Advance in Bioaerosol Removal Technologies; A Review

Ahmad Jonidi Jafari[1], Roohollah Rostami[2], Gholamreza Ghainy*[2]

1) Center for environmental health technology, and Department of environmental health engineering, School of health, Iran University of medical sciences, Tehran, Iran.
2) Department of environmental health engineering, School of health, Semnan University of medical sciences, Semnan, Iran.

Corresponding author's : ghaeny@gmail.com

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ABSTRACT
Bioaerosols are air pollutants that affect human health in various routes. They are characteristically diverse; such as bacteria, viruses and fungi, that everyone has different characteristics and effects, various solutions and technologies are studied or applied for their removal and inactivation. Regarding to lack of specific and integrated publications about the different air quality guidelines for bioaerosols and the methods and technologies, attending to approach the standards, purpose of this study was set on the development of the issue.
The importance of presence of bioaerosols in breathing air and related standards and guidelines, also controlling technologies such as filtration, ultraviolet (UV) radiation, photo catalyst, temperature and electrostatic precipitators were surveyed in this study by using the scientific literature.Given the results, UV irradiation and photocatalytic methods are ineffective for allergens. In this way, filtration is unable for inactivation of the bioaerosols, then there is the threat that they can aerosolize again. Hence, these technologies individually cannot provide the air quality standards which have established for sensitive conditions such as operation rooms.
Regarding the discussions, application of the methods that include collection and inactivation of the bioaerosols simultaneously, such as electrostatic precipitators, could be more effective in the likewise environments.

Key words: Air Pollution, Air Quality, Bacteria, Virus, Fungi

INTRODUCTION
Health and air quality play a key role in human health and quality of life, because each person daily breathes 12000-14000 litres of air [1]. On the other hand, natural or artificial factors such as dust, bacteria, fungi, soot, carbon monoxide, sulfur anhydride, and many other pollutants can cause the air pollution [2, 3].
Microorganisms, which are considered as the natural pollutants, can enter the human body through breathing and cause the infectious diseases, allergies, skin complications, and associated diseases. For the lack of nutrients, adequate moisture, inappropriate temperature, and a sunlight effect, the air is not an appropriate environment for growth of microorganisms, but is a suitable environment for transmission [1, 4]. Earlier studies have shown different biological factors in the environment air [5], but the standard levels of many of these factors cannot cause a problem for the normal people. Thus, the microorganisms in the air can be dangerous for health in some conditions such as:
For susceptible people, such as patients or people with weakened immune system, children, and elderly
Inpatient centers of patients with injuries such as hospitals and operating rooms
Pathogens with high risk of morbidity in the air, such as laboratories or the epidemic cases
Places such as landfills
In a general definition, the biological factors in the air are among the bioaerosol. According to the definition, bioaerosols including the pathogenic or non-pathogenic dead/alive bacteria, viruses, fungi, mold, allergens with high molecular weight, bacterial endotoxin toxin, fungal toxin, peptidoglycan, plant fibers and pollens [6]. Bioaerosols can cause infection, disease, or allergic reactions. The most common microorganisms that cause the allergic reactions are the environmental bacteria and fungi. Mold and fungi almost constitute 25% of Earth's mass [7]. So the bacteria and fungi can be spread from various sources such as soil, humans, animals, and plants in the environment air [8-10]. Due to the features of each biological factor, various methods are explained and suggested for sampling and identifying the biological factors from the air, such as filtration and a variety of impinger methods that can be found in the relevant resources [11].
Microorganisms can be found abundantly in environments with large human populations with inadequate ventilation. Numerous studies conducted on this area have shown the biological factors even in

susceptible places such as hospitals and its different parts [12]. In such a way that in some cases, there are even some values higher than the recommended limits, and increase in bioaerosols has been considered associated with the increased duration of activity and concentration of people [13]. The presence of bioaerosols in the urban and rural streets air has been also under numerous studies, and there are reports of different types of pollution in these studies [5]. But at the height of 300 m from ground level, the small amount of bacteria is detected, and concentration of fungal spores in the air depends on the wind speed, temperature, humidity [14]. Distribution of spores in the air is an effective factor to cause different forms of disease in the people, especially those with weakened immune systems, because the fungi can be grown at body temperature and easily infect the susceptible people [7]. In some industries and places such as processing industry and waste recycling, as well as the processing and storage of agricultural products, the bioaerosols are regarded as major factors for air pollution [14-16].

Respiratory infections accounted for 50-60% of the common diseases [14]. It is found that diseases such as otomycosis, keratomycosis, chronic bronchitis, emphysema, asthma, can be caused through the airborne fungi [1]. Among the important allergens fungi that can be transferred from the air, Cladosporium, Penicillium, Aspergillus, Alternaria, Fusarium are mentioned [17]. Moreover, fungi create the mycotoxins such as aflatoxin as well as Microbial Volatile Organic Compounds (MVOCs), which causes the mimic sick syndrome. Some opportunistic fungi can also cause infections in certain conditions. Some of these infections are the aspergillosis, cryptococcosis presented in Table 1 [7, 18] . According to the mentioned doses and studies that have been conducted in the presence of biological factors in the air of different environments, the health organizations have provided the standards and guidelines for concentration of bioaerosols in different environments. Some of these standards have been shown in Tables 2, 3, and 4 [19-21].

Table 1. Infection dose of some pathogens by inhalation inoculation route.

Pathogen/disease	Infectious doses of microorganisms
Histoplasma capsulatum	10 (mice)
Mycobacterium tuberculosis, *Mycobacterium bovis*	10
Coxsackie A21 virus (Enterovirus)	18 or fewer
Influenza	>790
Bacillus anthracis	8,000-50,000
Q fever (*Coxiella burnetii*)	10
Tularemia (*Francisella tularensis*)	5-10
Adenovirus	>150
Respiratory syncytial virus	>100 -640

Table 2. Classification of air quality based on the concentrations of bioaerosols.

aEU-GMP	bFS209E	eISO	cUS. NASA)		EU GMP		dIMA
Grades	Classes	Classes	CFU/m^3	fS.P	CFU/m^3	S.P	S.P
A	100	5	3.5	0.6	< 1	< 0.25	0
B	100	5	3.5	0.6	10	1.25	5
C	10000	7	17.6	3.0	100	12.5	-
D	100000	8	88.4	15.0	200	25	25

a) European Union Good Manufacturing Practice; b) Federal Standard for air contamination by inert particles; c) National Aeronautics and Space Administration; d) Index of microbial air contamination; e) International Organization for Standardization; f) settle plates 9cm in diameter exposed to air for 1 h.

Table 3. Maximum acceptable levels of microbial air contamination in environments at risk

Risk level	Maximum acceptable level, IMA (S.P)	Environments at risk
Very high	5	Ultra clean rooms: reverse isolation; operating room for joint replacement; some procedures of the electronics and pharmaceutical industries
High	25	Clean room: conventional operating theatres, continuous care units, dialysis unit
Medium	50	Day hospital, hospital wards, food industries, kitchens
Low	75	Facilities

Table 4. Air quality guideline for sections of hospital

Section	Total microorganisms (CFU/dm^2.h)		
	Desirable	Acceptable	Unacceptable
Medical sections	0-450	4521-750	> 751
Surgery	0-250	251-450	> 450
Pharmacy	0-100	101-180	> 180
Noninfectious room	0-50	51-90	> 91
Operation room (at rest)	0-4	5-8	> 9
Operation room (at work)	0-60	61-90	> 91

According to standard values and risks of bioaerosols factors, the air quality control is one of the inevitable biological factors, and due to the different conditions and factors, various factors are used in this regard that will be investigated.

MATERIALS AND METHODS

Many publication form different scientific resources including Science direct, NLM, Iran Medex, SID and Springer were serached to find and compare the related publications about guidelines of bioaerosols and the removal technologies. The screaned references were assessed for inclusion and summarized. Finally, the selected literatures were classified and compared regarding the applicability and efficiency of the removal methods.

RESULTS AND DISCUSSION

The results driven form the study of different litterateurs are presented as follows;

Controlling technologies for bioaerosols

However, technologies such as incinerators are highly effective in removal of bioaerosols, but they are not much noticed in the cases that the air purification of bioaerosols is merely considered. In this regard, the filtration and the use of ultraviolet radiation are widely used. Numerous studies have been conducted on removal of biological factors from the polluted air using the absorption, high temperature, and strong magnetic fields, and some of which have been mentioned in this study.

Filtration

Filters are one of the most popular methods for removal of biological particles in the air. The filters are used in various equipment such as laboratory hoods to control the biological particles. According to Fig. 1, the filters have the appropriate capability for isolating the particles in the size range of bioaerosols [22-24].

Different filters are used to control various particles as well as different particle concentrations. Filters are classified based on particles with the greatest influence on the respiratory system, and accordingly, particles with diameters of 0.3 μ have been considered, for example, N95 filter is a filter that removes 95% of particles with diameters of 0.3 μ, and N100 Filter approximately removes 100% of the particles. These filters are used for oil-free flows. Thus, there are various categories of filters, of which R-series filters and P-series filters can be mentioned, so the R-series filters are for short-term uses, such as a working shift, and P-series filters are for long-term uses, and these two filter series can also be used in the air flows containing oil. For each filter, a coefficient entitled as the assigned protection factor (APF) is defined as Equation 1, where Co is the pre-filter pollution concentration, and Ci is the post-filter pollution concentration [18].

$$APF = \frac{C_0}{C_i}$$ Equation 1: Assigned protection factor (APF)

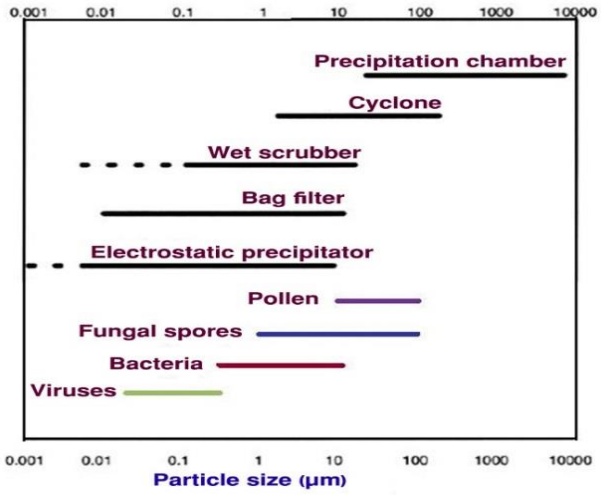

Fig. 1: Size range of bioaerosols and the ability for isolating the particles using various technologies for isolating particles from the air

HEPA (High Efficiency Particle Air) filters can also be used in these cases. Particularly that the efficiency of 99.99% is mentioned for removal of particles [24, 25]. However, the amount of isolation is not supplying the hazardous substances standards, known as Rule Six-Nine (efficiency of 99.9999%). The advantages of filters, including the simplicity in use, high reliability, and diversity. The disadvantages, including the corrosion, restrictions in use, and high pressure drop. However, one of the issues that should be considered in the use of filters is the activity of the microbial agents captured by the filter, resulting in the re-entrance of these agents in the air and further

pollutions. In order to overcome this problem, various solutions are used, including antibacterial agents such as some oils, metal nanoparticles such as silver nano particles on filters, and also the ultraviolet radiation to inactivate the microbial agents on filters.

The use of tea tree oil has a considerable impact in inactivating the bacteria agents such as *E. Coli*, *Pseudomonas* and *Bacillus subtilis*, so the inactivation efficiency of 99% for *E. Coli* and Pseudomonas is respectively reported at 8 and 2 min exposure time [26]. Also there are many reports for application of nanomaterials in the related publications, which are coated on the filters to enhancement of bioaerosol removal and their inactivation [27-30]. In the use of photocatalyst agents with negative charge in a mechanical filter, which is used with ultraviolet radiation at the wavelength of 365 nm and TiO_2 as a photocatalyst agent, the efficiency of 30-36% in removal of *E. coli*, 43-60% for Candida, and 69-93% for the phage alpha virus have been reported. The negative charge is also considered effective on removal of virus [31].

Ultraviolet radiation

Application of ultraviolet radiation to control biological factors is highly known and conventional, so that in the United States, it is the most widely used method to control the bioaerosols in the health centers. Microorganisms are susceptible to the ultraviolet radiation, especially at a wavelength of 254nm, because the wavelength has the maximum absorption for DNA. The mechanism is in such a way that after the collision of photons in the cell, their energy is absorbed by the nucleic acids. Energy absorption constitutes the pyrimidine dimers (Figure 2) and other killer products of cells. Formation of pyrimidine dimers causes a change in the DNA structure, mutation, and finally, death of the cell [32].

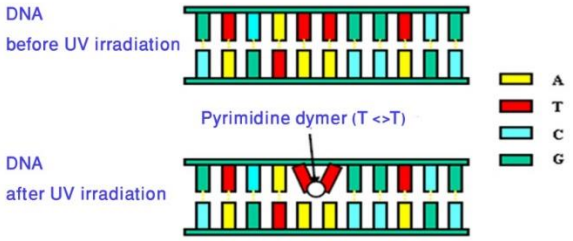

Fig. 2: Formation of pyrimidine dimers with absorption of ultraviolet radiation

Studies in this field indicated the susceptibility of all types of pathogenic bacteria to UV. According to studies, the humidity of air has a positive effect on survival of bacteria after exposure to UV. In the use of UV, there are various factors such as the intensity of radiation, distance from the lamp, exposure time, flow of air, and humidity of air to control the bioaerosols [20].

Although, it is suggested that all the pathogens are susceptible to UV, but the susceptibility is different. The susceptibility to UV is determined with an index called the susceptibility index to UV shown by the symbol Z. The value of Z is in fact the slope of the diagram, where the natural logarithm of the survival rate of bacteria is depicted against the radiation dose. The values of Z for some microbial species have been shown in Table 5. The higher values of Z-index show more susceptibility of the microorganisms to UV [32].

In use of UV, another index (SF) is also applied, which is calculated in Equation 2. In this equation, NUV is the average number of bacteria after exposure to radiation, and No is the average number of bacteria before exposure to radiation [32].

$$\boldsymbol{SF = \frac{N_{UV}}{N_0}}$$ Equation 2. Survival rate (SF)

Table 5: Susceptibility of microbial agents to UV in air

Microorganism	Z value (m^2/J)
Bacillus subtilis (spores)	0.0190
Bacillus anthracis	0.0510
Pseudomonas aeruginosa	0.5721
Serratia marcescens	0.2140
Micrococcus luteus	0.0120
Mycobacterium tuberculosis	0.4721
Staphylococcus aureus	0.9602
Escherichia coli	0.3759
Adenovirus	0.0546
Vaccinia	0.1528
Aspergillus	0.00344

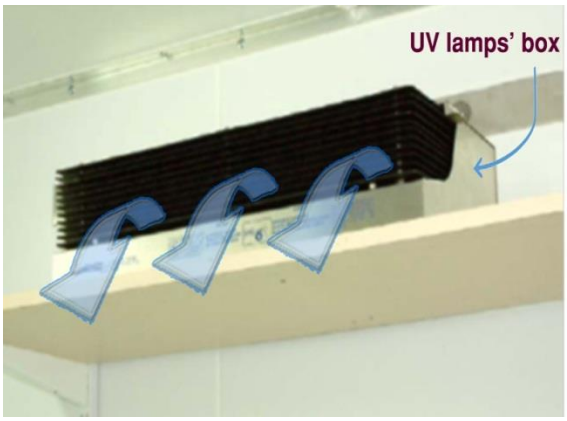

Fig. 3: A schematic of UV system for upper air of the room

Photocatalyst

By identifying the photocatalyst properties of materials such as titanium dioxide (TiO_2), and zinc oxide (ZnO), particularly at the nanoscale, many studies have been conducted in various fields as well as the removal of pollutants. In previous studies, there are numerous cases of photocatalyst factors in removal of bioaerosols that have been used in various methods to achieve the desired outcome [33, 34]. In an example of these studies, with use of TiO_2 on a transparent polymer in the normal room conditions, the bioaerosols are removed, and the results of this study indicated the competitive removal of pollutants using UVA against UVC, so that the removal is 68% using UVA with 15 watts of energy, and 76% using UVC with 16 watts of energy. The use of UVA has much less risk and cost than UVC. The results of this study indicated an emission of a lower amount of volatile organic compounds (VOCs) resulting from the removal of bioaerosols with use of UVA.

The effect of the photocatalyst in removal of bioaerosols has been known as cell membrane destruction, the loss of Coenzyme A by photochemical oxidation is also considered as mechanisms of the effect of these factors, causing a disturbance in the cellular respiration and death [35]. Production of hydroxyl radicals in the presence of the photocatalyst is effective in the cell membrane destruction [36]. Due to the high efficiency of the aforementioned process, the process has a relatively low efficiency about 30% in low concentration conditions with various microbial species. According to this study, the spore-forming bacteria species such as Bacillus as well as Staphylococcus hominis, Staphylococcus Pasteuri, and also the Acinetobacter species have been resistant against this process. No considerable efficiency has been seen in the removal of fungi [35]. Today, different studies have been conducted in increasing the photocatalytic activity, by adding impurity agents to photocatalytic or doping. Hence, in a study by doping the silver on TiO_2, the maximum removal rate of 93.5% for *E. Coli*, in the silver ratio of 7.5% to TiO_2, and air flow moisture of 60%, has been obtained under visible light stimulation. Presence of silver as impurities causes an increase in the electron holes, charge conduction between the valence band and the conduction band of TiO_2, which increases the reaction with water and oxygen molecules, and therefore, increases the production of oxidizing radicals. Finally, the reaction of these factors with organic compounds of bacteria cell would cause a death [34, 37]. Use of copper as a gross operating on TiO_2 in the same conditions and at a rate of 5%, has shown the removal efficiency of 87.8% [37]. Reactions of TiO_2 and silver in the aforementioned process are described as following [38].

$$\boldsymbol{TiO_2 + hv \rightarrow e^- + h^+}$$
$$\boldsymbol{h^+ + H_2O \rightarrow H^+ + \cdot OH}$$
$$\boldsymbol{e^- + Ag \rightarrow Ag^-}$$
$$\boldsymbol{Ag^- + O_2 \rightarrow Ag + O_2^-}$$
$$\boldsymbol{O_2^- + e^- + H^+ \rightarrow H_2O_2}$$
$$\boldsymbol{H_2O_2 \rightarrow \cdot OH}$$
$$\cdot OH + organic\ compounds\ of\ E.\ coli \rightarrow CO_2 + H_2O$$

Equation 3. Mechanism of photocatalytic effect on organic compounds of *E. Coli* cell

High temperature

One of the highly effective methods in inactivation of bioaerosols is the high temperature. The high temperature in a short time is effective on the fungal spores that are resistant to inactivation. Results of the studies indicated that the geometric mean of the diameter of spores is reduced in exposure to high temperature. By increasing temperature, a significant reduction in the concentration of 1-3-β-D-Glucan has been observed in spores. This material is composed of cell wall structure compounds which forms almost 60% of the fungal cell wall, and according to the studies, it plays a major role in updating the allergic symptoms caused by fungi. The 30% decrease in this compound at $700^{\circ C}$ is reported at the exposure time of 0.2s. It has been said that 99% of Aspergillus and Cladosporium spores during 0.2s at the temperature above $350^{\circ C}$ have lost the culture capability. As shown in Figure 4, the morphology of spore cell wall is changed by increasing the temperature [39].

This study has shown physical removal of *Aspergillus* spores at a temperature of 700 ° C equal to 48.6%, and lower temperatures such as 500 and 300 $^{\circ C}$, the smaller amounts of 28.4% and 15% has been obtained. The mean diameter of spores in this

study from 2.53 µ at 17 °C has reduced to 1.33 µ at 700 °C. According to the results, the reduced aerodynamic diameter, in one hand, increases the conduction of spores and higher penetration into the respiratory system. Researchers have found that at a temperature of 186 to 260°C, only the polysaccharides with low temperature resistance such as mannosamine hydrochloride, Galactoseamine hydrochloride, and N-acetyl glucose amine are destroyed, and destruction of other cell wall compounds such as Chitin-glucan, proteins and fatty acids is occurred in the higher temperatures range of 281-331°C, and 415 to 530 °C (40).

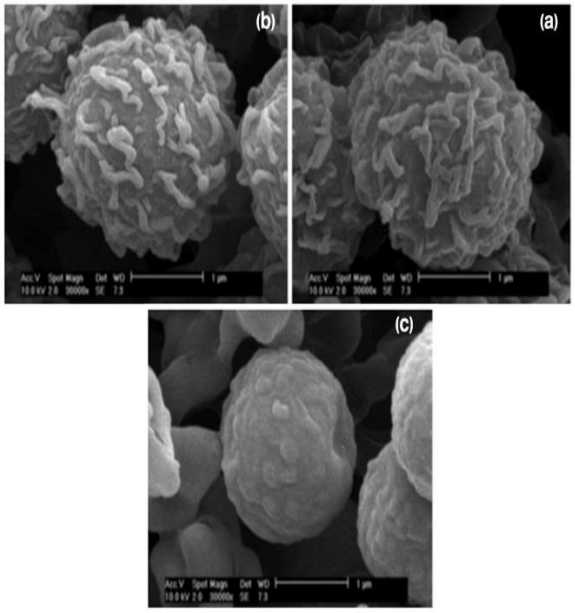

Fig. 4. Wall structure of Aspergillus spores at temperatures a: 20 °C, b: 400 °C, c: 700 °C

Adsorption on porous materials

One of the methods that has been studied in removal of bioaerosols is the use of porous materials in adsorption of bioaerosols on the surface of the material. In this regard, the granular activated carbon is used for removal of bioaerosols resulted from a wastewater treatment system. Absorption capacity of 2217 CFU/g for bacteria and 225 CFU/g for fungal spores had been under the air flow of 1.5 m^3/hr. This high removal efficiency has obtained 85% of the aforementioned bioaerosols. Most of the absorbed microorganisms have been in the size range of 4.7 to 0.65 µm. Results of the studies have shown the porous structure, high specific surface area, and hydrophobic properties in reinforcing the bioaerosols. For the carbon recovery, the method UV and high pressure vapor are used, and the use of high pressure vapor has achieved more favorable results. Fig. 5 shows the activated carbon before and also after the application to absorb the bioaerosols and after recovery by UV and high pressure vapor [41].

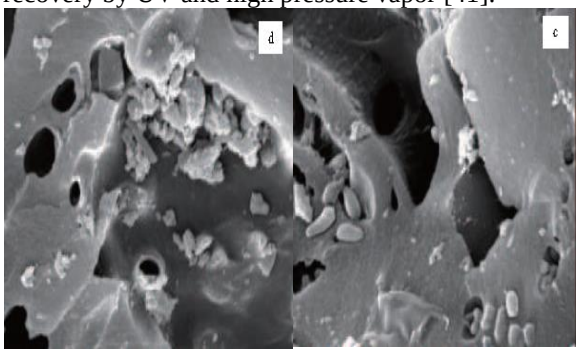

Fig. 5. Microscopic images of activated carbon. A: before use, B: after use, C: after UV recovery, D: after pressure vapor recovery

In use of UV for carbon recovery, for being far away from some microbial agents within the carbon seams, there will be a possibility for survival, as shown by the results. So that the inactivation efficiency of 91.53% for fungi, and 96.21% for bacteria is achieved after 20 and 60 min of UV recovery, respectively [41].

In addition to the activated carbon, other materials such as zeolite are also used, and the studies carried out with zeolite mesh of 20-40 in the removal of *Pseudomonas* have indicated the effect of flow and amount of zeolite used in the removal efficiency, and the reduction capability in the air microbial charge with microbial density of 105 per ml of air and 0.6 liter/minute during one hour of sampling has shown 20 bacteria [42].

Electrostatic precipitation

Electrostatic precipitators are widely used for the capability in isolating particles with small diameter. The systems are used in isolating and sampling the particles, of which various technologies are proposed [43-45]. Some researches have also been taken in the sampling and collecting the bioaerosols, using the electrostatic precipitators. There are also studies conducted on inactivation of the bioaerosols along with collections in these systems, and some of which will be mentioned later. The collection of bioaerosols using an electrostatic system for sampling is considered by some researchers, so that the use of a system with maximum voltage of ± 4000V for collecting the bioaerosols samples on an agar medium for collecting *Pseudomonas* fluorescence vegetative cells, Bacillus subtilisvar. Niger (BG) endospores, Penicillium brevicompactum have shown that the collection efficiency is different in various voltages in the cases with and without the input system charging, and air flow of 44 lit/min. In the case with the initial charging, in general, the average collection efficiency is higher than the case without

charge. The voltage gain had also a significant impact on the increased efficiency of collection, and using the initial charging at voltage of 4000v, the physical collection efficiency (active and inactivate) is obtained for all three species of bioaerosols above 80%. The biological collection efficiency (active bioaerosols) had a significant reduction with initial charging and negative voltage, and without initial charging and positive voltage, and reached to 10% for all three factors, however, the collection of *Pseudomonas* was lower and collection of Penicillium was higher. This means that in the conditions that the efficiency is reduced, the mentioned biological factors have become more inactivate, showing the effect of electrostatic precipitators in inactivating the biological factors, and effect of inactivation on bacteria is higher than fungi [46].

Viruses are among very small bioaerosols that are generally in the range of 0.01-1µ. Thus, the virus collection from the environment air has faced more problems. On the other hand, due to the lack of biological activity, the viruses can remain active in the air much longer than the bacteria. Considering the size of viruses, the electrostatic precipitators can be effective in their isolation. Using an electrostatic precipitator by applying the ±10 kV and flow rate of 12.5 lit/min for collecting the bacteriophages T3 and MS2, an extremely high efficiency has been reported in collecting and inactivating the bacteriophage agents. In this system, the soft x-ray is also used as an ionization reinforcing agent, and a significant efficiency is obtained in the removal and inactivation of the earlier factors in the voltages about ±10 kV. So that more than 2 removal logarithm bases and more than 4 inactivation logarithm bases were carried out. They have also shown that the efficiency difference in lower voltages (particularly less than ± 8 kV) and higher voltages. It is expressed that the use of soft x-ray has no impact on removal and inactivation efficiency of bacteriophages agents at high voltages. According to the findings, the use of soft x-ray can have a greater impact on the large electrostatic facilities and field use. Hence, ionizing and charging the smaller bioaerosols resulted in the adhesion of larger particles and isolation. Also, the ionization that is mainly carried out as photoionization, and also reduces the voltage in corona formation. However, it is noted that the effect of photoionization on charging the coarse particles is difficult. The corona formation is the main and effective factor in the collection of bioaerosols, and especially their inactivation. So that at the voltages of 8 kV and above where the corona is formed, the inactivation is increased considerably [47].

Another study carried out with soft x-ray has obtained the same conclusions for MS2 bacteriophage, so it has shown a more effective impact for soft x-ray. This study considered the effect of x-ray for charging the particles, particularly the small particles under photoionization of x-ray [48].

Examining the removal of Escherichia coli, Bacillus subtiils spores, Candida famatavar. flareri, and Penicilliumcitrinum, using the electrostatic precipitator in voltages of 5, 8, +10 kV showed reduced penetration of bioaerosols from 81% to 42% by increasing the voltage from 5 to 10 kV. It is shown that in the constant voltage of 10 kV, by increasing the flow rate from 60 to 90 lit/min, the penetration is increased from 42% to 79%, but the increased relative moisture is effective in increasing the removal efficiency of bioaerosols [49]. The removal efficiency of 79% and 31% for *E. coli* is obtained respectively in voltages of 7.5 kV and 1 kV, with moisture of 80% and a flow rate of 10 lit/min in the studies [50]. The effect of moisture factors on the removal of this system is intensifying the corona flow in the higher moistures.

Results of the studies indicated the higher efficiency of collection for fungi compared to the bacteria, and known the larger size of the fungi as the reason. According to the earlier studies, the formation of ozone in these systems is applied in proportion to voltage, and in the high voltages, the ozone concentration is increased. The other effective factors in the ozone concentration are the retention time and system amperage, which is raised by increasing the amperage and retention time of ozone formation. Due to the oxidizing properties of ozone, the impact on inactivation of biological factors is discussed. Therefore, in general, the retention time and amperage are very limited in electrostatic systems [49]. A breafe comparison of the bioaerosol removal methods are presented in Table 6.

Table 6: Comparison of the bioaerosol removal methods.

Removal method	Efficinency	Inactivation of bioaeroslos	Head loss	Energy Use
Filteration	E	N	H	N
UV radiation	VG	VG	L	L
Photocatalyst	G	G	L	L
High temperature	VG	E	L	H
Adsorption	G	N	H	L
Electrostatic precipitators	E	VG	L	L

G: good, VG: very good, E: excelent, N: None, L: low, H: high.

CONCLUSION

The use of methods such as ultraviolet ray and photocatalyst in inactivating the bioaerosols can have a proper efficiency, so in these methods, the inactivation is carried out with collecting, which will not be very successful on the allergen bioaerosols. Moreover, some species have shown resistance to these methods. Thus, the use of these methods in the susceptible points such grade A and B in ECTS grading scale, or the operating room, and allergic patient health care units cannot have a reliable efficiency. In the conventional filtration method, the collection is also performed with inactivation, and there are risks such as re-emission of pollution through the filters, and in the cases with susceptibility to allergy, there is a need for method reform and use of inactivating agents.

The use of high-temperature methods has a favorable efficiency in removal of bioaerosols, but the inactivation and removal of the allergen properties of bioaerosols require a higher temperature, and increases the energy consumption, and also don't have a proper impact on emission control of allergen agents such as spores. Although, the absorption methods can be used in the high flow rates and in low susceptibility, but the low efficiency in the removal of small bioaerosols, survival of absorber, and inactivating the bioaerosols are the limitations of this method. From the advantages of electrostatic precipitators compared to the mentioned methods, the high-efficiency inactivation as well as the collection from air flow can be mentioned, and this method is particularly effective, individually or with other methods, in the high-susceptible environments.

According to the results, the most effective factors in collecting and inactivating the bioaerosols in the electrostatic precipitators included the applied voltage, moisture, airflow, retention time, and electric current. The above factors, particularly the voltage, has shown a significant impact in the values above 8 kV. The use of factors such as x-ray, has shown no significant effect in removal and inactivation of bioaerosols, especially in high voltages, however, it has been effective in charge and removal of the small particles in the low voltages. Removal efficiency and higher inactivation for viral agents can be seen in these systems compared to the bacteria and fungi, the removal of fungi is also higher than the bacteria. In general, it seems that determining the optimum conditions for collecting and inactivating the various biological factors using the electrostatic precipitators required the further research.

ETHICAL ISSUES

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc.) have been completely observed by the authors.

CONFLICT OF INTEREST

All authors declare that they have no actual or potential competing financial interest.

AUTHORS' CONTRIBUTION

All authors read and approved the final manuscript.

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