Collection performance of charged filters and estimation of charge distributions

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Abstract

Electrically charged filter media have been commonly used for dust respirators because they have high collection efficiency at a low-pressure drop compared to mechanical filters. Recently, Kimura et al. (2004) have developed a new type of RWF which retains a high charge density and persists organic droplet challenge. The RWF media have been successfully applied to dust respirators. RWF consists of merino wool fibers, polyester fibers, and impregnating p-t-butyl-phenol-formaldehyde (PTBP) resin particles, so that the detailed local charge distribution of RWF and their effect on the collection efficiency are not yet well understood.

The charge density is estimated by applying prediction equations of single fiber collection efficiencies of electret filters with a dipolar charge distribution. The prediction equation of collection efficiency for uncharged particles is applicable to RWFs without the consideration for the effect of diffusion. However, the prediction of collection efficiency for charged particles is not applicable becasue the induced force prevails over the Coulombic force even for charged particles with small size. These results are shown that the additivity of capture mechanisms does not hold in the collection efficiency of charged filter with high charge density.

The charge distribution of RWF was studied by observing the deposition sites in RWF by using negatively/positively charged particles with a known size and a known number of electrical charges. As a result, it is found that the induced force prevails over the Coulombic force for singly charged 0.3-μm particles so that the particles with unit positive charge deposit on the surface of positively charged wool fibers.

The RWFs have no concerned with resin mass fraction for the formation of the initial electric field on them. However, the resin mass fraction is important in the stability of the initial charge against such a particle loading because the resin particles discharge to the filter fibers by liquid aerosol spreading on them as particle loaded on filter fiber.

In initial collection efficiency due to induced force, the densely packed charged filters have the electrical interaction inter-fiber. Consequently the induced force is so strong that it

dominates the collection of particles even for singly charged particles. As these results, it can be found that why the additivity of capture mechanisms does not hold in the collection efficiency of charged filter with high charge density.

1. Initial collection performance of RWF and estimation of charge density.

The initial collection performances of RWFs are measured for various particle sizes (0.03~0.3 μm) with different charging states at various filtration velocities (0.05~0.5 m/s). The initial penetrations through RWFs are extremely lower than those of conventional electret filters at the same pressure drop. Therefore, the RWF studied in the present work can achieve high collection efficiency at a low-pressure drop, satisfying the requirement of filter media for respirators. The prediction equation of collection efficiency for uncharged particles is applicable to RWFs without the consideration for the effect of diffusion. The estimated initial charge densities of three types' RWFs are showed that their initial charges are adjustable by impregnating various reagents. The estimated charge density on RWF fibers is much higher than those of conventional electret filter media. However, the prediction of collection efficiency for charged particles is not applicable becasue the induced force prevails over the Coulombic force even for charged particles with small size. These results are shown that the additivity of capture mechanisms does not hold in the collection efficiency of charged filter with high charge density.

2. Charge distribution of fibers in RWF.

The charge distribution of new-type PTBP-resin wool filter was investigated by observing the deposition sites in RWF by using negatively/positively charged particles with a known size and a known number of electrical charges. Furthermore, the particles size effect on the interaction between Coulombic force and induced force in collection is discussed through the results of selectiveness in deposition site in RWF. As a result, the polyester fibers and resin particles adhering on the polyester fibers are charged negatively while the wool fibers retain positive charge. For resin particles adhering on the wool fibers, some resin particles are negatively charged and that some of them are polarized by the charge of wool fibers. Furthermore it is found that the induced force prevails over the Coulombic force for singly charged 0.309-μm particles so that the particles with unit positive charge deposit on the surface of positively charged wool fibers.

3. Stability of Charge in RWF with DOP challenge

To investigate the stability of charge density with particle loading, the penetrations of particle were measured on RWFs loaded with DOP particles, further, the charge densities of the RWFs were estimated. As a result, it is found that the mass fraction of the resin particles on RWF were not effective to their initial collection efficiencies, however, the mass fraction play an important role in the stability of charge on RWF against DOP challenge. It is quite concluded that the resin mass fraction in RWF is most of important key for design of RWF.

4. Additibity between Mechanical and Electrical collection mechanisms

Based on the measured collection efficiencies of various charged filters (RWFs, loaded RWFs, and BMFs), the relationship between various capture mechanisms contributed to collection efficiency was discussed. The effects of charge density on fiber and packing density in the electrical interaction inter-fiber are discussed. The additivity between collection mechanisms does not hold in charged filter with high charge density because the collection is not depends on most of tested particle size. Although their collection depends on particle size, the decrease of Coulombic force effect to the collection is as a logical consequence because induced force effect is very high and close to that due to Coulombic force, when the filter have either high charge or packed densely.

学位論文審査結果の要旨

平成 18 年 2 月 3 日に口頭発表と質疑応答を行い、その後に開催した学位論文審査会において以下のように決定した。

本論文は、作業環境用マスクなどに用いられる帯電フィルタの一種であるレジンウールフィルタ（RWF）の捕集機構について検討したものである。RWF は羊毛繊維とポリエステル繊維を混合してフェノール系樹脂粒子を添着したフィルタで、捕集効率が高く、圧力損失の低いフィルタとして知られているが、その捕集機構、帯電状態は不明な点が多かった。本論文では、まず、粒径、帯電量の異なる粒子をフィルタに通して初期粒子捕集性能を評価し、繊維帯電量を測定することにより、従来の分極電荷を有するエレクトレットフィルタより繊維の電荷密度が極めて高いため、粒径 40nm 程度の微粒子まで誘起力によって捕集されることを示した。そして、帯電極性、粒子径の異なる粒子をフィルタに通して繊維に沈着させ、それら粒子の付着状態を観察することにより、羊毛繊維は正、ポリエステル繊維は負に帯電し、レジン粒子は主として分極電荷を有していることを明らかにした。

以上のとおり、本論文は、RWF の粒子捕集機構、帯電状態を明らかにしたもので、今後、さらに高性能な静電気フィルタを開発する上で重要な知見を与えており、博士（工学）の学位を授与するに値すると判断する。