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A review on surface modification of textile fibre by High Efficiency Particulate Air (HEPA) Filtration process

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ABSTRACT: *Nonwoven filter media in their simplest form are random fibre structures, that are used to separate one or more phases from a moving fluid passing through the filter media. Filtration is generally perceived as the removal of particulate phases from the moving fluid by entrapping the particulate matter in the tortuous structure of the filter medium. Particulate air filtration for Collective Protection Systems (CPS) uses High Efficiency Particulate Air (HEPA) filters. This paper delineates a review on the efficacy of HEPA filtration process at removing an extremely high percentage of biological and particulate material from the air, with relatively low pressure drop and energy consumption. These filters have been in use for decades and have proven themselves over the years as a valuable tool in protecting personnel and equipment.*

Keywords –*Air filtration,filter media,nonwoven,particulate matters, particle size*

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I. INTRODUCTION

Nonwoven filter media in their simplest form are random fibre structures that are used to separate one or more phases from a moving fluid passing through the filter media, where filtration is generally perceived as the removal of particulate phases from the moving fluid by entrapping the particulate matter in the tortuous structure of the filter medium [1]. In their gross structures, these media have the form of nonwoven fabrics, wet-laid papers, or air-laid glass fibre mats spun from continuous fibres or blown from molten glass. Some membranes and open-cell foams also have fibrous structures. The solids content of these media is low, with the fibre volume typically less than 10 % of the volume of the media. These media range in thickness from a fraction of a millimetre to several centimetres.Typically, nonwoven fabric manufacturers supply filtration media having from 1 to 500 Micron Mean Flow Pore (MFP) ratings. Below 10-15 micron, the fabrics must be calendered in order to achieve the finer micron ratings [2]. The exception being certain wet laid glass fabrics. Micron ratings depend significantly on the test procedure by which the manufacturer rates the media and whether the rating is liquid or air. In addition to the micron pore rating, there are a number of other considerations including dirt holding capacity, flow rates and differential pressure data to name a few. The market for nonwoven fabrics for filtration media on a worldwide basis is approximately $2 billion. The distribution is roughly in thirds across the major territories of North America, Europe and Asia [3]. Of the largest volume uses, needle felt fabrics for baghouse filtration represent the heaviest weight and most costly, whereas spunbonded fabrics, especially from polypropylene polymer for use in coolant filtration used in automotive and aircraft machining are the lowest weight and least expensive. There is no question that the there are many advantages of nonwoven fabrics, including theirversatility, low cost and diverse functionality. The price-performance ratio is outstanding. Nonwoven fabrics are made from standard and many specialty inorganic and organic fibres including common wood pulp, cotton or rayon. Surprisingly, the growing use of soft, highly flexible, fine diameter and non-kinking stainless steel, nickel and titanium metal fibres now permits the use of needlefelted, air and wet-laid nonwoven fabrics which have extraordinary temperature, chemical and wide pH properties [4]. The choices are almost endless. Fine glass fibres are traditional in air filtration from Heating, Ventilation and Air-Conditioning (HVAC) to HEPA filters. Resin bonded glass fibre liquid filter cartridges also provide many excellent properties [5]. Another advantage of nonwovens is the wide number of diverse processes fibres can be incorporated including needlefelt, air and wet laid, resin bonded et.al. In addition to media from discrete fibres, it is possible to simultaneously melt-spin a polymer fibre while forming a web construction without an intermediate fibre-forming step. The direct web manufacturing method offers a cost advantage and is very popular. These direct web processes produce fine and sometimes continuous filaments and in case of spun bond, a strong and non-shedding web which cannot be achieved by any other means for a comparable cost. No single media can or will ever satisfy every filtration requirement. In the case of nonwoven fabrics, the disadvantages are not so much the shortcomings of nonwovens, but the advantages of other media. For example, membranes provide narrow pore size distribution, particularly below 1 micron mean flow pore. Monofilament fabrics and wire cloth offer strength and straight through holes for use in sifting and excellent sieving capabilities [6]. Polymeric membranes, woven fabrics and metal media are surface filters, a feature not easily achieved for nonwoven fabrics, because of the nature of the manufacturing processes and resultant constructions [7]. Many filtration and separation applications require stiffness, minimal flex, and rigidity or even low stretch as is the case of dewatering belts, which by their nature are less favorable to the use of nonwovens. All, which proves, that even with the tremendous growth of nonwoven fabrics in filtration, there are many unmet market opportunities for nonwoven fabric manufacturers to further expand their business. So, gradually a dire need to design and engineer a sophisticated and precise medium which will be able to purify the air to the maximum possible level of purity evoked the emergence of HEPA filtration process [8]. HEPA is an acronym for “High Efficiency Particulate Air”. This type of air filter can remove least 99.97% of dust, pollen, mold, bacteria and any airborne particles with a size of 0.3 micrometres (μm) [9].Particulate air filtration for Collective Protection Systems (CPS) uses high efficiency particulate air (HEPA) filters. These filters are excellent at removing an extremely high percentage of biological and particulate material from the air, with relatively low pressure drop and energy consumption. These filters have proven themselves, over the years, as a valuable tool in protecting personnel and equipment. The primary issues that are always being pursued with particulate filter improvements are-lower energy consumption, longer filter life, greater dust load capacity, and easier maintenance without compromising filtering efficiency. However, recent changes in operational requirements have pushed the need for a review of current equipment and its applicability for dealing with new and emerging threats[10].

II. CONSTRUCTION OF HEPA FILTRATION MEDIUM AND ITS TYPES

Hepafilter is constructed of borosilicate microfibers the form of pleated sheet. The hepafilter media is a glass and polymer blend, and is pleated to provide more filter material in a smaller space. Sheet is pleated to increase the overall filtration surface area. The pleats are separated by serrated aluminium baffles or stitched fabric ribbons, which direct airflow through the filter. This combination of pleated sheets and baffles acts as filtration medium. It is installed into an outer frame made of fire-rated particle board, aluminium, or stainless steel [11].The frame-media junctions are permanently glued or ‘‘pot-sealed’’ to ensure a leak. The different types of HEPA filters are shown in Table I.

Table I: Types of HEPA Filters

Types	Application	Performance
A	Industrial, noncritical	99.97 % @ 0.3 μm
B	Nuclear containment	99.97 % @ 0.3 μm (certified by DOE*)
C	Laminar flow	99.99 % @ 0.3 μm
D	Ultra-low penetration air (ULPA)	99.9995 % @ 0.12 μm
E	Stopping toxic, nuclear, chemical and biological threats	99.999 % efficiency

*DOE =Department of Energy, Washington D.C., USA

III. HEPA FILTRATION MECHANISM

There are five ways particles are trapped in fine nonwoven HEPA type filter media, sieve effect, impaction, interception, Brownian diffusion, and static charge effect [12]. The first is the most obvious, sieve effect. This stops large particles that are just too big to fit through the open areas of the filter. For the type filter we are interested in, this would include all particles above 5um in size and larger. As the particle size decreases, say between 1um to 5um, occasionally some of these particles get through, but the efficiency for removal still lies well into the 99.9999+% range. This is still due primarily to sieve effect and the beginning of inertial impaction effect. Inertial impaction occurs when large particles are unable to quickly adjust to changes in the flow stream around fibres [13]. The particle, due to its inertia, impacts a fibre and is captured. Fig. 1below shows how this works.

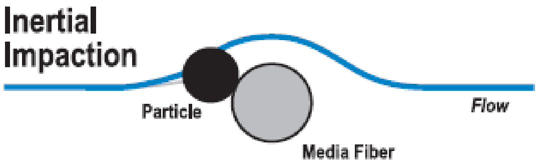

Figure 1: Inertial Impaction - Particle inertia causes it to leave the flow streamlines and impact on the fibre.

This effect is dominant from around the 0.5um region up to around 5um. The next effect is interception. Interception occurs when a particle following a gas stream comes within one particle radius of a fibre. When this occurs the particle is trapped by the fibre. Particles that are farther than one particle diameter will not be removed by this process. This is one reason for the high fibre volume density of the 200CFM media [14]. The denser, the higher the probability of particle capture. This effect is dominant from about 0.1um up to about 1um. Fig.2 below the working principle of interception.

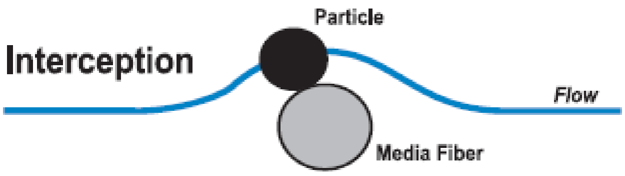

Figure 2: Interception - Particles are intercepted or captured when they touch a fibre.

Brownian diffusion is perhaps the most mysterious of the filtering effects since it tends to defy common sense [15]. Very fine particles in the air stream will collide with gas molecules and create a random path through the media as shown in Fig.3. The smaller the particle the longer the particle will zigzag around. This random motion increases the probability of the particle contacting a fibre. This effect is dominant for all particles smaller than 0.1µm [16].

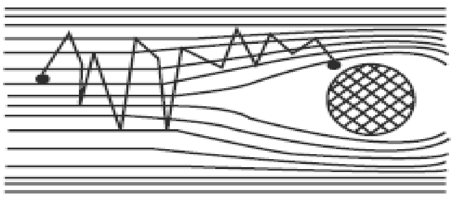

Figure 3: Brownian diffusion - The particles traverse the flow stream, they collide with the fibre and are collected.

The last effect is electrostatic effect. This effect is a function of the type of media used, the environment in which it is used, and the geometry of the fibres. Different materials will hold different levels of static charge [17]. A glass rod when rubbed with fur will build quite a static charge. It will also build a charge if placed in an air stream. In filters, as air passes over the fibre, a charge will build up much the same way, a very small charge certainly but a charge none the less [18]. Additionally, the material the fibre is made of, will play a part in how much charge will get build. Plastic is notorious for holding large static charges [19]. The geometry of the fibre will dictate how much localized electrostatic charge will build on the fibre surface. Humidity in the air will also affect how much charge the fibre will hold, as will the air flow rate through the media [20]. Electrostatic effect is not a dominant effect, but may play some part in particle capture and retention for the previous three effects mentioned. Fibre diameter, spacing between the fibres, fibre cross section, and media thickness are big drivers in how effective a filter is. The smaller the fibre, the greater the small particle capture efficiency and smaller the fibre spacing, the greater filter efficiency [21]. The larger the cross section, the greater is the capture capability [22].

IV. ADVANTAGES AND DISADVANTAGES OF HEPA FILTERS

Air purifiers have HEPA filters that aid in cleaning the air around that is circulated. They help get rid off contaminants and impurities from the air. HEPA filters can clear the air of dust, pollen, pet dander, smoke and almost all pollutants present in the air. But inspite of enjoying such advantages HEPA filtration has some disadvantages. The HEPA filter is extremely fragile and needs to be shipped, stored, and handled in the same manner as delicate instrumentation [23]. Personnel responsible for receiving and handling HEPA filters should receive training in proper handling technique. All incoming HEPA filters needs to be visually inspected.

V. APPLICATIONS

HEPA filters are used in a wide variety of applications. Filters can be used for office equipment to remove toner dust to applications for industrial vacuum cleaners for asbestos removal. Each application is unique. These critical applications require a dedicated team to design, prototype and commercialize in a very short time frame [24]. HEPA filters are also critical in the prevention of the spread of airborne bacterial and viral organisms. Used in surgical operating rooms, and other critical medical air filtration applications, HEPA filters are there to provide the highest quality of air cleanliness, helping safeguard the life and health of both patients and medical staff. The different applications of HEPA filters are surgical smoke evacuation, surgical respirator systems, negative pressure isolation rooms, microderm abrasion, biological safety cabinets, industrial vacuum cleanersetc. [25].

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