Journal of Aerosol Science 55 (2013) 57–65

Contents lists available at SciVerse ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

Effect of aerosol loading on breakthrough characteristics of activated charcoal cartridges

Yu-Mei Kuo [a], Chih-Wei Lin [b], Sheng-Hsiu Huang [b], Kuang-Nan Chang [b], Chih-Chieh Chen [b],*

[a] *Department of Occupational Safety and Health, Chung-hwa University of Medical Technology, 89, Wen-Hwa 1st St., Jen-Te District, Tainan 712, Taiwan, ROC*
[b] *National Taiwan University, Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, 17 Xu-Zhou Road, Room 718, Taipei 10055, Taiwan, ROC*

ARTICLE INFO

Article history:
Received 8 April 2012
Received in revised form
31 July 2012
Accepted 18 August 2012
Available online 25 August 2012

Keywords:
Activated charcoal
Breakthrough time
Aerosol loading
Sorption capacity

ABSTRACT

Charcoal cartridges are commonly employed to provide protection against a wide range of organic vapors at workplace owing to their excellent adsorption. In practical situations, not only organic vapors but also aerosol particles may exist in the workplace atmosphere. Focusing on aerosol particles, this study aimed to evaluate the effect of aerosol loading on both sorption capacity and breakthrough time of activated charcoal. Polydisperse corn oil aerosols with a mode of 0.2 μm and monodisperse acrylic powder of 0.15 and 10 μm were generated to load the test activated charcoal separately for conducting vapor sorption experiments. For liquid aerosol loading tests, the sorption capacities reduced by 14%, 38% and 46% and the 10% breakthrough times were shorten by 14%, 28% and 75% after loading 0.06, 0.14 and 0.25 g of corn oil aerosols per gram charcoal, respectively. For charcoal loaded with solid aerosols, the sorption capacity remained unchanged whereas the 10% breakthrough times were reduced by 26%, 27% and 35% after loading 0.019, 0.027 and 0.029 g of 0.15-μm acrylic powder per gram charcoal, and by 5%, 43% and 44% after loading 0.074, 0.13 and 0.18 g of 10-μm acrylic aerosols per gram charcoal, respectively. It was concluded that the breakthrough characteristics were affected by aerosol loading and the sorption capacity of activated charcoal can only be reduced by the loading of liquid aerosols. For the use of gas respirators with activated charcoal cartridges, it should be noted that the service life of the charcoal cartridges could be shortened due to aerosol loading in a work environment, from the perspective of respiratory protection.

1. Introduction

The sorption of organic vapors to activated charcoals occurs mainly through physical adsorption. The equilibrated amount, i.e., the sorption capacity, depends on the adsorption isotherm. Owing to the excellent adsorption capacity of activated carbon for organic vapors, charcoal cartridges are commonly used in gas respirators to protect workers' health in the industrial environment. Charcoal has a porous structure with variable gaps of molecular dimensions, being the micropores (Innes et al., 1989). The micropores of charcoal, generally in slit-shape, are characterized by the slit width in the size range of 0.4 to 2 nm and represent the bulk of the adsorption capacity. The mesopores with size varying from 2 to

---

* Corresponding author. Tel.: +886 2 33668086; fax: +886 2 23938631.
E-mail address: ccchen@ntu.edu.tw (C.-C. Chen).

0021-8502/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jaerosci.2012.08.002

50 nm are important for transport properties while the macropores denote those pores whose size exceed 50 nm. Micropores have higher surface area to pore volume ratios than mesopores and macropores. Micropores and available contact surfaces in the adsorbents play a dominant role in the adsorption and it is basically a process of volume filling. Then adsorption begins to shift gradually to multilayer adsorption in the meso- and macropores as the vapor pressure continues to increase. The adsorption behavior in mesopores depends not only on vapor-wall interactions but also on the attractive forces between vapor molecules, which may lead to capillary (pore) condensation (Stoeckli, 1990). Previous studies have concluded that two major barriers to gas molecule diffusion existed, namely pore entry and diffusion along the pore. The rate-limiting step in highly microporous carbons was pore entry (Rao, 1985).

A variety of studies on the factors affecting adsorption capacity and/or breakthrough time of a charcoal cartridge have been carried out (Nelson & Correia, 1976; Yoon & Nelson, 1990, 1992; Yoon et al., 1996). Studies showed that the breakthrough characteristics of charcoal cartridges may be affected by the constituent(s) and the concentration(s) of the vapor(s) adsorbed (Nelson and Harder, 1974; Nelson and Correia, 1976; Tanaka et al., 1999; Dharmarajan et al., 2001), temperature (Nelson et al., 1976; James et al., 1984; Wood, 1985), moisture content in the gas flow in terms of relative humidity (Nelson et al., 1976; Yoon & Nelson, 1990; Tsai, 1994; Wood, 2004; Kaplan, 2006; Li, 2008; Ye, 2008; Cao, 2010; Bradley, 2011), gas flow rate (Nelson & Correia, 1976), and charcoal packing density (Trout, Breysse et al., 1986).

A large number of previous studies have been on the performance of charcoal on vapor adsorption and influencing factors. However, little is known about the effect of aerosols deposited on the surface of activated charcoals. For practical situations, not only organic vapors but also aerosol particles may exist in the atmosphere at workplace. Subsequently, aerosol particles might penetrate and deposit on the charcoal inside the respirator cartridge and, therefore, induce extra air resistance. Moreover, the particles deposited on the surface of the granulated activated carbon may alter the breakthrough characteristics, thus affecting the service life of charcoal cartridges which is of great importance for respiratory protection in industrial applications. Therefore, this study aimed to evaluate the effect of aerosol loading on the breakthrough characteristics of activated charcoal.

2. Materials and methods

2.1. Test activated charcoal

The activated charcoal taken from the same lot of commercially available respirator cartridges (3M 6001, St. Paul, MN, USA) was employed to conduct the experiments in this work. This organic vapor cartridge was approved by the National Institute of Occupational Safety and Health (NIOSH). The granular size of the charcoal was measured by US standard testing sieves to be in the size range of 12–20 mesh (equivalent to 0.84–1.68 mm). Under the STP condition, the N_2-BET specific surface area was 1319 m^2/g. The micropore volume and the micropore area were 0.48 cm^3/g and 1047 m^2/g, respectively.

The granular charcoal was prepared by drying at 150 °C for at least 2 h, followed by purging with clean filtered air for another 2 h prior to test. After being preparation, the charcoal was packed in a cylindrical stainless steel sample holder, which is 7.16 cm in diameter and 2.56 cm in height. The homemade cartridge accommodated 35 g of granular charcoal with a calculated packed density of 0.34 g/cm^3 for all the tests unless otherwise specified.

The homemade charcoal cartridge was first tested for its sorption efficiency as a function of time to obtain the characteristic breakthrough curve of the cartridge before aerosol loading. Then the used cartridge was regenerated by following the same protocol of charcoal preparation as aforementioned. After regeneration, the charcoal cartridge was loaded with a given amount of aerosols in specified size range and was tested for the sorption efficiency again to obtain the breakthrough curve of the aerosol loaded cartridge.

2.2. Cyclohexane sorption test

The operating conditions for the sorption efficiency tests followed mainly the Chinese National Standard certification method (CNS 6636 Z2023): 3000 ppm cyclohexane as the challenge agent (Furuse et al., 2001), 15 L/min gas flow rate and $50 \pm 5\%$ relative humidity. Fig. 1 shows the schematic diagram of the experimental system set-up for charcoal sorption and aerosol loading tests. Cyclohexane vapor was generated by passing 15 L/min filtered air through the surface of liquid cyclohexane in a jar dipped in a water bath. The temperatures of the cyclohexane bath and water bath were set the same, 37 ± 0.5 °C. The cyclohexane vapor concentration was controlled at 3000 ppm by refilling the escaped cyclohexane at an injection rate of 0.204 mL/min using a syringe pump. The relative humidity of the gas flow was monitored by a hygrometer and was maintained at $50 \pm 1\%$ at 25 °C by passing the filtered air over a water reservoir. The gas mixture then passed through the test charcoal cartridge. The cyclohexane concentrations upstream and downstream of the cartridge were monitored by a flame ionization detector (FID, model 2005A, China Chromatography Co., Taiwan).

The cyclohexane breakthrough curve as a function of time was characterized by calculating the ratio of downstream vapor concentration (C) in ppm to upstream vapor concentration (C_0) in ppm. The sorption capacity of activated charcoal in mg-cyclohexane/g-charcoal was calculated by dividing the adsorbed amount of cyclohexane vapor by the amount of activated charcoal used in the cartridge. The adsorbed amount was estimated by the following equation.

$$W_{ads} = \frac{Q \times M.W.}{24.46}\left(C_0 t_{ads} - \sum_{i=1}^{n} \frac{(C_{i+1} + C_i)\Delta t_a}{2}\right) \times 10^{-3}$$