American Journal of Clinical and Experimental Medicine
2015; 3(5): 322-326
Published online December 3, 2015 (http://www.sciencepublishinggroup.com/j/ajcem)
doi: 10.11648/j.ajcem.20150305.32
ISSN: 2330-8125 (Print); ISSN: 2330-8133 (Online)

Overview of Development on Self-Inhalation Filter Type Respiratory Protective Technology Against Polluted Air in Residential Environment

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To cite this article:
Lei Yang, Yue Liu, Minghao Chu, Henggen Shen. Overview of Development on Self-Inhalation Filter Type Respiratory Protective Technology Against Polluted Air in Residential Environment. *American Journal of Clinical and Experimental Medicine.* Vol. 3, No. 5, 2015, pp. 322-326. doi: 10.11648/j.ajcem.20150305.32

Abstract: There are many types of respirators used in residential environment for individual respiratory protection. Many factors may influence the protective performance of respirators. This paper tries to review the factors in the research development of self-inhalation filter type respiratory protective technology against polluted air in residential environment. Those factors mainly include the leakage; respirator fit test panels, constructing fibers and respirator performance test method. The conclusions from the reviewed literatures show that: (1) the leakage of respirator worn on individuals may be an important reason for the decrease of respirator's protection. (2) The respirator fit test panels should be developed in advance because they are vital to the good design and the valid test of respirators. (3) The fibers for the filtering part of respirators may be also important to the protective performance of the respirators. Low inhalation resistance and high filtering efficiency are the expectation to a good respirator. (4) The respirator test method applied for evaluating the protective performance depends on the location or environment of the used respirator. Howsoever, the challenge and the most penetrating particle size should be considered before confirming the respirator test method.

Keywords: Respirator, Leakage, Fit Test Panels, Polluted Air, Residential Environment

1. Introduction

The respirator may be the last respiratory protection for the group in the polluted residential building environment. Many earlier literatures have shown that the negative pressure air-purifying respirators easily trended to having a leakage when they were worn by the group in residential building air [1, 2]. In the past years, researchers in personnel protect technology and ergonomics have been attracted by the leakage of respirators [2, 3, 4, 5] and have carried many studies on how to improve the performance of the respiratory protective technology. In this paper, we reviews the research development of self-inhalation filter type respiratory protective technology, especially summarizes the recent achievements for decreasing the leakage when the respirators are used in residential building environment.

2. Questions

2.1. The Leakage of Respirator

Many previous studies had demonstrated that many respirators cannot provide adequate protection because of poor face seal of the respirators [2, 3, 4, 5]. There are two recognized respirator fit testing methods, which are Controlled Negative Pressure method (CNP) [6] and Aerosol-Based Measurements (ABM) [7]. But many researchers had gotten the inconsistent results in their studies because of the disadvantages in those methods [8, 9, 10]. In ABM, aerosol streamlining passing the sampling probe can add positive or negative bias to in-mask sample results. CNP may give us the result of the combined effect of the leakages through purified materials and face seal. In 2005, a study pointed out that all of CNP and ABM with the laboratory testing method might make the experimental results with bias

[11]. In the same year, another paper had tried to quantify the relationship between leakage volume of N95 respirators and inhaled airflow in a new method against ambient respiratory aerosols [12]. It found that the collected N95 disposable respirators had the leakage of about 50% of total airflow, and the flat model disposable respirator can decrease leakage to about 20% of total airflow. In 2007, a study evaluated the leakages by analyzing the pressure and velocity field in the chamber between the respirator and the wearer's face for his inhaling period. Computational Fluid Dynamics was used in the study for simulating the pressure and velocity field with gap leakage and without leakage [13]. The results of CFD study illustrated that gap leakage affected the dynamics field significantly. Cheek leakage might decrease both the protective performance of the respirator and the stivy feeling of respirator wearers. Most of the above literatures disclosed the fact that the dangerous leakages might happen because of low efficiency of the filter or poor face seal of the respirators.

2.2. Respirator Fit Test Panels

Respirator fit test panels (RFTPs) may be an advanced strategy for improving the face seal of the respirator for a user. RFTPs firstly need the anthropometric data of respirator users. The proper facial anthropometric dimensions for defining respirator fit test panels will make respirator design suitably for tight-fitting with the wearer's face [14, 15, 16, 17, 18].

Current RFTPs used in China and other countries were developed by Los Alamos National Laboratory (LANL) in 1978 [16], based on American groups including few Chinese examples. These RFTPs have been widely utilized to determine how respirators fit the general working population. This raises the question of how well the American specification applies to Chinese faces.

Recently, China has been the largest supplier of national and international labor, and needs many respirators with good faceseal. In addition, Chinese is one of top 10 races for immigration to America [19] and Britain [20]. To a certain extent, immigration from China may have changed demography of those countries. So as migration and globalization end the possibility of focusing on just one race, the need to obtain anthropometric data effortlessly on different race groups has been growing rapidly, and new RFTPs based on facial characters of Chinese are needed within China and in other places where Chinese work.

In 2007, a pilot study was conducted to investigate the difference of facial anthropometric dimensions between Chinese and Americans, and whether American RFTPs are applicable to Chinese [13]. The results show that facial anthropometric measurements of 461 Chinese subjects are different from those of American groups described in the literature [16]. About 12–35% of the Chinese subjects fall outside the ranges derived from American panels. Chinese may have shorter and wider facial character than American groups. Current RFTPs, which are based on American facial anthropometric surveys, may not fairly represent the facial anthropometric characteristics of Chinese groups.

2.3. Respirator Materials

Non-woven and cotton fiber had been generally used as filter materials of respiratory protect facepieces. Respirators with different materials appear actually a great diversity of filtering performance [5]. The results of the Shen's study were including: (1) The filter efficacy of 16-layer cotton facepieces was always lower than 25%. The results from another measurement made with 3 lapped (48-layer) cotton facepieces showed that the filtering efficacy was lower than 40%. However, the inhalation resistance of 3 lapped (48-layer) cotton facepieces was also lower than other type samples. (2) The inhalation resistance of the facepieces with activated carbon fibers appeared a moderate result. The filtering efficacy of this type facepieces were 20.3%-56.1%. (3) The inhalation resistance of non-woven facepieces was higher than other type samples, and the filtering efficacy of this type facepieces were 70.0%-99.6%. (4) The inhalation resistance of a facepice with electret fibers was similar to that of 16-layer cotton sample. The filtering efficiency of this facepice was higher than 96%. The mean efficiency of the facepieces against PM10，PM 2.5 and PMl.0 in the ambient air were 99.6%, 97.1% and 99.4%, respectively.

2.4. Protection Performance Test Method

The authorized experimental strategy in CFR Part84 [21] and in EN149 [22] may be the recognized experimental methodology for testing the performance of the respirator.

The challenge in the test method is a factor with the marked influence on the protection performance of the respirator. Types of the filter particulates in the test are generally including dusts-solid particles usually generated by mechanical stress, fumes-solid particles generated by condensing a gas or by chemical reaction, usually refers to metals, mists-suspended liquid droplets, and biological and radiological agents [23]. However, recent research showed that airborne nanomaterials can be inhaled and deposited in the respiratory tract, and importantly can enter the blood stream and translocateto other organs [24]. Those mass doses of insoluble nanoparticles are more potent than larger particles of similar composition in causing pulmonary inflammation and lung tumors in laboratory animals. Moreover, changes in the chemical composition, structure of the molecules, or surface properties can influence potential toxicity. Until now, no specific data available to determine if nanoparticle face seal leakage is different and studies have validated effectiveness of current methods used to fit respirators for use against gases and vapors [25, 26]. However, Penconek's study found that diesel exhaust particle (DEP) is more penetrating for commercially available filtering facepiece half masks than the standard salt or paraffin oil test aerosols. His study also showed that the most penetrating DEP are probably in the 30- to 300-nm size range, regardless of the fuel type and the half-mask model. Commercially available half masks may not ensure a sufficient level of protection of the respiratory tract against diesel exhaust fumes [27]. The equipment for testing protective performance of respirators currently used in the labs are including TSI Portacount with N95 Companion and TSI 8120. TSI Portacount with N95 Companion uses ~40 nm particles. In the recent research, NIOSH plans to conduct controlled laboratory studies using manikins to measure face seal leakage of 5-400 nm particles [28].

The results of Yang's study illustrate that the polydisperse condition of ambient airborne particulate makes the performance of the samples more complicated than the monodisperse particle [13]. The polydisperse experimental challenge may be interactional and makes the most penetrating particle size (MPPS) larger than using monodisperse. The researchers had been considered MPPS as 0.3μm in the earlier literatures. In Yang's study [13], the approximate conclusions can be gotten for polydisperse challenge and different test fibers. It can be concluded that the most penetrating particle size varied for different type respirators varied and application conditions.

3. Developments

3.1. New Respirator Fit Test Panels

In response to needs for new anthropometric data for Chinese workers, a large-scale head-and-face anthropometric survey of 3000 Chinese civilian respirator users was conducted in 2006 [29]. Through comparison with the facial dimensions of American subjects, that study found that Chinese civilian adults have shorter face length and nose protrusion and larger face width and lip length.

In 2008, a new study conducted to investigate the differences of facial anthropometric dimensions between the Chinese and the American, and to establish new respirator fit panels applicable to the Chinese groups. The results show that facial anthropometric measurements of 461 Chinese subjects are different from those of the American groups in previous literatures. Those current respirator fit panels may not fairly present the facial anthropometric characteristics of the Chinese groups. New respirator fit panels is proposed basing on data of 2006 anthropometric survey from the earlier study [30]. The panels are defined with ten cells. Each cell contains a 10 mm range of face length and a 12mm range of face width. For new panels, the total ranges for face length and width are from 92.5mm to 132.5mm and from 119.5mm to 167.5mm respectively. New panels are also 25-member panels. The results of fitting data of the Chinese survey into new panels demonstrate that more than 97% of the Chinese population can be represented by new panels in terms of face length and face width. New panels may be applicable for the design and fit test of the respirator productions for the Chinese groups.

Another new study had developed new respirator fit test panels using the anthropometric survey data for Chinese workers in 2006 [31]. This research constructed principal component analysis (PCA) panels using the first two principal components obtained from a set of 10 facial dimensions. The Chinese bivariate panel has limits of 96.5mm to 132.5 mm for face length and 128.5mm to 158.5 mm for face width. Respirators designed to fit these Chinese worker-specific panels are also likely to accommodate >95% of Chinese worker samples from the 2006 survey [29].

3.2. New Respirator Testing Equipment

Yang constructed two new respirator testing facilities which were Ideal Testing System (ITS) and Dummy Testing System (DTS) [12]. Those test platforms were carried simultaneously for testing the filtering performance against the same challenge sample. In ITS, all airflow flow for the test could pass the through purified material of the sample respirator. DTS imitates the real condition of disposable respirator donned on face. The experimental data from ITS and TSI 8130 are in a good agreement.

3.3. New Respirator Materials

Recently, electret fibers had shown better characteristics than non-woven and cotton fiber in recent experimental researches [25, 32]. Electrets fibers for respirators rely heavily on their electrostatic charge to provide adequate filter efficiencies [28]. With electrostatic force, fiber can easily capture the fine particles smaller than 1μm. In the tests, the ambient aerosols with the sizes from 0.5μm to 1μm had the low mass concentration. However, all electret fiber respirator samples have MPPS of 0.5μm or 0.4μm, which is different from previously recognized MPPS with monodisperse challenge.

4. Discussions

Many factors can influence the protective performance of respiratory protective products. Leakage of respirator, respirator fit test panel, respirator materials and performance test methods had been studied in the earlier literatures.

Cheek leakage might markedly decrease the protective performance of the respirator and the stivy feeling of respirator wearers. Those conclusions proposed that a good respirator be designed in accordance with proper fit test panels and equipped with elasticated materials on their edge. The top and the bottom structure of the respirators should be improved for more spaces in order to reduce the leakages.

The recent anthropometric survey in China may be more representative of facial characteristics of the current Chinese civilian population. The new anthropometric data can provide respirator industries to design good respirators to meet the needs of their customers. Respirators designed on the fit panels are supposed to accommodate at least 95 percent of the wearers. However, respirator fit panels in U.S., such as LANL full-facepiece panels and new NIOSH panels cannot represent more than 85% of the Chinese population. Thus, it is necessary to assess and refine the current fit-test panels for being applicable to the Chinese groups. New fit test panels have been developed by Yang (2008) and Chen (2009). Those panels may be better application than the NIOSH's panels.

The filtering materials may be an important factor influencing the protective performance of the respirator. Respirators with different materials have apparently diverse performance. The manikin-based experimental study shows that the efficiency of electret fiber samples is higher than those of the non-woven samples and the cotton fiber samples. In addition, the inhaled resistance of the no-woven fiber respirator is relatively higher than other samples. However, the inhaled resistance of electret fiber samples was low.

5. Conclusions

An eligible respirator worn by individuals must reduce the effects of their exposure to a hazard. It is recognized that many factors can influence the protective performance of respiratory protective products.

(1) Many studies had demonstrated that many respirators could not provide adequate protection because of the poor face seal. The gap leakage affected significantly the dynamics field in the chamber between the respirator and the user.

(2) The difference between the facial dimensions of Chinese and those of American indicates that it may be necessary to construct new RFTPs for Chinese individuals.

(3) The efficiency of electret fiber samples show a good performance of higher efficiency for filtering particles in ambient air and low inhaled resistance.

Anyway, the conclusions from the literatures explain that more attention should be paid to personal respiratory protective technology to decrease the risk of respiratory disease for the workers.

Acknowledgements

The authors thank for the support from National Natural Science Foundation of China, No. 81450022 and No. 51308561.

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