The Effects of Strapped Spectacles on the Fit Factors of Three Manufactured Brands of Full Facepiece Negative Pressure Respirators

TERRY M. SPEAR, *§ ROCK HARDGROVE, † JULIE B. NORMAN, * DAVID T. WULF ‡ and RICHARD J. ROSSI *

*A School of Mines, Montana Tech of the University of Montana, 1300 W. Park Street, Butte, MT 59701-8997, USA; †Clayton Environmental, 22610 N.E. Inglewood Hill Road, Redmond, WA 98053, USA; ‡Conoco, Inc., P.O. Box 4569, Houston, TX 77210, USA

A study was conducted to determine the effects of strapped spectacles on the fit factors obtained during quantitative fit testing on three different brands of full facepiece negative pressure respirators. The three brands of respirators were evaluated with and without strapped spectacles worn by the test subjects. A total of 180 quantitative fit testing trials were conducted on ten male test subjects. For each test subject, three quantitative fit testing trials were performed with each brand of respirator with and without the spectacles. The average of the fit testing trials for each subject with each respirator was used for statistical analysis. The results demonstrated that the fit factor values were significantly lower during use of the spectacles (p < 0.05). The estimated percentage of test subjects who failed the American National Standards Institute pass/fail criteria for quantitative fit testing (1000) increased by 15–36% when spectacles were worn. © 1999 British Occupational Hygiene Society. Published by Elsevier Science Ltd. All rights reserved.

Keywords: respirator fit testing; quantitative fit tests; fit factor; spectacles

INTRODUCTION

Respiratory protection has become commonplace in industries that expose workers to harmful contaminants. It has been estimated that the number of workers in the United States who rely on respiratory protection ranges from 2.6 to 7 million (Brosseau and Traubei, 1997). When respirators are worn in the workplace, the worker (and employer) are relying on the respirator to serve as the last line of defense in protecting the worker from excessive exposure. In order to accurately assess the exposures of workers wearing respirators, the protection provided by the respirator, or protection factor, must be known or estimated. The protection factor (PF) represents an expression of the performance of a respirator based on the ratio of two generalized concentration variables, \( C_o \) and \( C_i \). The variable \( C_o \) is defined as the measured concentration of the contaminant outside the facepiece of the respirator and \( C_i \) is defined as the measured concentration of the contaminant inside the facepiece of the respirator (NIOSH, 1987). PFs, such as assigned protection factors (APF), are used by regulatory agencies and industrial hygienists to determine the limiting concentration of contaminants in the ambient environment against which a given respirator would provide adequate protection to the user, assuming the respirator was properly selected, fitted and used.

The fit factor is a special application of the PF ratio that represents a quantitative measure of the fit of a particular respirator facepiece to a particular individual, defined under the conditions of quantitative fit testing as the aerosol concentration in the test chamber \( (C_o) \) divided by the penetration that occurs through the respirator face seal interface \( (C_i) \) (NIOSH, 1987). For \( C_i \) to reflect only face seal leakage, high efficiency filters are installed on the respirator. The fit factor is measured on a complete respirator worn by a test subject who follows a regimen of slow head movements, deep breathing and talking.
The PF of a respirator to a given individual is strongly dependent on the properties of the facepiece, including how well the facepiece seals to the wearer’s face (Nelson, 1995). Any condition that interferes with the face-to-facepiece seal should not be permitted. Research has shown that facial hair interferes with the fit of a respirator (Hyatt et al., 1985; McGee and Oestenstad, 1983) and the National Institute for Occupational Safety and Health (NIOSH, 1987), the American National Standards Institute (ANSI, 1992) and the Occupational Safety and Health Administration (OSHA, 1998) all restrict the presence of facial hair in respirator wearers. Additionally, the above mentioned agencies and organization recommend that nothing be allowed between the sealing surface of a respirator facepiece and the wearer’s face that will prevent a good seal. NIOSH even states that eye glasses with temple bars or straps that pass between the sealing surface of a full-facepiece seal and the worker’s face should not be used (NIOSH, 1987).

The objective of this research was to evaluate the effect of strapped spectacles, designed for use under full facepiece respirators, on the fit factors of three brands of full facepiece negative pressure respirators. We were recently made aware of a situation where workers wore strapped spectacles under full facepiece respirators and realized that very little research has been published on full facepiece respirators in such cases. One previous study reported significant differences in fit factors obtained for two of three brands of full facepiece negative pressure respirators, when strapped spectacles were worn (Los Alamos National Laboratory, 1985).

METHODS

Respirators and adaptors

Three brands of full facepiece negative pressure respirators were used in this study: 3M 7800 (3M Corporation, St. Paul, MN), Survivair 4200 (Survivair Incorporated, Santa Ana, CA) and North 7600-8A (Siebe North Incorporated, Cranston, RI). The 3M 7800 full facepiece respirator has a double-flap face seal, nose cup and six adjustable head straps. This respirator is also equipped with a speaking diaphragm and a large face shield made from scratch resistant polycarbonate. The Survivair 4200 full facepiece respirator has a single-flap face seal made of lightweight, pliable silicone and is not equipped with a nose cup. This respirator has four adjustable head straps and also uses a speaking diaphragm. The North 7600-8A full facepiece respirator has a dual flanged face piece made of silicone, an oral/nasal cup, speaking diaphragm and a five strap head harness. In order to facilitate the quantitative fit testing (QFT) of different test subjects, different sizes of each of the three manufactured brands of respirators were obtained (three sizes of 3M respirators and two sizes each of Survivair and North respirators).

QFT using each of the respirators described above was performed using QFT adaptors provided by each respirator manufacturer. The adaptor used with the 3M 7800 respirator was the 3M 7898 QFT probe, which was installed through the speaking diaphragm of the respirator. The adaptor used with the Survivair 4200 respirator was the Survivair 420025 QFT adaptor, which enters the mask through the inhalation valve of the respirator. The adaptor used with the North 7600-8A respirator was the North 7700-21 QFT adaptor, which also enters the mask through the inhalation valve of the respirator.

Spectacles

The eyewear used under the full facepiece respirators during QFT were Mag 1 spectacles, U.S. Patent number 4,391,498, manufactured by Criss Optical Manufacturing Company, Incorporated, in Wichita, Kansas. These spectacles are made of DuPont nylon and have a specially constructed rubber strap that attaches the spectacle to the head. The strap or head band consists of a thin section, which passes under the facepiece of the respirator, and then becomes thicker towards the back strap section, which mounts around the back of the head. The entire strap is 0.95 cm wide and 0.13 cm thick in the thicker back strap section. The thin section of the strap which passes under the respirator facepiece is 0.06 cm thick in a relaxed condition and decreases to approximately 0.04 cm when the strap is stretched around the head. The Mag 1 Spectacle is designed for military use under gas mask canister respirators and by military pilots. The Mag 1 spectacle is shown in Fig. 1.

Aerosol measurement

The Portacount Plus Model 8020, manufactured by TSI Incorporated (St Paul, MN; TSI Incorporated, 1996), was used for all QFT performed in this research. This is a miniature continuous-flow condensation nuclei counter which can measure particles as small as 0.02 micrometers by laser light scattering. Respirator fit factors and filter penetrations were measured using ambient air particles as the challenge aerosol.

The Portacount Plus has a set airflow rate, which is used along with the time and particle count to determine particle concentration. The airflow rate is maintained by a diaphragm vacuum pump that operates at a continuous flow rate of 0.71 min⁻¹. The airflow can enter the instrument from one of two ports, which sample either ambient air or air from within the respirator according to a programmed sequence. The airflow is then split within the instrument, with only 0.11 min⁻¹ being drawn through the
laser counting system and the remaining airflow being exhausted from the instrument.

**Number and selection of test subjects**

A total of 180 QFT trials were conducted on ten test subjects chosen from a group of volunteers. In order to minimize population variables, the experimental protocol was designed to accept only males between the ages of 18 and 25 years old as test subjects. Additionally, the test subjects had to be literate, to understand and follow instructions, and to be capable of obtaining an acceptable QFT with at least one size of each of the three brands of respirators. For each test subject, three QFT trials were performed with each brand of respirator without the spectacles and three QFT trials were performed with the same respirators with the test subject wearing the spectacles under the facepiece. The QFT trials were conducted in sets of three, as recommended by the American National Standard for Respiratory Protection (ANSI, 1992). For each of the ten test subjects, a total of 18 QFT trials were performed.

**Quantitative fit testing (QFT) procedures**

Prior to QFT, each test subject was fully educated on the use of full facepiece respirators and the steps that would be taken during the QFT. The subject was shown the proper respirator donning and doffing technique, including the location of the straps used to tighten the respirator to the face. Each subject was shown, and allowed to practice, the proper method of performing negative and positive pressure fit checks to assure they had a good face-to-facepiece seal. The fit checks were also used to determine the proper size of each respirator brand for each of the test subjects. The test subjects were then instructed in and allowed to practice the QFT protocol which consisted of the following exercises: normal breathing, deep breathing, head movement side-to-side, head movement up-and-down, reading the ‘rainbow passage’, and normal breathing. Each test subject was given detailed instruction as to how to perform these exercises. Finally, each individual was instructed not to smoke for thirty minutes prior to the test.

After being instructed, each subject was provided with a randomly selected respirator. A random number sequence was used to determine when QFT was to be conducted with or without the spectacles. Once a respirator brand was selected for a given test subject, the subject was provided with the proper size of respirator determined from the earlier fit testing instructions. After equipping the respirator with HEPA filters and the appropriate fit test adaptor, the respirator was donned, re-fit checked and a QFT trial was performed to determine if an acceptable fit factor could be obtained. The Portacount Plus was pre-set at a pass-level of 100. If an acceptable fit factor could not be obtained, the subject was re-fitted with a different size of the same respirator brand and re-tested.

During the QFT trials, each exercise lasted approximately 80 seconds and concluded with an audible signal from the Portacount Plus. During the exercises, a metronome was used to standardize the movements of the test subjects. The metronome was set at the lowest setting of 40, which corresponds to a pace of approximately one second.

**Statistical analysis**

Because of the obvious skewness of the fit factors, the data were transformed as follows prior to statistical analysis. First, average fit factors were determined for each subject based upon the three independent trials per subject. Then natural logarithms of these subject-specific mean fit factors were used for all subsequent analyses. Lognormality of subject-specific mean fit factors were evaluated both qualitatively, by probability plotting of the relative cumulative frequency distributions, and quantitatively, using a standard chi-square goodness of fit test and the Shapiro–Wilks W test. All distributions of fit factors were judged to be adequately described by lognormal distributions using these criteria. Descriptive statistics and proportions of fit factors exceeding the ANSI criterion of 1000 for negative pressure full facepiece respirators were estimated with LogNorm2 Software (In Tech Software
Ratios of subject-specific mean fit factors for each brand of respirator, with and without spectacles, were similarly evaluated. The mean values of the lognormal distributions (subject-specific means) were estimated as minimum variance unbiased estimates (MVUE). The confidence limits of the MVUEs were estimated using Land's 95% confidence limits (Hewett and Ganser, 1997).

The effect of spectacles on subject-specific mean fit factors was evaluated with a randomized block 2-factor Analysis of Variance (ANOVA) and Tukey Multiple Comparison Tests. This ANOVA analysis was repeated for data collected during each exercise (normal breathing, etc.). Minitab computer software (McKenzie, 1995) was used for this analysis.

**RESULTS**

Descriptive statistics of the fit factors for each respirator brand with and without spectacles are shown in Table 1. Obviously, fit factors were greater without spectacles in each case. The highest mean fit factor was obtained with the North respirator without the use of the spectacles, followed by the Survivair and then the 3M respirators. However, the greatest exceedance of the ANSI criterion (fit factor of 1000) was observed for the Survivair respirator (99% without spectacles), followed by those of the North and 3M respirators (87–88% without spectacles). Both the mean fit factors and the probabilities of exceeding the ANSI criterion were lower for all three brands of respirators when the spectacles were worn. Comparisons of the fit factors obtained during QFT with and without the spectacles are shown graphically in the lognormal probability plots depicted in Figs 2, 3 and 4. These plots show the fractions of subject-specific mean fit factors below a particular value and can be used to estimate exceedances of any given fit factor. In each case, the reduction in fit factor is clearly observed when spectacles are worn.

Descriptive statistics of the ratios of subject-specific mean fit factors, with and without spectacles, are shown in Table 2 for each respirator. The mean fit factor ratios and the lower 95% confidence limit of the mean fit factor ratios were greater than unity for all three brands of respirators. The probability of the ratios exceeding unity was approximately 88% for the 3M respirator and greater than 90% for both the Survivair and North respirators.

Results of the 2-factor ANOVA of the subject-specific mean fit factors are shown in Table 3. The only variable with a significant effect upon the fit factor was the wearing of spectacles ($p=0.001$). Interestingly, the type of respirator had only a marginal effect ($p=0.126$). There was also no significant interaction present between respirator and spectacles ($p=0.369$).

**Table 1. Analysis of the subject-specific mean fit factors for the 3M, Survivair and North full facepiece negative pressure respirators with and without Mag 1 Spectacles (10 subjects per trial)**

<table>
<thead>
<tr>
<th>Respirator types</th>
<th>3M without spectacles</th>
<th>3M with spectacles</th>
<th>Survivair without spectacles</th>
<th>Survivair with spectacles</th>
<th>North without spectacles</th>
<th>North with spectacles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3,226</td>
<td>1,652</td>
<td>60,050</td>
<td>2,676</td>
<td>291,400</td>
<td>9,907</td>
</tr>
<tr>
<td>LCL*</td>
<td>2,171</td>
<td>1,215</td>
<td>30,390</td>
<td>1,784</td>
<td>89,911</td>
<td>3,333</td>
</tr>
<tr>
<td>UCL†</td>
<td>6,852</td>
<td>2,725</td>
<td>450,564</td>
<td>5,855</td>
<td>3 x 10^5</td>
<td>2.7 x 10^6</td>
</tr>
<tr>
<td>GM‡</td>
<td>2,438</td>
<td>1,401</td>
<td>26,251</td>
<td>1,995</td>
<td>22,750</td>
<td>1,180</td>
</tr>
<tr>
<td>GSD</td>
<td>2.22</td>
<td>1.84</td>
<td>4.08</td>
<td>2.77</td>
<td>13.87</td>
<td>10.67</td>
</tr>
<tr>
<td>% Fit Factors &gt; 1000 (95% LCL¶)</td>
<td>86.78% (66.35%)</td>
<td>70.95% (49.00%)</td>
<td>99.00% (89.59%)</td>
<td>80.06% (58.42%)</td>
<td>88.26% (68.29%)</td>
<td>52.78% (32.53%)</td>
</tr>
</tbody>
</table>

* Lower 95% confidence limit of the mean.
† Upper 95% confidence limit of the mean.
‡ Geometric mean of fit factors.
¶ Geometric standard deviation.
¶ Exceedance fraction 95% lower confidence limit.
The 2-factor ANOVA results obtained during each of the exercises showed similar results in that the wearing of spectacles had the most significant effect upon fit factors (not shown). However, during deep breathing, side-to-side head movement, up and down head movement and the last normal breathing exercise, there was a significant interaction between brand of respirator and spectacles. Whenever a significant interaction was present, significant differences in fit factors, with and without the spectacles, were observed for the North and Survivair respirators ($p<0.05$) but not for the 3M respirator.
DISCUSSION

If a worker wears corrective eyewear and is required to wear a full facepiece respirator as part of his or her job, then the employer should provide eyewear that can be worn under the facepiece. It is accepted industrial hygiene practice and it is stated in the revised OSHA Respiratory Protection Standard (OSHA, 1998) that if an employee wears corrective glasses, the employer must ensure that the eyewear does not interfere with the seal of the facepiece.

Our results are in reasonable agreement with a previous study (Los Alamos National Laboratory, 1985) which showed that the wearing of strapped spectacles can significantly reduce the fit factors obtained during QFT. Based on lognormal probability plots, the estimated percentage differences in the number of test subjects who failed the ANSI criterion of 1000 while wearing the spectacles versus

![Lognormal probability plot of subject-specific average fit factors for North respirators with and without Mag 1 Spectacles.](image)

Fig. 4. Lognormal probability plot of subject-specific average fit factors for North respirators with and without Mag 1 Spectacles.

| Table 2. Analysis of the ratios of the subject-specific mean fit factors with 3M, Survivair and North full facepiece negative pressure respirators obtained with and without Mag 1 Spectacles (10 subjects per trial) |
|---|---|---|---|
| Respirator brands | 3M | Survivair | North |
| Mean | 1.92 | 46.40 | 90.53 |
| LCL* | 1.51 | 19.93 | 35.49 |
| UCL† | 2.72 | 1053 | 4504 |
| % Fit factor ratios > 1; (95% LCL)‡ | 88.12% (68.10%) | 92.79% (74.96%) | 93.29% (75.79%) |

* Lower 95% confidence limit of the mean.

| Table 3. Results of ANOVA (balanced design) for the logarithms of the subject-specific mean fit factors for the ten subjects using 3M, North, and Survivair respirators with and without Mag 1 Spectacles |
|---|---|---|---|
| Source | Degrees of freedom | Sum of squares | Mean square | F value | p value |
| Subject | 9 | 33.70 | 3.75 | 1.01 | 0.449 |
| Respirator | 2 | 16.16 | 8.08 | 2.17 | 0.126 |
| Spectacle | 1 | 47.23 | 47.23 | 12.69 | 0.001 |
| Respirator * Spectacle | 2 | 8.23 | 4.13 | 1.11 | 0.339 |
| Error | 45 | 167.50 | 3.72 | | |
the number of test subjects not wearing the spectacles were 16%, 19%, and 36% for the 3M, Survivair and North respirators, respectively. For those test subjects who did obtain fit factors above 1000, the fit factors were nonetheless lower than those obtained when not wearing the strapped spectacles.

There is a general lack of agreement between fit factors based upon QFT criteria and measured workplace protection factors (Dixon and Nelson, 1984; Grunberg, 1991; Liu et al., 1984; Meyers and Peach, 1983; Meyers et al., 1984). The study conducted at Los Alamos National Laboratory (1985) reported that the use of spectacles under positive pressure Self Contained Breathing Apparatus (SCBA) resulted in little, if any, variation in the protection factors obtained during actual field use of the respirators. We are not aware of any workplace protection factor studies which have evaluated the use of goggles or spectacles under full facepiece negative pressure respirators. Furthermore, our results cannot be used to determine the effects of strapped spectacles worn under full facepiece respirators on the protection factors attained in actual workplace situations. However, our results clearly demonstrate that the wearing of spectacles significantly reduced the fit factor afforded to the wearer and suspect that a substantial reduction in the protection factor would result during actual working conditions.

REFERENCES

McKenzie, 1995 (Minitab software) — No reference data supplied.


