Indian Journal of Fibre & Textile Research
Vol. 47, September 2022, pp. 350-355
DOI: 10.56042/ijftr.v47i3.50279

Impact of activated carbon contents on cabin air filter performance at different fume flow rates

Sudev Dutta[1,a], Arunangshu Mukhopadhyay[2] & Tathagata Das[2]

[1]Bannari Amman Institute of Technology, Sathyamangalam, Erode 638 401, India

[2]Dr. B R Ambedkar National Institute of Technology, Jalandhar 144 011, India

Received 23 May 2021; revised received and accepted 29 November 2021

The present study has been undertaken to analyze the filtration performance of two different nonwoven polypropylene filter media, viz. needle felt and spun-bonded sandwiched with granular activated carbon of varying concentration under different face velocities. The materials are studied on a laboratory based cabin air filter test rig. Spun bonded material reveals relatively lower emission and pressure drop. Interestingly, lower face velocity reveals relatively improved filter behavior in case of both the filter materials. Further, a reduction in downstream emission in terms of $PM_{2.5}$ & PM_{10}, number concentration and peal pressure drop is observed at higher concentration of activated carbon.

Keywords: Cabin air filter, Granular activated carbon, Nonwoven needle felt, Number concentration, Pressure drop, Polypropylene filter, Spun-bond fabric

1 Introduction

The studies pertaining to effects of air pollution exposure on human health is well documented from the previous researches[1,2]. It is reported that air pollution is the major reason for the surge in overall morbidity and mortality rate at global level. Further it has also been surveyed that people spend most of their time in indoor environments, including vehicle cabins[3]. The in-cabin microenvironment also causes exposure to various air pollutants available in indoor environment. The sources release harmful pollutants and compounds, such as particulate matters (PM), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), carbon monoxide and nitrogen oxides[4-9]. Even though the time spent by human in automobiles is reported to be only 5.5% on daily basis, the health risks pertaining to the in-cabin air quality are relatively high for some pollutants[3]. In a study, the monitoring of emission concentrations specific to vehicle cabins was typically reported in the range from 100,000 particles/cm^3 to 500,000 particles/cm^3 (refs 4&5). This emission levels is much higher as compared to that in the related ambient environment, involving high levels of exposure to PM inside vehicle cabins. This suggests that proportion of compounds and particulates within vehicles could vary under various driving conditions, but the average concentrations of VOCs in a vehicle cabin could be much higher than the normal ambient levels[8,9].

Mandalakis *et. al.*[10] studied that the inhalation of polybrominated diphenyl ethers (PBDEs), a flame retardant, during an 80 min drive is equivalent to 16.5 h exposure at home. In moving vehicles, the drivers and co-passengers could be exposed to high pollutant concentrations either emitted from surrounding mobile sources or interior fittings for short periods. In another research, Xu *et. al.*[11] reviewed the pollutant species, their sources and concentrations, control measures inside different motor vehicles' cabins [new and used vehicles; cars, suburban utility vehicle (SUVs) and buses; driving and stationary vehicles]. The findings specific to air quality inside the vehicles' cabins, including chemical species, related sources, measurement methodologies and control measures were summarized. Further in a survey it was reported that in cabin the contaminant proportions are often high for newly manufactured cars, at high interior temperatures, or with low air exchange rate[12-15]. Various kinds of vehicle cabin designs are found responsible for wide variation in the occurrence of in-cabin pollutants species and exposure levels[11].

The above related studies confer that there has been consistent efforts made to control the indoor pollutants through numerous sources. But, the

[a]Corresponding author.
E-mail: sudev89@gmail.com

research related to minimizing the pollutants at indoor atmosphere using varying concentrations of activated carbon has not analyzed thoroughly. Since activated carbon is used in various industrial applications for the adsorption of harmful gaseous matters, it can be presumed that the said material will be effective for the efficient control of indoor pollutants also. The present study is, therefore, undertaken to analyze the filtration performance of two different nonwoven polypropylene filter media, viz. needle felt and spunbonded sandwiched with granular activated carbon of varying concentrations.

2 Materials and Methods

The experiments were carried out using two types of polypropylene nonwoven filter fabric viz. needled felt and spun bond fabric both sandwiched with varying concentrations of granular activated carbon. The specifications of the investigated materials are given in Table 1. Activated carbon specifications and operating conditions are given below:

Specifications of activated carbon

- Carbon grade : GAC (granular activated carbon) coconut base
- Carbon surface area : 900-1000m²/g
- Carbon size : 16×30 US Mesh
- Surface area of filter : 900 cm^2 media

Operating conditions

- Test standard : ISO 111052-2 2009
- Temperature : 23±3°C
- Relative humidity : (50±2) %
- Face velocities : 0.1 m/min, 0.2 m/min, 0.3 m/min
- Dust concentration : 50 g/m^3
- Specimen size : 600mm×300mm

It may be noted that the activated carbon content was incorporated over the nonwoven materials using meltblown technique and hot melt adhesive. The adhesive was incorporated in quantity ranging between 40 g/m^2 and 60 g/m^2 over the nonwoven media. The parameters for the materials are: $PM_{2.5}$ μg/m^3 (weight of particulate matter smaller than the size of 2.5 microns emitted per cubic meter), PM_{10} μg/m^3 (weight of particulate matter smaller than the size of 10 microns emitted per cubic meter), particle number concentration P/cm^3 **(**number of particles emitted per cubic centimeter), efficiency, % (ratio of amount of contaminant removed or reduced by the filter relative to the amount exposed to it), and peak pressure, pascal (maximum pressure across the filter material).

2.1 Experimental Setup

The investigation of materials was carried out on a cabin air filter test rig as represented in Fig. 1. The rig has been equipped with diesel engine used as the source of fume filtered through cabin air filter followed by the dilution chamber in which the fume is

Table 1 — Material specifications

[Iodine number of activated carbon : 850 mg/g]

Fabric	Fabric areal density, gsm	Adhesive gsm	Activated carbon contents, gsm	Average pore size, μm	Porosity %	Air permeability m^3/ m^3/min
Spun bonded material	130	70	200	38	68	12
			300	31	57	9
			400	23	40	7
Needle felt material	50	60	200	34	52	9
			300	25	41	6
			400	18	33	5

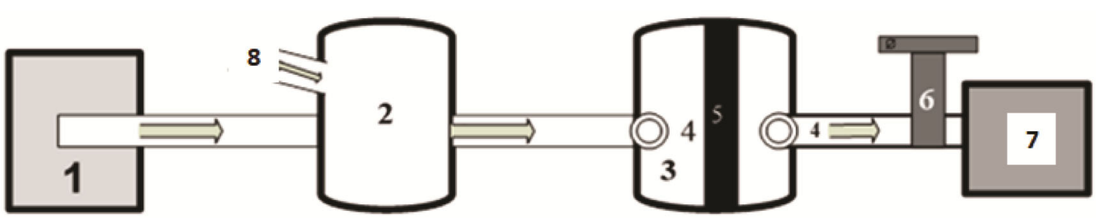

Fig. 1 — Cabin air filter test rig (1- Diesel engine, 2- Dilution chamber, 3- Specimen chamber, 4- Pressure sensor and $PM_{2.5}$ meter, 5- Test filter, 6- Suction control valve, 7- Suction motor, 8- Clean air duct)

diluted to 1:4 ratios with open air. Further, a specimen chamber is provided in which the test filter is mounted for testing, pressure sensor rig to measure the pressure drop due the filter media. The pressure sensor is followed by $PM_{2.5}$ meter for measuring the downstream particulate emission of particle size smaller than 2.5 microns, control valve, suction motor and clean air duct. It may be added that the test specimen is placed on the specimen frame and then clamped on the specimen window. Two pressure sensors (placed symmetrically) are provided on either side of the test specimen for measuring the pressure differential across it. Figure 2 represents the experimental plan followed to carry out the investigation of materials.

3 Results and Discussion

An increase in downstream emission is observed with the rise in filtration velocity, as represented in Tables 2 and 3 for both needle punched and spun bonded materials. This can be attributed to more chances of particle penetration through the filter media as there are relatively large amount of particles approaching the media at higher face velocity. The values are the average data of two experiments conducted for assessing the behavior of materials. The spun bonded filter material is known to exhibit relatively less downstream emission and pressure drop as compared to the needle punched material at all levels of face velocities and activated carbon.

3.1 Effect on Downstream Emission Behavior

The behavior of downstream $PM_{2.5}$ and PM_{10} emission with increasing face velocity is shown in Figs 3 (a) & (b) and Figs 4 (a) & (b) for needle punched and spun bond material respectively. It is observed that at higher concentration level of activated carbon the particulate emission is reducing at all levels of face velocities.

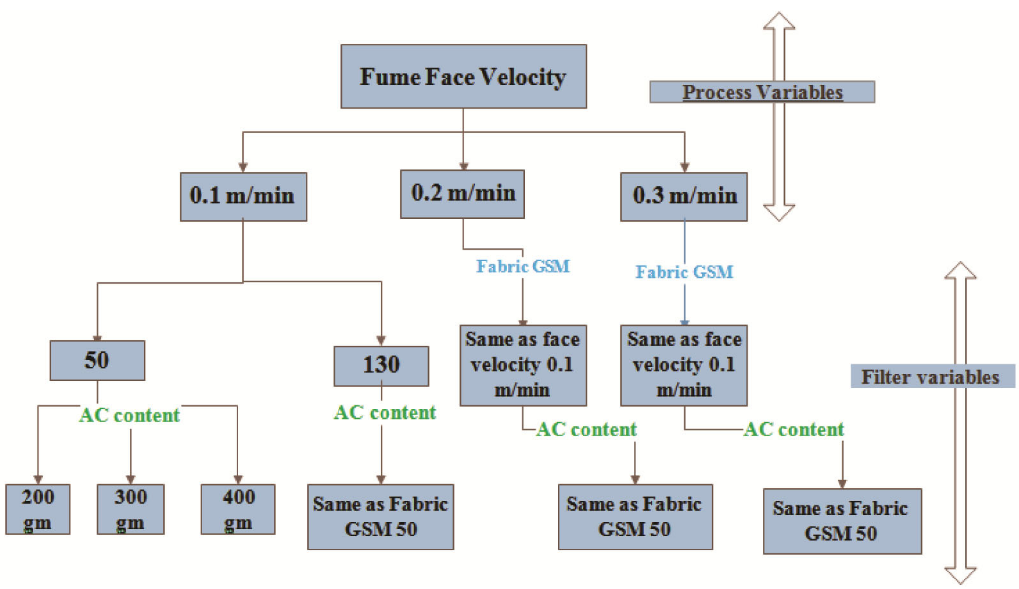

Fig. 2 — Experimental plan

Table 2 — Performance of needle punched material at varying face velocity

Activated carbon content, gsm	Face velocity m/min	$PM_{2.5}$ μg/m^3	PM_{10} μg/m^3	Particle No. conc. P/cm^3	Peak pressure Pa	Efficiency %
200	0.1	6965	10005	20797	68	99.9799
	0.2	7562	11303	28802	89	99.9773
	0.3	8846	11838	34665	102	99.9763
300	0.1	6419	9395	17262	54.0	99.9812
	0.2	7124	10802	26802	69.0	99.9783
	0.3	8069	11534	30184	82.0	99.9769
400	0.1	5817	8558	12624	47.2	99.9828
	0.2	6625	10445	23440	61.0	99.9791
	0.3	7741	11392	28477	77.0	99.9772

Table 3 — Performance of spunbond fabric at varying face velocity

Activated carbon content, gsm	Face velocity m/min	PM2.5 µg/m^3	PM_{10} µg/m^3	Particle No. conc., P/cm^3	Peak pressure Pa	Efficiency %
	0.1	4465	6559	14550	53.0	99.9868
200	0.2	5818	7278	18636	61.0	99.9854
	0.3	6759	8143	20027	68.0	99.9837
	0.1	4190	5913	12943	34.0	99.9881
300	0.2	4746	6634	15334	49.0	99.9873
	0.3	5916	7313	17922	52.0	99.9853
	0.1	3708	5215	11403	27.2	99.9895
400	0.2	4323	6093	13417	41.0	99.9878
	0.3	4841	6722	14781	47.0	99.9865

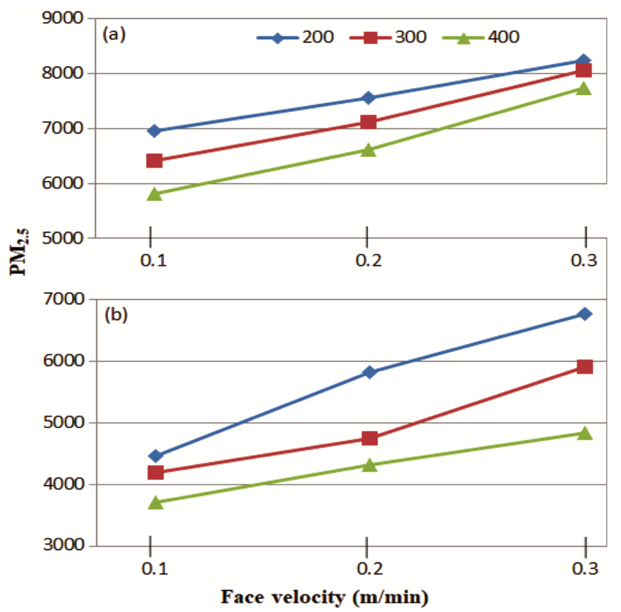

Fig. 3 — Effect on $PM_{2.5}$ emission (a) needle punched material and (b) spun bond material

The reason for this can be ascribed to relatively thicker coating of granular activated carbon at its increased concentration assisting in better entrapment of particulate matters. Further an increase in emission is observed at higher level of face velocities. However, the proportion of capturing fine particulate matter is noted be better in case of higher face velocity. This can be ascribed due to relatively early filling of media surface pores at increased face velocity, thus preventing the fine particles to penetrate through the filter media. A significant difference in emission levels can be observed among the three levels of face velocities and activated carbon levels at 95% confidence level in case of both the materials.

It may also be added that the behavior of downstream PM_{10} is found similar to that of $PM_{2.5}$

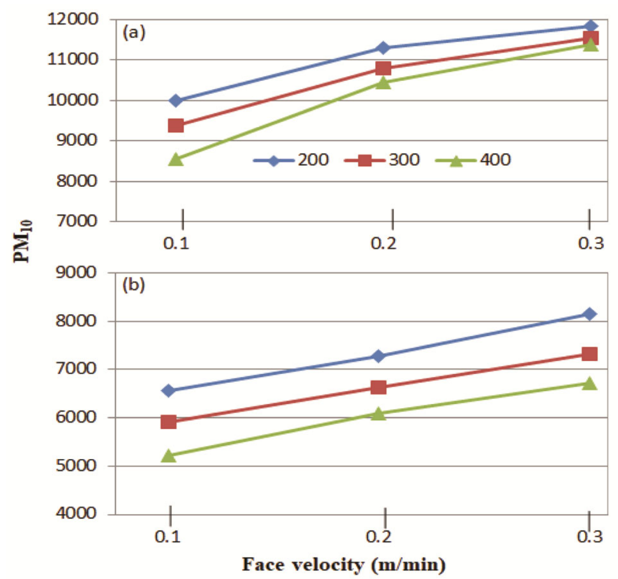

Fig. 4 — Effect on PM_{10} emission (a) needle punched material and (b) spun bond material

emission. Further, it is noted that the particulate emission is relatively lower in case of the spun bonded material at all levels of face velocity and activated carbon. This can be attributed to relatively lower surface pores in the said material as compared to that in the needle punched material, which is responsible for resisting the particles to penetrate and seeping at a greater extent in the spun bond material.

Further, ANOVA results show that among all the factors the activated carbon concentration level is having the highest contribution for the particulate emission behavior as represented in Table 4 followed by face velocity. Their interaction for both the materials has also been taken for investigation. However, the effect of each factor has been found to be significant. The reason for the highest impact of activated carbon concentration in the emission behavior is due to the fact that the thickness of activated carbon layer will govern the mode of

Table 4 — Contribution percentage derived from ANOVA

Parameter	$PM_{2.5}$		PM_{10}		No. Conc.		Pressure drop	
	NP	SB	NP	SB	NP	SB	NP	SB
Activated carbon	47	43	42	39	41	35	38	37
Face velocity	26	29	28	31	31	27	35	34
Interaction	19	21	24	22	18	22	20	18

NP = Needlepunch. SB = Spunbond.

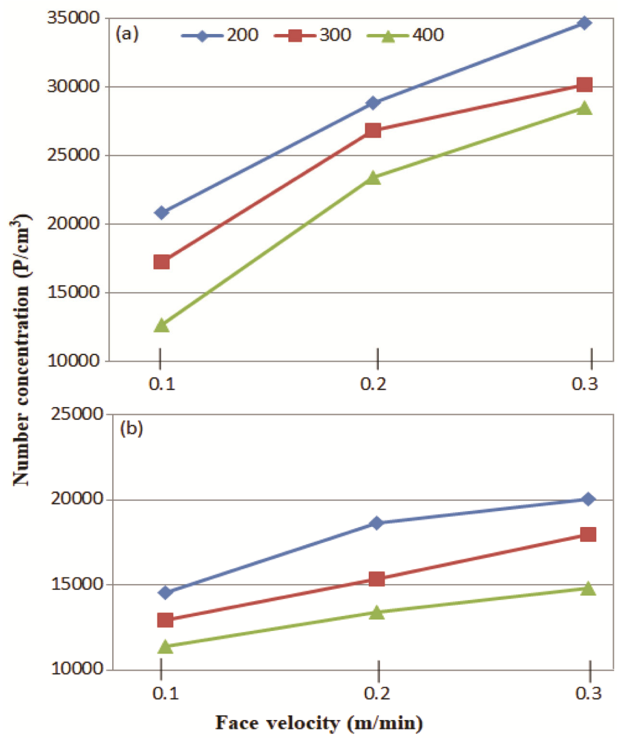

Fig. 5 — Effect on particle number emission (a) needle punched material and (b) spun bond material

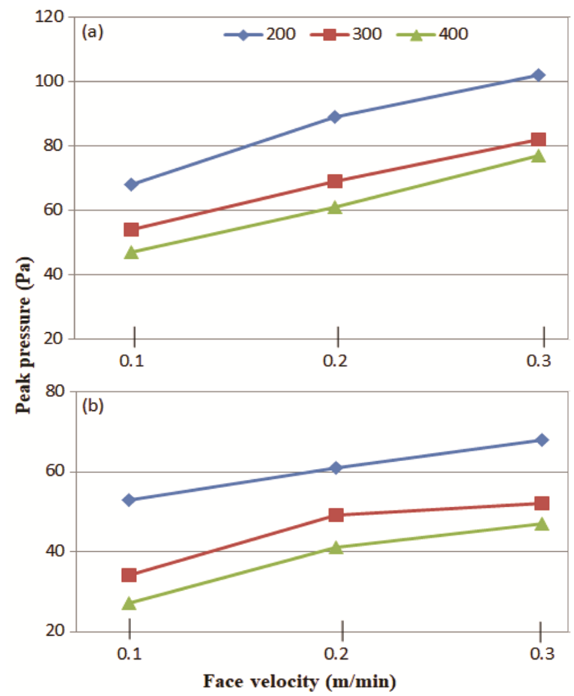

Fig. 6 — Effect on peak pressure (a) needle punched material and (b) spun bond material

filtration (surface and depth). Lower thickness will suggest a relatively quicker depth filtration of aerosol particles and vice-versa.

A significant impact of the interaction behavior indicates that besides the individual effect of activated carbon content and face velocity, their cumulative behavior is also playing an important role in the particulate emission outcome.

Figures 5 (a) & (b) illustrate the downstream particle concentration behavior for the investigated materials. The interpretations drawn for number concentration has been found to be similar to the particulate emission behavior. This can be ascribed to the apparent reason that, as the mass at downstream is increasing with the rise in face velocity and decrease in activated carbon thickness, the downstream particle number is also supposed to increase. The seepage and straight through of particles across the filter material at a higher face velocity is a strong possibility due to relatively higher approaching speed of the aerosol towards the filter media. The spun bond material exhibits lower downstream particle number concentration as compared to needle punched material. This can be attributed to the similar reason as mentioned previously for particulate emission results.

The ANOVA results reveal highest contribution of activated carbon content in particle number emission behavior of materials followed by face velocity and their interaction effect. It is also observed that for both the examined materials, the role of each factor is found to be significant.

3.2 Effect on Differential Pressure Drop

Pressure behavior of a filter media is one of the most important parameters for any filtration industry as it refers to the energy utilized by the system. In the present investigation, the materials are investigated for peak pressure drop. Figures 6 (a) & (b) represent an increase in peak pressure with rise in face velocity for both the materials. This can be ascribed to the higher approaching speed of the aerosol towards the filter media in case of

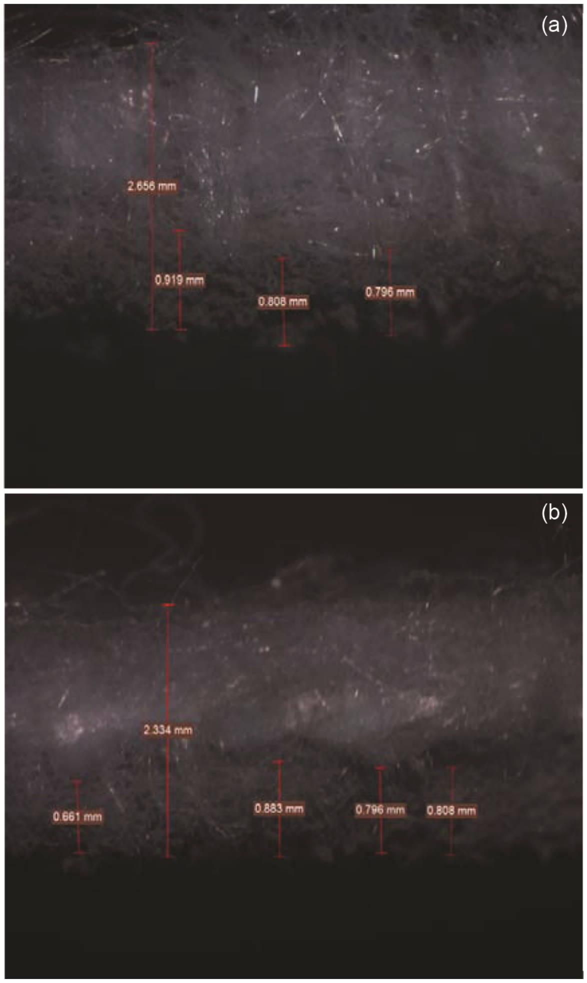

Fig. 7 — Cross-sectional image of tested filter materials (a) spunbond media and (b) needle punched media

higher face velocity, thereby increasing the probability of depth penetration and hence the material becomes susceptible to exhibit higher differential pressure. However, at increased activated carbon content, a reduced pressure drop is noted for both the materials. This can be attributed to reduced particle penetration at higher thickness of activated carbon, thereby resulting in relatively reduced pressure difference.

Further observation reveals a reduced pressure drop for spun bond filter media as compared to the needle punched material under all levels of face velocity and activated carbon concentration. This can be associated to the reduced surface pore size of the spun bonded material, providing an increased surface and thus facilitating improved cake deposition and reduced depth penetration of particles. Hence, a reduced pressure drop is resulted.

Table 4 illustrates the ANOVA behavior of the each factor, viz. activated carbon content, face velocity and their interaction behavior. It is observed that both activated carbon content and face velocities are having almost equal impact on the pressure drop behavior of the two materials. However, the role of their cumulative effect is also found to be significant. Further, it is added that the cross-sectional image of tested filter materials is illustrated in Figs 7 (a) & (b).

4 Conclusion

The overall interpretations reveal a relatively improved filtration performance of spun bonded filter material under all operating conditions. Further, the study also reveals that the role of activated carbon has been the most vital in determining the filtration behavior of the materials. However, the cumulative effect of face velocity and activated carbon content has also been significant for the outcome. At higher face velocity, the emission and pressure drop are known to increase. Further, the filter media with higher concentration of activated carbon have been able to entrap particles more efficiently with reduced pressure drop. Although, the given interpretation has been for the present case, but there is always an optimization required between the activated carbon content over the filter media and the aerosol flow velocity to achieve enhanced filter media performance.

References

1 Dockery DW, Pope CA, Xu XP, Spengler JD, Ware JH, Fay ME, Ferris BG & Speizer FE, *New Engl J Med*, 329 (1993) 1753.
2 Araki A, Kawai T, Eitaki Y, Kanazawa A, Morimoto K, Nakayama K, Shibata E, Tanaka M, Takigawa T, Yoshimura T, Chikara H, Saijo Y & Kishi R, *Sci Total Environ*, 408 (2010) 2208.
3 Klepeis NK, Nelson WC, Ott WR, Robinson JP, Tsang AM, Switzer P, Behar JV, Hern SC & Engelmann WH, *J Expo Anal Environ Epidemiol*, 11 (2001) 231.
4 Hudda N, Kostenidou E, Sioutas C, Delfino RJ & Fruin SA, *Environ Sci Technol*, 45 (2011) 8691.
5 Zhu Y, Eiguren-Fernandez A, Hinds WC & Miguel A, *Environ Sci Technol,* 41(2007) 2138.
6 Bigazzi A & Figliozzi M, *Atmos Environ* , 60 (2012) 495.
7 Knibbs LD, Cole-Hunter T & Morawska L, *Atmos Environ*, 45(2011)2611.
8 Leung PL & Harrison RM, *Atmos Environ*, 33(1999)191.
9 Geiss O, Tirendi S, Barrero-Moreno J & Kotzias D, *Environ Int* , 35 (2009)1188.
10 Mandalakis M, Stephanou EG, Horii Y & Kannan K, *Environ Sci Technol*, 42 (2008) 6431.
11 Xu B, Chen X & Xiong J, *Indoor and Built Environ*, 27 (2016) 1.
12 Fedoruk MJ & Kerger BD, *J Exposure Anal Environ Epidemiol*, 13 (2003) 31.
13 Yoshida T & Matsunaga I, *Environ Int*, 32 (2006)58.
14 You KW, Ge YS, Hu B, Ning ZW, Zhao ST, Zhang YN & Xie P, *J Environ Sci*, 19 (2007) 1208.
15 Chen XK, Feng LL, Luo HL & Cheng HM, *Environ Sci Pollut Res*, 21 (2014)12868.