Properties, charging processes and depositions of particles in electrostatic filtration systems

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Abstract: Due to a growing environmental awareness the application of high voltages in environmental technology, in particular of high d.c. voltages, is becoming more and more important. The application this paper deals with is the process of electrostatic air filtration. Electrostatic precipitators (ESP) share one common feature: particles are charged and attracted by electrical forces, they are led to a collecting electrode. This separation of charged particles in electrostatic fields represents a simple and very efficient possibility of filtering the air. The field of application of electrostatic filters comprises medical engineering, tunnel exhaust cleaning, gas cleaning in industrial plants and room air cleaning. A new interesting field is the particle filtering of diesel exhaust fumes, where different methods and technologies are applied. Therefore this paper deals with basics of particle qualities and the qualities of bio-aerosols, viruses and fungus cultures are presented as well. A further field this paper deals with is the charging process and deposition of particles in electrostatic filtration systems, referring to the size, electrical agility and health risk of particles.

1 INTRODUCTION

ESP processes are based upon the basic use of electrostatic forces to move position and deposit small particles. The charge and forces on a particle strongly depends upon the particle size and shape.

A dark horse in the field of electrostatic filtration systems is the behaviour of organisms in ESP's. There are several products which deal with the filtration of bacteria's, pollen, spores and viruses but there isn't any concrete research on the analysis of the behaviour of these micro organisms. This paper deals with the basics of those particles and shall be a cornerstone for the work on electrostatic filtration systems for micro organism.

In our environment a lot of micro organisms have different useful features. But some of these organisms can cause bad diseases. The duty is very interesting under the aspect of all the different applied sciences like micro biology, organic chemistry, electrical engineering and process engineering as well.

2 AERODYNAMIC AND STOKES DIAMETER

Particles which are carried in the air have different shapes and forms. Due to this reason there can not be any analogy done, therefore one has to affiliate models in which the particle size can be converted in equivalent globe diameter. To act on the assumption that the settling rate of the models will be the same settling rate of the particles. First of all you have to consider the unshaped particle with its own density. Now one can assume that a globe, with the same settling rate and same density has the relevant diameter (Stokes Diameter). According to the aerodynamic diameter you have to consider the density as well as the unit density.

To get the settling rate you have to equate the gravitation and the friction:

$$F_D = F_G = m \cdot g \qquad (1)$$

Exchange the mass by volume and density of a particle.

$$3 \cdot \pi \cdot \eta \cdot \vec{u}_p \cdot d_{st} = \frac{(\rho_p - \rho_g) \cdot \pi \cdot (d_{st})^3 \cdot g}{6} \qquad (2)$$

And by converting you'll receive the settling rate.

$$v_{TS} = \frac{\rho_p \cdot d^2 \cdot g \cdot C_c}{18 \cdot \eta} \qquad (3)$$

With C_c as the Slip- or Cunningham – Revision Factor. Due to the import of the Slip- Factor the application of the equation widened also for particles of the size smaller than 1µm.

For this reason you get two diameters:

- Stokes Diameter (d_{st}): The diameter of a globe with the same density and the same settling rate as the considered particle.
- Aerodynamic Diameter (d_{ae}): The diameter of a globe with the same settling rate as the considered particle but with the unit density $\rho_0 = 1\frac{g}{cm^3}$.

Thus you receive the possibility to compare particles with different forms and shapes and different density.

$$d_{ae} = d_{st} \cdot \sqrt{\frac{\rho_p}{\rho_0}} \qquad (4)$$

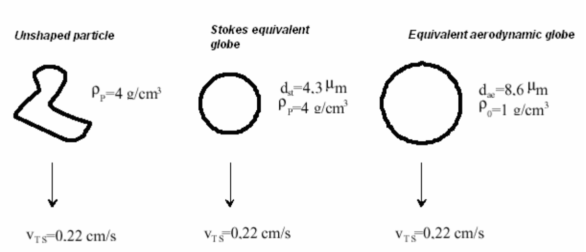

Fig. 1 Stokes- and Aerodynamic Diameter

3 ELECTRICAL MOBILITY

In an electrical field E, a particle with n fundamental charges adept an electrostatic force:

$$\vec{F}_E = n \cdot e \cdot \vec{E} \qquad (5)$$

Due to this electrostatic force the particle will be accelerated to a final velocity v_p. After the particle receives this velocity there will be a balance of forces between the electrostatic force F_E and the resistibility F_W.

$$\vec{F}_E = \vec{F}_W \qquad (6)$$

Due to the surrounded gas medium there shall be the resistibility F_W affecting on the particle because of the Stokes law,. The force affects towards the relative speed between the movement of the gas medium and the speed of the particle.

$$\vec{F}_W = \frac{(3 \cdot \pi \cdot \eta \cdot \vec{\nu}_p \cdot d_{st})}{C_c} \qquad (7)$$

The Slip – Factor was developed by Cunningham to ease the calculation with particles smaller than 1µm so that you can still use the Stokes Law. This revision factor is very important in that case when the particle size is decreasing and the collision of the particles with gas molecules is becoming more and more influence on the particle movements.

$$C_c = 1 + \frac{\lambda}{d_{st}} \cdot \left[2{,}514 + 0{,}8 \cdot e^{(-0{,}55 \cdot \frac{d_{st}}{\lambda})} \right] \qquad (8)$$

By an ambient air temperature from 20°C and a pressure from 1atm (normal terms and conditions) the middle free path length of the gas molecules will be $\lambda = 0{,}066\mu m$.

The electrical mobility is defined as the relationship between the relative speed to the electrical force.

$$Z_p = \frac{\nu_p}{E} \qquad (9)$$

$$Z_p = \frac{n \cdot e \cdot C_c \cdot d_{st}}{3 \cdot \pi \cdot \eta \cdot d_{st}} \qquad (10)$$

When you equate the electrostatic force with the friction force you will get the settling rate.

$$\vec{F}_E = \vec{F}_W \qquad (11)$$

4 BIO AEROSOLS

The discovery of micro organisms goes back in the 16th century. In principle bio aerosols are not limited on bacteria's. They also can be composed of organic components, viruses, algae's, pollen but in general they are air based micro organisms [3].

Inorganic aerosols like fume, smoke or industry dust can be characterised by qualities like size, mass and conductivity. By contrast bio aerosols are composed of living micro organisms. Their biological attitude like metabolic activity, cultivable activity and their biological affect on humans and environment shall be considered as well [1].

Table 1 Particle diameter

Particle	Aerodynamic diameter
Virus	0,02-0,3µm
Bacteria	0,2-10 µm
Bacteria spores	0,5-1,5 µm
Fungus cell	10 µm
Fungus spores	2-8 µm
Moss spores	5-30 µm
Fern spores	20-60 µm
Pollen	5-250 µm

Aerosols are solid and liquid particles in the air with a diameters range from 0,001 - 100µm. Their effects on breathing organs are in the centre of inspection. Bio aerosols result from dispersion of solid and liquid matter. The basis of their description lays in their density, electrical properties, particle size distribution and their hydrophobic attributes. Main sources for aerosols are micro organisms which are growing on animals, plants and their out coming products. Another main source for parasites and micro organisms are water surroundings.

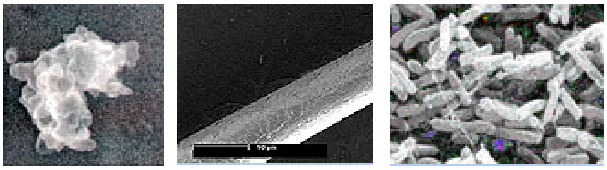

Fig. 2 Examples of aerosol particles: aerosol particle, human hair, bacteria

4.1. Diesel particles

The particles are composed of microscopic carbon globules with a diameter from approximately 0,05µm on which hydrocarbons accumulate and attach. Water and sulphates generate on the surface as well. The measured particles in the flue gas stream have a diameter of 0,09µm.

Particles from the flue gas stream can cause cancer. The microscopic small unburned carbon particles reach across the respiratory tracts to the lung. When one takes a breath the smallest of the particles can go across the respiratory tracts into the alveolus. Till then most of the "bigger" particles like dust, pollen and bacteria's are filtered out by the mucous membrane in the nose and the cilia in the bronchia. A bigger amount of particles can result cancer and genotype affliction for people that are weak, old and in a bad state of health.

5 ECOLOGY OF THE MICRO ORGANISMS

Bacteria's were the first organisms in the evolution. Therefore all higher organisms, which were developed afterwards, have to fulfil the assumption that these organisms will survive and grow in the presence of the bacteria's. That means that there was no time during the evolution in which the organisms didn't live together with the bacteria's [2].

For this reason all higher organisms have developed special mechanisms to stand against bacteria's. There are several sources for the growing and surviving of the bacteria's.

5.1. C-, N- sources, mineral nutrients

For the growing of most of the bacteria's there must be a certain specific organic carbon source. Alongside there must be mineral nutrients as well. The ideal percentage of C to N to P should be approximately 100:5:1.

5.2. Temperature

Micro organisms are growing in a temperature range from 0-110°C. Bacteria's, which show ideal growth by room temperature, are called psychrophil or cryophilic, if they are growing in a temperature range from 20-42°C they are called mesophil. Thermo tolerant organisms are growing up to 50°C. Thermophil bacteria's are growing in a range from 40°C to approximately 55°C. Extreme thermophil organisms are growing in the temperature range between 55-80°C.

5.3. Water

Micro organisms are quite different in their need of water. To compare the available water one uses the term of "water activity" (a_w). The water activity shows how much water is in a steam room associated to an assay compared to pure water. That means that a_w is always smaller than 1. Micro organisms are growing well by an a_w between 0,998 and 0,6.

5.4. Oxygen

Strict aerobe bacteria's are quite reliant on oxygen. There will be no growth without oxygen. But the most of the aerobe bacteria's will survive without any oxygen. Strict anaerobe bacteria's are growing only without any oxygen. Most of this bacteria's oxygen will be toxic and they will die by the presence of O_2.

6 TOTAL MICROBIC COLLECTION (TMC)

The basic principle for the TMC is the generation of ions. Therefore the next picture will show you the procedure for ion generation. Ions are atoms which have won or lost electrons. If an atom wins an electron there will be a new negative ion, when an atom losses an electron it will be a positive ion. The creation of the ions and their neutralisation via "ionic change" is a basic electrical rule which takes place everyday all day long among us and it is a living part of our metabolic life.

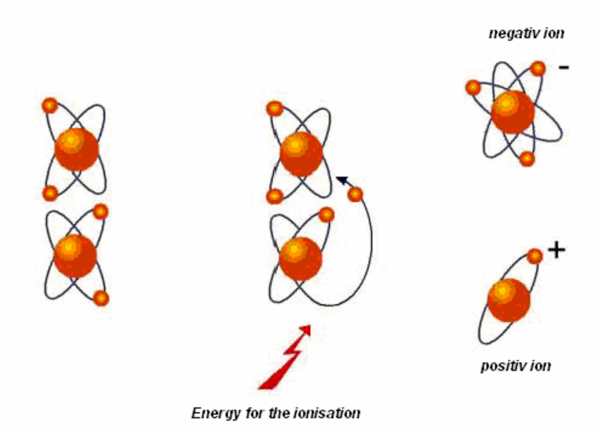

Fig.3: Procedure of the ionization

The effect to dispatch microbes is produced by the electrostatic filtration system; there is one common instance: the micro organisms will attach very powerful to dust which has a diameter between 5 and 0,5pm. The dust goes through the ESP and will be charged by free-electrons. Due to this reason the microbes will be dispatched by a physical action: electrification. The phase of ionisation in the ESP is capable to provide a quantity of energy from 6eV this energy is enough to destroy the cell membrane of the microbes [4]. This however is not the only reason of the global and dispatch effect of the ESP system.

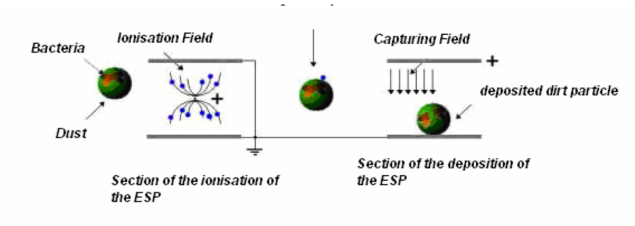

Fig.4: Interaction between dust and bacteria

The dispatch effect of the ESP can also be explained by the fact of the ionisation in the air. In this case the linkage of the oxygen molecule will be destroyed and it comes to the generation of the free oxygen O^{--} . This free oxygen in gaseous state has also a dispatch effect on bacteria's.

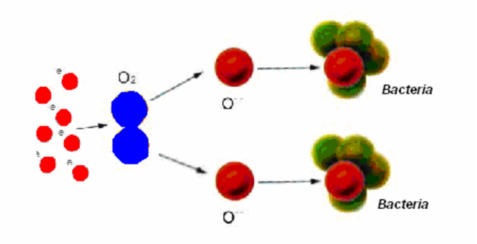

Fig.5: Interaction between Oxygen and bacteria

7 SUMMARY

The effect to dispatch microbes is produced by electrostatic filtration systems (ESP) . It is very important to know more about the life cycle of all the different organisms. It is also known that the different bacteria's have different properties and that these properties play a significant role in the dispatch effect of the ESP's. One the one hand the required energy for collision ionisation processes is in the range between 10 eV - 25 eV. On the other hand results of investigations show that the energy of 6 eV is able to destroy the cell membranes. Therefore one can assume that microbes can be destroyed and dispatched by an ESP. But it is necessary to focus the further investigations on the electrical properties of the particles and their behaviour under different electrical fields and forces.

8 REFERENCES

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