

Evaluation of User's Ability to Seal Respirator Cartridge Inlet Openings of Different Sizes and Shapes

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ABSTRACT

This study was conducted to evaluate the ability to seal respirator inlet openings during a simulated negative pressure user seal check. One goal of this research was to determine the percentage of subjects that could achieve an adequate seal to a variety of commonly used respirator cartridges. A secondary goal was to identify factors that might limit an individual from obtaining an acceptable seal. An apparatus was constructed to present 12 different respirator cartridges to each subject ($n = 33$) in a way that would maximize their ability to seal the inlet opening with the palm of their hand. Using a pump, rotameter and digital manometer, each cartridge was kept at a pressure of $-2\text{H}_2\text{O}$ ($\pm 5\%$). An adequate seal was confirmed when the rotameter showed a complete restriction of airflow. Standing height, palm length and width measurements were obtained for each subject. None of the subjects was able to adequately seal 100% of the respirator inlet openings. The percentage of subjects who were able to achieve an acceptable seal had a negative correlation with an increase in the area of the inlet opening. The percentage of subjects able to achieve an acceptable seal increased with a decrease in the area of the inlet openings. Based upon the findings of this study, 95% of the study population was able to adequately seal a respirator inlet opening with an area of $\leq 24\text{ cm}^2$. The type of equipment developed in this study could be used by respirator manufacturers and certifying agencies to verify the probability that an adequate seal can be achieved during negative pressure user seal checks whenever a newly designed inlet opening is created.

Keywords: User seal check, respirator, fit testing, negative pressure

INTRODUCTION

In the United States, current Occupational Safety and Health Administration (OSHA) regulations require that a worker must pass a fit test before using a respirator. This test can be qualitative or quantitative, and must be preceded by a medical evaluation to determine the user's ability to safely wear respiratory protection when required (US Department of Labor, 2006). To help respirator wearers evaluate fit during donning and respirator use, workers are also trained to perform user seal checks. The user seal check is performed by the respirator wearer and is a requirement of the OSHA Respiratory Protection Standard,

29 CFR 1910.134. When properly performed, it helps the user identify potential leakage before entering a hazardous environment. OSHA defines a user seal check as “an action conducted by the respirator user to determine if the respirator is properly seated to the face” (US Department of Labor, 2006).

In some parts of the world, cartridges and filters have different meanings. Therefore, for the purposes of this manuscript, the term “cartridge” will be used generically to identify an air-purifying element and housing assembly that can be used to remove gases, vapors, or particulates.

There are two types of user seal checks (negative and positive pressure) performed by respirator wearers to evaluate the donning and seal of a tight fitting respirator. A negative pressure user seal check is generally performed by closing off the inlet opening of the cartridge, such as with the palm of the hand(s) and inhaling. “If the facepiece remains in its slightly collapsed condition and no inward leakage of air is detected, the tightness of the respirator is considered satisfactory” (US Department of Labor, 2006). Inward air leakage may come through the sealing surface, possibly damaged areas, or the exhalation valve (Delaney et al., 2003). The user determines if he/she passes or fails, so adequate training on user seal checks is crucial.

A user seal check should not be confused with a quantitative or qualitative fit test. A fit test also detects respirator leakage, but is usually only administered on an annual basis. User seal checks are conducted every time a respirator is donned, whenever leakage is suspected, and prior to fit testing. However, even when user seal checks are performed in the presence of a trained observer, such as during fit testing, they may not be done correctly. This may help explain why a user may fail a fit test and not realize why. This situation can lead to the notion that user seal checks are not predictive of mask failure and make the user question the method of performing user seal checks (Crutchfield et al., 1999).

To perform a successful negative pressure user seal check, the user must be able to fully seal the inlet opening to the respirator cartridge(s) completely. If a user is physically unable to conduct a negative pressure user seal check, he/she may not recognize that the respirator is improperly sealed to the face. A person can be limited in performing an acceptable user seal check if his/her hands are too small or if the intake opening is unusually shaped for the user to cover.

In the United States, the National Institute for Occupational Safety and Health (NIOSH) is responsible for certifying air purifying respirators and their accompanying cartridges. This organization is charged under the Department of Health and Human Services law 42 CFR Part 84, Respiratory Protective Devices, to certify respirators and their components (Code of Federal Regulations, 1995). Under this law and its subparts, there are minimum requirements to be certified. However, the law does not specify cartridge shape, size, or design for the purpose of conducting user seal checks.

Dozens of manufacturers produce respiratory protection products. These companies make cartridge openings of different sizes and shapes. Respirator selection is usually determined by the employer, based primarily on knowledge of the type and concentration of the airborne hazard and other workplace factors. The cartridge inlet opening's size and shape are not a primary consideration. In addition, respirator manufacturers generally do not make different size and/or shape inlet openings for any one specific make or model respirator. Consequently, respirator users usually do not have a strong influence on the selection of respirators based upon their ability to seal the respirator inlet opening.

Apart from anecdotal observations, there is a lack of data regarding the users' ability to adequately cover different shape and size cartridges during the performance of negative pressure user seal checks. The purpose of this study was to assess how cartridge intake opening size and shape affect the users' ability to create an adequate seal with their hands during a simulated negative pressure user seal check.

MATERIALS AND METHODS

An apparatus was built consisting of a medium-flow personal air sampling pump (SKC Airchek® 224-52), a custom built user interface platform made of wood with an acrylic glass top, digital manometer (Airflow™ PVM100 micromanometer), rotameter (SKC® 5000ml), and 12 different respirator cartridges (2 from each of 6 manufacturers). The cartridges were chosen based on availability from online retailers. To avoid purchasing unnecessary cartridges, the selection was further narrowed to those sold in packs of 2 or by donation to the study. Single contaminant cartridges were chosen instead of combination cartridges, with one exception.

The respirator cartridges used, with numerical study designation in parenthesis, are as follows: North® N7500-1 (1), AOSafety® 8057 (2), Moldex® 8990 (3), Scott® 7422-BA1 (4), Scott® 7422-FP1 (5), AOSafety® 8051 (6), 3M™ 6001 (7), MSA™ 815303 (8), 3M™ 60926 (9), MSA™ 815141 (10), North® 7580P100 (11), and Moldex® 8100 (12). Figure 1 shows the top view of the apparatus and displays each cartridge's shape, size, and location on the grid. The numbers on the grid correlate with the numerical designation of the cartridges.

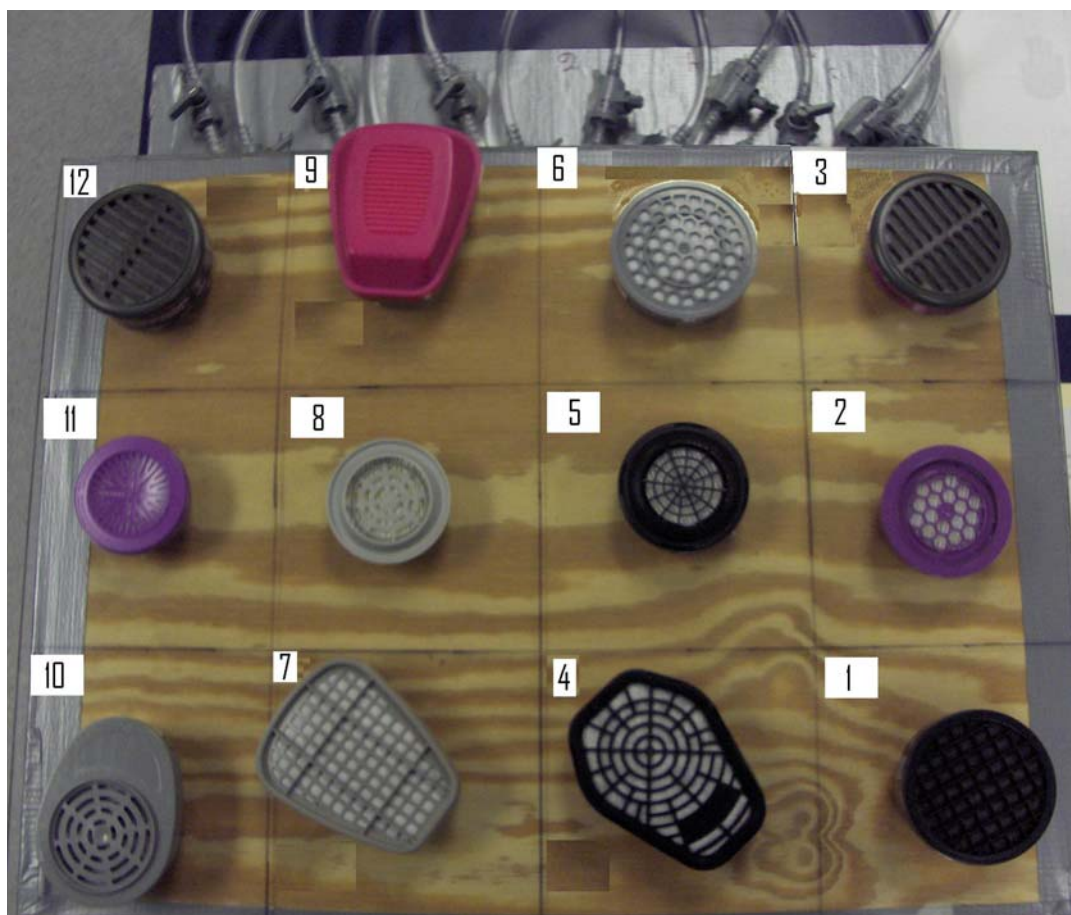


Figure 1. Photograph of respirator cartridges and study designation number.

Figure 2 shows a schematic of the airflow through the system and the equipment used as follows: the pump created the flow rate, which was connected to a rotameter and a Tee splitter. The Tee split the flow between air lines and branched off to the digital manometer. The far end of the Tee splitter remained open to be manually connected individually, in order from 1 to 12, to each of the cartridge lines for testing.

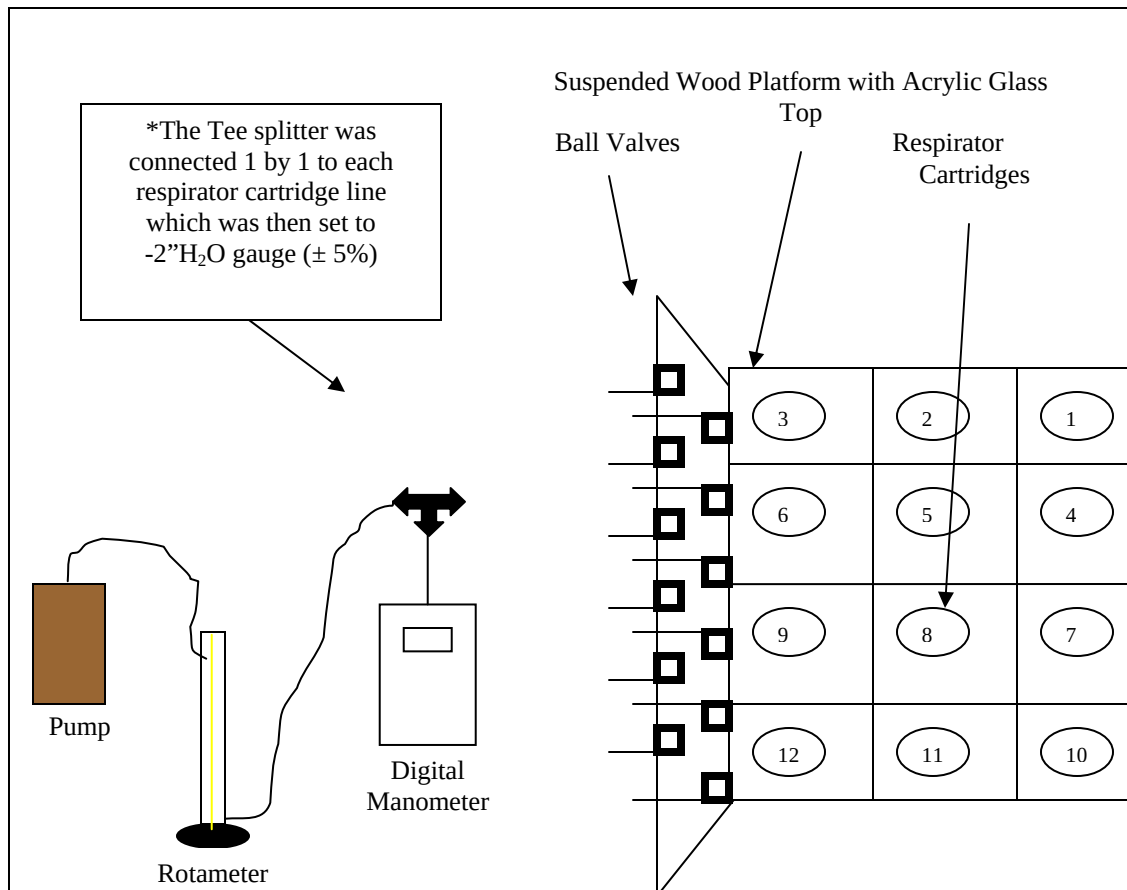


Figure 2. Diagram of the experimental set-up.

Starting from the point where the Tee splitter was attached, there was an open hose connection leading to a ball valve, which was connected to a changeover connector ($\frac{1}{4}$ " hose barb to $\frac{1}{2}$ " threaded). The connector was screwed into the underside of an acrylic glass platform where the respirator cartridges were secured. All airflow was drawn through $\frac{1}{4}$ " inner diameter tubing connected by $\frac{1}{4}$ " inner diameter hose barb connectors.

The pump pulled air at a near consistent flow rate (around 1.5 l/min), variation depending upon the specific cartridge, to create a significant negative pressure (-2 " H₂O, $\pm 5\%$) for a representative negative pressure user seal check simulation (Crutchfield et al., 1993). Each ball valve was calibrated with the manometer and kept in a specific restricting position respective to the cartridge to which it was connected. Each cartridge produced a different static pressure in its respective line of flow, so the ball valve was used to adjust the static pressure within 5% of the desired value. A rotameter was used to detect an adequate seal by the subject. An adequate seal was obtained when the rotameter confirmed a complete restriction of airflow long enough to nearly seize the pump.

Thirty-three subjects participated in this study. The population consisted of unpaid adult volunteers who were employees or students at the University of Cincinnati. There were no prerequisites for inclusion in the study and it did not require approval by the institutional review board. The volunteers were obtained by convenience. Subjects' heights without shoes were measured and recorded to the nearest sixteenth of an inch and converted to the nearest tenth of a centimeter.

Palm surface area was calculated by multiplying the measured length and width on each subject. Length was measured from the base of the middle finger to the base of the hand (wrist). Width was measured from the base of the thumb to the edge of the outside of the palm directly across from the thumb. The dimensions were measured in centimeters and multiplied to obtain an estimate of palm surface area in square centimeters.

The final step in the process was to have each subject attempt to adequately seal the respirator cartridges by using the palm of their hand. The attempts were sequential following the numerical order on the platform grid. The subjects were told they could move anywhere about the platform, which was located on a standard laboratory bench top in position for the subjects to look down upon the cartridge inlets while standing. They were instructed to wait until the pressure was set within parameters before attempting a seal, and then told to stop if a seal was obtained. The subjects could give up whenever they decided a seal was unobtainable.

RESULTS

Results for 33 subjects are shown in Table I. Each cartridge is listed by its assigned numerical designation followed by whether or not an acceptable seal was obtained and the success rate by percentage. Five of the 12 cartridges had a 100% success rate, indicating that every subject was able to achieve an acceptable seal. Cartridges 4 and 7 had the lowest success rates, 6.1% and 3.0% respectively. For the remainder of the cartridges the success rate varied between 69.4% and 93.9%.

The surface area of cartridge openings ranged from 17.4 cm² to 67.3 cm² with an average of 33.6 cm². Thus, some cartridges had inlet openings nearly four times larger than the smallest opening. Figure 3 shows graphical representation of the decline in the subjects' ability to create an adequate seal as the surface area of the cartridge opening increased. The downward trend line is a negative second order polynomial created for best fit to the 12 points of data gathered. As labeled by an intersection in the figure, the 95th percentile was calculated at 24 cm². This value represents the maximum surface area of the opening that 95% of the study population was able to adequately seal. The figure also provides a graphical representation of the shape of the opening. The three shapes represented by the 12 cartridges used were circles (1,2,3,5,6,8,10,11,12), hexagons (4), and trapezoids (7,9).

The percentage of acceptable seals obtained for each subject is shown graphically in Figure 4. None of the 33 subjects was able to adequately seal all 12 cartridges used in this study. However, every subject was able to obtain an adequate seal on at least 50% of the cartridges. An upward trend of success rate is represented in Figure 4.

The average height measured for the 33 subjects in this study was 5'8" (173 cm), with a range from 4'11" (149.9 cm) to 6'4" (193.4 cm). The average palm surface area measured was 95.5 cm² with a range of 58 cm² to 115.5 cm². When comparing height to the surface area of the palm, the R² value was 0.56, which supports a moderate correlation between height and hand size. However, when comparing the percentage of acceptable seals obtained, neither height (R² = 0.39) nor palm surface area (R² = 0.27) were highly predictive.

Table I. Number and percentage of acceptable seals achieved by cartridge number

Respirator Cartridge Number	Acceptable Seal Achieved		% of Subjects Achieving Acceptable Seal
	YES	NO	
1	23	10	69.7
2	31	2	93.9
3	30	3	90.9
4	2	31	6.1
5	33	0	100.0
6	24	9	72.8
7	1	32	3.0
8	33	0	100.0
9	33	0	100.0
10	33	0	100.0
11	33	0	100.0
12	29	4	87.9
33			Total Subjects

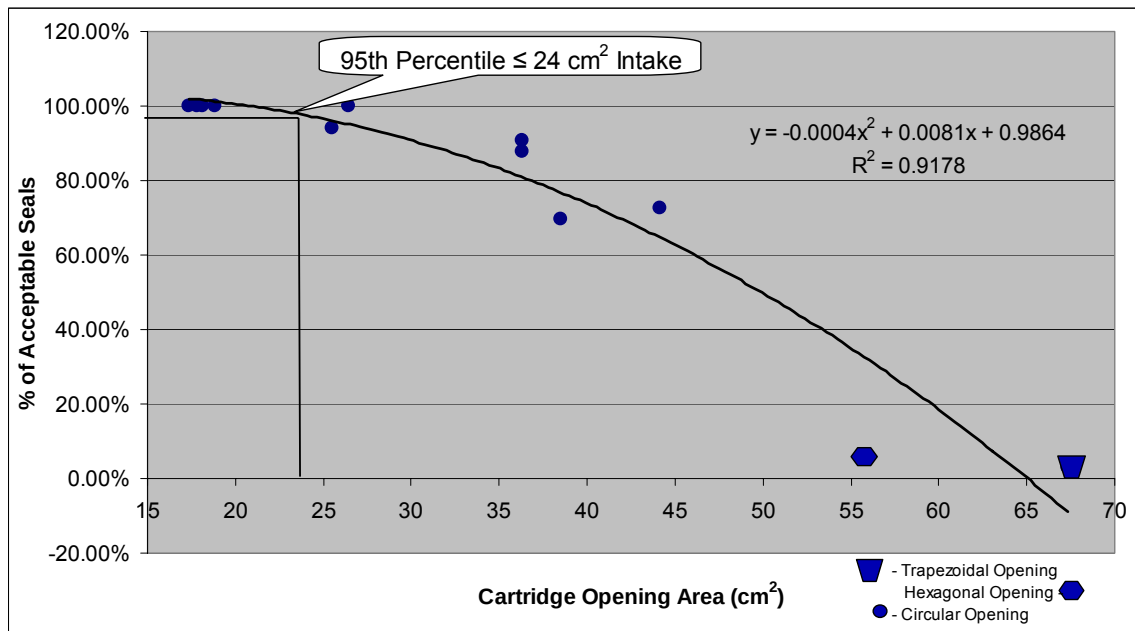


Figure 3. Acceptable seals vs. cartridge opening area. Note: The second data point from the left is also a trapezoid.

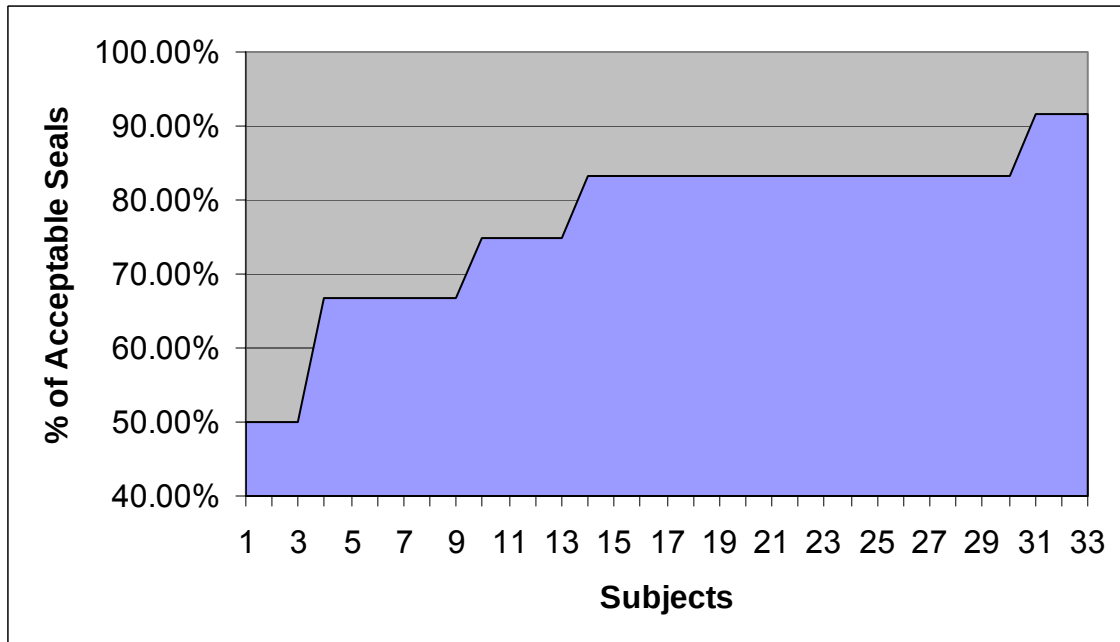


Figure 4. Range of subjects' ability to obtain acceptable seals.

DISCUSSION

The inlet opening surface area was found to be the most important factor that determines whether an acceptable seal can be obtained when conducting a simulated negative pressure user seal check. Based upon this study (Figure III), the area of the inlet opening should be $\leq 24 \text{ cm}^2$. This represents the size sealed by 95% of the study population. Larger inlet openings would likely require the use of additional equipment such as latex/rubber gloves, cardboard cards, etc. to achieve an acceptable seal. If the respirator wearer cannot adequately seal the inlet opening with his or her hands alone, they may be less likely to perform the procedure and may not identify an improperly fitting respirator.

Cartridges 4 and 7 were infrequently sealed by our study population. There are two observed reasons for this. First, their shapes were odd in comparison to the shape of the human hand. Cartridge 4 was an oblong hexagon with variable width about its length. Cartridge 7 was similarly oblong but it was a trapezoidal shape. The second and most notable reason for each was their large sealing surface areas. The calculated surface area for cartridge 4 was approximately 55.9 cm^2 and the area for cartridge 7 was 67.3 cm^2 . Only 2 of our 33 subjects were able to achieve an acceptable seal to cartridge number 4 and only 1 of 33 to number 7. These cartridges have surface areas approximately 2.3 and 2.8 times the surface area recommended in this study.

Working populations encompass a wide variety of heights, hand sizes, and other physical characteristics. This analysis compared standing height to the percentage of subjects obtaining an adequate seal based on the assumption that height is positively correlated to hand size. However, our data does not provide convincing evidence that height or palm surface area individually limit a subjects' ability to obtain an adequate seal to respirator inlet openings. Other factors, not evaluated in this study, such as palm shape and usable surface area may be more important.

Cartridges 7 and 9 both come from the same manufacturer and can be used with similar respirator facepieces. However, the ability of our study subjects to seal the inlet opening is dramatically different. Cartridge number 7 is approved for gases and vapors. It was also the poorest performer in our study. Cartridge number 9 is essentially the same as number 7, except it has a particulate filter permanently mounted to the top of the cartridge with a different size and shape of the inlet opening. The ability to seal the inlet opening is much improved with the addition of the particulate filter. This means the probability a respirator wearer can acceptably seal the inlet opening can vary depending upon which cartridge they need for workplace exposure. Ideally, the workers ability to perform a negative pressure user seal check should be the same irrespective of which cartridge or filter they need, for a given make and model respirator.

Many factors, including proper respirator training contribute to the ability of a respirator wearer to perform negative pressure user seal checks correctly. Obviously, hand size cannot be changed. However, an inlet opening which is difficult for a user to adequately cover may force the individual to use excessive force. Pushing too hard on the inlet opening could seal a previous leak at the facepiece due to compression of the sealing surface. In the absence of the excessive external hand pressure, the leak would reappear and potentially increase worker exposure. A user may also inhale to an extreme, with the resulting high negative pressure causing the mask to falsely seal to the face. Inlet openings that are difficult to cover, may require the user to perform multiple user seal checks. A wearer can continuously adjust a respirator and seal check it again and again until it seems to fit right, but this further instills the wrong practice and continually causes false positive results (Janssen et al., 2002).

In this study, the respirator cartridges were placed on an open platform in front of the subject. This differs from cartridges attached to respirators worn on the face. For this study, cartridges were laid out so that they would be in an orientation similar to being worn on the user's face, but not nearly as awkward to get at. The subjects were also able to move about the platform and reposition their hands as

much as desired when attempting to seal the inlet opening. Although not studied, we believe it is easier to seal the cartridge on our platform. Study subjects could have used higher downward forces to seal the inlet openings than if the respirator was worn on the face. If true, the percentage of subjects able to obtain an acceptable seal in this study may actually be higher than that achieved in the workplace. Study subjects could also clearly see the cartridges in this study, which would not be true when worn on the face (unless a mirror is used). The ability to clearly see the cartridge may overestimate the percentage of subjects achieving an acceptable seal. Overall, the rate of acceptable seals reported in this study is likely higher than those achieved in the workplace.

In the United States, the OSHA respiratory protection standard states that if the users' hands alone are not adequate to create a seal when performing user seal checks, he/she should use a latex or nitrile glove (US Department of Labor, 2006). We rarely observe this. Some respirator designs may incorporate caps or covers that eliminate the need for the wearer to cover the inlet opening with his or her hands. Alternatively, other approaches including odorous or irritating challenge agents may eliminate the need for workers to use their hands. Positive pressure user seal checks can also be used; however, there are limitations to positive pressure user seal checks. When it is necessary to cover the respirator inlet opening the workers' hands are the most readily available resource to do so. Respirator certifying organizations should therefore consider, the size and shape of cartridge inlet opening or the ability to occlude the opening when manufacturer instructions recommend using the hands. Respirator manufacturers could also develop alternative designs that would help ensure every respirator wearer can adequately check the seal of the respirator to the face.

CONCLUSIONS

In conclusion, this study showed that the surface area of the respirator's inlet opening is the most important factor that determines whether an acceptable seal can be obtained when conducting a simulated negative pressure user seal check. An inlet opening $\leq 24 \text{ cm}^2$ resulted in over 95% success rate in user seal checks. Respirator manufacturers as well as certifying organizations should consider the ability of users to successfully occlude the inlet opening when this method is recommended by the manufacturer. This could be accomplished by including a requirement for a test panel to achieve an acceptable seal using an apparatus similar to that developed in this study as part of the certification process. Alternatively, certifying agencies could request data from manufacturers that demonstrate the ability to occlude the inlet opening.

ACKNOWLEDGEMENTS

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