

Laboratory Performance Testing of Powered Air Purifying Respirators

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ABSTRACT

Laboratory performance testing has been conducted on two powered air purifying respirator (PAPR) systems using the TSI PortaCount Plus Model 8020. The two PAPR systems evaluated were: the 3M BE-10 blower system connected to a PC4 respirator and a Carlton blower connected to a PC4 respirator. Initial study revealed some unusual protection factor results depending on whether the blower motors were turned on or off. In an attempt to explain these unusual effects, the aerosols generated by the blower motors themselves were measured. It was found that the amount of aerosol generated by the motors was significant, and was higher when the Carlton blower system was used. Although the amount of aerosol generated by the 3M BE-10 system was quite low, it was large enough to affect the results and was comparable to the amount of subject-generated aerosol measured previously in this laboratory. Inserting these numbers of blower-generated aerosol into the model that was proposed for "modeled respirator protection factor" (Harrison & Liang, 2005), the observed protection factor data were readily explained. Precautions therefore need to be taken when measuring protection factors of powered PAPR systems with a PortaCount.

Keywords: performance test, TSI PortaCount, powered air purifying respirator, PAPR, blower-generated aerosol, protection factor

INTRODUCTION

This report summarizes our findings in conducting laboratory performance testing of powered air purifying respirators (PAPR) using the TSI PortaCount Plus Model 8020. This is a continuation of our current effort in respirator testing at the Royal Military College of Canada (Liang & Harrison, 2005; Harrison & Liang, 2005) and is intended to advise researchers conducting testing with PAPR of errors that may be introduced by "blower-generated aerosols". The objective is to show examples of "blower generated aerosols" from two different blower motors (using the same respirator) and illustrate how they can affect the results.

The US Army Soldier and Biological Chemical Command at Aberdeen Proving Ground, Maryland has published a series of technical reports (Campbell & Pappas, 1999; Campbell et al., 2001, Campbell et al, 2002; Seiple & Pappas, 2003) in measuring the protection factor (PF) of PAPRs using a polydispersed corn oil aerosol inside a test chamber. Penetration of aerosol into the PAPR systems was measured whilst the test volunteers performed 10 exercises (including reciting the "Rainbow Passage").

Aerosol concentrations were measured with light-scattering laser photometer at 0.4-0.6 μm size range. The results indicate that the 3M Breathe Easy (with BE-10 blower system) PAPR system consistently met or surpassed the required 10,000 PF levels, while some other commercial PAPRs did not. The 3M BE-10 blower was therefore included in this study for comparison purposes.

MATERIALS AND METHODS

The evaluations were conducted the 3M BE-10 blower system connected to a PC4 respirator, or a Carlton blower system connected to a PC-4 respirator as shown in Figures 1A and 1B. The latter system is employed by the Explosives Disposal and Technology Section of the Royal Canadian Mounted Police and consists of the commercial version of the Canadian Military C4 gas mask (PC4 mask) marketed by Allen-Vanguard, and is installed with a motor-blower manufactured by Carleton Life Support Technologies Ltd. (referred to as "Carleton" in this report), Mississauga, ON, Canada, with batteries and associated electronics made by Med-Eng of Ottawa, ON, Canada. Both systems have been evaluated using the TSI PortaCount Plus Model 8020. The BE-10 system usually employs three 3M SP3 filter canisters and produces an airflow of about 210 LPM (with no back pressure) whilst the Carlton blower uses two C7 filter canisters and produces an airflow of about 80 LPM (with no back pressure).



Figure 1A. The 3M BE-10 blower system connected to a PC4 mask.

For this work, the motor-blower from the 3M BE-10 system was connected to a C4 gas mask via the corrugated rubber hose with a hose clamp, as shown in Figure 1A, instead of the usual white shroud that sits over the user's head. This allowed us to conduct protection factor measurements of the 3M BE-10 system at the drink tube adapter on the C4 gas mask. The C7 canisters on the Carlton blower were replaced by carbonless C7 canisters with the same pressure drop from 3M.

Two types of tests conducted. In the first, tests were conducted with test subjects in a test chamber with a sodium chloride aerosol concentration (generated with the TSI Model 8026 particle generator) between 1,000 and 70,000 particles/mL and using a 3-exercise routine detailed before (Liang & Harrison, 2005). The results shown are for one test subject but are typical of what was obtained with multiple test subjects.



Figure 1B. The Carlton blower [Note: B indicated the adapter where this system normally screwed onto the C4 mask at the canister mount].



Figure 2. The 1 m³ "particle free" chamber.

Secondly to measure the aerosol generated from the motor blowers, a "particle free environment" was required. A test chamber (1m x 1m x 1m) was constructed to create a "clean environment" where a particle count below 1 particle/mL could be maintained, as shown in Figure 2. The sides of this chamber consisted of clear plastic with access provided to insert equipment and hoses. This chamber was vacuumed for dust particles before each experiment. An overpressure was created inside this chamber by blowing air from another 3M BE-10 motor-blower, installed with three 3M SP3 HEPA filters. This

helped in reducing the ambient aerosol count in the chamber. By this process it was found that the ambient aerosol concentration could be maintained at around 1 particle/mL when measured with a TSI PortaCount 8020. The Carlton or 3M BE-10 motor-blower was then placed inside this chamber and the aerosol concentration at the end of the corrugated rubber hose from both systems was measured through a TSI 8025-40 mm (8025-CEN) mask sampling adapter. With this "particle free environment" set up, it could be assumed that the aerosols measured for both systems were generated by the blowers and did not arise from ambient aerosol that had overcome the filtration capacity of the canisters mounted on the systems, or from leaks in the system itself.

RESULTS AND DISCUSSION

With the powered PC4 respirator some very unexpected protection factor (PF) results were observed. At an ambient aerosol (sodium chloride) concentration of 30,000 particles/mL, the measured PF of the test subject and mask with the blower turned off varied between from 38,000 to 46,500. This is what would have been expected for a well-maintained negative pressure C4 gas mask. However, when the power to the blower was turned on, the PF dropped to as low as 3600. When the blower was turned off again, the PF rose back to the original value. Thus the system appeared to perform worse when the blower was used which is not what was expected.

For the 3M BE-10 system, it was possible to vary the ambient (challenge) sodium chloride aerosol concentrations, and thus able to obtain the results shown in Figure 3 when the blower was either on or off. With the blower turned off, the system behaved very similar to what had been observed before (Liang & Harrison, 2005; Harrison and Liang, 2005), where the subject-generated aerosol dominate the measurement at low ambient aerosol concentrations. Only at high challenge concentrations did subject-generated aerosol become less significant and the measurement begins to reflect the actual protection factor of the respirator. When the 3M blower was turned on, the measured protection factor showed a linear relationship with the challenge concentration. It was not therefore immediately clear how one could extract a realistic number for the protection factor of the 3M BE-10 PAPR system using the TSI PortaCount.

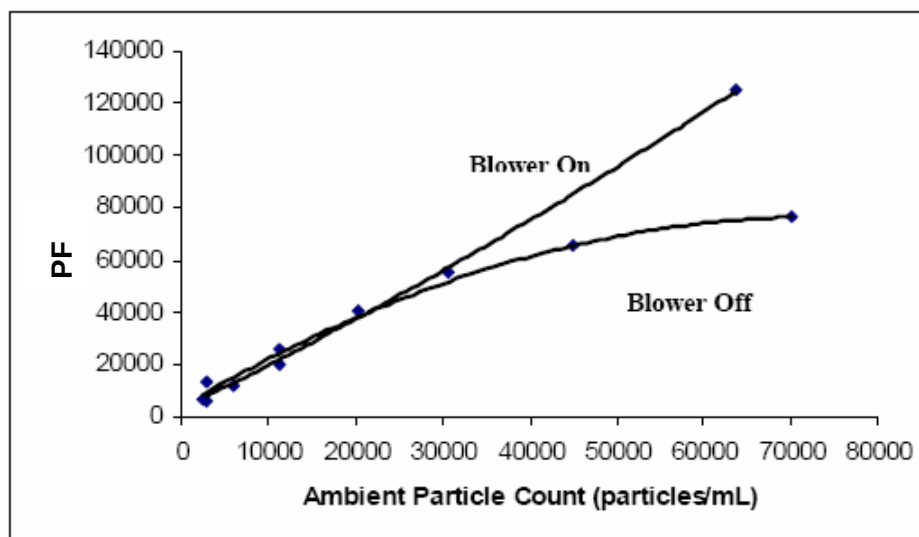


Figure 3. Measured Protection Factor of the 3M BE-10 blower system connected to the PC-4 mask vs Ambient Aerosol Counts.

At this point, it was postulated that three factors may affect the protection factor measurements observed above. Firstly, the motor-blowers on both systems could be generating enough aerosol themselves to affect the PF measurements, either from friction or from the motor itself. Secondly, there could be a significant penetration of aerosol through the canisters at the high ambient aerosol concentration and high flow rates. This should not apply to the Carlton motor-blower because the flow rate per canister was only 35-40 L/min and no problems had been observed with particulate matters in the past with this type of flow rate. Thus, this may not contribute to the observed data. Thirdly, other factors, such as leaks in the system could have interfered with the PF measurements. However, if this situation exists, then the PF data should have been higher when the blower was turned on. Thus, an experiment was set up to focus on the first factor: the blower-generated aerosol.

Blower-Generated Aerosol

Aerosol counts (particles/mL) versus time for both systems are shown in Figures 4 and 5. It could be clearly shown that aerosol is generated by both systems when the blowers are running. For the Carlton motor blower, there was considerable scatter in the data and the average particle count over a period of time (10 to 30 minutes) was in the 8-9 particles/mL range. It should be pointed out that this average would vary widely if the sampling time were much shorter. For the 3M BE-10 blower, it was much less at about 0.4-0.5 particle/mL, but not insignificant considering the high protection factors to be measured.

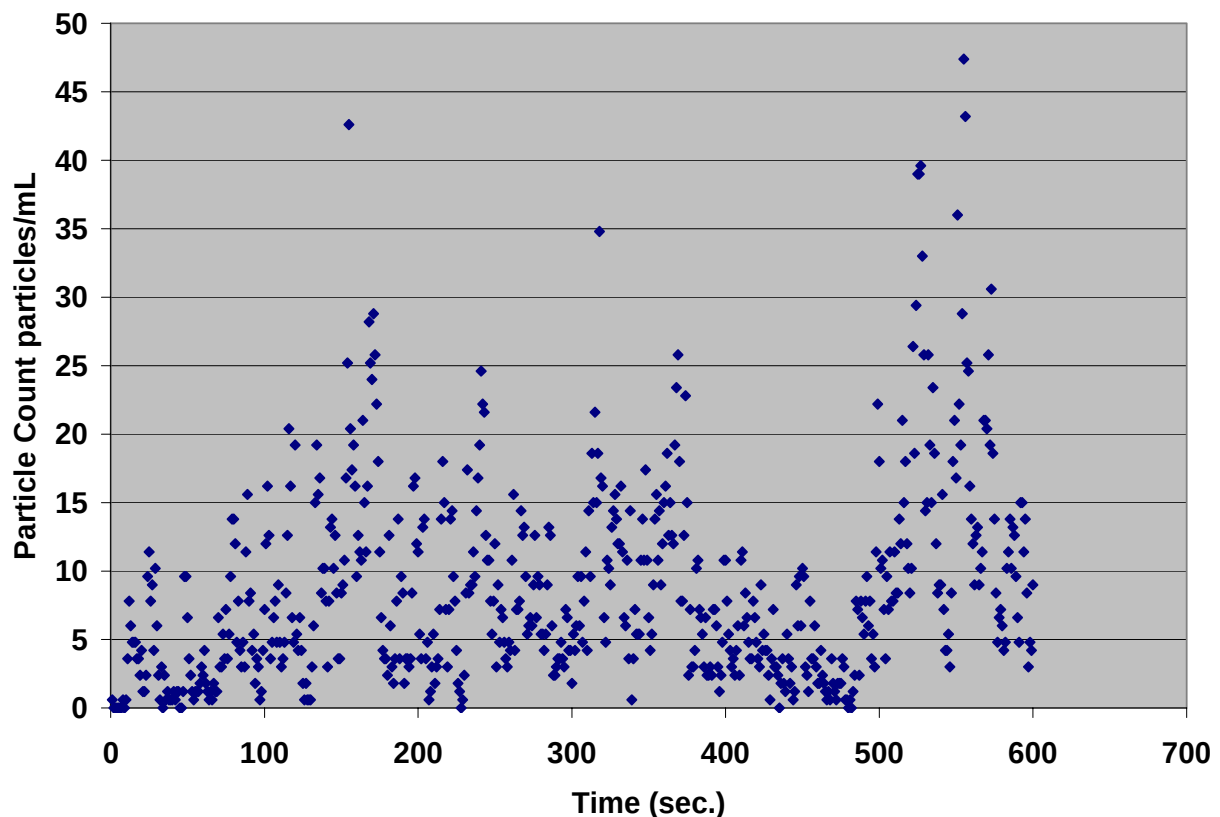


Figure 4. Particle Count Generated by the Carlton Blower vs. Time.

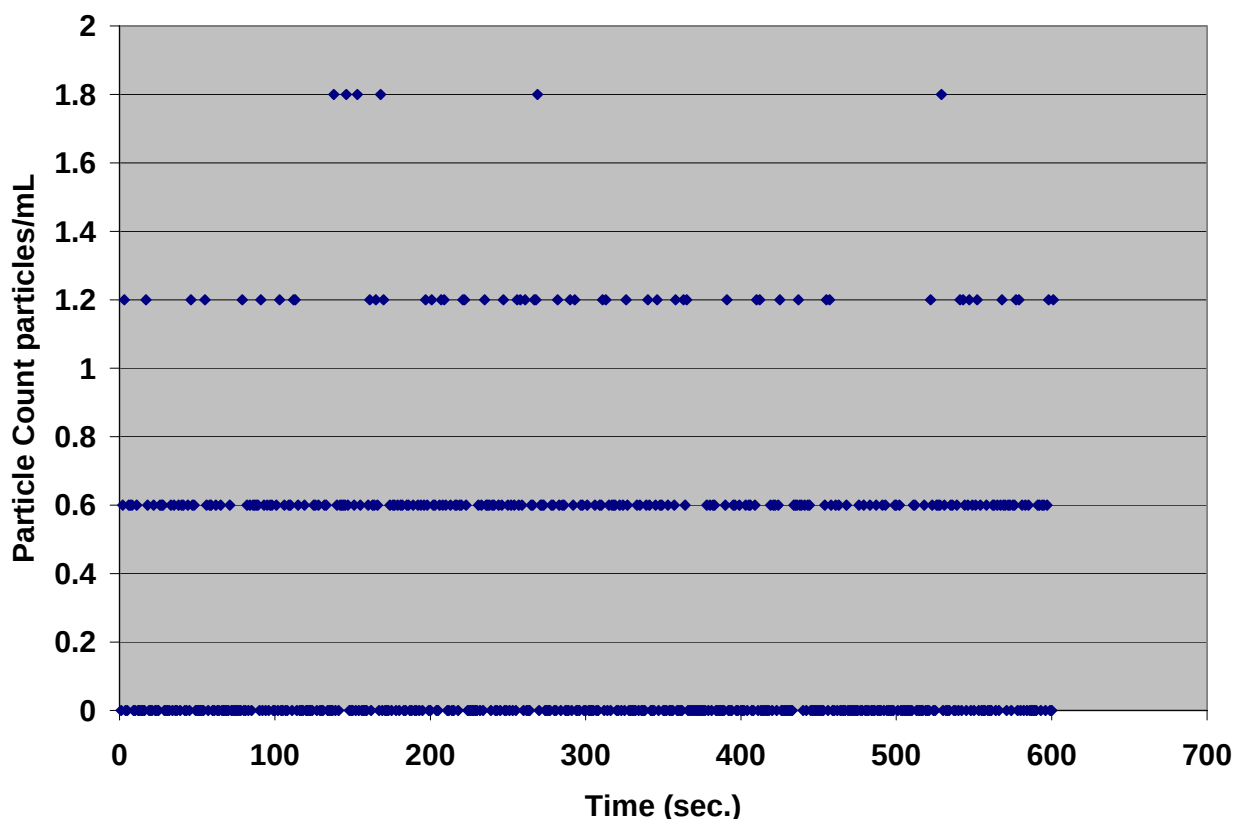


Figure 5. Particle Count Generated by the 3M BE-10 Blower vs. Time.

Measured Protection Factor

The measured protection factor, PF is defined as the ratio of ambient concentration of aerosol (outside the respirator) to the concentration of aerosol inside the respirator. For military style respirators that achieve PF in excess of 10,000 it has been shown earlier (Harrison & Liang, 2005) that ambient aerosol concentrations of 30,000 to 60,000 particles/mL are required, and that subject-generated aerosols (typically 0.1-0.6 particles/mL from normal breathing under ideal conditions and up to 10 particles/mL when talking) can influence the results and the calculated PF. It was concluded that activities such as talking (i.e. reading the rainbow passage) could cause major errors in the measurement. Thus blower generated particles of 8-9 particles/mL from the Carlton motor-blower would have a similar effect and cause unusually low PF similar to those observed. This is illustrated by the following calculation. If it is assumed that the blower generated particles dominate the measured PF when the blower is on, the observed PF would have been the ambient concentration, i.e., 30,000 particles/mL in the chamber divided by the particle concentration from the blower (9 particles/mL) to give an apparent PF of 3300. This is very close to the number observed (i.e., 3600) and clearly shows that blower generated particles controlled the measurement. It is clear that an in-line filter must be used to remove these aerosols if accurate measurements are to be made.

As shown in Figure 5, the 3M BE-10 seemed to generate lesser amounts of aerosol, at about 0.4-0.5 particles/mL when the blower is on. This small amount of measured aerosol indicates that the high

airflow rate has not overcome the filtration efficiency of the system. However, this number is again not insignificant. Using the same calculation described above, the results shown in Figure 2 can be readily explained because protection factor would be a linear function of the ambient aerosol concentration (i.e. [ambient aerosol concentration]/0.5).

CONCLUSIONS

This result confirmed previous discussions with Dutch researchers (van der Gijp, 2004) on the problems with equipment-generated aerosol, in their case with self-contained breathing apparatus. These results clearly show that the blower-generated aerosol needs to be removed for accurate measurements of the protection factor of the PAPR using a condensation nucleus counter like the TSI PortaCount. One solution is to put an in-line HEPA filter between the blower and the facepiece of the system. However, without other remedial action this will cut down the airflow into the system. Therefore a combination of increased airflow from the blower and an in-line filter (with a resulting flow rate equivalent to that of the original system) is required to measure the actual protection factor of the system. This is not a trivial problem, and neither is the solution.

Acknowledgments

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