J. Inst. Eng. India Ser. E (January–June 2016) 97(1):63–73
DOI 10.1007/s40034-015-0071-3

REVIEW PAPER

Fibrous Filter to Protect Building Environments from Polluting Agents: A Review

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Received: 29 May 2015 / Accepted: 12 August 2015 / Published online: 5 September 2015

Abstract This paper discusses the use of fibrous filter to protect the building environments from air born polluting agents and especially of concern chemical, biological and radiological agents. Air-filtration includes removal of particulate from air and toxic gases from air. In air filtration, particulate which are mostly biological and radioactive types of agents can be removed by using mechanical and electrostatic filters. Some biological agents, which cannot be removed by air filtration alone, special techniques like antimicrobial finish, UV germicides, coated filters etc. are required. Biocide agent can be added into the fibre itself by grafting reaction to impart antimicrobial activity. Chemical agents like toxic gases can be removed by integrating adsorbents and sorbents in filters or by fibre modifications. It is also possible to impart catalytic conversion properties into the fibre to remove volatile gasous. Radioactive agents can be removed by particulate filter if present in the form of aerosol or by gas cleaning by the use of specific fibre impregnate.

Keywords Nonwoven · CBR agents · Building environments · Air filter · HEPA

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Introduction

With increase of pollution level in atmosphere it is essential to protect building environment from air born polluting particles and CBR agents for getting healthy environment of particular concern for places like hospitals. The CBR agents may be in the form of arsine, nitrogen mustard gas, anthrax, radiation from a dirty bomb etc. and it can enter the body through a number of routes including inhalation, skin absorption, contact with eyes or mucous membranes, and ingestion [1].

Filtration is the simplest and most common method for particle control and air cleaning [2]. In air and gas filtration, non-woven fabrics have made great inroads in recent years [3]. Over past decade, there has been quite significant attention over the development of nonwoven fabric specific to CBR agents. According to a recently released report [4], the global air filters market is estimated to surpass $19 billion through 2020. The Indian pharmaceutical industry is one of the leading users of HEPA/ULPA (High Efficiency Particulate Air/Ultra Low Penetration Air) filters, accounting for around 8 % of global production is seeking the establishment of a complete manufacturing environment in this sector [5]. In the following section, design and development of nonwoven fabric to protect building environments from polluting agents have been discussed. The article also thoroughly reviews state of the art technology and their effectiveness to protect building environment.

CBR Agents

Chemical, biological, and radiological agents can be dispersed in the air we breathe, the water we drink, or on surfaces we physically contact [6]. They are present in different forms and sizes, Fig. 1 shows the relative sizes of common air contaminants (e.g., tobacco smoke, pollen, dust). CBR agent are generally much more toxic than common indoor air pollutants and cause specific symptoms depending on the agents [7, 8]. Radiological hazards can be divided into three general forms: alpha, beta, and gamma radiation. These three forms of radiation are emitted by radioisotopes that may occur as an aerosol, be carried on particulate matter, or occur in a gaseous state.

The basic techniques used for detection and identification of bioagents are described by Švábenská [9, 10]. The varieties of agents present in air vary in terms of size, phase and toxicity [11]. So the system for all inclusive agents for detection and removal is complex and difficult to design.

Fibrous Filter for Protection

A fibrous filter media is an assembly of fibers that are randomly laid in the structure. Media is mostly nonwoven fabric wherein fiber size may range from less than 1 µm to greater than 50 µm in diameter. In dust filtration, where penetration has to be kept to a minimum, only fabric filters can give the required efficiency [12]. Different principles of filtration used in fibrous or nonwoven filters to remove CBR agents from air are shown in Fig. 2. The focus on particular type of principle of filtration is given depending upon the agent present in surroundings, e.g., focus is to be given for the removal of biological agent while designing a filtration system for hospital. In the following sections, designing of nonwoven filters for removals of CBR alongwith other form of particulates are discussed.

Removal of Particulate Contamination from Air

Filter to remove the particulate from air base can be classified into two categories based on principle of separating particles from the air, as a mechanical filters and electrostatic filters (electrostatically enhanced filters). Although there are many important performance differences between the two types of filters, both are fibrous media and first one is used extensively in HVAC (Heating, Ventilation and Air-Conditioning) systems to remove particles, including biological and radioactive materials from the air. It is important to note that air filters are commonly described and rated based upon their collection efficiency, pressure drop (or airflow resistance) and particulate- holding capacity.

In case of mechanical filters, the particulate are removed by different collection mechanisms govern by single fibre theory and porous structure of fiborous assembly. Under particle capturing based on single fiber theory [13, 14]' capture of particles on a stationary cylindrical object (in this case a fiber of the fabric) follows one or combinations of the following mechanism—diffusion, inertial impaction, direct interception, and electrostatic attraction (Fig. 3). Relatively larger size particles can exhibit inertial impaction and interception. In case of inertial impaction, a

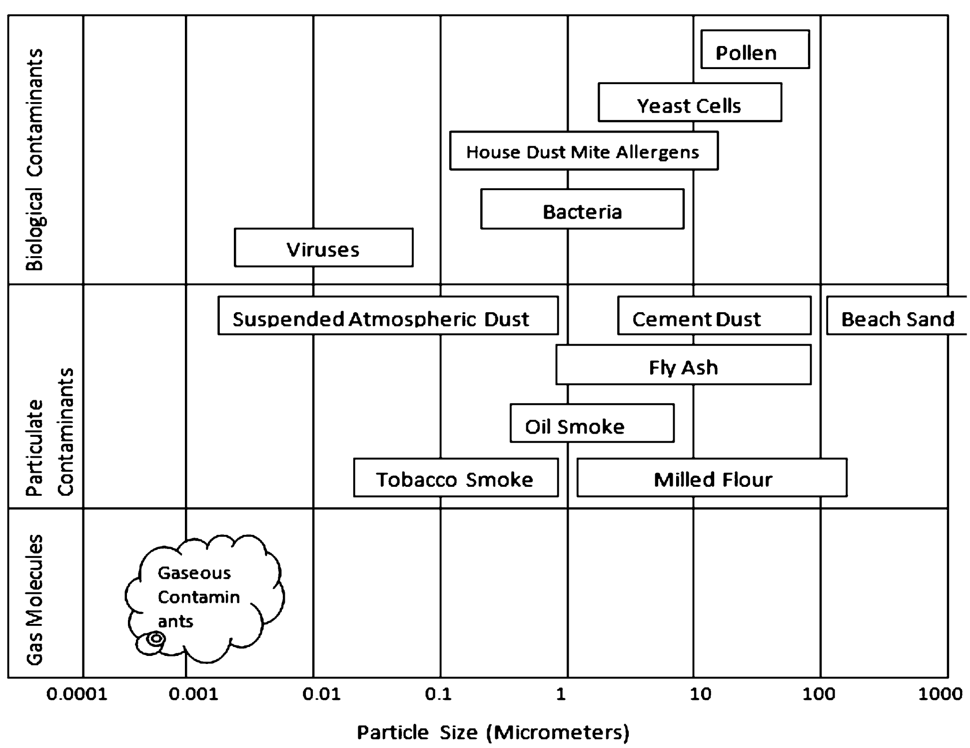


Fig. 1 Common air contaminants and their relative sizes

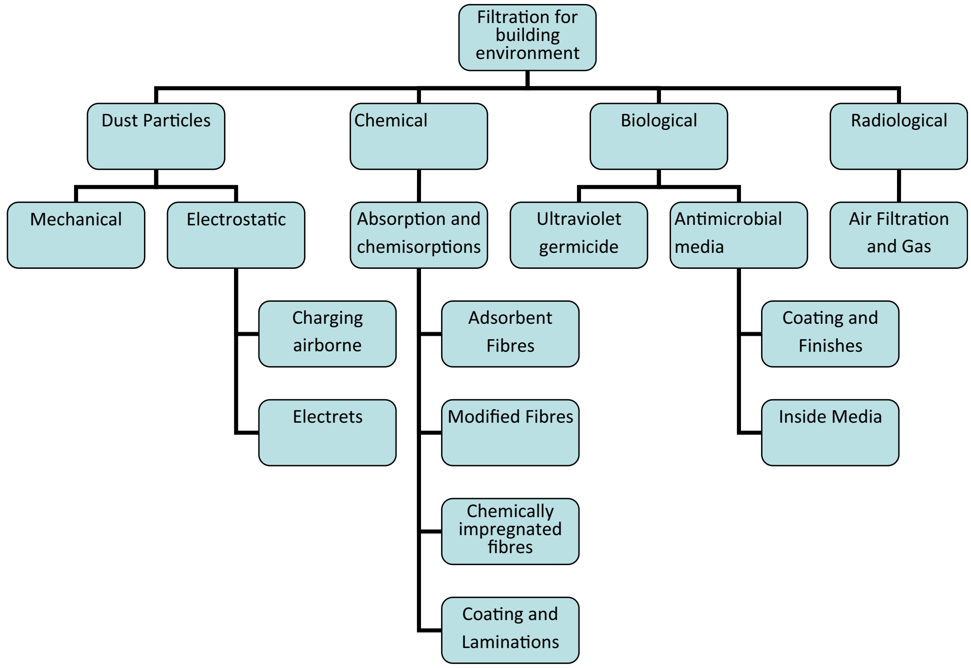


Fig. 2 Different principles of filtration to remove CBR agents

suspended particle in the fluid may not be able to move along with fluid if its momentum is high (for particles of larger size/higher mass); higher inertia may be sufficient to break away from air streamlines and impact the fibre. The interception occurs when a particle does not have sufficient inertia to break away from stream line, however, comes close enough to the fibre so that natural forces will attach the particle to the fibre.

Diffusion occurs when the random (Brownian) motion of a particle causes that particle to contact a fiber. Diffusion phenomenon is significant when flow velocity is low, particles are smaller (collection by diffusion decreases as the particle diameter increases). To illustrate, the removal efficiency of the HEPA media against a 0.027 micron viral particle is dominated by the diffusion filtration mechanism. Relatively larger size particles can exhibit inertial

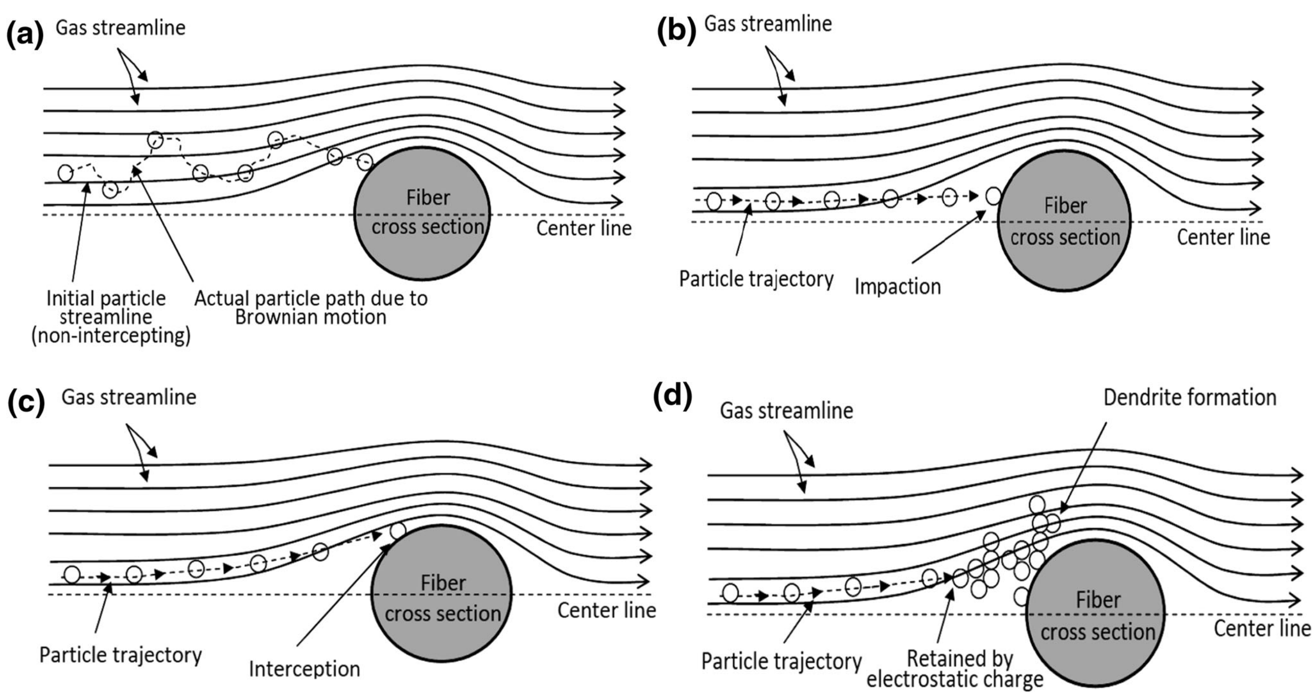


Fig. 3 **a** Diffusion, **b** Inertial impaction, **c** Direct interception, **d** Electrostatic attraction

impaction and interception. Particle separation by electrostatic attraction is based on an electric or electrostatic charge on the particles and/or fiber that will force the particle to divert from the streamline and attract to the fiber.

Electrostatic attraction, the fourth mechanism, plays a very minor role in mechanical filtration. After fiber contact is made, smaller particles are retained on the fibers by a weak electrostatic force [15]. Diffusion predominates below the 0.1 µm diameter particle size and impaction and interception predominate above 0.4 µm. In between, near the Most Penetrating Particle Size (MPPS) 0.3 µm, both diffusion and interception are comparatively inefficient [16]. Which collection mechanism finally will be the most effective depends on particle size and its mass, velocity, density and viscosity of the gas, electrostatic forces and the filter used. Moreover, the different mechanisms are not independent but operate simultaneously.

All the aforementioned mechnisms are based on single fibre theory; however, besides the above, role of fibre assembly in filter media plays important role in governing paricle capture. Two distinct mechanism such as surface filtartion and depth filtration are common in media; wherein most often depth filtartion is prominent mechanism for particle capture for building environment as since media is not cleaned intermittently for regeneration as in industrial situation and also for lower energy requirement. In case of depth filtration, the mechanism as shown in Fig. 4 is govern by depth starining and depth retaining [13] wherein pore size and its distribution, pore configuration, surface area offered by the fibres in filter media influence particle capture behaviour.

Depth Straining

For a filter media, particles will travel along the pore until they reach a point where the pore is confined to a size too small for the particle to go any further, so that it becomes trapped. Particles are also trapped while passing through the blind pores.

Depth Retaining

A particle can also be retained in the depth of the medium, even though it is smaller in diameter than the pore at that point. Such behavior involves a complex mixture of physical mechanisms. In a tortuous pore, the particle losses its velocity and become attached to the pore wall, or to another particle already held, by means of Vander Waals and other surface forces.

There is different gradation of depth filter media available as shown in Fig. 5. HEPA filters are also graded based on filtration efficiency as shown in Table 1 and the desired

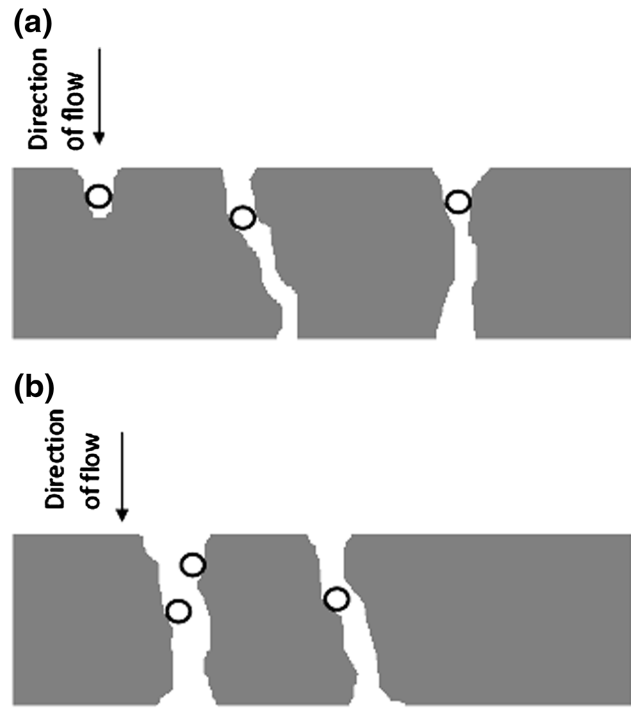


Fig. 4 Depth filtration: **a** depth straining mechanism, **b** depth retaining mechanism

filtration efficiency require for HEPA filter against different types of particles based on their size is shown in Fig. 6.

Filter media includes the blends of synthetic fiber and glass microfiber and composite media using cellulose or synthetic fiber nonwovens as a backing support. Mrozewska et al. [17] have described the use of special nonwoven materials as the filter elements in dust resistant for short-term use. The electrospun nanofiber media shows the potential in application as HEPA and ULPA grade filter media, by comparing the filtering performance of nanoweb with the conventional melt-blown nonwoven media. In study by Zhang et al. [18], Nylon 6 is electrospun to produce ultra-fine nonwovens and its characteristics as filter media are investigated. Hung CH and Leung WW [19] investigate the filtration of nano-aerosols (50–500 nm) using nanofiber filter for strong diffusion capture.

In case of electrostatic filters, it relies on charged fibers which actually attract the particles to the fibers, in addition to retaining them. There are basically two ways of applying significant electrostatic forces to augment the collection efficiency of a filter: charging the airborne particles [20] and creating an electric field in the filter. Electrets are dielectric materials that exhibit an external electric field in the absence of an applied field. There are two distinct categories of electrets; space charge electrets and dipolar electrets. Space charge electrets are formed by the deposit or injection of an electric charge directly into the dielectric

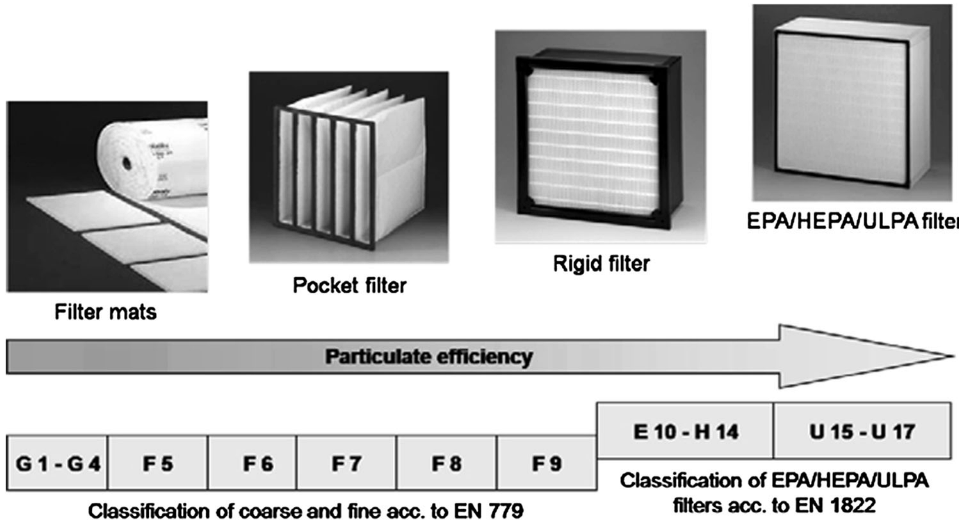


Fig. 5 Classification of depth-loading filters according to EN779 and EN1822

Table 1 Classification of HEPA filters

Classification of HEPA/ULPA filters (Standard EN 1822)			
Filter group	Filter Class	Overall MPPS efficiency %	Local MPPS efficiency. %
HEPA (H)	H10	>85	_
	H11	>95	_
	H12	>99.5	_
	H13	>99.95	>99.75
	H14	>99.995	>99.975
ULPA (U)	U15	>99.99955	>99.9995
	U16	>99.99995	>99.99975
	U17	>99.999995	>99.9999

material. Dipolar electrets are polarized by the application of an electric field [15].

Lifshutz identifies four basic families of electret filter media: electrostatically spun fibers, fibrillated electret film, corona treated melt-blown fibers, and carded blends of tribo-electric fibers [21]. Films, fibers, and nonwoven web structures are among the materials that can be formed into electret [22, 23]. Fine fibre materials that are charged during extrusion are produced by electrostatic extrusion of a solution of polycarbonate is presented in the literature [24, 25]. The experiments on blended fibre in the form of nonwoven, surface charged by triboelectrical effect were also studied for filtration efficiency [26, 27]. The results showed that a nonwoven, manufactured by polycondensational polymeric fibrous material and polypropylene fibres, has very valuable filtering properties and that those properties are stable in time.

A method for improving the efficiency of electret filtration nonwovens for nanoparticles by using polypropylene (PP) admixed with additives with is studied. The studies proved the strengthened electrostatic interaction effects owing to the modifiers [28]. The improvement of filtration efficiency by electrostatically charging the meltblown polypropylene (PP) webs using the techniques developed at the University of Tennessee as compared with other techniques have been discussed by Peter and Larry [29, 30]. A spunbond composite can also be used as produced by Kimberly-Clark Worldwide Inc. from a patented spunbond process. It is a dual layer gradient density medium that is electrostatically charged [15]. Needle punch felt media can also be used for air purifier applications for removing very fine air born contaminants as in case of Technostat® [31]. A fibre filter can also be produced by electrostatic spraying of a solution of polycarbonate in a volatile solvent onto a conductive support, followed by evaporation of the solvent to leave a fibre fleece with a porous surface structure [32]. Filtrete™ air cleaning filter manufactured by 3 M company, covers a varities of filters with use of electrostatic charging for indoor air cleaning [33]. However, the uses of electrostatic filters are limited due to their inefficacies for long term performance.

Filters for Removal of Biological Agent from Air

Most of the biological agents of low-level pathogens like pollen grains etc. can be removed as a particulate agent (as discussed in

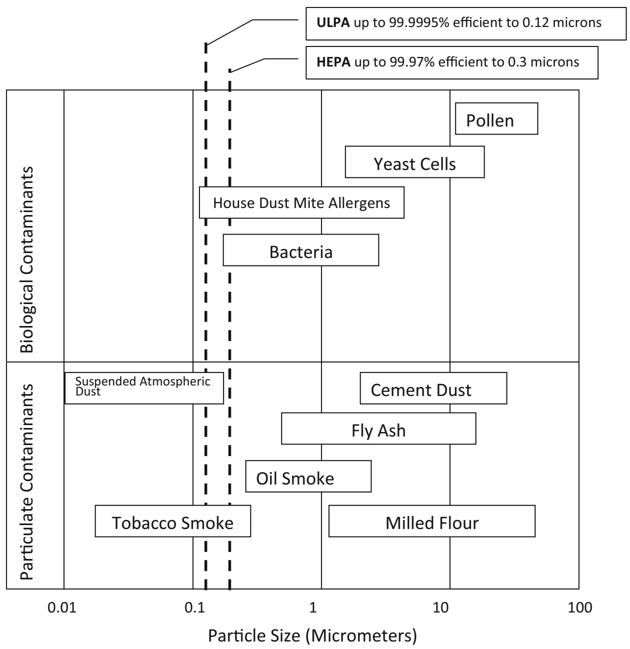


Fig. 6 Filter efficiency required for different particles size

previous section). For a biological agents of higher level pathogens like bacteria and viruses—can be removed either by fibrous filter (through diffusion mechanism) or special techniques such as use of different treated fibres, UV light, oil coated plate etc., and their combination thereof.

Types of Fibre Used

Fibrous assembly made from cotton, fiberglass, polyester, polypropylene, or numerous other materials can be used in filter to remove the biological agents. One of the first of these was by Terjesen and Cherry [34], have showed that 3 inches (7.62 cm) of slag wool removed greater than 99.9998 % of *Bacillus subtilis* spores moving in low-velocity air streams.

Different fibrous media were tasted for removing aerosolized *Staphylococcus aureus* cells and found that single thickness glass fiber mat (50 FG Filter down) retained 98.5–98.7 % of nebulized aerosol [35]. The combined use of an electrostatic precipitator and a spun-glass fiber filter pad [0.5 inch (1.27 cm) thick with a fiber diameter not exceeding 1.25 μ,] was reported to remove 95.7–100 % of airborne viruses for *E. coli* [36].

Antimicrobial Media

Antimicrobial filter media contains an agent to protect the filter by inhibiting the growth of bacteria, fungi, and yeast. In some cases the antimicrobial action is also intended to prevent the migration of biological microorganisms into the filtrate or filtered product. The antimicrobial, agent can be applied to a medium as a finishing step or it can be incorporated into the fiber [37, 38]. In general, antimicrobial agents are either organic or contain a metal component such as silver, zinc, copper [39–41].

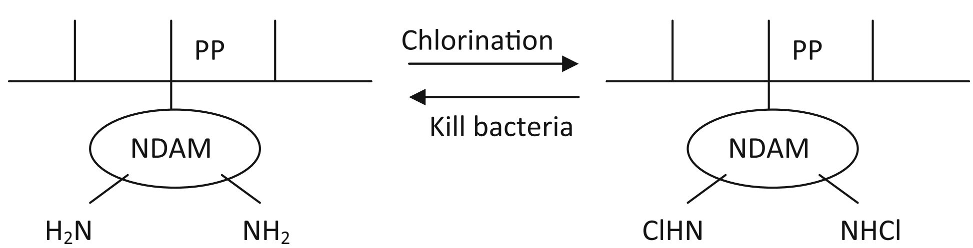
One of the company under Irgaguard® trade name markets both organic and inorganic antimicrobial agents like Irgaguard® B 5000 which is an inorganic based sliver zeolite based antimicrobial [42]. Antimicrobial agents can be incorporated into the medium as a surface treatment or they can be formulated into fibers that make up the nonwoven. Foss Manufacturing Co. has patented a fiber technology incorporating a silver zeolite [43]. The additive can be included in monocomponent and bicomponent fibers.

A bioactive agent can be added during melt blown process at different stages [44]. Antimicrobial nonwoven can be produced by first doing the grafting reaction of fibre polymer with additives like grafting reaction of polypropylene with *N*-halamineprecursor, 2, 4-diamino-6-diallylamino-1, 3, 5-triazine (NDAM) and followed by melt blown process [45]. In above mensioned case antibacterial melt blown PP-g–NDAM, active chlorine kill bacteria as shown in Fig. 7 while in case of nanosliver antibacterial media nanosilver damages the cell wall and genetic composition of bacteria.

NDAM is a fibrous element, which includes a container member and an antimicrobial agent, wherein the antimicrobial agent is disposed within the container member [46]. It is found that the bacteriostasis of silverpadded nonwovens is excellent against *S. aureus* and *K. pneumonia* [47].

Nonwoven bioactive filter with Sanitized® T 99-19, containing quaternary ammonium salts have been produced by different production technologies (melt-blowing, needle punching), methods of biocide incorporation (bath, spraying). Higher biological activity was found in nonwovens subjected to a bath than in those which underwent spraying. As compared to melt-blown nonwovens, the needled variety were more efficient [48].

Fig. 7 Line diagram showing the mechanism of antimicrobial PP -g –NDAM



Filtration in Combination with Ultraviolet Germicidal Irradiation (UVGI)

Ultraviolet radiation in the range of 2250–3020 Angstroms is lethal to micro-organisms. All viruses and almost all bacteria (excluding spores) are vulnerable to moderate levels of UVGI exposure. A design utilizing a combination of filtration and UVGI can be very effective against biological agents. Smaller microbes, which are difficult to filter out, tend to be more susceptible to UVGI; while larger microbes, such as spores, which are more resistant to UVGI, tend to be filter out easily [29, 49]. Research by Kujundzic et al. [49]. Showed that air filters alone or combined with upper-room air UVGI can remove and inactivate bioaerosol at significant rates, which can be linearly superposed.

Removal of Biological Aerosols by Coated Filters

An high risk associated with exposure to bioaerosols needs for the development and implementation of new, efficient and cost effective methods of airborne biological particle control. It was found that precoating of filter fibres with TTO (Tea Tree Oil) and following usage of such filters for bioaerosol control could provide significant benefits in terms of rapidly inactivating captured microorganisms [50].

Other Techniques

There are numerous techniques for the collection of bioaerosols, many of these based on filtration technology [46]. Electrostatically charged filter media in HVAC systems can also used for bioaerosols filtration. More recent developments include use of photocatalysis principle in filters to deactivate bioaerosols, a technology which has met with significant attention [51]. Such filters, however, are very expensive, complex, difficult to produce and may produce toxic by-products such as phosgene as a part of the catalytic de-composition process.

Cell lytic enzymes represent an alternative to chemical decontamination or use of antibiotics to kill pathogenic bacteria, such as listeria. Three facile routes for the surface incorporation of the listeria bacteriophage endolysin has been given by Solanki et al. [52]. These enzymes depending upon the target bactria can be selected and attached to silica nanoparticles [53], and from this a coating can be created.

Recently a light activated antibacterial and antiviral coating technology is reported which can be applied on woven, nonwovens, natural and synthetic fabrics and a variety of polymers for the removal of bacteria and virus [54].

Needlepunched nonwoven filters like Texel's tribo-filter offers enhanced performance in air, and biofiltration. The tribo line covers a range of weights from 70 to 400 g/m [2] and is aimed at application such as respirators, clean rooms, cabin air filters [55].

For the removal of biological agents first step is selecting a type of fibre and its parameters; and thereafter suitable antimicrobial treatments or coating may be applied to enhance filtration performance against a particular type of bacteria or virus. Furthermore external techniques can also be employed like light irradiation for extra protection.

Fibrous Filters for Removal of Chemical Agents

Most of the chemical agents present in the air is in the form of toxic gases. Removal of gas from air is mostly a chemical phenomenon in which different types materials like sorbents, impregnates and fibres as well as structures of these materials need to be consider. Sorbents uses one of two mechanisms for capturing and controlling gasphase air contaminants, physical adsorption and chemisorptions. Physical adsorption results from the electrostatic interaction between a molecule of gas or vapor and a surface. Some solid adsorbents are activated carbon, silica gel, activated alumina, zeolites, porous clay minerals, and molecular sieves. In chemisorption the gas or vapor molecules react with the sorbent material or with reactive agents impregnated into the sorbent. The sorbent forms a chemical bond with the contaminant or converts it into more benign chemical compounds [1]. Both capture mechanisms remove specific types of gas-phase contaminants from indoor air.

To remove gases from the air using fibrous filter, fibres can be used alone but generally fibres are incorporated with adsorbent or sorbents materials. The adsorbent materials may be laminated or coated over a filter or can be combined with nonwoven layers to form a composite structure. Adsorbents can also be incorporated into the fibres itself. Unlike particulate filters, sorbents cover a wide range of highly porous materials, varying from simple clays and carbons to complexly engineered polymers. The U.S. Environmental Protection Agency [1] [EPA 1999] states that a well-designed adsorption system should have removal efficiencies ranging from 95 to 98 % for industrial contaminant concentrations, in the range of 500–2000 ppm; higher collection efficiencies are needed for high toxicity CBR agents.

Simple example of using sorbent for air cleaning is use of baking soda (sodium bicarbonate, NaHCO) for odor removal as in case of flanders filters [56]. Another example [57] as shown in following euations the uses of copper and zinc aluminates to capture the CO_2.

$ZnAL_2O_4 + CO_2 \leftrightarrow ZnCO_3 + AL_2O_3$

$CuAL_2O_4 + CO_2 \leftrightarrow CuCO_3 + AL2O_3$

Activation partially oxidizes the carbon to produce submicrometer pores and channels, which give the high surface area-to-volume ratio needed for a good sorbent [1]. In some applications, the activated carbon is combined with nonwoven layers to form a composite structure. Other forms of nonwovens containing activated carbon are utilized, such as wet laid webs impregnated with carbon particles and webs coated with activated carbon particles. For severe chemical applications, the activated carbon may be treated with metal salts of copper, silver, zinc etc. for enhanced chem-sorption properties [15].

Silica gel and alumina are common inorganic sorbents that are used to trap polar compounds. ASZM-TEDA carbon (activated carbon, impregnated with copper, silver, zinc, molybdenum, and triethlyenediamine) is the current military sorbent recommended for collecting classical chemical warfare agents [1]. Synthetic polymeric sorbents are designed to collect specific chemical classes based upon their backbone structure and functional groups. Activated version of thin pre-oxidized material, PAN-OX, which provides adsorption characteristics and is claimed to be substantially superior to charcoal and used in the absorption of toxic gases, fumes and liquids etc.

Another mechanism for cleaning gas is chemical filtration which involves the catalytic conversion of one volatile compound into another, less hazardous, compound at the surface of fibre. In one of the experiment polyurethane (PU) nanofibers were modified by particles of SnO_2 and CrO_2 in the ratio 95/5 to impart catalytic properties in the reaction with emission gases (CO, NO_x) in the form of nanofibrous filtering materials [58].

Fibres for Purification of Gases

Active carbon fibres with high surface area have advantage over traditional materials for effective elimination of SO_2 and NO_x from flue gases from combustion of coal and gasoline fuels [59, 60]. The excellent acid-combining potential of wool fibres has been found to be very useful to combat air pollution by SO_2 vapours. In a controlled environmental chamber, it have been demonstrated [51, 61] that wool carpet can reduce high levels of introduced formaldehyde to virtually zero in 4 h also to nitrogen dioxide produced with similar results, but with slower absorption.

The manmade fibres, used in the purification of gases, is composed of a polymer containing vinyl pyridine groups or aliphatic amino groups with Teflon [3]. Nylon spunbonded media can be used for this purpose by bonding autogenously and exposing the web to a chemically activating gas phase that is later removed from the web, Cerex® nylon fabric is manufactured by using this technique [62].

A new version of Fibertect®, a nonwoven decontamination wipe created by researchers [63] at by all-cotton version of nonwoven wipe paired with an activated carbon center which is more viable at cleaning up a nerve chemical surrogate than the powdered decontaminant substance.

Fibre Modification for Filtration

To remove ammonia, traditional activated carbon is not as effective. A new alternative method of removing ammonia with metal-silk fibroin complex fibers through a coordination displacement reaction is reported. Experimental results show that the $Cu(O)_4$ complex is more effective than the $Cu(N)_4$ complex in term of ammonia adsorption [64]. A structured fibre having a three-dimensional reticulated structure and chemisorption properties can be effectively used for gaseous separation [65]. Morozova et al. [66] have studied the adsorption of CO_2 gas on modified activated-carbon fibre. It has been found that the maximum adsorption was obtained with fibres that had a 50–60 % combustion weight loss and was nine times as great as the capacity of granulated activated carbo.

The fibres can be modified in stage of wet or dry spinning after the addition of structuring agents, such as hydrazine, peroxides, or epichlorohydrin. It was reported that the use of nonwoven polypropylene-fibre-pvc-fibre fabrics bonded with poly (vinyl acetate) emulsion and annealed at 90–100 °C for the removal of particles from industrial gaseous wastes [3].

Chemically Impregnated Fibers (CIF)

CIF are a recently developed technology, using smaller, more active sorbent particles of carbon, permanganate/alumina, or zeolite incorporated into a fabric mat. In application such as environmental protection, a rayon based ACF cloth impregnated with organo-metallic compound such as copper (II) nitrate has been shown [67] to be a useful adsorbent for hydrogen cyanide gas.

One type of impregnated are activated carbon, ASZM-TEDA carbon. Which can provides a high level of protection against a wide range of toxic chemicals. INDA provides a list of the chemical impregnates and the air contaminants against which they are effective.

Coated or Laminated Filters

The activated carbon can be coated over the fibre surface and used in air-filtration applications. Henis and Tripodi have reported the use of coated porous fibres for gas recovery and separation [15]. Roger Bradshaw Quinc has patented a substrate that contains an odor control coating, comprised of activated carbon, a binder, and a masking agent [68]. Laminated filters have higher elasticity, filtration efficiency, density and lower gas-permeability than random-blend filters. Lewcott Chemicals have developed an active filter by a process for charcoal impregnation of non-woven material [69]. In one other technique porous layers of polypropylene fibre fabrics laminated with an active carbon [10].

Hollow fibre carbon membranes has been reported to possess good gas separation properties and stability at elevated temperatures and in harsh environments. It can be produced by pyrolysis of cellulose precursors, were introduced in 1983 [70]. Recently a range of hollow fibre carbon membranes with high porosity and good mechanical properties were obtained by the carbonization of highly asymmetrical PAN precursors. Linkov et al. reported that hollow carbon fibers have been used for gas separation and show high fluxes and good selectivities [71]. One such flexible and highly porous membrane have developed, by using composite zeolite membrane in the form of hollow fine fibre by deposition of various zeolites onto hollow fibre carbon membrane [72].

Removal of Radioactive Agent

The radioactive particles can be removed using the principles of particulate filter and air cleaning. HEPA filters were first developed for nuclear processing facilities to provide a barrier against any radioactive dust or contaminants leaking to the outside world. The activated charcoal can be impregnated with chemicals to enhance the removal efficiency for organic iodides. These chemicals are usually either iodine (I), potassium iodide (KI) or triethylenediamine (TEDA) [73]. Carbon fibre impregnate with potassium iodide, hydrogen sulfide, phosphine, mercury, arsine, TEDA, can be used to remove the particles from radioactive methyl iodide.

Carbon bonded carbon fiber composites as well as carbon bonded ceramic fiber composites were designed for air filtration, in particular for the filtration of radioactive particles [74]. Obruchikov and Lebedev have studied the removal of radioactive methyl iodide from an air-vapor mixture by adsorption on a Busofit carbon fabric modified with different additives [75].

Micrometer-sized aerosols from a radiological event are effectively removed from air streams by HEPA filters. This collection could prevent distribution of radiological agents throughout a building; however, subsequent decontamination of the HVAC system would be required. Effects of temperature, humidity and gamma irradiation were investigated by Ramarathinam et al. related to the performance of micro-glass fibre filter media, iodine removal on impregnated activated charcoal and overall performance of HEPA filter [76].

A filter is designed in one patent for removal of radioactive element in small amounts in gas phase using a nonwoven fabric constituted from activated carbon fiber, wherein an average single fiber diameter of activated carbon fiber is not more than 25 µm [77]. Some HEPA filters has been specially designed to remove radioactive particle from exhaust air of nuclear industry like Hepatex N with H13 grade [78]. INDA standard (JIS Z 4812:1995) is related with HEPA Filters for Radioactive Aerosols.

Conclusions

Filtration using fibrous filter play important role in protecting a building and its occupants from the effects of air born particulates and CBR agents. The CBR agents which are present in particulate form can easily be removed with higher efficiency by mechanical filter like some radioactive agents and most of the biological agents. Further more the efficiency can be enhance by using electrostatic charges either by charging the air or by charging the fibrous filter as in case of electroststic filters. Biological agents which cannot be removed by air filtration alone like viruses and bacterias, they can be inactivate or killed by using biocide chemicals incorporated into the fiborous filter. The antimicrobial agent may be applied on to the surface of fibrous filter in the form of finish or coating or it may be incorporated inside the fibre. Some other techniques like UV germicides are also used in conjunction with fibrous filter to increase the filter efficiency.

For the chemical agents which are present in the form of gasous are removed by integrating adsorbents and sorbents in filters or by imparing catalytic properties to the fibre. The fibre can also be impregnate into specific chemical to remove the particular gas. Radioactive agents can be removed by particulate filter if present in the form of aerosol or by gas cleaning by the use of specific fibre impregnate.

According to the type of place and environmental condition a perticular technique or combination of filteration techniques can be selected. For a particulate filter depending upon a size of particle a filter with desired filtration efficiency has to be considered. It is important to note that very stringent control is generally related to higher energy cost. By designing and modeling building for a given attack, it is possible to some extent to know the performance of filter system against attack [79, 80] and accordingly filter may be designed.

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