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Study on Electret Technology of Air Filtration Material

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Abstract. The air filter material of high efficiency and low resistance was prepared by electric field poling method. Through orthogonal experiment, the influences of process parameters on the electrets' surface potential and filtration efficiency were studied. The results showed that the most significant influence factor was the charging voltage, followed by charging speed and distance, and the temperature minimum. Besides, it was found that grid electrode could contribute to form uniform and stable surface charge. Twice poling treatment was conducive to obtain higher surface electrostatic potential and the filtration efficiency, and better storage of charge.

1. Introduction

Along with the rapid development of modern industry and the impact of human life, the air quality of big cities is getting worse and worse currently. Inhaled particulate matter (PM2.5) in the body can cause diseases such as asthma, bronchitis, and endanger people's health [1]. Air filtration is one of the most effective ways to diminish this problem, in which the air filter materials are focused. The traditional air filter materials are composed of fine fibers or some porous materials, which mainly capture dust particles by means of blocking, inertia and diffusion. But most of the air dust (the nicotine in cigarettes, quartz and glass fiber in industrial dust, asbestos and all kinds of piezoelectric ceramic dust etc.), viruses and bacteria are particle of sub-micron or nanometer size. To achieve higher filtering efficiency, the traditional filter materials usually adopt inspissated or thick structure, which greatly increases the air resistance, leading to poor permeability and bad usability [2].

The electret air filter material has the characteristics of loose structure, large dust holding capacity, high filtration efficiency, good chemical resistance and crease resistance. Beside the traditional dust trapping way, the electret filter material can absorb dust particles by electrostatic force, which improves filter efficiency of tiny particles and has little effect on air resistance. It can reduce energy consumption of the filter and prolong the service life. Besides, it has sterilization and bacteriostasis function at the same time, showing unique advantage in the field of medical and health, biological pharmaceutical industry, food processing, clean of hotels, families and public places [3-6].

Most study on the electret technology of air filter material before are theory study, which has little practical application meaning in terms of industrialization. Based on researches of traditional electret technology, this study adopts polling method of high voltage to polarize the air filter material on-line continuously. The influences of grid electrode and the twice poling method on filtering properties and charge storage are studied, which has some reference value on application and production of electret air filter material.

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2. Experiment

2.1. Materials and equipments

Materials: needle punched non-woven air filter (made from fibrillation fiber), self made in Shenzhen Selen Science & Technology Co., Ltd, Shenzhen. Grammage 90g/m^2, fiber's average diameter 25μm.

Equipment: high voltage dc power, DW-SA503-1ACF1, -50KV～+50KV, Tianjin Dongwen High Voltage Power Supply Corp.; High voltage poling device, Shenzhen Selen advanced materials science research institute co. LTD, shown in figure 1. Automatic filter material tester, Certi Test 8130, TSI Precision Measurement Instruments company; Fabric permeability tester, YG461DA, Wenzhou Fangyuan Instruments co., LTD. Fabric moisture permeability tester, YG501D, Wenzhou Fangyuan Instrument co., LTD. Electrostatic field tester, Kleinwachter efm-023, German knavoat.

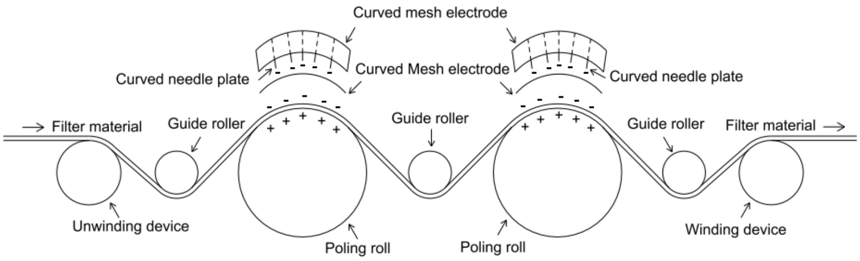

Figure 1 High voltage poling device

2.2. Experimental method

High voltage poling method: the air filtration material is first unwound by the unwinding device, and then pass through the first poling roller and the second one, and then pulled by the guide roller into the winding device, last the filter material is packed and set aside.High voltage dc power supply is connected to the poling pad, and static generating needles is distributed evenly on the pad, forming a strong and uniform electric field with the grounding roller. When the air filter material gets poling, corona happens in the air near to high voltage needles, where the air gets ionized and start to partial discharge. Part of the carriers deposit to the sample surface under electrical field, the others go through the deep surface and captured in traps. As the material passes through the poling roller, it is evenly polarized so as to make it electret air filter material of high efficiency and low resistance [7]. The output and direction of the voltage can be adjusted by high voltage dc power supply, and the once poling and twice poling can be controlled by the supply switch. The poling mechanism is shown in figure 2 below.

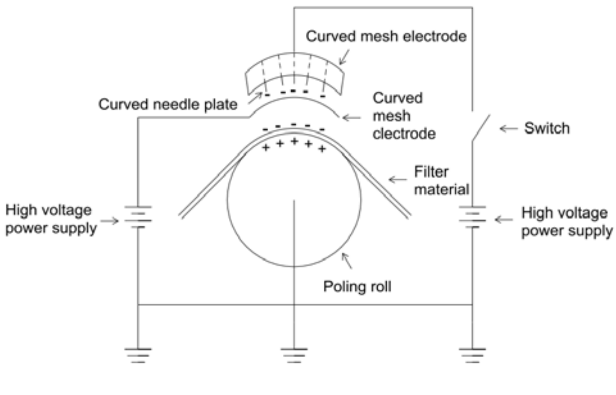

Figure 2 The poling mechanism

2.3. Test and analysis

Filtration efficiency and airflow resistance: the automatic filter material tester, respectively (GB/T 2626-2626 "respiratory protective equipment Self-priming prevent particulate respirator filter type "and GB/T 19083-2010" medical respirator technical requirements "testing filtration efficiency of filtering material and air resistance. The gas flow is 30L/min with 0.3 μm of NaCl particles. Test environment: preprocessing 48 hours in a clean room environment (22.0±3℃/ RH 50±5%).

Breathability rate: using the fabric breathability tester, test the permeability of the filter material according to GB/t54556-1997, the Measurement of the Breathability of Textile Fabric. Test pressure is 200Pa.

Moisture permeability: the moisture permeability of the filter material is tested according to GB/T 12704.2-2009, Test Method of Moisture Permeability of Textile Fabrics.

Charge storage stability: using the Kleinwachter EFM-023 electrostatic field tester of the German knavorots company, test the charge storage stability of the filter material. The test distance is 20mm. Change of surface electrostatic potential is measured after preprocessing of 24h, 7d, 28d and 90d respectively.

3. Results and analysis

3.1. The poling parameter research

After the preliminary experiments, some parameters such as charging voltage (A), distance (B), temperature (C) and speed (D) are selected as factors of orthogonal experiment design. According to the experimental equipment and poling parameters, each factor has four levels respectively. The poling voltage is the output of the high voltage power supply which is connected to the poling pod. The charging distance is the average distance between the material surface and the needle tips. The charging speed is rollers' speed in the process of poling. The temperature is pretreatment temperature in an infrared drying tunnel before poling, processing time for 10 min. The factors and the parameter levels are shown in table 1.

Table 1 The factors and the parameter levels

Level	A / -kV	B / cm	C / ℃	D / (m/min)
1	4	0.5	20	3
2	8	1	40	6
3	12	2	60	9
4	16	4	80	12

To ensure that the sample can actually reflect the overall situation, a blank column was added and a L16 (4^5) table was designed for the orthogonal experiment. The surface electrostatic potential and filtration efficiency of the 16 samples were measured under different poling parameters. The orthogonal experiment table and the obtained results are shown in table 2.

Table 2 The orthogonal experiment

Sample	A	B	C	D	E Blank	Surface potential（-V）	Filtration efficiency（%）
1	1	1	1	1	1	412	80.22
2	1	2	2	2	2	650	83.42
3	1	3	3	3	3	818	84.79
4	1	4	4	4	4	486	82.05
5	2	1	2	3	4	1383	87.87
6	2	2	1	4	3	1019	86.49
7	2	3	4	1	2	773	84.45
8	2	4	3	2	1	814	85.00
9	3	1	3	4	2	1588	89.58
10	3	2	4	3	1	1800	93.01

11	3	3	1	2	4	1406	88.89
12	3	4	2	1	3	978	86.16
13	4	1	4	2	3	1021	86.50
14	4	2	3	1	4	869	85.47
15	4	3	2	4	1	937	85.81
16	4	4	1	3	2	1117	86.51

Table 3 Numerical analysis of electrostatic potential

	A	B	C	D
K1	2366	4404	3954	3032
K2	3989	4338	3748	3791
K3	5772	3834	3889	4818
K4	3944	3295	4080	3830
k1	591	1001	939	758
k2	947	1084	937	948
k3	1368	958	972	1204
k4	984	824	1020	958
R	777	260	83	446

Table 4 Numerical analysis of filtration efficiency

	A	B	C	D
K1	330.48	344.16	342.12	336.30
K2	343.79	348.39	343.26	343.80
K3	357.64	343.94	344.83	352.18
K4	344.30	339.72	346.01	343.93
k1	82.62	86.04	85.53	84.08
k2	85.95	87.10	85.81	85.95
k3	89.41	85.98	86.21	88.04
k4	86.07	84.93	86.50	85.98
R	6.44	2.17	0.97	3.97

Among them: Ki - sum values of ith level under this factor;
ki -average value of Ki;
R - range, R = kmax - kmin.

Seen from table 3 and table 4, the maximum rang of the surface potential and filter efficiency was in the charging voltage column, showed that voltage is the most significant factor, followed by the charging speed and distance, and the influence of the temperature minimum. As can be seen from table 2, when the parameters came to A3B2C4D3 combination, the surface reached the lowest (-1800v), while the filtration efficiency measured was the maximum value (93.01%) at the same time. Namely under this condition, the selection voltage - 12 kV, the speed 9 m/min, temperature 80 °C,and the charging distance 1cm are the optimal parameters to obtain higher surface electrostatic potential and filtration efficiency. It can be seen from table 2 ~ 4 that there is a positive correlation between the filtration efficiency and the surface electrostatic potential.

In some degree, the electrostatic potential of the filter material increases with the increase of the charging voltage. When the charging voltage exceeds a certain value, the air medium between the charging voltage and the filter material is breakdown, resulting in the escape of electrostatic charge and the reduction of the surface electrostatic potential. It also occurs when the charging distance is short. Therefore, when the distance is 0.5 cm, the filter material does not obtain higher surface electrostatic potentials. In this experiment, although poling is in a very short time (less than 10 s), the surface electrostatic potential has not reduced with increasing charging speed, but an increase trend before downward. In a very beginning of poling, charge in the materials quickly reaches saturation. Further poling is likely to make the medium breakdown, leading to a drop in the surface electrostatic charge [8].

3.2. Study of the grid electrode

When the parameters was the same as $A_3B_2C_4D_3$ (sample 10), a grid electrode was added to the premier equipment and sample17 was prepared after poling. The surface potential and the filtration efficiency were tested, and the results were shown in table 5.

Table 5 The surface potential and the filtration efficiency of 10th and 17th samples

Sample	Grid electrode	Surface potential（-V）					Filtration efficiency（%）				
		1	2	3	average	variance	1	2	3	Average	variance
10	N	1757	1809	1851	1800	1510	92.94	91.65	94.45	93.01	1.31
17	Y	1866	1909	1814	1863	1132	94.31	93.67	95.42	94.47	0.84

It can be seen from table 5 that when increasing the grid electrode the surface potential of the filter material is larger than that of the ungrid, and its variance is much smaller than that of the latter. This indicates that the presence of the grid electrode not only improves the surface electrostatic potential, but also helps the filter material obtain a uniform and stable one. This may be due to the electric field produced by needle tips is not evenly distributed between medium. Also static charges in different places obtained from air are not uniform, but the grid electrode can make the field distribution more uniform, thereby improving the surface electrostatic potential and the filtration efficiency[9].

3.3. Study of single poling and twice poling

On the basis of sample 17, the differences between single time poling and twice poling on the surface potential and filtration efficiency of the filter material are studied. As shown in table 6.

Table 6 Influence of poling time on the surface potential and filtration efficiency

Sample	Poling time	Surface potential（-V）					Filtration efficiency（%）				
		1	2	3	average	variance	1	2	3	Average	variance
17	1	1866	1909	1814	1863	1132	94.31	93.67	95.42	94.47	0.84
18	2	2054	2023	1989	2022	704	95.62	94.43	95.47	95.17	0.12

From table 6 surface electrostatic potential of the filter material after twice poling was obvious higher than that of single time poling, so was the efficiency. It shows that the twice poling method helps electret air filtration material make a higher surface potential, and contributes to the preparation of filtration material with higher efficiency.

3.4. Comprehensive performance

For electret air filtration material in sample 18, some comprehensive performance was tested, including filtration efficiency, air permeability, moisture permeability and the charge storage stability and so on. The results are shown in table 7 and table 8 below.

Table7 The filtering and some other performances

Sample	Surface potential （-V）	Filtration efficiency （%）	Air resistance （Pa）	air permeability （$L/m^2.s$）	moisture permeability （$WVT(g/m^2\cdot 24h)$
18-1	2054	95.62	26.3	1784	886
18-2	2023	94.43	28.9	1871	865
18-3	1989	95.47	27.2	1829	867

Table 8 The charge stability of the filter material

Sample	The surface electrostatic potential （-V）				
	0h	24h	7d	28d	90d
18-1	2054	1860	1700	1680	1654
18-2	2023	1854	1714	1654	1629
18-3	1989	1834	1712	1644	1638

From table 7 and table 8, the attenuation of surface charge mainly occurs in the initial stage of storage (7 d), and then remains almost the same. After poling process, the surface and the inner surface of the electrets material are charged with space charge and polarized charge. Under the influence of the environment (temperature and humidity), the space charge reduce gradually, while the polarized charge will be stored in the filter material. It leads to a downward trend of the surface electrostatic potential. For the high voltage electret, the charge is mostly concentrated near the surface of the fiber, forming the space charge distribution. In the initial period of charge attenuation, the charge density in the surface is very high. As the humidity in the air increases, the charge decays. However, the polarized charge has been stored in the filtration material basically unchanged[10].

The electret air filtration material prepared under optimal conditions in this study has high filtration efficiency, low flow resistance, excellent air permeability and moisture permeability, and good charge storage performance. It can be applied to personal respiratory protections, air filter, vacuum cleaners, motor air purification, indoor air purification and other fields. And with the deeper research and development of the filter material, its application in the field of air purification will be more extensive.

4. Conclusion

(1) The surface electrostatic potential of the air filtration material is related to the charging voltage, distance, speed and temperature. Orthogonal experimental results show the charging voltage is the most significant influence factor, followed by the charging speed and distance, and the influence of the temperature minimum.

(2) The filtration efficiency of the air filtration material presents a positive correlation with the surface electrostatic potential.

(3) Adding a grid electrode helps the air filter material gain uniform and stable surface electrostatic potential.

(4) Twice poling contributes to the higher surface electrostatic potential of the air filter material, which is conducive to prepare the filter material with higher filtering efficiency.

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