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Research Article

Review of the Patented Electrostatic Air Filter-Materials and Designs Controlling Technology

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Nano particles play a major role in research and high-end applications including composite [1–4], functional surfaces [5,6], analysis [7,8] and new materials [9]. However, controlling the nanoparticles is critical since nanoparticles itself could a significant health concern. Many patented efforts have been contributed looking approaches to developing a new material to control the particles including nanoparticle. About 600 DC, people started to notice exist of electrostatic force. After that, increasing attention was paid to the application of electrostatic. Until 1912, people began to use electrostatic force in air filtration field [10]. Electrostatic Air Filter is a technology that makes full use of electrostatic to catch particulates including nanoparticles in air flow.

Compared with current air filter, including HEPA Filter, Negative ion, PCO technology in purifying air process, electrostatic air filter has a higher efficiency for it can remove particulates, dust, bacteria, virus, germs, VOC, smoke and all other particles in the air. Currently, the effectiveness of the electrostatic air filter can reach more than 97%. Besides, the electrostatic filter is very durable and washable, which made it cost effective. All that desirable performances make it the best choice in air condition systems.

There are three kinds of air electrostatic cleaners: electrostatic precipitators, passive electrostatic filters, and active field polarized media air cleaners. Electrostatic precipitators charge particles first and then absorb these charged particles by oppositely charged collection plates. A passive electrostatic filter uses media that can produce electrostatic charges when air goes through and then capture particles in the air flow. An active field polarized media air cleaner uses an electrostatic field created by a voltage difference between two electrodes. A dielectric filter media is in the middle of the two electrodes, which increase the efficiency of the filter [11]. Though the variety of electrostatic air filters, filter media and electrostatics are two necessary parts of it. In the inside of air filter, electrostatic is a force, responsible for absorbing particles and at the same time, filter media provides space to hold air particles. So they are crucial to the quality of the filtered air. That is also the key reason why human beings kept trying to redesign the device and improve the filter media efficiency from two aspects, namely the change of materials and the design of filter structure.

This paper will focus on the improvement of filter media from the modification of filter media materials and the design of filter media structure from the birth of the filter. As filter media, it is required to have strong ability of adsorption. At the very first, people used steel wool, mineral wool, excelsior or glass fibers coated with an adhesive such as petroleum oil, tricresyl phosphate, or ethylene glycol [12]. However, it costs much energy to force air to get through the media. Besides, the steel wool media cannot hold some small particles. Moreover, it is hard for steel wool media to reuse to a next life cycle because of these trapped particulates are tough to clean. Then people started to figure out a better material as the filter media. Fortunately, with the development of industry, polyethylene became accessible on a large scale. At 1950, William H. Nicol, Cuyahoga Falls Ohio, took polyethylene filaments as the key media for electrostatic air filter [3]. This patent explains a new material- polyethylene to replace the filter media at that time. Moreover, the author also claimed the polyethylene is in a form of filament and the underlying structure of the filter, see below figure 1. Besides, the author carried out an experiment to compare the efficiency among none-filter medium, coated glass fiber medium, and polyethylene filament medium.

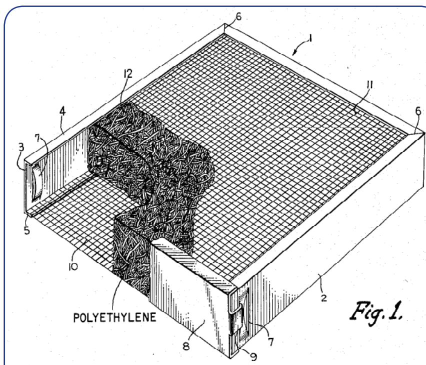

Fig 1: Filament fiber layer electrostatic filter

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By Table 1 below, we can see the high reliability of this material used by William H. Nicol, Cuyahoga Falls.

Table 1: The comparison of efficiency of different filter medium [12]

Filter Medium	Weight of Residue	Percent retention
None	0.0202	0
Coated glass fiber	0.0445	None
Polyethylene	0.0012	94.5

Two years later, Herbert A. Endres, Cuyahoga Falls, patented rubber hydrochloride filament yarn as the filter media in electrostatic filter [13]. Theoretically, Rubber hydrochloride can get electrostatic charges when air flow passes. Moreover, the filament will give higher surface energy to hold dirties and particles in the air flow. However, this patent is very similar with the patented referred above. Moreover, the experiment they cited are very similar, the result table 2 is almost identical to each other. So it highly doubts the efficiency of the rubber hydrochloride filter media. If the authors want to make it reasonable, the authors should provide a comparison between rubber hydrochloride filament based filter and polyethylene filament based filter. With the development of chemical and spinning industry, people continued to try different fibers, such as polyester [14], polypropylene [15], and all kind of Nanofibers [16]. Especially, they start to change the materials according to fiber's dielectric properties, such as what Charles W. Soltis, 647 W. Forest make at 1973, who use dielectric fiber (polyester and open cell plastic foam) as the first layer of the filter media [17]. What's more, people never gave up modifying the fibers through chemical finishing [14] and plasma treatment [18] to improve the surface properties of the fiber used in electrostatic air filters. In the patent [14] the author claimed cotton fibers treated by antistatic agents are used in the non-woven filter mat. In the patent 6419971, Kumar Ogale treated non-woven webs by fluorine-containing plasma treatment to improve the electrostatic charges stability, to increase resistance against oils and the particle-capture ability [9]. The highlight of this patent is the broad application of plasma technology on different kinds of fiber. The author listed polycarbonates, poly halocarbons, polyesters, nylons and polyolefin [18]. However, though it is better to use nonwovens as air filter medium for its high space for air, the author claimed plasma treatment can also be used on woven fabric as an air filter and can be laminated with another kind of layers, including scrim and netting.

Table 2: Comparison of efficiency of different filter medium [13]

Filter Medium	Weight of Residue	Percent retention
None	0.0202	0
Coated glass fiber	0.0445	None
Rubber Hydrochloride	0.0012	94.5

As the author list in Table 3, the efficiency of the fabric increases obviously. Here, Penetration=1-efficiency. Type 1 has more plasma treatment than type 2. Type 3 has no plasma treatment at all. No 20080198820 patent also offers a plasma treatment technology to get high dielectric nonwoven fabrics [19]. Indeed, the ability of filtration increase don a large scale after plasma treatment, but we should consider the cost of this process. As a technology aims at applied to market, its cost and sustainability should be taken into consideration. All the improvements mentioned above promoted the gradual development of air electrostatic filter.

Table 3: The nonwoven medium efficiency comparison after plasma treatments [18]

Sample type	Type 1	Type 2	Type 3
Before wash	10.25	22.6	40
After wash, 40 Degree C Dry	1.2	40.6	41

For the design of filter media, we cannot deny that people have been trying. The very first one is a plane single layer media make by fibers directly, just like described above in figure 1. Actually, another highlight uniqueness of No. 3118750 [14] is adding some chemical bond in this single layer structure in order to make it rigid with the support of the frames to decrease the resistance. Moreover, the author uses fibers in different length to let the structure strong and of high particle-absorption. Just like the structure shown in figure 2 [14]. The air flow was used by the author to produce chemical bonding nonwovens, which provides a better anisotropy and more pores for air to get through. Moreover, the structure here is changed to an intact one from separation fibers, which makes the whole filter more stable and durable. As we all know, single fiber will be pulled out by the air force and arise environment pollution or health damage.

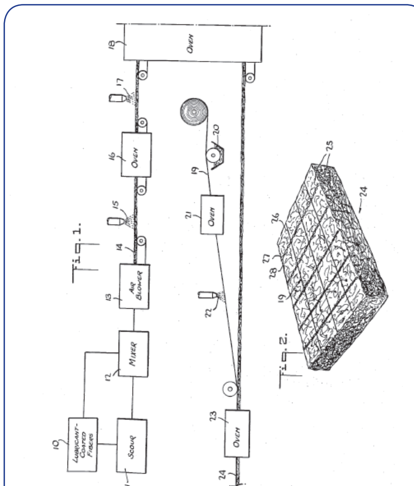

Figure 2: Non woven mat invented at 1964

After that at 1973, Charles W. Soltis, 647 W. Forest came up with the idea that is combining the different layers with different structure and fibers, please see blow figure 3[17]. There is a highlighted claim on the multi-layer structure, which gives filter medium a better capability to absorb particles in air flow and to hold them in a period. In figure 4, the integrity of the filter medium increased by combination the multi layers with the woven structure [20]. Figure 4 is very close to what we use today; please see Figure 6.

Since the first application of pleated structure in the air filter of aircraft [21], see figure 5, inventors started to take pleated structure

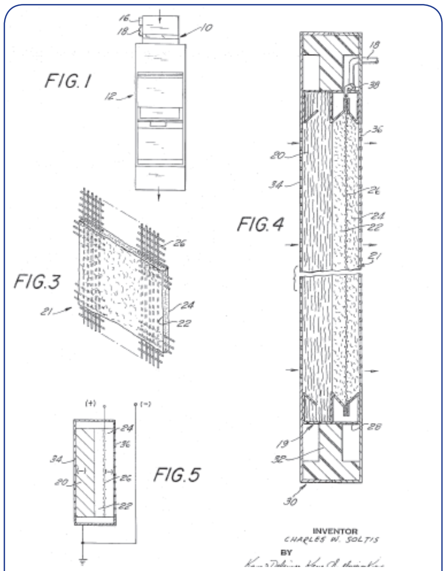

Figure 3: The improved structure based on single layer

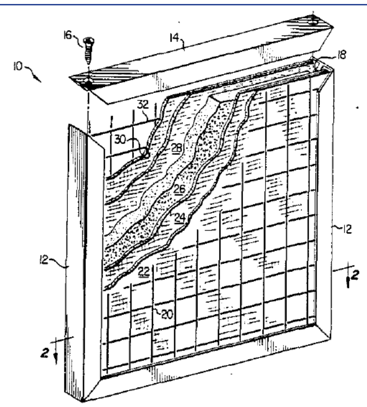

Figure 4: the developed multi-layer structure combined with woven fabric

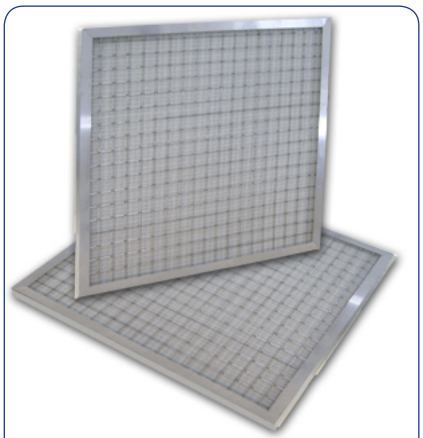

Figure 5: The widely used air medium filters today

as one of the necessary skill to increase the efficiency of the air flow filtration. According to simple calculation on the folding plane and the smooth plane in figure 7, we can know the more (100/ *cosα-100) % air flow can get through it. As the result, the efficiency increases with the increase of α.

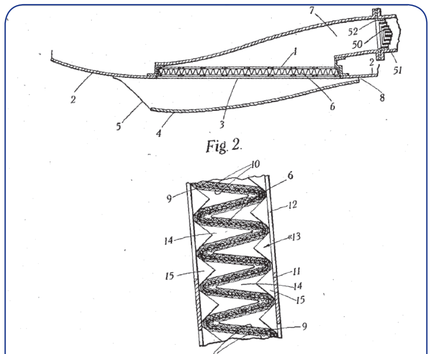

Figure 6: The structure of pleated filter

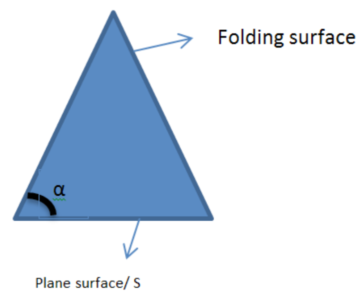

Figure 7: The basic math model of pleated filter.

In patent No 6065809, the pleated electrostatic filter got well developed by Rick L. Chapman. Figure 7 below shows a detailed figure of the pleated filter and its produce procedure [22]. There are three highlight advantages of this design. The author offered a practical manufacture way to make this pleated structure. Besides, different substrates are involved in order to support the filter. Moreover, in claim 14, this patent shows a method to make the filter medium washable and cleanable, so it owns a better durability than the previous design. Nowadays, this structure is widely applied in electrostatic air filters, see figure 8.

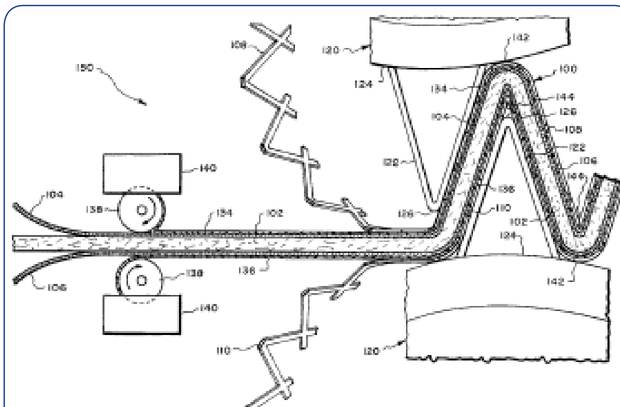

Figure 8: The manufacture ofpleated multilayer filter

Until now, development of filter efficiency and durability come to an optimization, as showed in Figure 9. With the intensive study going on related to nanoparticles, more and more research are interested to see how the nanoparticles are interacting with filter materials. Seong Chan Kim et al. studied the nanoparticles passing through a commercial filter media using SEM, as showed in Figure 8.

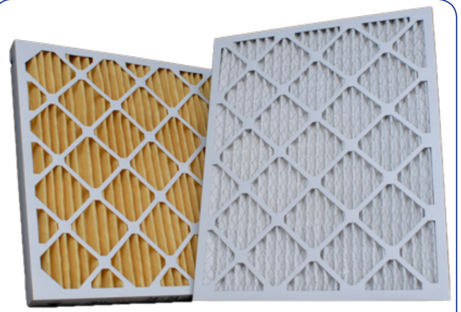

Figure 9: The current air filter in themarket

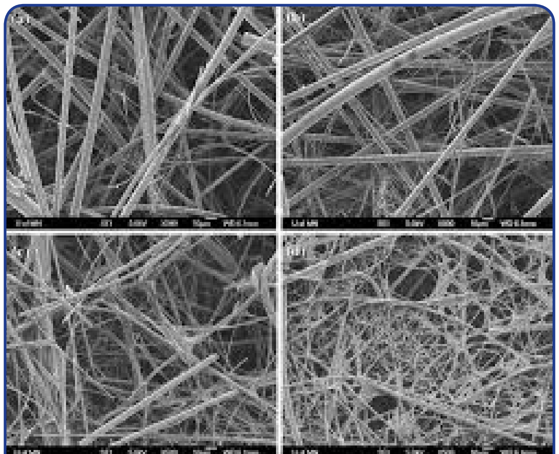

Figure 10: The experiment study of nanoparticles on commercial filter media [23].

After 2000, engineers started working a new direction of electrostatic air filter- the maintenance of filters. Sunita Satyapal and Harvey Michels invented a way to prevent microbial growth in an electronic air cleaner by using ultravioletlight [24]. One ultraviolet lamp is placed upstream or downstream of the array of collector's plates, and a reflector is used to increase the efficiency. This method can kill germs and other microbial growth around the collector, which is indeed a good idea to maintain the filter capability and durability. Moreover, I think we can further develop the maintenance of electrostatic air filters (1). Invent some smart filters, which can give out a warning when the filter collector is full (2). Consider about the sustainability of these widely used filters. Currently, most filter media is made of synthetic fibers, most of them are non-disposable, therefore, we need to find new degradable fibers but with the same dielectric properties to replace them or find a better way to dispose of these used synthetic fibers (3). Find some better way to clean the filters. Nowadays, people wash filter by water, but this may cause a spread of disease and the pollution of water. Therefore, a new technology on washing filter and some professional filter washing companies will be beneficial (4). Smaller fibers using emerging material is another trend going on, including carbon nano tube [25], electron spinning material [26], and graphene-based membranes [27]. By smaller fibrous structure, smaller particles can be captured.

In all the above patents, the structure and material development of electrostatic air filter are changing with the improvement of textile industry, and they are very mature to the current air filter market. Though not all of these patents can apply to practice, these ideas have been accepted by the market gradually. It is believed that more and more smart air filters supported by electrostatic air filter will take the place of the current electrostatic air filter to provide better nano manufacturing environment for industries such as medicine, sensors, Nano carriers, and life sciences [28-35].

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