Single-Stage Air Filtration of Particles and Gaseous Contaminants in Buildings: A Literature Study

Orlando, Roberta; Fojan, Peter; Mo, Jinhan; Bergsøe, Niels Christian; Afshari, Alireza

Published in:
IOP Conference Series: Earth and Environmental Science

DOI (link to publication from Publisher):
doi.org/10.1088/1755-1315/588/3/032073

Publication date:
2020

Citation for published version (APA):
Orlando, R., Fojan, P., Mo, J., Bergsøe, N. C., & Afshari, A. (2020). Single-Stage Air Filtration of Particles and Gaseous Contaminants in Buildings: A Literature Study. In *IOP Conference Series: Earth and Environmental Science* (3 ed., Vol. 588) https://doi.org/doi.org/10.1088/1755-1315/588/3/032073

PAPER • **OPEN ACCESS**

Single-Stage Air Filtration of Particles and Gaseous Contaminants in Buildings: A Literature Study

To cite this article: Roberta Orlando *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **588** 032073

IOP Conf. Series: Earth and Environmental Science **588** (2020) 032073 doi:10.1088/1755-1315/588/3/032073

Single-Stage Air Filtration of Particles and Gaseous Contaminants in Buildings: A Literature Study

Roberta Orlando[1] Peter Fojan[2] Jinhan Mo[3] Niels C. Bergsøe[1] and Alireza Afshari[1]

[1]Department of the Built Environment, Aalborg University, DK-2450 Copenhagen, Denmark
[2]Department of Materials and Production, Aalborg University, DK-9220 Aalborg, Denmark
[3]Department of Building Science, Tsinghua University, Beijing 100084, China

Email: roo@sbi.aau.dk

Abstract. A variety of air filtration technologies are commercially available for reducing particles and gaseous contaminants that may enter buildings from outside. According to the World Health Organization (WHO), there is an increasing range of adverse health effects linked to air pollution, at even-lower concentration of pollutants. This article presents a short literature overview of air filtration technologies, which focus on assessing their ability in removing both particles and gaseous compounds. The aim is to provide information about current research development of air filtration technologies as well as their advantages, limitations and performance in terms of removal efficiency, pressure drop and formation of by-products. Mechanical filters and electrostatic filters are efficiently used for the removal of particles. Photocatalytic oxidant and adsorbent air filters are commonly used for gas removal. These last two types of filters are not feasible for particles removal. Air filtration using electrospun nanofiber filters have been studied, however, the performance of such filters for the removal of particles and gaseous contaminants at the same time has to be further investigated.

1. Introduction

In this study, air pollutants are distinguished by their physical state between particles and gaseous contaminants as Volatile Organic Compounds (VOCs) that may be present in the indoor air in buildings. A large variety of air filtration technologies are commercially available for removing different types of pollutants. Simultaneous removal of particles and VOCs is required in order to improve Indoor Air Quality. The present review focuses partly in investigating the removal efficiency of the available filtration technologies towards particles and VOCs in order to assess whether there is the possibility to use a single-stage filter for removing both pollutant types. The present study also discusses the challenges facing the future air filtration directions and development in achieving sustainable ventilation and acceptable indoor air quality in residential buildings, in accordance with the UN Sustainable Development Goal (UN SDG) "Good Health and Well Being". A comprehensive literature search through Scopus yielded 1429 relevant hits in the period between 2000 and 2019. Only original papers without conference articles have been considered in the current study, as articles that do not refer to indoor air in buildings have been disregarded. Twenty-three most relevant publications have been selected for this short review.

2. Removal efficiency towards particles and gaseous compounds

Seven air filter technologies are investigated and compared in their ability of removing particles and gaseous compounds, as shown in Table 1. Filter technologies are rather selective in terms of which pollutants they can remove. Mechanical and electrostatic air filters are efficient and commercially used in the removal of particles. High Efficiency Particulate Air (HEPA) filters remove up to 99.97% of particles with 0.3 μm diameter or larger [1]. Electrostatic air filters present lower removal efficiencies compared to mechanical filters [2][3]. Ardkapan et al. (2014) showed that the filtration efficiency for an electret filter can vary from 45% to 80% depending on the particle concentration and particle sizes [2]. None of the above mentioned air filters is capable of removing gaseous compounds. Indeed, adsorbent filters are highly efficient on the removal of gaseous pollutants, through materials such as activated carbon or zeolites. Chen et al. (2005) have stated that sorption materials are the most effective technology for the removal of indoor VOCs. Activated carbon cannot remove very volatile gases alone but the removal efficiency can be improved when combined with other sorption media [4]. An alternative to adsorbent materials is degradation of VOCs through photocatalytic oxidation (PCO) [5]. The photocatalytic degradation of VOCs using titanium dioxide TiO_2 as catalyst has been investigated with initial VOCs concentration close to indoor air conditions (ppbv levels) [5]–[7]. In the study of Vildozo et al. (2011), the removal efficiency of VOCs ranged from 50% at a gas flow´s relative humidity of 60%, and 100% removal in dry conditions [6]. Both adsorbent and PCO filters are not effective in removing particles from the air. Another filtration technology presents in the literature is Non-Thermal Plasma (NTP) filters. NTP filters precipitate particles and promote oxidation of VOCs, although it operates unsteadily and with low efficiency [8],[9]. Electrospun nanofiber filters have shown promising results in the simultaneous removal of particles and VOCs [10], [11]. Those filters have demonstrated high particle removal efficiency, comparable to HEPA filters, as well as degradation of VOCs through TiO_2. Indeed, the electrospinning technique allows the use of additives as activated carbon or TiO_2 which enhances the capture selectivity of the nanofibrous filters. Chuang et al. (2014) prepared an electrospun nanofiber filter with a 99% acetone removal efficiency and 90% removal efficiency of particles above 200 nm diameter [11].

3. Pressure Drop

The energy consumption of a fan in a ventilation system is affected by the pressure drop applied by the operating air filter. Therefore the pressure drop across the filter needs to be addressed when evaluating different air filter technologies. Mechanical filters are characterized by an increase of pressure drop over time, due to clogging of the filters [12]. A characteristic of HEPA filters is their relative high pressure drop, in the range between 250-500 Pa [13]. Electrostatic air filters present a lower pressure drop compared to mechanical fibrous filters [2]. The air resistance imposed by nanofiber filters is lower compared to conventional mechanical filters made by microfibers, due to a slip flow dominance in the air flow [14]. Wan et al. (2014) demonstrated that the use of additives as TiO_2 on electrospun nanofiber filters promoted a decrease of pressure drop compared to the pure nanofiber filter [15]. Electrospun nanofiber filters have been investigated mostly at face velocities around 0.05-0.2 m/s in a controlled environment [16] . In the future works, the pressure drop of such filters has to be evaluated under realistic ventilation face velocities in buildings (1-1.5 m/s), in order to assess the filtration performance of nanofiber filters in comparison to conventional microfiber filters. Table 1 summarizes also the pressure drop of the investigated air filtration technologies.

4. By-products

The aim of air filters is to improve the indoor air quality. When a filter becomes a source of secondary pollution releasing particles or introducing by-products, the indoor air quality is degraded. Indeed, mechanical filters can be a source of contamination from micro-organism, as electrostatic filters may increase the concentration of ultrafine particles, ozone and formaldehyde [17], [18]. Adsorbent air filters are not generating by-products but there is a possibility of pollutant reemission when saturation occurs. PCO and NTP filters are both sources of by-products [9], [19]. When partial oxidation occurs during PCO filter operation, its products can be reemitted in the air stream and they can affect people´s health to an even greater extent than the oxidation reactants [19]. As summary, Table 1 includes information about filters as source of by-products.

Table 1. Summary of air filter technologies´ performance

Air filter technology	Particles removal	VOCs removal	Remarks	Ref
Mechanical filters	+	-	99.99% efficient for particle size > 0.3 µm. Economic. In time pressure drop increase, efficiency decrease and release odor. Source of contamination.	[1], [12], [13], [17]
Electrostatic filters	+	-	Lower pressure drop compared to mechanical filter, lower particle removal efficiency. Source of ozone and other compounds. Require high maintenance.	[2], [3], [18], [20]
Adsorbent filter	-	+	Most efficient commercial technology in VOCs removal. Saturation, cause of re-emission. Need regeneration. Humidity and temperature affect the adsorption.	[4], [21]
Photocatalytic oxidant (PCO)	-	+	TiO_2 most investigated photocatalyst. Can degrade a broad range of pollutants. Affected by water vapour and pollutants concentration. Production of harmful by-product.	[5]–[7], [19], [22]
Non-Thermal Plasma (NTP)	+	+	NTP degrades VOC and it removes also particle with low efficiency. Formation of by-products. High energy consumption and low energy efficiency.	[8], [9]
Electrospun nanofiber filters	+	+	High surface-to-volume ratio. Slip flow dominance – lower pressure drop compared to microfiber filter. Versatile. Emerging technology, mostly tested at very low face velocity (0.05-0.20 m/s).	[10], [11], [14]–[16], [23]

5. Conclusion

The present review discussed the challenges facing the future air filtration directions and development in achieving sustainable ventilation and acceptable indoor air quality in residential buildings. The results have shown that electrospun nanofiber filters are an emerging technology with promising filtration performance with regards to the simultaneous removal of particle and harmful gases. However, it is necessary to conduct more investigations of such filters in terms of filtration efficiency and pressure drop under realistic ventilation system conditions.

References

[1] American Society of Mechanical Engineers 2004 *Addenda to ASME AG-1–2003 Code on Nuclear Air and Gas Treatment.* ASME AG-1a–2004 (ASME).
[2] Ardkapan S R, Johnson M S, Yazdi S, Afshari A and Bergsøe N C 2014 Filtration efficiency of an electrostatic fibrous filter: Studying filtration dependency on ultrafine particle exposure and composition. *J. Aerosol Sci.* **72** 14–20.
[3] Lin W, Chang Y, Lien C and Kuo C 2011 Separation Characteristics of Submicron Particles in an Electrostatic Precipitator with Alternating Electric Field Corona Charger. *Aerosol Sci. Technol.* **45** 393-400.
[4] Chen W, Zhang J S and Zhang Z. 2005 Performance of Air Cleaners for Removing Multiple Volatile Organic Compounds in Indoor Air. *ASHRAE Trans.* **111** 1101–14.

[5] Debono O, Thevenet F, Gravejat P, Hequet V, Raillard C, Lecoq L and Locoge N 2011 Toluene photocatalytic oxidation at ppbv levels: Kinetic investigation and carbon balance determination. *Appl. Catal. B Environ.* **106** 600–608.
[6] Vildozo D, Portela R, Ferronato C and Chovelon JM 2011 Photocatalytic oxidation of 2-propanol/toluene binary mixtures at indoor air concentration levels. *Appl. Catal. B Environ.* **107** 347–354.
[7] Quici N, Vera M, Choi H, Puma G L, Dionysiou D D, Litter M I, Destaillats H 2010 Effect of key parameters on the photocatalytic oxidation of toluene at low concentrations in air under 254 + 185 nm UV irradiation. *Appl. Catal. B Environ.* **95** 312–319.
[8] Yu B F, Hu Z B, Liu M, Yang H L, Kong Q X, and Liu Y H 2009 Review of research on air-conditioning systems and indoor air quality control for human health. *Int. J. Refrig.* **32** 3–20.
[9] Park J H, Byeon J H, Yoon K Y and Hwang J 2008 Lab-scale test of a ventilation system including a dielectric barrier discharger and UV-photocatalyst filters for simultaneous removal of gaseous and particulate contaminants. *Indoor Air* **18** 44–50.
[10] Su J, Yang G, Cheng C, Huang C, Xu H and Ke Q 2017 Hierarchically structured TiO2/PAN nanofibrous membranes for high-efficiency air filtration and toluene degradation. *J. Colloid Interface Sci.* **507** 386–396.
[11] Chuang Y H, Hong G B and Chang C T 2014 Study on particulates and volatile organic compounds removal with TiO2nonwoven filter prepared by electrospinning. *J. Air Waste Manag. Assoc.* **64** 738–742.
[12] Joubert A, Laborde J C, Bouilloux L, Callé-Chazelet S and Thomas D 2010 Influence of humidity on clogging of flat and pleated HEPA filters. *Aerosol Sci. Technol.* **44** 1065–76.
[13] Chuaybamroong P, Chotigawin R, Supothina S, Sribenjalux P, Larpkiattaworn S and Wu C Y 2010 Efficacy of photocatalytic HEPA filter on microorganism removal. *Indoor Air* **20** 246–254.
[14] Park H and Park Y O 2005 Filtration Properties of Electrospun Ultrafine Fiber Webs. **22** 165–172.
[15] Wan H, Wang N, Yang J, Si Y, Chen K, Ding B, Sun G, El-Newehy M, Al-Deyab S S and Yu 2014 Hierarchically structured polysulfone/titania fibrous membranes with enhanced air filtration performance. *J. Colloid Interface Sci.* **417** 18–26.
[16] Xia T, Bian Y, Zhang L and Chen C 2018 Relationship between pressure drop and face velocity for electrospun nanofiber filters. *Energy Build.* **158** 987–999.
[17] Simmons R B and Crow S A 1995 Fungal colonization of air filters for use in heating, ventilating, and air conditioning (HVAC) systems. *J. Ind. Microbiol.* **14** 41–45.
[18] Waring M S and Siegel J A 2011 The effect of an ion generator on indoor air quality in a residential room. *Indoor Air* **21** 267–276.
[19] Mo J, Zhang Y, Xu Q, Lamson J J and Zhao R 2009 Determination and risk assessment of by-products resulting from photocatalytic oxidation of toluene. *Appl. Catal. B Environ.* **89** 570–576.
[20] Day D B, Xiang J, Mo J, Clyde M A, Weschler C J, Li F, Gong J, Chung M, Zhang Y, Zhang J 2018 Combined use of an electrostatic precipitator and a high-efficiency particulate air filter in building ventilation systems: Effects on cardiorespiratory health indicators in healthy adults. *Indoor Air* **28** 360–372.
[21] Jo W K and Yang C H 2009 Granular-activated carbon adsorption followed by annular-type photocatalytic system for control of indoor aromatic compounds. *Sep. Purif. Technol.* **66** 438–442.
[22] Mo J, Zhang Y and Xu Q 2013 Effect of water vapor on the by-products and decomposition rate of ppb-level toluene by photocatalytic oxidation. *Appl. Catal. B Environ.* **132–133** 212–218.
[23] Sundarrajan S, Tan K L, Lim S H and Ramakrishna S 2014 Electrospun nanofibers for air filtration applications. *Procedia Eng.* **75** 159–163.