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Nonwoven Composite in Particle Filtration

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ABSTRACT

Nonwoven is engineered fibrous material designed according to the application's requirements. Nonwoven is used for filtration applications because of its structure. The filtration efficiency depends upon the effectiveness of catching the particles in the stream. The filtration properties of the nonwoven are permeability, pressure drop, and filtration efficiency. All these parameters determine the total quality of the filtration materials. The nonwoven composite is manufactured by combining different nonwoven fabrics manufactured from different fiber materials. The composite nonwoven has lower energy consumption, longer filter life, good filtration efficiency and easy cleanability.

Keywords: *nonwoven composite, filtration efficiency, permeability, pressure drop, fibrous material.*

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I. Introduction:

A nonwoven is an engineered fibrous assembly, primarily planar, which has been given a designed level of structural integrity by physical and/or chemical means [1]. The most important technologies for manufacturing nonwoven are needle punch nonwoven, spunlace nonwoven, spunbond and meltblown nonwoven, chemical and thermal bonding nonwoven. Each nonwoven fabric has its own application. Nonwoven fabrics are widely used for the filtration of particles due to random fibrous structure and higher air permeability.
Fiber is a unit of matter characterized by fineness, flexibility, and a high length-to-width ratio. The fibrous substance provides large surface area because the fibers are very small in cross-section, therefore more overlaps. The inherent porosity in the fibrous substrates can be effectively used as a filter media**.**

Filtration [2] is the process of separation of dispersed particles from a dispersing fluid such as air or liquid with the help of a porous medium. Various physical mechanisms contribute to a high-efficiency fibrous filter's effectiveness in capturing particles. The most predominant mechanisms are interception, inertial impaction, and diffusion.

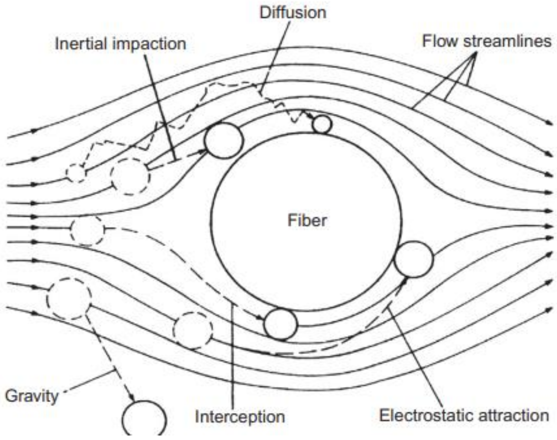

Figure 1: Mechanism of filtration

Filtration properties of the nonwoven [3] are permeability, pressure drop, and filtration efficiency. The permeability is directly proportional to the flow rate, fluid velocity, fluid viscosity, and filter thickness and inversely proportional to the filter area and fluid density. The pressure drop is the difference between pressures in front of the filter and behind it during the constant flow rate. The filtration efficiency is effective in trapping particles in the stream. All these parameters determine the total quality of the filtration materials. Therefore, to achieve better filtration properties the composite nonwoven is better solution for this.

1. Factors affecting filtration:

In filtration, the flow of liquid through a filter follows the basic rules that govern the flow of any liquid through the medium offering resistance [4]

$$Rate\ of\ flow = Driving\ force/Resistance$$

- Rate of filtration is expressed in $liters/unit\ time$
- Driving force = $Pressure\ upstream - Pressure\ downstrem$
- Resistance is not constant – it increases with an increase in position of solids on filter
- Therefore, filtration is not steady state

Kozeny-Carman equation is widely used for filtration,

$$V = \frac{A}{\eta S^2} x \frac{\Delta P}{KL} x \frac{\varepsilon^3}{(1-\varepsilon)^2} \qquad (1)$$

Where,

$V =$ Rate of flow, m^3/s (l/s)
$A =$ surface area of porous bed (filter medium), m^2
$\eta =$ viscosity of filtrate, Pa. s
$S =$ specific surface area of particles comprising the cake $m^2\ /m^3$
$\Delta P =$ Pressure difference across the filter, Pa
$K =$ Kozeny constant (usually taken as 5)
$L =$ thckness of filter cake, m
$\varepsilon =$ porosity

2. Evaluating the performance of the filter

Though it is possible to achieve [5] higher filtration efficiency by using composite nonwoven at lower pressure drop. The performance of filter is measured in terms of Quality factor which is determined by using following formula

$$Quality\ factor\ (QF) = \frac{-l_n(1-E)}{\Delta P} \qquad (2)$$

Where E is the particle collection efficiency and is calculated by

$$E = \frac{(C_u - C_d)}{C_u}\ x\ 100 \qquad (3)$$

where C_u and C_d are related to the particle concentration measured upstream and downstream of the filter. The experimental setup to measure filtration efficiency and pressure drop is shown the figure 2.

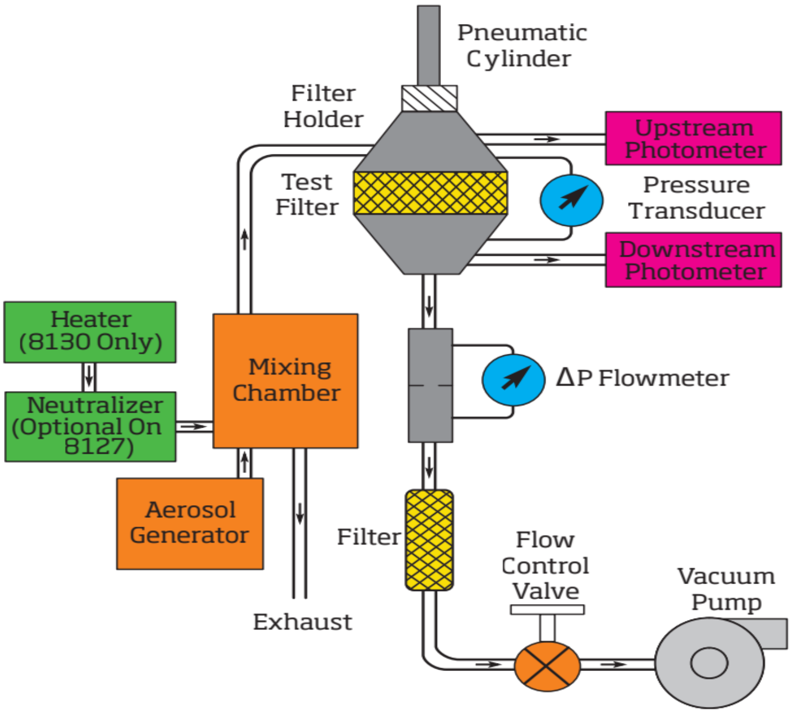

Figure 2:Experimental setup to measure filtration efficiency and pressure drop [6]

The following international and industry standards specified the filtration performance of various air filtration applications [7]:

- National and international standards: ISO, IEC, CEN (European Committee for Standardization), CENELEC, BS, ANSI, and ASTM.
- In the US, the Occupational Safety and Health Administration (OSHA)
- National Institute for Occupational Safety and Health (NIOSH)
- ASHRAE (American Society of Heating and Refrigerating and Air-conditioning Engineers),
- SAE (Society for Automotive Engineers),
- ISIAQ (International society of Indoor Air Quality and Climate),
- UL (Underwriters Laboratories),
- AHAM (Association for Home Appliance Manufactures),
- IES (Institute of Environmental Sciences).

3. Filter Efficiency Versus Particle Size:

Effect of particle size on filtration [8] efficiency is shown the figure below. The figure 3 shows that a filter's ability to remove particles from a stream is directly related to the size of the particles in the stream.

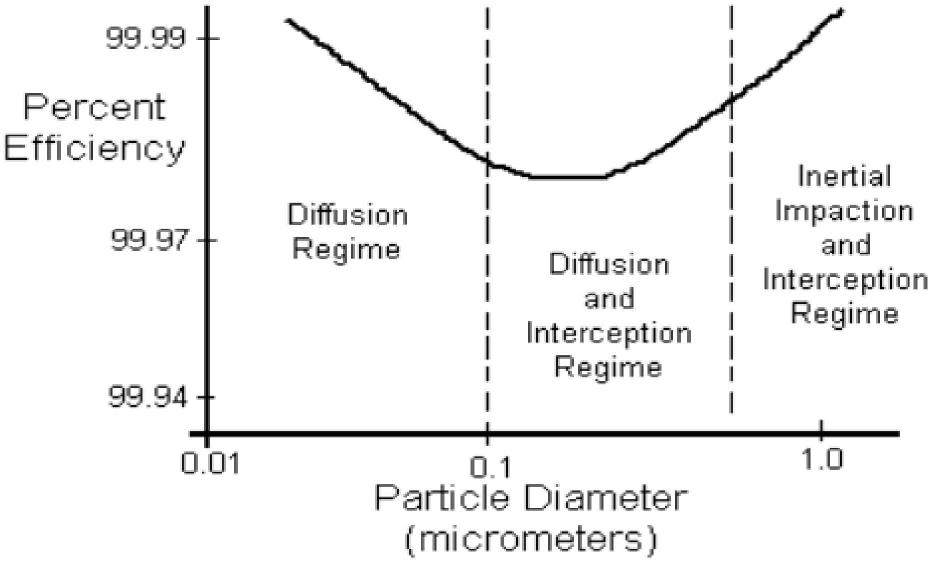

Figure 3:Filter Efficiency Vs Particle Size

For particle size less than 0.1 µm in diameter, the primary filtration is by diffusion mechanism and filter is very efficient. For particles between 0.1 and 0.4 µm the filter is less efficient as the particles are too large for a great diffusion effect and too small for a large interception effect. The filtration efficiency of filter is more effective for particles above 0.4 µm through interception and inertial impaction.

particle size and flow rate is used to express the filtration efficiency of fibrous material. The filtration efficiency is calculated for 0.3 μm particle size and flow rate of 85 liters per min (LPM). 0.3 µm in diameter of particle is called as critical particle size because it is likely to get though the filter than any other size.

4. Requirement of good filter

The requirements of the good filter media are as follows: high filtration efficiency; low pressure gradient; Good dimensional stability under the filtration conditions; low resistance to fluid flow; Good thermal and chemical stability; it should have good microbial resistance property; good compatibility with another environment where it is used; Easy to handle and maintain.

5. Manufacturing of composite nonwoven filter:

The composites can be manufactured by reinforcing or laminating same fabric with different fabric characteristic or fabric from different nonwoven manufacturing technology or by mixing different fibers/polymer with different characteristics as shown in figure 4 as per requirement of the applications

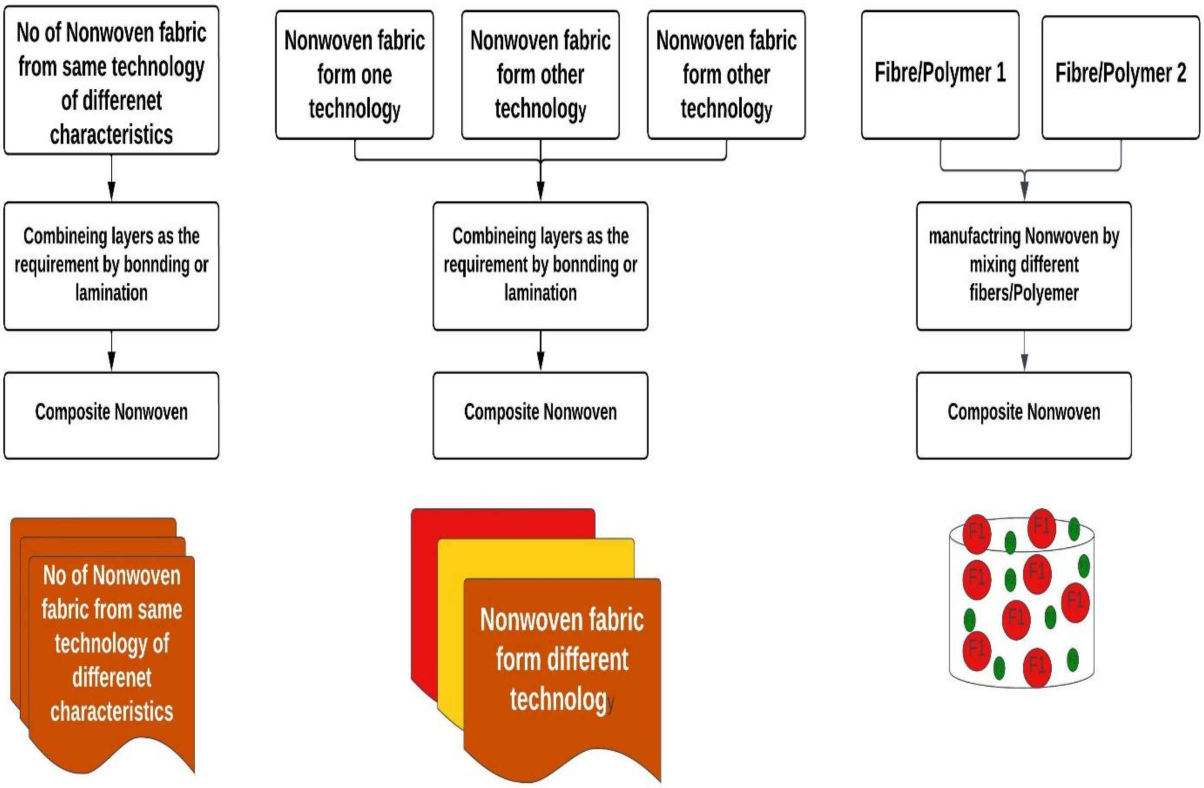

Figure 4:Manufacturing of composite nonwoven

Nonwoven filters are designed to remove ultrafine dust, aerosols, and viable organisms to meet highest requirements to the cleanliness of air in a wide range of applications, such as clean rooms, hospital operating theatres, microelectronics, optical and precision industries, and the pharmaceutical and food industries. There are three categories of air filter products based on their filtration performance, ie, efficient particulate air filter (EPA), high-efficiency particulate air filter (HEPA), and ultra-low penetration air filter (ULPA).

6. Structural advantages of nonwoven composites for filters:

Composite structures are usually [5] multilayered filter media, each layer serving a specific purpose in filtration. The development of composite filter media has lower energy consumption, longer life of the filter, good filtration efficiency, and easy cleanability. To have in-depth filtration the composite nonwoven filter should be graded so as to increase the fineness of fibers in the direction of flow, the upper layer should be made from coarser fiber which will act pre-filter which retains the coarser particles are held, while fine particles are retained by next layer of fine fiber. This will maximize the dirt holding capacity, and hence its life before it is discarded.

Composite nonwoven serves the following purposes:

- Mechanical support for other structural, giving enhanced durability.
- Two or more layers of different filtration efficiency.
- The outer layers serve as a containment to inhibit medium migration, dusting, and particle fallout from the inner layers.

7. Properties of composite nonwovens

The purpose of development of composite nonwoven filter is to enhance the filtration effectiveness. Several studies were conducted to see the effect of fiber characteristics, method of manufacturing nonwoven, process parameter, and structural features on filteration properties of nonwoven composite.

Priyal Dixit and et al [9] modified the manufacturing method of is developed to produce filter. Polyester fibre of 1.5 denier, 44 mm length was used. The nonwoven fabric produce is of 300 g/m^2 having punch density (PD) 200 punch/cm^2. In the first stage of the experiment, three nonwoven with different punch densities were produced (PD1<PD2<PD3) in such way that the total punch density in combined fabric should be 200 punch/cm^2 i.e. PD1+PD2+PD3=200 punch/cm^2, and in second stage these three samples where combined as

shown in the figure 5. Similarly the nonwoven is produced by varying the leaner density of the fabric and by chaining the laying sequence.

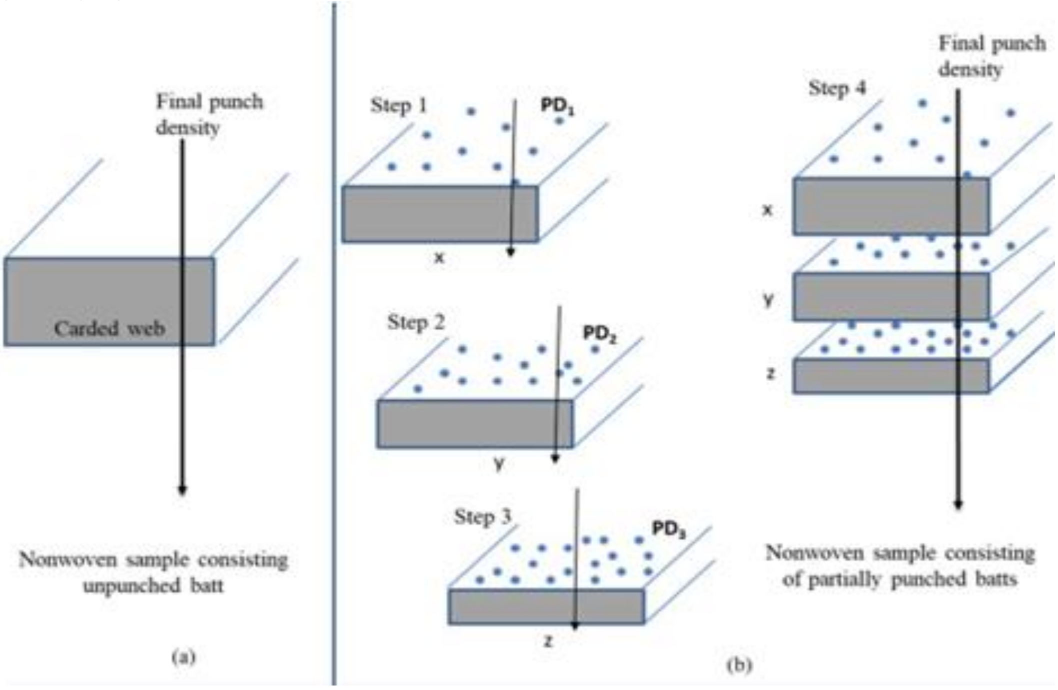

Figure 5: Nonwoven Production

Fiber configurations are redistributed because of the sequential punching idea used to consolidate the fiber arrangement in partially punched batts positioned at certain locations in layered structures. In the bats has pores that are distributed unevenly and vary in size depending on Different punch densities and base weight created the potential for the convoluted pore route that regulates the mean flow pore size nonwoven**.**

It's important to notice that, compared to gradient structure, inverse gradient structure produced a better value of filtration efficiency. However, it was discovered that the non-gradient structure's filtration effectiveness fell somewhere between the gradient and inverse gradient structures of pore diameters. As a result, the built-in layered structures direct the dust particles according to their diameters, lowering the pressure drop and increasing the effectiveness of the filtration.

Haifeng Zhang et al. [10] designed nonwoven composite for enhancing the performance of the filter. Process to produce composite nonwoven is shown in the figure 6. Multilayer air filter was produced by PP needle punch, PP melt blown nonwoven and corona discharge technology.

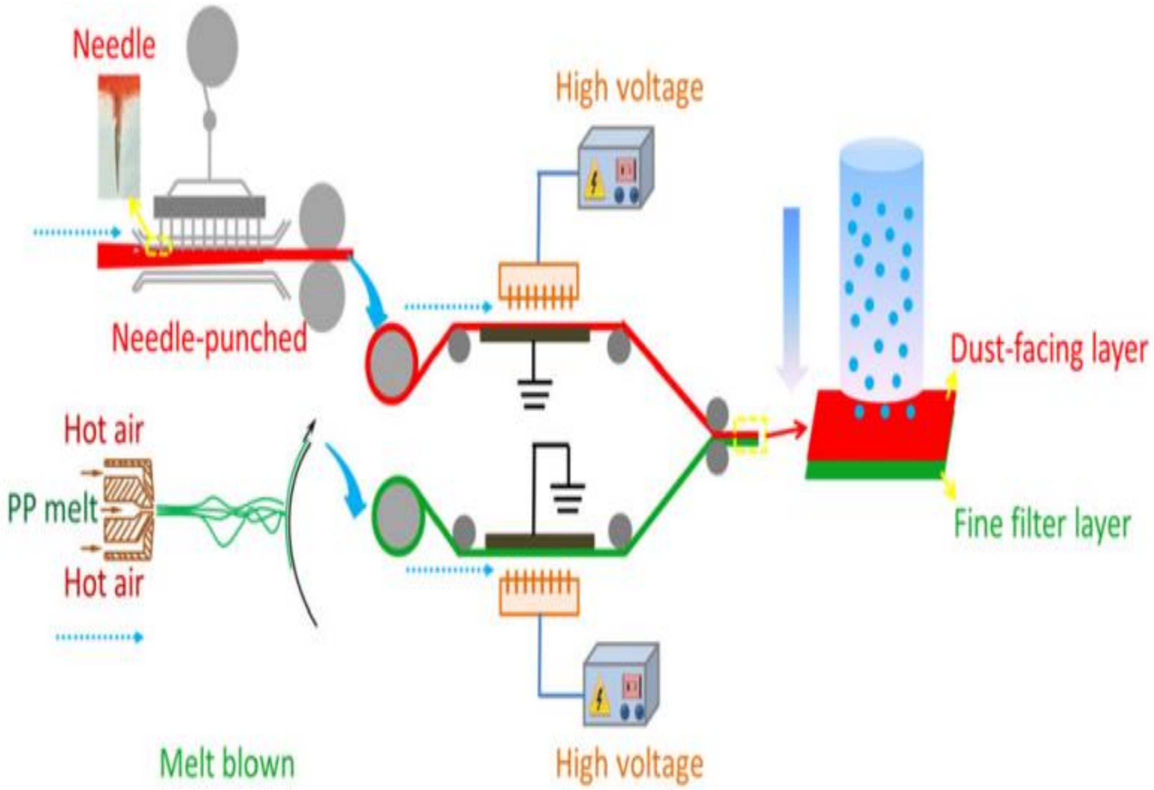

Figure 6:Manufacturing of needle punch and meltblown nonwoven composite

The composite filter could achieve a high filtration efficiency up to 99.52 ± 0.01%, a low pressure drop of 136.87 ± 0.49 Pa. Also filter exhibited a large dust holding capacity of 23.5 ± 0.41 g m^{-2} this is attributed to small pore size and fiber diameter of melt-blown nonwoven, the high porosity and fluffy structure of needle-punched fabric, and good electret characteristics assisted by corona charging technology, which will increase service life of the filter.

Feng Jianyong et al.[11] prepared hemp based composite nonwoven and assess its filtration efficiency. In this research, spunlace nonwoven of hemp/cotton (40/60) blend, hemp/viscose (40/60) blend, hemp/viscose impregnated polyacrylic adhesive, hemp woven fabric, and PA6 nanofiber which was collected on the surface of hemp/ viscose spunlaced nonwoven and to study the filtration properties, two/multilayer nonwoven is manufactured. The SEM images of hemp blended treated nonwoven fabric is shown in the figure 7.

Multilayer nonwoven with PA6 nanofiber shows smaller thickness, weight and pore diameter, therefore better filtration property and higher pressure drop this could bebecause of higher surface are of the nanofiber. mean pore diameter, maximum pore diameter, air permeability, decreased and best filtration effect for multi-layer composite materials.

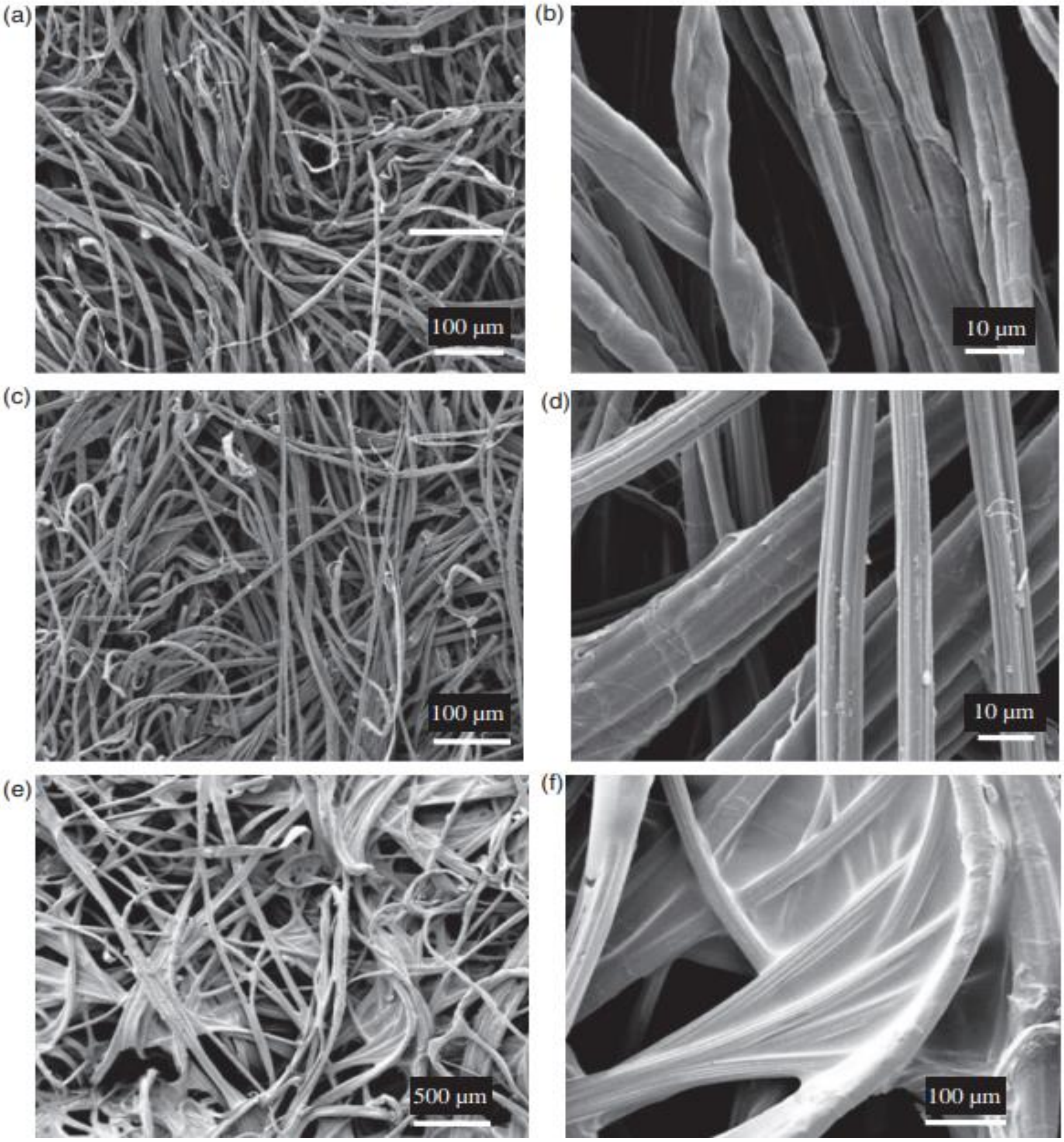

Figure 7:The SEM images of spunlaced nonwoven (a and b Hemp/cotton spunlaced nonwoven, c and d hemp/viscose spunlaced nonwoven, e and f hemp/viscose spunlaced nonwoven impregnated polyacrylic emulsion adhesives

Ahsan Nazir et al [12] developed the heigh efficiency nonwoven by incorporation of polymeric nanoweb. In this experiment filtering facepiece respirators (FFRs) are developed by using polyamide-6 (PA-6) nanofber layer which is sandwiched between meltblown and spunbond nonwoven fabric as shown in the figure 8. The polyamide nonofiber web is prepared by using electrospinning

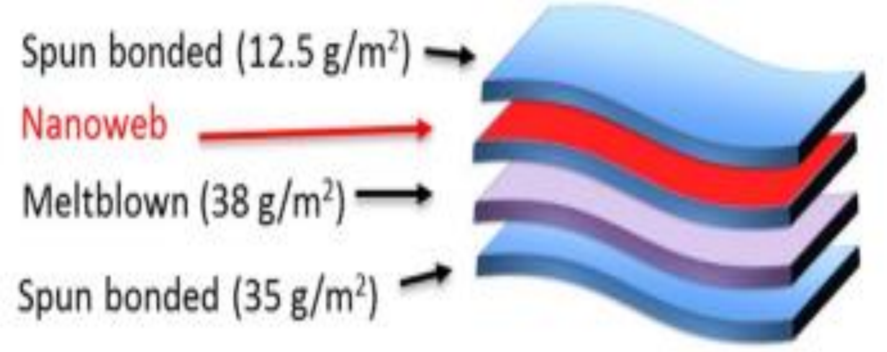

Figure 8:layers of filter media incorporated with electrospun nanowebs

The filtration testing of PA-6 nanofbers-based FFRs was conducted as per test standard (BS EN 149:2001+A1:2009).

The pressure drop across the FFRs is very much important parameter. For the evaluation of pressure drop during inhalation and exhalation was done by passing compressed air through the sample at controlled rate (30 l/min and 95 l/min at inspiration; 160 l/min and 85 l/min at exhalation).

It was interesting to note that better filtration properties in comparison with the sample with nanoweb. It was observed that as exposure time to paraffin was increased the penetration of paraffin is increased. As per the standard EN 149 +A, the maximum penetration is 3% and with addition of nanofiber it was reduced to 0.28%. this is because of finer diameter of fiber produced from electrospinning which will give more surface area.

Comfort properties of the nonwoven respirator is very important which includes water, air permeability and thermal conductivity. The thermal conductivity of FFRs without nanowebs was 31×10^4 W/cm. °C which was increased remarkably to 39 W/cm °C. This is because nanofibers increase the density of media by filling the interstices which enhances the thermal conductivity.

The air permeability nonwoven with nanofiber was affected due integration of nanowebs between the layers, the pore size is reduced because of smaller diameter of nanofiber and provide resistance to the flow of air as without nanofibers web. The air permeability decreases because of nanofiber web.

water vapor permeability of filter media containing nanowebs is better. this can be because of smaller pores in nanowebs therefore the wicking power is increased due to capillary action

S. Yadav et al [13] studied the effect of fibre diameter and hierarchically arrangement of the fiber and fibre shape on filtration efficiency of automotive engine filter. The needle punch nonwoven fabric was produced by using Polypropylene fibres of three different cross-sectional areas 19.13 µm (2.5 den), 30.17 (6 den) µm and 48.24 µm ((15 den) and polyester 6 den having fibres of three different cross-sectional shapes (round, trilobal and deep-grooved).

the composite nonwoven filter was produced as per hierarchically arrangement shown in the fiber figure 9

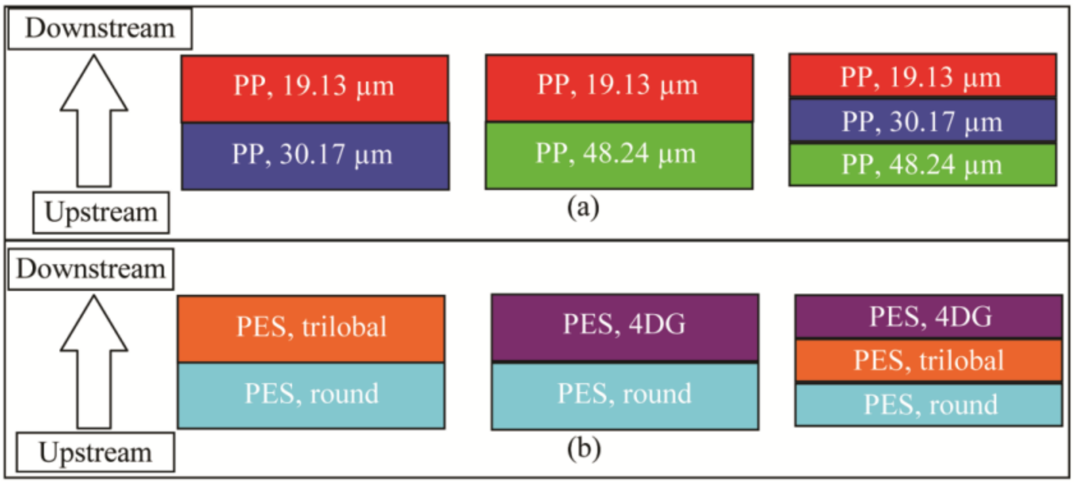

Figure 9: Schematic diagram of nonwoven filter media with hierarchically arrangement of different size and shapes

The two types of filters are produced, one is composite filter media as shown in figure 9 and hybrid filter media by homogeneous mixing of the fibers same type of fibers and proportion. The filter media were tested for basis weight, thickness, filtration properties and pressure drop. The filtration efficiency was carried out for six different particle size ((0.3 µm, 0.5 µm, 1 µm, 3 µm, 5 µm, and 10 µm). The composite filter shows better filtration efficiency with lower pressure drop than the hybrid filter this is because of graded structure of the composite filter and this trend was observed in case of different cross-sectional area and shape.

II. Conclusion:

- It has two or more layers of combination of two or more material in one structure which has different separation principles in single filter media.
- The composite nonwoven filters are different in terms of structure like combination of mechanical support and serviceability with filtration,
- Applications of composite nonwovens is increasing in the field of air, liquid filtration.
- The composite nonwoven filtering media will lower energy consumption, longer filter life, high filtration efficiency, in depth filtration and easier maintenance.
- The composite nonwoven for filtration application is manufactured by using nanofibers.
- filtration efficiency can be also improved by inducing the charge on the surface the fabric

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