalton. Further separation processes include nanofiltration and reverse osmosis. In both systems, a semipermeable membrane acts as a barrier in front of the fluid flow. However, the operating principle of NF and RO processes is different from that of UF. The liquid to be used in NF and RO is a solution which does not contain suspended solids or is prefiltered. The last two processes mentioned do not physically contain holes. The molecules are distributed across the membrane under high transmembrane pressure, and the liquid is removed from the other side of the membrane in pure form [15].

3.2. Textile media

Textile fibers are obtained from many natural and synthetic sources. Natural sources include materials of wood/cellulosic and vegetable origin, such as cotton, towel (flax), and jute, and materials of animal origin, such as silk, wool, fur, and hair. Synthetic materials are produced from natural sources such as glass, ceramics, carbon, metals, or reconstituted cellulose. They can also be obtained synthetically, extruded from thermoplastic polymers. The natural fibres are extremely long by comparison with their diameters, except in the case of wood cellulose, where the manufacturing process produces short fibres (in millimetres).

Fabrics are the largest component of filter materials. They are composed of fibers or filaments made of natural or synthetic material and are relatively soft. They are also not rigid like dry paper. For this reason, they need some kind of support when they need to be used as a filter medium. The fibers or filaments can be made into a fabric as is by a series of drylaying operations to produce a felt or the like. Such 'noninterlaced' fabrics are often referred to as 'nonwoven.' They are mentioned in the following sections of nonwoven fabrics [15]. A filter media classification (Ipurchas, 1967) based on rigidity is shown in **Table 3**.

3.2.1. Woven fabrics

Flexible and nonmetallic materials have been widely used as filter media for many years. These materials can not only be found in the form of fabric or as preformed nonwoven materials, but also as perforated plates. The fabric filter media is characterized by the number of weaves, mesh size, yarn size, and mesh type. The number of mesh or the number of thread of a fabric is the number of threads per inch. The number of yarns in the warp and weft direction are equal to each other and are represented by a single number.

The warp threads are placed longitudinally in a fabric and are parallel to the fabric edge. Weft or fill yarns also pass through the width of the fabric across the width of the warp. The space between the threads is the mesh opening and is measured in units of mm or inch. Different yarn sizes are normally defined as a diameter measurement in micrometers or mils (thousands of an inch). In warp and weft directions, the yarn sizes are normally the same and are represented by a single number. Fabrics are available in different mesh openings and different yarn diameters. The yarn diameter affects the amount of open space in the cloth to which it belongs, which determines the filtration flow rate or yield.

The diameter of the natural fibers varies according to their source, and is usually bigger than 1 mm. Synthetic fibers and filaments are formed by a kind of extrusion process that has a diameter that matches that of the extruded bending mouth. For this reason, their diameters may be in a much wider range than natural products, and in a wide range of sizes. The length and diameter of a natural fiber can be increased by turning the material into a yarn, but the

Type	Example	Minimum trapped particles (μm)
Edge filters	Wire-wound tubes Scalloped washers	5–25
Metallic sheets	Perforated plates Woven wire	100 5
Woven fabrics	Woven cloths Natural and synthetic fibers	10
Cartridges	Spools of yarns or fiber	2

Table 3. Filter media classification [6].

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yarns can also be made from fibers at the same time. Because the lengths are much longer, the fibers can usually be brought together to make a yarn, but the bundles are usually twisted to have a reasonably constant diameter. In order to impart sufficient strength to the resulting yarn, the shorter fiber filaments must be firmly twisted after being rotated for sequencing. Yarns made from fibers usually have a thin, smooth, and glossy appearance. Staple yarns are generally thicker, more hairy, and with less or no shine in appearance. Yarns can also be made from various types of tapes. For the filter medium, these bands are most likely fibrillated or made from other perforated material. The woven fabrics then consist of monofilaments or multifilament yarns or twisted staple yarns. The latter is normally used as a single yarn, but two or more spun yarns may be joined to the yarns which are twisted together; this is usually the opposite of the twist of each thread.

Fabric materials can be considered as a physically stronger alternative filter medium than paper materials and are used in a similar way for pleated elements. Fabric elements are in fact the most commonly used filter material for fine-size filtration and can be easily compared with modern paper filters in terms of filtration performance. Until the appearance of processed paper filters, fabric filters were more advantageous than conventional paper filters. While processed papers are now more commonly preferred as filter material due to lower cost, fabric filters can withstand higher working pressures with similar geometry. However, the fabric elements have a lower specific resistance than the paper elements. Though thicker than paper, fabric materials can carry a heavier pollutant load per unit area. However, when the same volume of packaging is taken into consideration, this advantage is offset by the decrease in surface area since the fabric material is thicker. Fabric filters may be preferred when large size filters are needed or when adsorption is required in addition to mechanical screening. The fabrics may contain a range of materials, woven and nonwoven, and may be modified by impregnation with synthetic resin or the like. In the same way, 'cloth' is often used to describe a natural or synthetic fabric media and even a woven wire cloth [15]. Some typical filtration performance curves for fabrics and papers are shown in **Figure 8**.

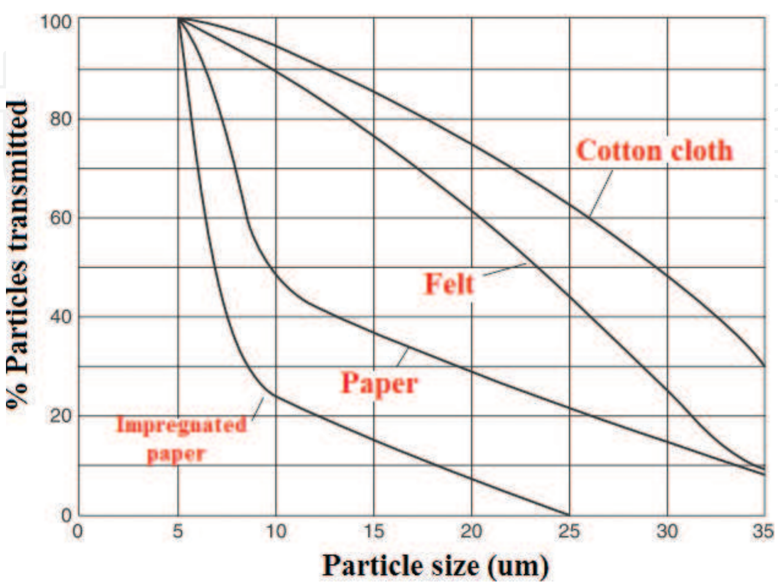

Figure 8. Filtration performance comparison [15].

Synthetic fiber-produced fabrics are superior to natural fabrics due to their resistance to swelling, acid-alkali, and various solvents and their resistance to the growth of fungi and bacteria, such as natural fibers. In addition, many synthetic fibers are resistant to high temperatures and can be easily cleaned due to their smooth surface. The physical properties of the most commonly used synthetic filter materials are shown in **Table 4** [14].

3.2.1.1. Woven yarn fabrics

Fabrics can be woven from a wide variety of yarns. Generally, the warp threads (extending longitudinally on the counter) are stronger, whereas the weft threads (running along the counter) may be more bulky and more tightly twisted. A weft is a thread of a very different material, while it is quite common that warp is a single, relatively stiff staple. Equally, it is normal to make both warp and weft from the same fiber or yarn. The properties of a fabric, especially as regards its behavior as a filter medium, are highly dependent on the way yarns are woven together. Many properties of the filter media are attributed to the natural properties of the fiber or filament or to the method of conversion to yarn. There are three basic yarn types commonly used for filter media: (i) monofilament, a single continuous filament composed of synthetic material (or silk); (ii) multifilament, a large number of filaments; and (iii) staples, spun or twisted filaments from natural materials such as cotton and wool, or synthetic ones cut from extruded filaments. The main feature of yarn type affecting filtration performance varies with monofilament and multifilament/staple fabrics. In monofiber fabrics, the filtration takes place in the spaces between the filaments, while, in multifilament and staple fabrics, yarn twisting is also important as filtration can also occur within the yarns as well as between them. The physical and chemical properties of a yarn are often due to the

Fibers	Acids	Alkalis	Solvents	Fiber tensile strength	Temperature limit (°F)
Acrilan	Good	Good	Good	High	275
Asbestos	Poor	Poor	Poor	Low	750
Cotton	Poor	Fair	Good	High	300
Dacron	Fair	Fair	Fair	High	350
Glass	High	Fair	Fair	High	600
Orlon	Good	Fair	Good	High	275
Saran	Good	Good	Good	High	240
Teflon	High	High	High	Fair	180
Wool	Fair	Poor	Fair	Low	300
Dyne1	Good	Good	Good	Fair	200
Nylon	Fair	Good	Good	High	300

Table 4. Properties of woven filter cloth fibers [14].

physical and chemical properties of the fibers or filaments that make up the yarn. In addition to the number of natural fibers (mostly cotton, but some wool and silk) and a small but growing number of inorganic fibers, the bulk of filter fabrics is based on an increasingly wide variety of synthetic polymer fibers. The physical and chemical properties can then be adapted to the filtration needs by selecting the appropriate polymer.

In textile filtration, the basic material (fiber or filament type) of a woven fabric and its shaping are the most important parameters in the selection of the fabric. The variety of woven fabrics available to be used in filtration is virtually unlimited, even if only the way in which the materials of the fillers or yarns and the way the threads are touched is taken into account. Then the weaving process and the final process to be applied to the fabric after weaving should be added to the fabric structure. Woven fabrics consist of a specific and regular thread which is called knitting. There is no need for the warp and weft yarns to be parallel or perpendicular to each other, but this is true for most fabrics and this structure is also present in the filter medium. The basic properties of a woven fabric result from the geometric uniformity of its components and are retained by friction at the contact points, not by any solid connection.

The binding system or weave is the fundamental factor that determines the character of the woven fabric. Although there are many complex types of knitting in industrial textiles, three main types of knitting (plain, twill, and satin) are used (**Figure 9**). The differences between the wefts are dependent on the length of the weft threads formed when the threads are touched on or under the warp threads. In the plain weave, the weft thread passes over succeeding warp threads along the loom. The return weft then passes through the opposite direction of the subsequent warp threads, so that each weft is held firmly by engaging the warp threads together. Plain weaves can give the most dense fabric and the most robust woven fabric with the highest leverage efficiency. The texture braids are characterized by a strong diagonal pattern. The weft yarns are formed by being passed over two or more warps at one time, and then one or more underneath, regularly along the counter. The next weft thread follows the same and upper pattern, but is replaced by a warp thread. The essential feature of a twill is due to its regularity which leads to the diagonal pattern. In a twill weave, more weft threads can be crammed to a unit length fabric, which gives the fabric more bulk. Compared to a plain weave with the same yarns, the twill fabrics are more flexible and therefore it is easier to place them in a filter [14, 15]. A summary of the main types of weaves for wire cloth is given in **Table 5**.

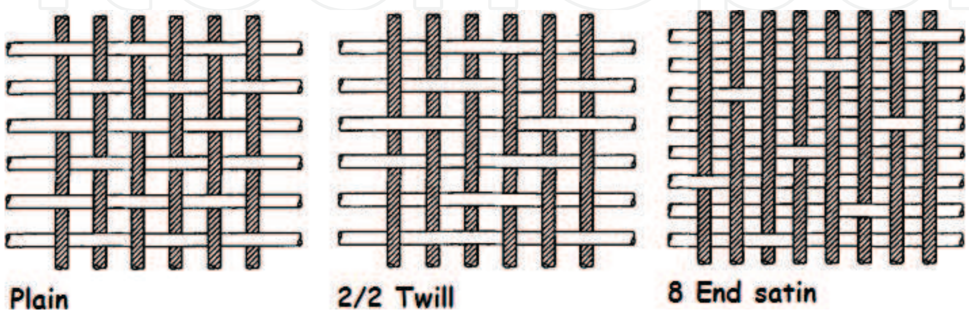

Figure 9. Weave patterns in woven cloths [6].

Name	Characteristics	Absolute rating range (μm)	Remarks
Square plain or twilled	Largest open area and lowest flow resistance. Aperture size is the same in both directions	20–300	Most common type of weave. Made in all grades from coarse to fine
Plain Dutch single weave	Good contaminant retention properties with low flow resistance	20–100	Openings are triangular
Reverse plain Dutch weave	Very strong with good contaminant retention	15–115	
Twilled Dutch double weave	Regular and consistent aperture size	6–100	Used for fine and ultrafine filtering

Table 5. Principle weaves for wire cloths [15].

Satin texture broadens the twill weave concept with wider spacing between touch points. Satin does not have the normal tissue pattern of the tissue, resulting in an irregular appearance with a smooth surface with relatively long layer of warp threads. Most satin fabrics are made from flat, slightly twisted yarn, so visual effects are enhanced. Satin weave fabrics are more flexible than the other two weave types because of the increased ease of thread twisting: this reduces the likelihood of trapped particles. The longer floats allow for the insertion of more warp threads in proportion, thereby further improving the smoothness of the surface resulting in easier cake drainage (**Table 6**). However, unless both warp- and weft-oriented yarns are compacted tightly, satin weaves generally do not provide high filtration effects, while long floats are more susceptible to abrasive wear. In addition to cleaning, all kinds of fabrics are subjected to a number of finishing processes, usually after weaving, to stabilize the fabric, modify surface properties, and regulate the permeability of the fabric. Calendering and singeing are two familiar surface processing methods that change the permeability.

3.2.1.2. Synthetic monofilament fabrics

Monofilaments are woven by extruded synthetic fibers produced with diameters from 30 μm to 2–3 mm. These fabrics are important as filter material in a wide range of industries and applications. Because they have corrosion resistance, vibration fatigue withstanding capacity,

Property	Weave			
	Plain	Chain	Twill	Sateen
Rigidity	1	2	3	4
Bulk	4	3	1	1
Initial flow rate	4	3	2	1
Retention efficiency	1	2	3	4
Cake release	2	3	4	1
Resistance to building	4	3	2	1

Table 6. Filtration requirements of weave [6].

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uniformity, and economic resilience, they have taken the place of several other filter media types. Chemical and food processing industries, industrial hydraulics, and medical, automotive, and appliance markets are the main users of monofiber fabrics. These fabrics are available in a range of 5–5000 μm openings and are made from polymeric materials including nylon, polyester, polypropylene, and fluorocarbon. Synthetic monofiber fabrics, due to ductility and memory, can be flexed repeatedly without fatigue. Compared to a metal cloth, they can be folded or dented with less damage and they are lighter in weight. Some applications, at the same time, may require the filter medium properties of a synthetic monofilament and a metallized surface for static electricity dissipation. Accordingly, a metallized polyester monofilament fabric coated with nickel of 2 μm thickness is produced. Combined mono- and multifiber fabrics now have useful additional properties. Thus, such material is used in disc filter pieces that are elastic and will expand in the kickback phase to help release the cake. New belt press filters and large automatic filter presses are mainly used for fabric filters with heavy fibers [15].

In selecting the fiber to be used in the filtration process, the material with the highest chemical, thermal, and mechanical resistances should be preferred. For example, in **Table 7**, the resistance of different fiber materials to various chemical substances is roughly presented [14].

3.2.2. Nonwoven fabrics

The nonwoven medium is made from cotton, wool, synthetic and asbestos fibers, or mixtures thereof and from paper mass in the form of belts or plates. They can be used in different design filters such as filter presses, horizontal disc filters and rotary drum vacuum filters for liquid filtration. Most of these applications have low suspension concentrations; examples are milk, beverages, lacquers, and lubricating oils. The individual fibers in the nonwoven filter media are generally connected between them as a result of the mechanical treatment. A less common approach is the addition of binding agents. Sometimes, loose woven fabrics can be used on both sides of the filter to protect the filter media. Both absorbent and nonabsorbent raw materials can be used to produce nonwoven filter media with different materials and properties, different weights, and different filtration efficiencies. These filter media hold particles that are less scattered on their surface (more than 100 pm) or particles that are more dispersed in the depths of the filter media.

Wool felt is probably the oldest kind of textile fabrics and for many years is the only nonwoven fabric in practice. A strong adhesivebonded felt is developed, and drylaid synthetic fibers are collected and transformed to the shape of nonwoven media. Thus, nonwoven fabrics can sometimes be obtained by agglomeration of fibers, and sometimes continuous filaments are glued together to obtain desired flexibility.

The chemical properties of an untwisted fabric relate to the natural structure of the fiber that is used almost completely, as long as no binder is used that has significantly different properties. Nonwoven materials are classified into two main groups. These two classes are based largely on the methods and tools used to hold loose fibers together:

(i) The felts that utilize the basic fiber features to obtain mechanical strength or the mechanical processing (especially needling) and

(ii) Bonded cloths, which use some extra adhesive material to hold the fibers together.

Type of fiber	Insect proof	Resistance to aging	Acid	Alkali	Chlorocarbonic hydride	Ketone	Phenol	Benzene
Cotton	Medium	Low	Unstable	Low resistance, swelling	Resistant	Resistant	Resistant	Resistant
Silk	Medium	Low	Low R.	Unstable	Resistant	Resistant	Resistant	Resistant
Wool	Bad	Low	Low R.	Unstable	Resistant	Resistant	Resistant	Resistant
Glass	Good	Good	Low R.	Unstable	Resistant	Resistant	Resistant	Resistant
Steel fibers (Brunsmet®)	Good	Good	Low R.	Resistant	Resistant	Resistant	Resistant	Resistant
PA 6 (Perlon®)	Good	Good	Unstable	Resistant	Resistant	Resistant	Unstable	Resistant
PA 6.6 (Nylon)	Good	Good	Unstable	Resistant	Resistant	Resistant	Unstable	Resistant
PA 11 (Rislan®)	Good	Good	Low R.	Resistant	Resistant	Resistant	Unstable	Resistant
PA 12 (Vestamid®)	Good	Good	Low R.	Resistant	Swelling	Resistant	Unstable	Swelling
PA Nomex®	Good	Good	Low R.	Resistant	Resistant	Resistant	Unstable	Resistant
Polyester	Good	Good	Resistant	Low R.	Resistant	Resistant	Unstable	Resistant
Polyacrylonitrile	Good	Good	Resistant	Low R.	Resistant	Resistant	Resistant	Resistant
Polyvinylchloride	Good	Good	Resistant	Resistant	Resistant	Unstable	Unstable	Unstable
Polyvinylidenechloride(Saran®)	Good	Good	Resistant	Resistant except NH_4OH	Resistant	Resistant	Unstable	Resistant
Polyolefins								
Polyethylene								
High-pressure	Good	Good	Resistant	Resistant	Swelling	Resistant	Resistant	Resistant
Low-pressure	Good	Good	Resistant	Resistant	Swelling	Resistant	Resistant	Resistant
Polypropylene	Good	Good	Resistant	Resistant	Resistant	Resistant	Resistant	Resistant
Polytetrafluoroethylene	Good	Good	Resistant	Resistant	Resistant	Resistant	Resistant	

Table 7. Chemical resistances of fibers [14].

The more common method is to rely on the natural thermoplastic properties of the polymeric material to obtain adhesion when properly heated. Bonded cloths are divided into two groups based on whether the fiber formation is an integral part of the manufacture of the filter medium or not. The basic felt does not contain binders: some wooly fibers have the ability to assemble together to form a coherent mass due to protrusions on the fiber surface [14, 15].

The first step in making any felt is to scan the fibers so that the fibers are roughly aligned in one direction and drawn into a thin web. The pieces of this web are placed on top of one another to achieve the desired thickness of the felting. Consecutive layers can be placed in the same direction as the fibers or they can be aligned in different directions to increase strength. When sufficient thickness is achieved, the felt is compressed, heated, and often finalized after the dampening process has been carried out. The strength of this felt is basically weak. For this reason, the strength of most felts is reinforced by the inclusion of a woven layer called scrim.

Since the fibers in a felt are not tightly bonded to the mass of the fabric, there is a risk of fibers moving away from the filter media during filtration. For this reason, the use of various bonding elements, the integration of the thermoplastic fibers into the fabric, and the consolidation of the fibers in the filter medium by means of various mechanical joining processes based on needling or suturing braids are done. Modern felts are produced from synthetic or natural fibers or mixtures thereof. The fibers are mechanically or with the help of an adhesive bonded and passed through a controlled production to obtain a consistent density, pore size, and mesh geometry. Thus cutoff performance can be reasonably predicted. The structure of the felt is much looser than the paper, so depth filtration could be performed, the specific resistance is reduced, and higher flow rates can be achieved with smaller filter volumes and at lower pressure drop. The high-temperature-resistant meta-aramid filter has helped the industry to move one step closer to the zero emission target by providing a combination of high separation efficiency and low differential pressure of hot gas filtration technology.

3.2.2.1. Wool resin media

In solid-gas filtration and, more rarely, in solid-liquid filtration, the particles desired to be retained in the filter may carry an electrostatic charge. In this case, the use of filter material carrying an electrostatic charge opposite to that of the particles will provide a more effective filtration. For this purpose, many different filter media can be electrostatically charged. For example, long-term electrostatic effects can be obtained by adding a special resin to the wool felts used in the submicroscope aerosol filtration. Electrostatic charge is achieved by resin transfer by adding the resin powder into the wool matrix enabling charge transfer. The wool then has a positive charge and the resin has a negative charge. In this case, the filter is electrically neutral in general. The random distribution of resin powder on the wool fibers and the random arrangement of the wool fibers in the filter means that the electric field is not uniform and is therefore very effective for trapping both charged and unloaded particles. This electric charge gives wool resin a very low resistance to airflow, allowing submicrometer particles to achieve a higher than 99.5% efficiency in their filtration. Thanks to the resin's very high electrical resistance, the resin filter can maintain its filtration efficiency for many years despite the adverse effects of tropical conditions. Wool resins were first developed for use in respiratory devices for World War I and are still widely used in the respiratory industry, 90 years after its development. It is preferred against many new materials with low resistance to breathing and high filtration efficiency. Vacuum cleaners and other independent dust collectors also benefit from the high retention of wool resin against asbestos and other harmful dusts. In addition, wool resins are used as prefilters for high efficiency particulate air (HEPA) filters and for heating and ventilation in clean rooms for computer suites.

3.2.2.2. Needlefelts

For some simple filtration applications, it is possible to use the felt directly. In most other applications, however, mechanical or chemical treatment is required because of the low mechanical resistance of the felts and because of the disassembly of the fibers and mixing to the filtrate. Needle punching is one of the mechanical strengthening methods used for this purpose. This method has emerged as the most preferred mechanical strengthening technique for natural fibers in the 1880s, but since the early 1970s, it has been suitable for many synthetic fibers for processing the felts. In this method, carded fibers are pounded and compressed into a more dense structure by punching with a series of specially barbed needles moving back and forth at 2000 strokes/min and moving perpendicular to the felt layer. With 100 needle punches/cm^2, it is possible to circulate the fibers in the felt thickness both together and to reduce the felt thickness considerably. The punching operation can be carried out by one or both sides of the felt, so that the felt has a homogeneous structure. Needle felts are commonly used as bag filters for filtering dust and gases. Typical applications include cement industry, steel and aluminum plants, spray drying, coal grinding, sandblasting, food industry, detergent manufacturing, pneumatic conveying, and hot gas filtration using metal fiber felts and ceramic fibers. Some typical applications for filter fabrics of various kinds are shown in **Table 8** with their key characteristics. Felt is mechanically strengthened by needling, but alternatively the hydroentanglement method is used as a more professional technique. In this method, the fibers are tried to be fixed with the help of pressure water jet.

3.2.2.3. Meltspun materials

The use of new synthetic meltspun fibers has begun to spread quickly, while filtration applications are commonly used with needle felts and woven fabrics. These fibers are obtained by extruding a molten thermopolymer from a fine nozzle. As the fiber leaves the syringe, it is quickly quenched in an air stream and then collected on a moving collecting belt running underneath the nozzle. The filaments on the collector are then pressed at a certain temperature for consolidation. Thus, the fibers adhere to the points where they touch each other, and the fiber network is strengthened. This consolidation process is called spun bonding. If the airflow is placed immediately at the exit of the nozzle and along the line where the filament falls onto the collector, the fibers break off due to the air flow and fall on the collector in short pieces. When these fibers are pressed and sintered, this process is called melt blowing [15].

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Material	Suitable for	Maximum service temp (°C)	Principal advantage(s)	Principal disadvantage(s)
Cotton	Aqueous solutions, oils, fats, waxes, cold acids, and volatile organic acids	90	Inexpensive	Subject to attack by mildew and fungi
Jute wool	Aqueous solutions	85	Easy to seal joints in filter presses	High shrinkage, subject to moth attack in store
Nylon	Acids, petrochemicals, organic solvents, alkaline suspensions	150	High strength or flexibility	Absorbs water; not suitable for alkalis
Polyester (Terylene)	Acids, common organic solvents, oxidizing agents	100	Easy cake discharge. Long life. Good strength and flexibility. Initial shrinkage	Not suitable for alkalis
PVC	Acids and alkalis	Up to 90		May become brittle. Heat resistance poor
PTFE	Virtually all chemicals	200	Extreme chemical resistance. Excellent cake discharge	High cost
Polyethylene	Acids and alkalis	70	Easy cake discharge	Soften at moderate temperatures
Polypropylene	Acids, alkalis, solvents (except aromatics and chlorinated hydrocarbons)	130	Low moisture absorption	
Dynel	Acids, alkalis, solvents, petrochemicals	110		
Orlon	Acids (including chromic acid), petrochemicals	Over 150		
Vinyon	Acids, alkalis, solvents, petroleum products	110		
Glass fiber	Concentrated hot acids, chemical solutions	250	Suitable for a wide range of chemical solutions, hot or cold (except alkalis)	Lacks fatigue strength for flexing. Abrasive resistance poor

Table 8. Typical applications for filter fabrics [15].

4. Recent processes in fabric filtration

4.1. Nanofiber spun membranes

Compared to other polymeric membranes, nanofiber membranes have attracted great interest in recent years due to their advantages such as high selectivity, hydrophilicity, and mechanical strength. Nanofibers are very thin polymeric fibers with a thickness of less than 100 nm which are preferred in various industrial fields, such as electronics [16], biomedical [17], textile [18], and environment [19]. Nanofibers stand out among similar polymeric membranes with high specific surface area, high porosity, and interconnected pore networks [20]. The nanofibers used in applications where microfiltration and ultrafiltration are used provide high water flux by reducing membrane resistance in water and wastewater treatment [21].

4.2. Electrospinning processes

Nanofibers can be obtained by one of the methods: drawing, template synthesis, phase separation, or electrospinning. Electrospinning is a frequently preferred method in recent times in obtaining high porosity nanofiber mat. In this method, nanofibers are obtained from a charged polymer solution under a high electric field. Parameters affecting the process (voltage intensity, feed rate of the polymer solution, nozzle-collector distance, polymer concentration and type, and duration of electrospinning) can easily be changed and controlled (**Figure 10**). Conditions such as room temperature and humidity are also factors that affect nanofiber morphology [22]. The molecular weight of the selected polymer directly affects the fiber properties. The uniformity of the pore size of the nanofiber mats is obtained when uniform and continuous collection of nanofibers from the nozzles to the collector is achieved [23]. The nanofiber layer, consisting of nanofibers ranging from 50 nm to 10 mm, offers many advantages such as high aspect ratio (length to diameter ratio), broad specific surface area, unique physicochemical properties, and design flexibility for chemical/physical surface functionalization [24].

4.3. Nanofibers in water and wastewater treatment

Nanofiber membrane processes are preferred in many industrial applications due to energy-saving use, environmental friendliness, operational simplicity, and flexibility during design. As the nanofiber production technology improves, the use of nanofibers as an alternative to membrane processes, such as conventional microfiltration, ultrafiltration, and nanofiltration, has opened the way [21]. In one study, nanofibers produced from the polysulfone polymer were used for prefiltration to remove microscale particles prior to the ultra/nanofiltration process, thus extending the ultra/nanofiltration membranes' life span [26]. The performance of

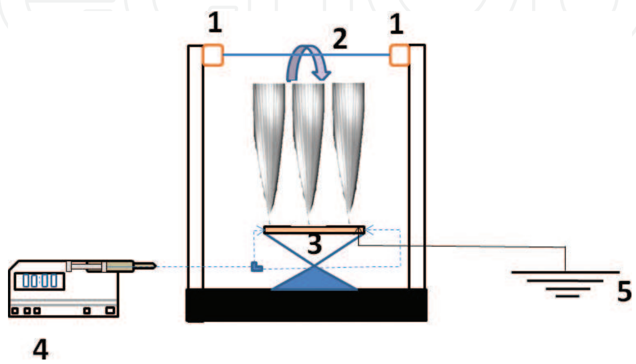

Figure 10. Schematic illustration of electrospinning setup: (1) rotating backing material, (2) conductive wire, (3) nozzle tray, (4) syringe pump, (5) high voltage power [25].

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the membrane processes (retention of particles and the amount of permeate flux) strongly depends on the particle size. It has also been reported that the addition of nanofiber material and additives (such as nanoparticles and nanotubes) to the polymer solution affects the separation performance [27].

One of the latest nanofiber studies is the work of Aslan et al. [25]. In this study, nanofibers were obtained at the scale of ultra/microfiltration by means of electrospinning from the solution prepared by polyacrylonitrile polymer. For the first time in the literature, nanofibers were collected on a tubular support layer. The new membrane was tested with both standard particle solution and a surface water. The novel tubular nanofiber membrane removes 95% turbidity and 29% total organic carbon, which can be evaluated as high removal efficiencies when compared to the commercial microfiltration membrane. Membrane surface and cross section SEM images are given in **Figure 11**.

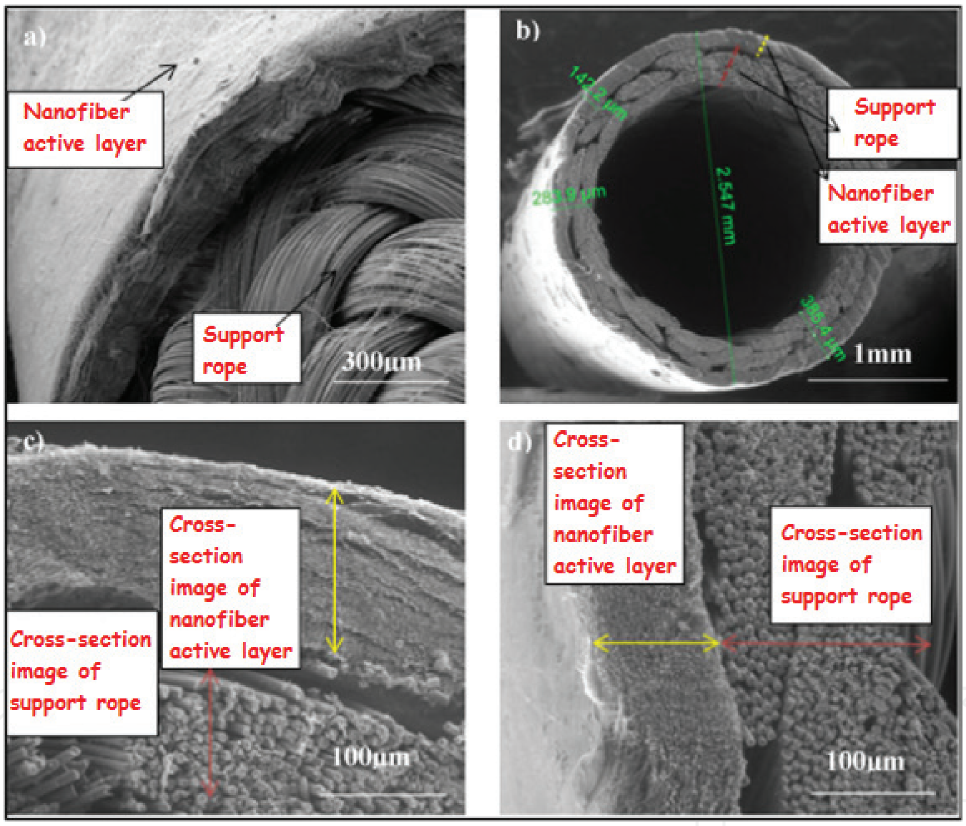

Figure 11. SEM images of tubular backing material and nanofiber layer at different scales [25].

5. Conclusions and recommendations

Filtration is considered the keystone of water and wastewater treatment and is used for various purposes such as sludge dewatering and concentrating any solution. Moreover, as an advanced filtration technology, membranes can remove materials ranging from large visible particles to molecular and ionic chemical species. Filtration performance depends on operating conditions, such as fluid characteristics, filtration rates, and filter media. Among them, proper selection of filter media/membrane material in filtration processes is often the most important consideration for assuring efficient separation.

Filter media can be classified by their materials of construction, such as cotton, wool, linen, glass fiber, porous carbon, metals, and rayons. Recently, new polymeric materials have been used both individually and/or blended in filtration processes for the treatment of waters and wastewaters. The purpose of this chapter is to bring an overview on the textile-originated filter materials in filtration applications from conventional filtration to advanced membrane processes. Although many researches on filter media are available, very few reports are represented on the cutting-edge technologies about using filter materials on filtration processes from classical to advanced membrane processes.

Textile materials and membranes are two important elements of surface filtration. The performance of surface filtration is closely related to the physicochemical properties of the filter surface. New materials are produced or the surface of the existing material is modified in order to improve the performance of the filter surface. These modifications may involve the use of different chemicals (e.g., polymer blends) in the production of the filter material, as well as the addition of additives to the base material (e.g., nanoparticles, nanotubes). In recent years, textile nanofibers have emerged in liquid filtration with their unique properties such as high aspect ratio, broad specific surface area, unique physicochemical properties, and design flexibility for chemical/physical surface functionalization, and they will attract more attention in near future as filter material in both liquid and gas filtration.

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