Filtration Mechanisms of Particulate Respirators

By Erik Johnson, BA, MPH, CIH

Objectives

After completion of this self-study activity, the learner will be able to:

1. Describe how airborne particles are captured in respirator filter media.
2. Explain why smaller particles aren't necessarily more difficult to filter.
3. Discuss the different classes of particulate filters/respirators.
4. Understand why a properly fitting respirator is essential.

Many thanks to the team at 3M Health Care for working with Managing Infection Control *to provide the following accredited course. IAHCSMM has awarded 2 contact point for completion of this continuing education lesson toward IAHCSMM recertification. This inservice is 3M Health Care Provider approved by the California Board of Registered Nurses, CEP 5770 for 1 contact hour. This form is valid up to five years from the date of publication. Instructions for submitting results are on page 68.*

Managing Infection Control *and 3M Health Care will be working collaboratively to provide continuing education courses in monthly editions of* Managing Infection Control.

Test Questions

1. Smaller particles are always harder to filter.
   A. True
   B. False

2. Biological aerosols are filtered similar to non-biological aerosols.
   A. True
   B. False

3. A properly fitting respirator is important because air will take the path of least resistance.
   A. True
   B. False

4. OSHA tests and certifies respirators.
   A. True
   B. False

5. Surgical masks offer the same level of respiratory protection as respirators.
   A. True
   B. False

6. NIOSH uses strict test conditions so that a N95 respirator will often have greater than 95% filtration efficiency in the work place.
   A. True
   B. False

7. Filtration efficiency is the same as the assigned protection factor.
   A. True
   B. False

8. The assigned protection factor may be used to estimate the reduction in respiratory exposure if the respirator is properly maintained and used.
   A. True
   B. False

9. Respirable particles are filtered using which mechanisms (select one):
   A. Impaction
   B. Interception
   C. Diffusion
   D. All of the above

10. Respirators are the preferred method of controlling employee exposure.
   A. True
   B. False

Introduction

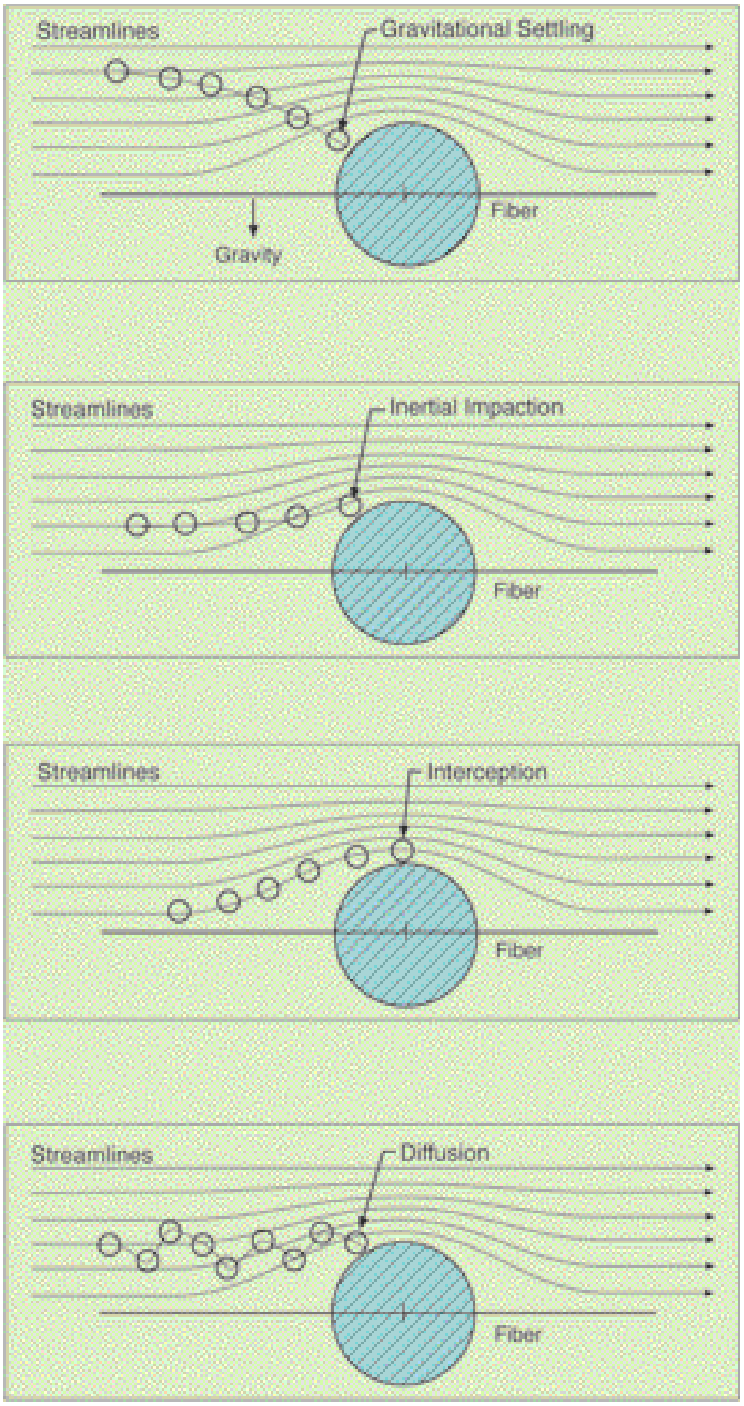
The need for respiratory protection has been recognized in the areas of mining, stone cutting, milling, measuring and sifting grain, and baking for centuries. The Romans wore animal bladders for protection against red oxide of lead in mines. Sackcloths were also attached for protection against dust. Later, Leonardo Da Vinci recommended the use of a wet cloth against chemical warfare. A modification of this came into effect during World War I as respirators were developed for protection against either poison gasses or highly toxic particulate matter.[1]

Today there are many different types of respirators available to help reduce respiratory exposure to various airborne contaminants. Some respirators use carbon or treated carbon to filter harmful gases and vapors, or are designed to supply breatheable air from a compressed air source. However, this paper will focus solely on how particulate respirators use fibrous filter media to capture either solid or liquid particles.

Particulate Filtration

Many particulate respirators use a non-woven fibrous filter media to capture particles. Fibers from less than a micrometer to 100 um in size crisscross to form a web of many layers which is mostly air. It is the spaces between fibers that allow for breathability. Therefore, a particle does not become trapped because it tries to go through a hole that is too small. Rather, while "trying" to navigate through the layers of filter media, a particle becomes attached to a fiber due to a number of different mechanisms. The most common of these are gravitational settling, inertial impaction, interception, diffusion, and electrostatic deposition.[2]

Figure 1: Mechanisms of Particle Filtration



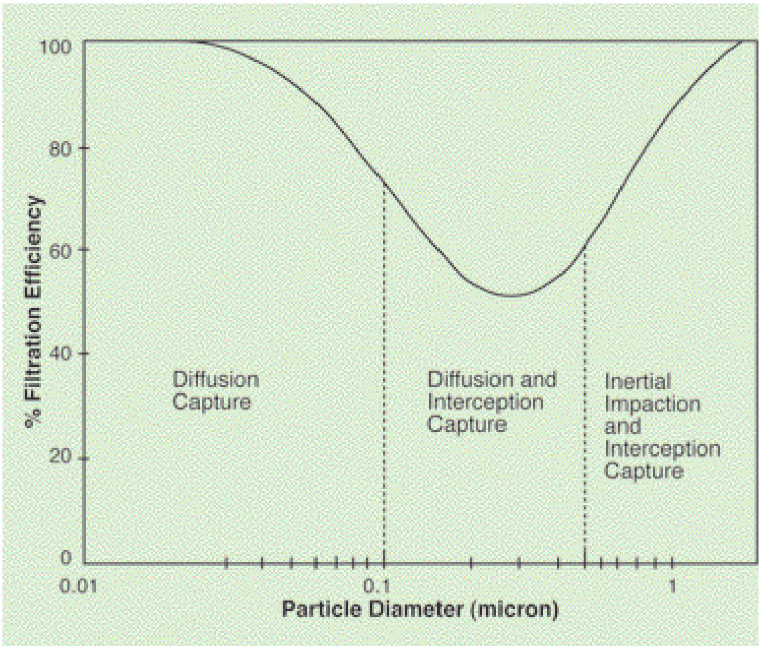
To understand how a particle is captured, one must first consider the movement of air through the filter media. The path of the air around a fiber may be described in terms of imaginary streamlines. Any particle carried by the air may or may not stay within the streamlines depending largely upon the particle's size (aerodynamic diameter). See Figure 1 for Mechanisms of Particle Filtration.

Very large particles in slow moving airstreams may settle out due to gravity. However, most respirable particles are too small for this mechanism. Respirable particles above 0.6 um in diameter may be captured by interception and inertial impaction.[3] Inertial impaction occurs when a particle cannot follow a streamline around a fiber because of its inertia and instead impacts into the fiber. In the interception mechanism, the particle holds to the streamline, but that streamline will naturally bring the particle close enough to come in contact with the fiber. In contrast, diffusion mainly affects particles under 0.1 um. Random movements of air molecules cause these very small particles to wander across streamlines due to Brownian motion until they come in contact with a fiber.

Because of the complex methods by which particulate filtration occurs, the smallest particles are not always the most difficult to filter. Figure 2 (Filtration Efficiency vs Particle Size) shows the interaction of the different capture mechanisms on one type of filter media for the purpose of illustration.[3] Filtration efficiency is shown as a function of particle diameter. While the filtration efficiencies are not representative of actual filters used in respirators today, it does demonstrate that most particulate filters have a region of minimum filtration efficiency somewhere between 0.05-0.5 um.[2] Particles in this range are too large to be effectively pushed around by diffusion and too small to be effectively captured by interception or impaction.

Electrostatic attraction is an entirely different particulate capture mechanism. Since the introduction of the resin-wool filter in 1930, many of the filters used in respirators are electrostatically charged.[1] Although it may be difficult to quantify the charge on either the particle or the fiber, electrostatic attraction can be an extremely effective

Figure 2: Filter Efficiency vs. Particle Size



means of capture.[2] A charged particle will be attracted to fiber that has an opposite charge. In addition, a charged particle or fiber will induce an electrostatic field that will further serve to draw the two together.

NIOSH Particulate Respirator Classes and Testing

In the United States, respirators are tested and certified by the National Institute for Occupational Safety and Health (NIOSH), which is part of the Centers for Disease Control and Prevention (CDC). NIOSH tests and certifies nine classes of negative pressure particulate respirators based upon filtration efficiency and resistance to oily mists.[4] ("Negative pressure respirators" means that the negative pressure inside the lungs during inhalation is used to draw air through the cartridges or filters.) Respirators classified as 95, 99 or 100 must demonstrate filtration efficiency greater than or equal to 95, 99 or 99.97%, respectively.

The "N" series is tested against a solid sodium chloride particle. They are for use against **N**on-oily aerosols such as silica, asbestos, wood dust, etc. There is no restriction from NIOSH regarding length of use. However, good industrial hygiene dictates that particulate respirators must be replaced if physically damaged, increased breathing resistance is noted, or according to administrative policies. The "R" and "P" series are tested against a liquid dioctyl phthalate (DOP) particle. They are for use against oily mists such as cutting and grinding fluids. The "R" series is "oil-**R**esistant" and may be limited to eight hours of continuous or intermittent use against oily aerosols. The "P" series is "oil-**P**roof" and may be used against oily aerosols for the duration recommended by the manufacturer. "R" and "P" series filters may also be used against non-oily aerosols. NIOSH also tests and certifies high efficiency particulate air (HEPA) filters for powered air purifying respirators (PAPRs).

NIOSH selected their particulate filter test criteria to be a "combination of worst-case and very severe test criteria."[4] For example, the particle size that is the most penetrating will depend upon the filter being tested, but as mentioned above, most filters have a region of minimum filtration efficiency somewhere between 0.05-0.5 um. Therefore, NIOSH uses 0.3 um particles to test particulate filters and respirators.

The next concern is whether or not the test aerosol has been electrically neutralized. As noted previously, a charged particle will be much easier to capture and will thus give a higher filtration efficiency. Thus, NIOSH uses an aerosol that has been neutralized to the Boltzman equilibrium state. This means that while some charged particles remain, the distribution of charge is a bell shaped curve with center at zero.

The length of the test will also have an effect on the filter efficiency. A solid test agent will normally cake on the surface of the filter over time. This will allow less material to pass through, and raise the filtration efficiency over the duration of the test. However, other aerosols may degrade filter media and reduce filtration efficiency over time. Therefore, NIOSH measures filtration efficiency at the beginning and throughout the test to ensure that it is never below the 95, 99, or 99.97% filtration rating.

Sodium chloride and dioctyl phthalate are used because they are known to degrade certain types of filter media. A flow rate of 85 liters/minute is used because high flow will decrease filtration efficiency against smaller particles.

Healthcare Environments

Particulate respirators are often used to help reduce respiratory exposure to biological hazards such as *M. tuberculosis* or the virus that causes severe acute respiratory syndrome (SARS). Published research indicates that biological aerosols are filtered similarly to non-biological aerosols having the same aerodynamic diameter.[5,6,7,8,9] CDC recommends and OSHA allows the use of any of the current particulate filters/ respirators (95, 99, 100 or HEPA) to help reduce TB exposure.[10,11]

Healthcare workers often ask how a respirator differs from a surgical mask. A simple explanation is that, historically, the primary purpose of the surgical mask has been to protect the patient or wound site from the exhaled microorganisms of the mask wearer. More recently, surgical masks have also been employed to help reduce exposure of the wearer to blood or other potentially infectious body fluids. However, surgical masks are not necessarily designed to provide a seal to the face, and are not normally submitted by the manufacturer to NIOSH for filtration efficiency testing.

Facial Fit

While a respirator may have excellent filter media, particles will go around the sides of the facepiece unless there is an adequate facial seal. Air will preferentially pass through facial leaks because they offer much lower resistance than the respirator itself.[12] With substantial leaks, a respirator with a higher filtration efficiency rating may actually offer *less* protection than a properly fitted respirator that has a lower filtration efficiency rating.[13] It is for this reason that OSHA requires fit testing of employees who wear tight fitting respirators.[14] This is true whether the respirator is a filtering facepiece (dust mask) or an elastomeric facepiece. Fit testing must be repeated annually and whenever there are changes to respirator design or facial structure that could affect proper fit. Wearers must also perform a "user seal check" each time the respirator is donned prior to entering the hazardous area.

Assigned Protection Factor

Filtration efficiency is often confused with the assigned protection factor (APF). While filtration efficiency is a measurement of the filter, the APF looks at the respirator as a whole (including any potential face seal leakage in a workplace environment). The American National Standards Institute (ANSI) defines the APF as "the expected workplace level of respiratory protection that would be provided by a properly functioning respirator or a class of respirators to properly fitted and trained users."[15] APFs are published by ANSI, NIOSH and OSHA, and the values are not always in agreement. APFs are stated for a class of respirators, independent of the manufacturer. For example, negative pressure half mask respirators are usually given an APF of 10 (regardless of the filter class). This means that this style of respirator may reduce exposure by a factor of 10 (90%) when properly used, maintained, etc. The APF is, therefore, used to determine whether or not a given type of respirator may reduce respiratory exposure to below published exposure limits.

Hierarchy of Controls

OSHA requires a hierarchy of controls such as substitution with a safer material, designing engineering controls to minimize exposure and limiting time spent in the hazardous area in order to eliminate or minimize exposure to harmful substances. In healthcare, this might include early identification of suspect patients, isolation, ventilation, etc. Personal protection equipment—such as a respirator—is only allowed while such controls are being implemented, or if they are not adequate.[14]

Summary

Particulate respirators may be used to help reduce respiratory exposure to airborne particles, including biological aerosols. NIOSH uses a very stringent test protocol, including aerosols in the most penetrating particle size range to assess filtration efficiency. Therefore, filtration efficiency against workplace aerosols will be equal to or greater than the marked rating. However, the employer is still required to implement a respirator program compliant with OSHA standards in order for the respirator to help reduce exposures according to its assigned protection factor. This includes among other things, proper selection, medical evaluation, fit testing, usage, training, maintenance, storage, etc. Respirators are normally the last choice in the hierarchy of controls used to help reduce employee exposure. ✢

References

1. Pritchard, JA. A Guide to Industrial Respiratory Protection. National Institute for Occupational Safety and Health. Cincinnati, OH. (5-8), 1976
2. Hinds WC. Aerosol Technology: Properties, Behavior and Measurement of Airborne Particles. J Wiley & Sons. New York. (164-186), 1982.
3. Lee, KW and BYH Liu. On the Minimum Efficiency and the Most Penetrating Particle Size for Fibrous Filters. Air Pollution Control Association Journal 30(4): 337-381, 1972.

4. Respiratory Protecive Devices; Final Rules and Notice. Federal Register 42 CFR 84 60(110): 30336-30404, June 8, 1995.
5. Chen, S.K., Vesley, D., Brosseau, L.M., and J.H. Vincent. Evaluation of single-use masks and respirators for protection of health care workers against mycobacterial aerosols. Am. J. Infect. Control 22:65-74; 1994.
6. Brosseau, L.M., McCullough, N.V. and D. Vesley. Mycobacterial aerosol collection efficiency of respirator and surgical mask filters under varying conditions of flow and humidity. Appl. Occup. Environ. Hyg. 12(6):435-445; 1997.
7. McCullough, N.V., Brosseau, L.M. and D. Vesley. Collection of three bacterial aerosols by respirator and surgical mask filters under varying conditions of flow and relative humidity. Ann. Occup. Hyg. 41(6):677-690; 1997.
8. Qian, Y., Willeke, K., Grinshpun, S.A., Donnelly, J. and C.C. Coffey. Performance of N95 respirators: Filtration efficiency for airborne microbial and inert particles. AIHA Journal 59:128-132; 1998.
9. Willeke, K., Qian, Y., Donnelly, J., Grinshpun, S.A. and V. Ulevicius. Penetration of airborne microorganisms through a surgical mask and a dust/mist respirator. AIHA Journal 57:348-355; 1996.
10. Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Facilities, 1994 Centers for Disease Control and Prevention. Morbidity and Mortality Weekly Report. (43):33. Oct. 28, 1994.
11. CPL 02-00-106 Enforcement Procedures and Scheduling for Occupational Exposure to Tuberculosis. Occupational Health and Safety Administration. February 9, 1996.
12. Weber, A et al. Aerosol Penetration and Leakage Characteristics of Masks Used in the Health Care Industry. American Journal of Infection Control 21(4): 167-73. Aug, 1993.
13. Chen, CC and K Willeke. Characteristics of Face Seal Leakage in Filtering Facepieces. American Industrial Hygiene Association Journal 53(9): 533-539. Sept. 1992.
14. Respiratory Protection. Code of Federal Regulations, Title 29 Part 1910.134. Occupational Health and Safety Administration. www.osha.gov.
15. American National Standard for Respiratory Protection Z88.2-1992. American National Standards Institute, Inc. New York. 1992.

IAHCSMM has awarded 2 CEUs for completion of this continuing education lesson toward IAHCSMM recertification.

Nursing CEU Application Form

This inservice is 3M Health Care Provider approved by the California Board of Registered Nurses, CEP 5770 for one (1) contact hour. This form is valid up to five years from the date of publication.

1. Make a photocopy of this form.
2. Print your name, address and daytime phone number and position/title.
3. Add your social security number or your nursing license number.
4. Date the application and sign.
5. Answer the CE questions.
6. Submit this form and the answer sheet to:
   Workhorse Publishing
   Managing Infection Control
   PO Box 25310, Scottsdale, AZ 85255-9998
7. Participants who score at least 70% will receive a certificate of completion within 30 days of Managing Infection Control's receipt of the application.

Application

Please print or type.

Name ________________

Mailing Address ________________

City, State, Country, Zip ________________

Daytime phone (   ) ________________

Position/Titile ________________

Social Security or Nursing License Number ________________

Date application submitted ________________

Signature

Offer expires March 2010

Erik Johnson, BA, MPH, CIH, is a technical service specialist with 3M Occupational Health and Environmental Safety Division, St. Paul, Minnesota. He holds his bachelor's degree in physics and a master's degree in industrial hygiene.

Answer Key

1. B	2. A
3. A	4. B
5. B	6. A
7. B	8. A
9. D	10. B

70-2009-7000-5