Fall 2010

The effects of relative humidity on respirator performance

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THE EFFECTS OF RELATIVE HUMIDITY ON RESPIRATOR PERFORMANCE

by

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A thesis submitted in partial fulfillment
of the requirements for the
Master of Science degree in Occupational and Environmental Health (Industrial Hygiene)
in the Graduate College of
The University of Iowa

December 2010

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee
for the thesis requirements for the Master of Science
degree in Occupational and Environmental Health (Industrial Hygiene)
at the December 2010 graduation.

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Patrick T. O'Shaughnessy, Thesis Supervisor

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The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' but, 'That's funny...'

Isaac Asimov

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CHAPTER I
INTRODUCTION

Respirators are used in a variety of occupational settings to protect workers from hazards. These hazards are airborne and range from the small, such as nanoparticles, to the large, such as coal dust. Ensuring that respirators offer the correct level of protection is vital in protecting workers health. Respirators are tested in lab settings, but their use in the field is not under ideal lab conditions. One of the factors that may affect respirator performance that has not been well researched is relative humidity (RH). High humidity can occur in places ranging from enclosed rooms with a high use of water to outdoor areas in the summer

One occupational location with high humidity and dust is swine confined animal feed operations (CAFOs). Pressure washing is done to clean the swine barns after a group of swine has been moved to another location. Anecdotal evidence provided by swine CAFO workers during a personal field visit suggests that respirators are less likely to be worn during the pressure washing of a swine barn because they become hard to breathe through in a short period of time

The motivation of this study, therefore was to investigate the effect of relative humidity on respirator performance.

Health Effects of Working in a

Swine Confinement Building

Workers in swine CAFOs are exposed to a number of hazards that can affect their health, in particular respiratory health. One study found swine workers to have higher frequencies of respiratory symptoms, colds, and absence due to chest illness (Donham et al., 1989). The increased symptoms were associated with years worked in a swine barn, respirable dust, total dust, endotoxin level, and microbe level. The study found personal dust levels to average 6.8 mg/m^3. Larsson et al. (2002) found an increase in bronchial response to methacholine and a decrease in peak expiratory flow among workers after the pressure washing of a swine confinement building and dust levels of 0.94 mg/m^3. One study found the average dust levels to be 3.08 mg/m^3 (Clark et al., 1983). Donham et al (1986) found dust in a swine barn was composed mainly of animal feed, swine feces, swine dander, mold, pollen grains, insect parts and mineral ash. OSHA has a recommended exposure level of 15 mg/m^3 for total dust and 5 mg/m^3 for respirable dust. This standard is for all dust and there is not a separate standard for swine dust. Donham et al. (1995) recommended a time weighted average for total dust in swine buildings to be 2.5 mg/m^3

Clark et al.(1983) found the endotoxin level in swine barns to be 0.12 $\mu g/m^3$. O'Shaughnessy et al. (2010) found endotoxin levels in the swine barn increase from 3450 EU/m^3 before the washing to 88110 EU/m^3 during the pressure washing. Heederik et al. (1991) found that exposure to endotoxin was significantly related to decrease in FEV_1. There is no OSHA PEL or ACGIH TLV for endotoxin. Haglind et al. (1984)

recommended a level of 90 EU/m^{3}, because it is thought to be the threshold for acute mucus membrane irritation.

Respirators

The qualifications for respirator filter classes are listed in the code of federal regulations (42 CFR 84). NIOSH certifies respirators at the following levels: N-95, N-99, N-100, R-95, R-99, R-100, P-95, P-99, and P-100. N is for respirators not resistant to oil, R is for somewhat resistant to oil, and P is for respirators that are strongly resistant to oil. The 95 means the respirator filters at least 95% of airborne particles, 99 filters out 99% of airborne particles and the 100 filters out 99.97% of airborne particles. An N-95 respirator is defined as being at least 95% effective against the test aerosol of sodium chloride. A P-100 respirator is defined as being at least 99.97% effective against a test aerosol of dioctyl phthalate. Both the N-95 and the P-100 are classified as air-purifying respirators; they provide protection against particles but not against gases, vapors, or oxygen deficient environment. These filters remove particles by four different methods: interception, sedimentation, impaction, and diffusion (Colton, 2002). Particles larger than 0.6 µm are removed by sedimentation, interception, and impaction; those smaller than 0.1µm are removed by diffusion (Colton & Nelson, 2003). This range from 0.1µm to 0.6µm is where the greatest penetration of respirators occurs (Colton, 2002). Because of this, NIOSH tests the penetration of a respirator in this range. Therefore, an N-95 is at least 95% effective for particles from 0.1µm to 0.6µm but can be close to 100% effective at larger particle sizes. With regards to CAFOs O'Shaughnessy et al. (2010) used a cascade impactor during power washing and found the mass mean diameter by weight to be 12.7 µm. They also used a GRIMM optical particle counter to determine a count median diameter of 0.328 µm. The count median diameter is in the middle of the range in which NIOSH test and would be expedted to have the highest penetration through the filter.

Several studies have found that wearing respirators in swine confinement buildings can be beneficial. The study by Larsson et al. (2002) found that wearing a P3 respirator, similar to the P-100, during the cleaning of a swine confinement building decreased but did not eliminate acute inflammatory reaction in the upper airways. Another study found that the wearing of an N-95 by a naïve worker comes close to eliminating acute respiratory symptoms, shift changes in FEV_1, and improving the results of other respiratory test (Dosman, et al., 2000). Popendorf et al. (1995) found half mask with an ammonia cartridge and a dust prefilter provided more protection than a disposable N-95. They also reported that swine workers preferred the half mask over the disposable mask. However, Jones (2005) found the majority of swine CAFO workers either never wear or seldom wear respiratory protection. Respirators are far down on the list of control measure but are often the first choice in swine barns. This is because they do not require a redesign of the building's ventilation that was designed for temperature control.

In three studies the effect of the inhalation resistance, the pressure drop across the respirator, on work performance was studied. One study showed that as inhalation resistance increases peak inspiratory flow decreases (Coyne et al., 2006). Another study showed that as the resistance level increases performance time decreases linearly

(Johnson, et al., 1999). The third study found that performance time, performance rating and minute volume decreases as inhalation resistance increases (Carretti et al., 2006). These studies combine to demonstrate that as the pressure drop increases the workload and the time a worker can work will decrease.

Pressure Drop Across Filters

Studies have shown that relative humidity can have effects on the efficiency of bag house filters, an air pollution control device that uses fabric to remove dust from the airstream (Durham & Harrington, 1971) (Ariman & Helfritch, 1977). In the study as relative humidity increased the pressure drop across the filter decreased, while they could not prove how this was happening they hypothesized it was because the adhesive forces between the particle and fibers were increased.

Pressure drop across a filter can be thought of as the combined total of the pressure drop across the filter, Δp_{filter}, plus the pressure drop across the dust cake, Δp_{cake},:

$$\Delta p_{filter} = K_1 V \qquad \text{Eq 1}$$

$$\Delta p_{cake} = \frac{3\pi\mu}{(\pi/6)^{1/3}\rho_p C \upsilon_g^{2/3}}\left(\frac{VM}{A}\right) exp\left(-4ln^2\sigma_g\right) \qquad \text{Eq 2}$$

where K_1 is the clean filter resistance, V is the velocity across the filter, μ is the gas viscosity, ρ_p is the particle density, A is the area of the filter, C is the Cunningham slip correction factor, υ_g is the geometric volume mean, and σ_g is the geometric standard deviation of the volume (Gupta et al. 1993). Equation 2 assumes that the aerosol making up the dust cake is log normally distributed. As the dust collects on a filter, it forms a dust cake, which can be seen as a network of particle agglomerates (Hoflinger, 1998).

The growth rate of these agglomerates depends upon the collection mechanism with inertial capture being the slowest and diffusion being the fastest (Kanaoka & Hiragi, 1990). In theory, pressure drop across a filter will increase linearly as the dust cake grows. In practice, this is often not the case as it is affected by external variables. One of these external variables is water as relative humidity or water droplets. While it is not fully understood how relative humidity affects pressure drop, it has been shown that it will affect the pressure drop across a filter and the dust cake (Durham & Harrington, 1971). Studies on the effects of relative humidity on filters for pollution control show that as relative humidity increases the pressure drop will decrease (Ariman & Helfritch, 1977) (Durham & Harrington, 1971). One study showed this effect to be greater when the relative humidity was increased from 61%-90% than when the relative humidity was increased from 32%-53% (Minguel, 2003). The reason for this effect is that relative humidity affects adhesive forces between particles and fibers (Durham & Harrington, 1971). The change in adhesive forces is caused by liquid bridges between particles and the changing of electrostatic and van der Waal forces (Hoflinger, 1998). These changes causing greater adhesive forces cause the particles to form a cake with chain-like structures that have straight paths between the chains. For nonhygroscopic particles with a mass median diameter (MMD) of 0.5 μm this effect was only seen above 90% RH, but for nonhygroscopic particles with an MMD of 1.0 μm the effect was seen at all RH levels (Gupta et al., 1993). McMurry et al. (1989) found that hygroscopic atmospheric aerosol increased in size by a factor of almost 1.5 for 0.4-0.5 μm sized particles when the relative humidity was increased from 50% to 90%. These channels allow air to flow with less resistance than it would through a cake with particles in a random configuration. Two studies, however, show that this does not hold true for all dust types. A study on fabric dust filters showed no apparent effect of relative humidity when testing with cement dust, pulverized limestone, or amorphous silica dust (Durham & Harrington, 1971). The other study showed that sodium chloride in relative humidities above its deliquescent point did not exhibit this pressure drop (Minguel, 2003). This is because the sodium chloride particles are in droplets, and they fill the interstitial spaces rather than forming a dust cake on the filter (Gupta et al., 1993). The presence of water droplets can also have an effect on the pressure drop. The water droplets cause the pressure drop to increase. This is because the water droplets collect on the fibers and reduce the effective voidage, the area between the fibers in the filter (Liew & Conder, 1985).

Penetration of Filters

Particulate penetration of a filter is calculated by using either the mass of the particles or the count of the particles:

$$P = \frac{N_{out}}{N_{in}} \qquad \text{Eq. 3}$$

$$P_m = \frac{C_{out}}{C_{in}} \qquad \text{Eq. 4}$$

where P is the penetration based on particle count, P_m is the mass penetration, N_{out} is the particle count after the filter, N_{in} is the particle count before the filter, C_{out} is the mass concentration after the filter, and C_{in} is the mass concentration before the filter. The ratio can be, and usually is, transformed to a percent by multiplying by 100. In general, penetration of an aerosol through a filter will decrease exponentially as the dust cake grows (Chen & Lehtimaki, 1993) (Hinds & Kadrichu, 1997). The effects of relative humidity on penetration vary depending on the type of particle and the filter material.

One study found that penetration increases in some situations but not in others (Raynor & Leith, 1999). In high humidity conditions there is a decrease in collection efficiency by diffusion but an increase in collection efficiency by impaction. Penetration may also increase with relative humidity because, as water collects on the filter, the droplets occupy space making some fibers unavailable for collection (Raynor & Leith, 1999). Durham et al. (1971) found that for fly ash, penetration increases at a lower relative humidity, but relative humidity had no effect on the penetration of cotton fiber filters, cement dust, pulverized limestone, or amorphous silica dust. Miguel (2003) found that for non-hygroscopic particles penetration increases as relative humidity increases. Miguel also found that as relative humidity increases, filter permeability will increase for the same particle loading. For hygroscopic particles it is expected that penetration will decrease because the particles will increase in size due to absorbing water from the environment (Hinds, 1999).

Objectives

This study was part of a larger one studying workers in swine confinement buildings. This study specifically stemmed off from the part of the study that was assessing the exposures of workers during the pressure washing of the barns. The specific objectives include determining how humidity affects respirator performance by measuring pressure drop across, and penetration of, the filter; the second objective was to find a method for protecting a P-100 in supersaturated environments with dust.

CHAPTER II

THE EFFECTS OF HUMIDITY ON RESPIRATOR PERFROMANCE

Introduction

Respirators are used my workers in a variety of settings to protect them from airborne hazards. The testing of respirators occurs in a controlled environment but field conditions are varied and can be constantly changing. One variable that is not tested is relative humidity. High relative humidity can occur in many occupation environments from confined spaces where water is being used to the summer in many places. One place that has high humidity and dust are swine barns especially during pressure washing.

During the pressure washing it was found that endotoxin levels increased from 3450 EU/m^3 before the washing to 88110 EU/m^3 during the pressure washing (O'Shaughnessy et al., 2010). Exposure to endotoxins has been linked with respitory symptoms among swine workers (Donham et al., 1989). Respirators have been shown to be effective at lowering the occurance and severity of respitory disease among swine workers (Dosman et al., 2000). One study has looked at respirator use during the pressure washing operation and found them to lessen the sevarity of the sypmtoms (Larsson et al., 2002). What is not known is are the respirators acting as effectivly in the pressure washing conditions as in other condistions.

Studies on bag house filters and HEPA filters have shown that generally as relative humidity rises the pressure drop will decrease (Durham & Harrington, 1971) (Ariman & Helfritch, 1977). This does not, however, hold true in all cases, as certain combinations of particulate and filter material are not affected by relative humidity (RH)

(Durham & Harrington, 1971) (Gupta et al., 1993). The relative humidity is thought to affect the formation of the dust cake that forms on the filter (Hoflinger, 1998). It is believed that the relative humidity affects the formation of the dust cake by affecting the adhesive properties of the particles causing firmer bonding between dust particles (Gupta et al., 1993). Humidity effects the adhesion forces indirectly by changing the electrostatic and van der Waal forces and directly by way of liquid bridges (Hoflinger, 1998). The increased attraction caused by high relative humidity causes the particles to form chain-like structures instead of an unorganized mass (Gupta et al., 1993). This structure allows air to flow through with less restriction, causing less of a pressure drop with the same amount of dust on the filter. It is likely that the effect on pressure drop is effected by both the filter material as well as the hygroscopicity of the dust though no study has fully demonstrated this yet.

Relative humidity can also have an effect on the penetration of a filter. Just as with pressure drop, the effects on penetration depend greatly on filter material and the particles being filtered. In general, non-hygroscopic particles tend to penetrate more as relative humidity increases (Gupta et al., 1993), while hygroscopic particles tend to penetrate less as relative humidity decreases (Minguel, 2003). There are exceptions to these observations, however, and some instances in which there is no effect at all (Ariman & Helfritch, 1977).

Air-purifying respirators, such as the N-95 and the P-100, use interception, sedimentation, impaction, and diffusion to remove particles from the air (Colton, 2002). Pressure drop across respirators is an important factor as an increase in pressure drop has been shown to decrease the productive working time of a worker (Carretti et al., 2006).

Previous work on relative humidity and filters dealt with HEPA and bag house filters and not respirators.

The objectives of this study were to quantify at the effect of humidity on respirator pressure drop and penetration. The study also evaluated the use of foam as a prefilter in conditions with dust and water droplets in the air.

Materials and Methods

Description of Filters

The filters used in this study were a P-100 cartridge (North by Honeywell, Cranston, RI) and an N-95 filtering facepiece (AO Safety, Indianapolis, IN). The P-100 cartridge is normally attached to either a full facepiece or a half-mask respirator. It is rated to be at least 99.97% effective at collecting a test aerosol of dioctyl phthalate. The P-100 is also resistant to oil. The N-95 is a particulate filtering facepiece respirator. The N-95 respirators used in this study did not have an exhalation valve. It is rated to be at least 95% effective against the test aerosol of sodium chloride.

Description of Experimental Dust

The dust used for testing the respirators in this study was Arizona Test Dust Fine, ISO 12103-1 A2, (Powder Technology Inc., Burnsville, MN). Which is composed of SiO_2, Al_2O_3, Fe_2O_3, Na_2O, CaO, MgO, TiO_2, and K_2O (Powder Technology Inc. 2010). This dust was used because it is a well studied dust with known characteristics. The dust covers a range of sizes ranging from less than 1 µm to 80 µm. 50% of the dust is less than 10 µm by volume which is close to the MMD of 12 µm measured by O’Shaughnessy et al. (2010) during the pressure washing of the swine barn. Dust from animal operations tends to be hygroscopic in nature (Auverman, 2005) but a non-hygroscopic dust was chosen so the dust would not behave differently in high humidities.

Description of the Test Apparatus

An exposure chamber was used to measure the pressure drop across the respirator under various relative humidity conditions in a laboratory setting (Figure 1). Steam for humidifying the air was generated by heating water in a pressure cooker. The lid of the pressure cooker was modified so steam could exit the pressure cooker through attached tubing. The tubing was then split into two tubes. One tube was used to vent the excess steam. The second tube was attached to the test chamber to raise the humidity level. A valve was used to control the amount of steam that entered the system so that the desired humidity level could be reached and maintained.

A pressure transducer that measures 0-14 inches of water via a proportional voltage output of 0-50 mV was used to measure the pressure drop across the respirator. The pressure transducer was connected to an analog-digital converter that was used to measure the voltage signal and convert back to water pressure every 10 seconds. The analog to digital converter was plugged into a computer to log the pressure drop over time.

A Wright Dust Feeder (BGI, Waltham, MA) was used to inject Arizona Test Dust into the top of the chamber. A fan in the chamber was used to mix the air inside the chamber. Additional ports on the top of the chamber allowed for the insertion of a Q-Trak (TSI, Shoreview, MN) to monitor the relative humidity and an IOM sampler (SKC

Inc., Eighty Four, PA) for determining the dust concentration in the chamber. The P-100 cartridge was attached directly to a threaded pipe that was threaded to allow the cartridge to be directly attached. The N-95 respirator was placed in a two-piece polymethyl methacrylate holder. The two sides were held together with a screw in each corner that could be tightened down to ensure the respirator was held firmly in place and that no air leaked around the respirator. This holder was attached to the same threaded pipe as the P-100 cartridge.

Air was pulled through the N-95 respirator at 85 L/min and the P-100 cartridge at 42 L/min. 85 L/min was used because it is the airflow used in NIOSH's respirator test and designated in the Code of Federal Regulation (Approval of Respiratory Protection Devices, 1995) (NIOSH, 2005). 42 L/min was used for the P-100 as just one cartridge and not a mask with two cartridges was being tested. The air was pulled through the system by a shop vac. Air flow was monitored by a monometer attached to a calibrated brass venturi. A valve attached to the venturi allowed for adjustment of the air flowing through the respirator.

For testing the penetration of the respirator, two tubes for sampling were inserted into the chamber. One was placed behind the respirator, and the other was inserted so the end was beside the respirator. Both tubes were connected to a two-way valve. After the valve the sampled air was passed through a dryer tube and then into a Scanning Mobility Particle Sizer™, SMPS (model 3080 TSI, Shoreview, MN). An SMPS was used because it covers the size range where the greatest penetration is expected to occur.

Description of Trials

The trials were set up to determine what effect relative humidity has on the penetration and pressure drop of a respirator. The dust was either present or absent. The relative humidity levels were 50%, 95%, and a supersaturated or "cloud" condition. For the formation of the cloud, the valve controlling the steam input was opened more than needed for the 95% RH trial.

For each trial the filter was weighed before being placed in the chamber. The filter was weighed immediately after the trial to determine the total mass, water and dust, collected by the filter. The filter was then left to dry at room conditions, 45-50% RH and approximately 70° F, for 24 hours. After the drying period the respirator was weighed again to get the mass of the dust collected.

Each trial continued until the pressure drop reached 50 mm of water or the trial ran for 3 hours, whichever came first. 50 mm of water was chosen as an end point because it is listed as the maximum resistance on final inhalation of a dust, fume, and mist with a single-use filter respirator in NIOSH's determination of exhalation resistance test (NIOSH, 2005).

For trials where penetration was being measured, the SMPS was set up to do one scan per sample. Samples were taken when the pressure drop across the filter was 20 mm of water. A total of six samples were taken for each respirator, three after the filter and three before the filter. The before and after samples were taken in an alternating fashion.

Three trials were performed with an open cell foam prefilter in front of the P-100 in the cloud with dust condition. The foam was either 1”, 2”, or 3” thick for the trial with each thickness being tested once. The pores per inch of the foam is not known.

Data Analysis

Pressure drop measurements were collected in an MSDOS program as millivolts and stored as comma-separated-value data file, CSV files. The CSV files were then imported into Microsoft Excel (2007, Microsoft, Seattle, WA), where the millivolts readings were converted into mm of water. To determine the time to reach 50 mm of water the results were graphed and a second-order polynomial trend line was fit to the data. The equation for the trend line was then used to solve for the end time. A trend line was used to determine the end point as the data fluctuated and would often rise above the end point and then go below it several times. The times for each experimental condition were compared to the times of the 50% RH with dust trials using a T-test.

Data from the SMPS was collected in Aerosol Instrument Manager software (TSI, Shoreview, MN) and then imported into Excel for analysis. For each penetration test, and each size bin the number concentration for the three samples from upstream of the respirator were added together and the three samples from downstream of the respirator were added together. From these combined samples, the penetration for each size range was calculated as the total number concentration downstream divided by that upstream.

Results

Test Chamber Results

The dust concentrations were measured as 89 mg/m^3 for the P-100 and 69 mg/m^3 for the N-95. The dust conditions were measured in the 50% RH environment and the levels were assumed to be the same in the other environments.

P-100 Results

The time to reach the end point is recorded in Table 1. Graphs of pressure drop for each condition over time are given in Figures 2 through 6. The time to end for the 95% RH with dust condition was significantly ($p=0.007$) greater than that for the 50% RH with dust condition. The time to end for the cloud with dust condition was significantly ($p<0.001$) less than the 50% RH with dust condition. The 95% RH without dust condition did not reach the end point in the time allowed. Figure 7 shows the pressure drop for each condition at 1 hour.

There was no significant difference in the mass of dust collected on the respirators for any of the test conditions. The cloud without dust condition did have a significantly ($p<0.001$) higher total weight gain. All mass increases can be seen in Table 2.

When using the foam as a prefilter in the cloud with dust condition, as the foam thickness increased there was an increase in the time it took the respirator to reach the end point. This can be seen in Figure 8.

N-95 Results

The time to the end point can be seen in Table 3. Graphs of the pressure drop can be seen in Figures 9 through 12. For the N-95 respirators there was no difference in time to the end point between the 50% RH with dust and the 95% RH with dust. The cloud with dust and the cloud without dust conditions did not reach the end point in the time allowed. Figure 13 shows the pressure drops of each condition at 1 hour.

The 50% RH with dust condition collected a significantly greater amount of dust over the 95% RH with dust condition ($p=0.04$) and over the cloud with dust condition ($p=0.02$). This was true despite the fact that the cloud with dust ran for 180 minutes without reaching the end point and the 50% RH with dust reached the end point in an average of 126 minutes. The cloud with dust did have a significantly ($p=0.03$) higher total weight gain than the other two test conditions. All weight gains can be seen in Table 4.

The penetration of the N-95 was tested with the 50% RH with dust condition and in the cloud with dust condition. In the cloud with dust condition there was an increase in penetration over the 50% RH with dust condition in the size range of 50µm-300µm. This can be seen in Figure 12.

Discussion

Relative humidity does play a role in the performance of respirators, though its effect depends on the type of filter being used. For the P-100 the increase from 50% RH to 95% RH caused an increase in the time it took for the pressure drop to reach 50mm of water. This result was unexpected. Studies of high efficiency particulate air filters, which have the same collection efficiency as the P-100, have obtained similar results (Gupta et al. 1993). Gupta et al. (1993) states that this is due to the relative humidity affecting the formation of the dust cake on the filter. At higher relative humidities particles have a higher adhesive force, which causes the formation of chain-like structures. These structures allow for air to flow through the dust cake with less resistance than a normal dust cake. When increased to the cloud level with dust, the respirator reaches the end point at a much quicker rate. The 95% RH without dust condition did not cause any increase in pressure drop. In the cloud conditions the water is the driving force for weight gain. The cartridges are able to hold a greater weight of water compared to dust before reaching the end point. This could be due to fibers absorbing water but this cannot be said for sure.

The foam prefilter worked well at extending the time it took the P-100 to reach 50 mm of water. The separation of the water droplets from the dirt helped to keep the P-100 from clogging.

For the N-95 the increase from 50% RH to 95% RH did not affect the pressure drop. Why the same decrease in pressure drop as in the P-100 is not seen is unknown. One probable explanation is that there is a difference in the structure of the respirator and how the particles collect on its surface. The cloud level showed an increase in the time it took to reach the end point. This could be due to the water particles acting on the fibers in the respirator and increasing the size of the voidage. When the size of the holes in the respirator are increased the efficiency of the collection mechanisms decreases allowing more particles to penetrate the filter. This increase in penetration is visible in Figure 12. This increase is only seen among particles less than 150 nm.

More research is needed to fully understand this topic. Research should be carried out with organic dust typical of what is found in swine barns. The dust used in this experiment is a poor model for swine barn dust in terms of size and hygroscopicity. The hygroscopicity and smaller size of typical swine barn dust could yield completely different results. Field research should also be conducted to determine what conditions the respirators are under when the workers are no longer able to wear the respirator anymore.

Conclusion

The effects of humidity and water droplets on a respirator will depend on the type of respirator. For the P-100 the higher the relative humidity up to 100% RH causes an increase in the time to reach 50 mm of water. When the humidity reached a supersaturated condition the P-100 reached the end point at a quicker rate. The N-95 did not experience any change in time to reach the end point as humidity increased to 100% RH. The supersaturated condition caused an increase in penetration with the N-95.

For workers in high humidity conditions both the P-100 and the N-95 provide the protection needed against dust. If the condition involves a supersaturated environment the N-95 is the better choice. The penetration increase seen with the N-95 is minimal and still below the penetration level allowed by NIOSH for certification.

Table 1 Time to Reach 50 mm of Water for the P-100 filter

	Mean, minutes	Standard Deviation, minutes	Sample Size
50% RH with dust	120	14.83	4
95% RH with dust	157	8.73	4
Cloud with dust	21	3.21	3
95% RH without Dust	-[1]	-[1]	3
Cloud without dust	114	5.89	4

[1] No increase in pressure drop was observed.

Table 2 Mass Increases at Endpoint for P-100 Trials

	Dust and Water		Dust	
	Mean, g	Standard Deviation, g	Mean, g	Standard Deviation, g
Cloud without dust	4.606	1.389	0.000	0.000
50% RH Dust	0.955	0.081	0.955	0.081
95% RH Dust	1.013	0.249	0.925	0.304
Cloud Dust	1.283	0.306	0.243	0.248

Table 3 Time to Reach 50mm of Water for the N-95 Filter

	Mean, minutes	Standard Deviation, minutes	Sample Size
50% RH with dust	125.67	8.14	3
95% RH with dust	123.00	5.00	3
Cloud with Dust	-[1]	-[1]	3
Cloud Without dust	-[2]	-[2]	3

[1]An increase in pressure drop was observed, but 50 mm of water was not reached in 3 hours

[2] No increase in pressure drop was observed

Table 4 Mass Increases at endpoint for N-95 Trials

	Dust and Water		Dust	
	Mean, g	Standard Deviation, g	Mean, g	Standard Deviation, g
50% RH Dust	0.935	0.021	0.935	0.021
95% RH Dust	0.89	0.036	0.87	0.03
Cloud Dust	1.776	0.257	0.833	0.041

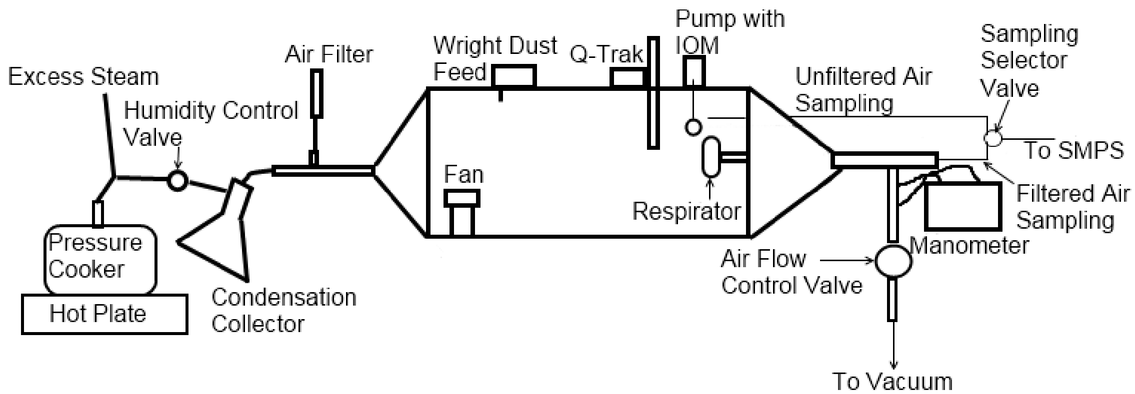

Figure 1 Experimental set up

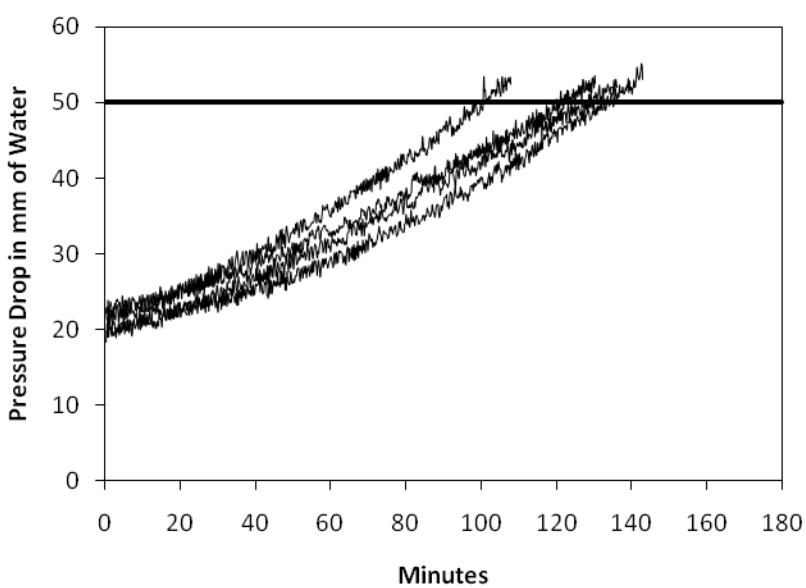

Figure 2 Pressure drop of the P-100 50% RH with dust

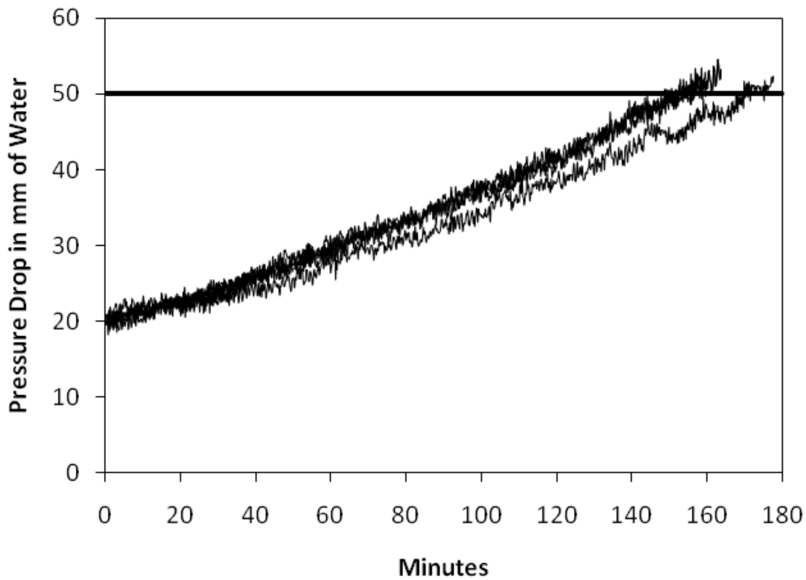

Figure 3 Pressure drop of the P-100 95% RH with dust

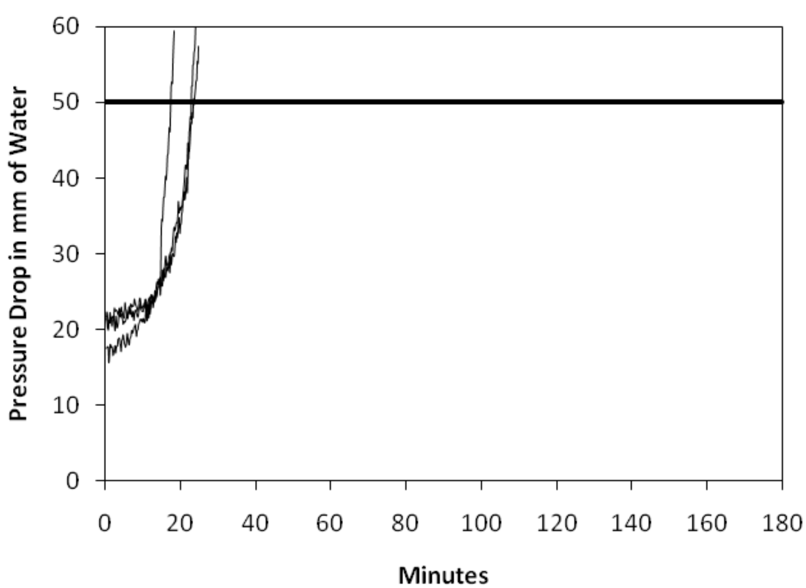

Figure 4 Pressure drop of the P-100 cloud with dust

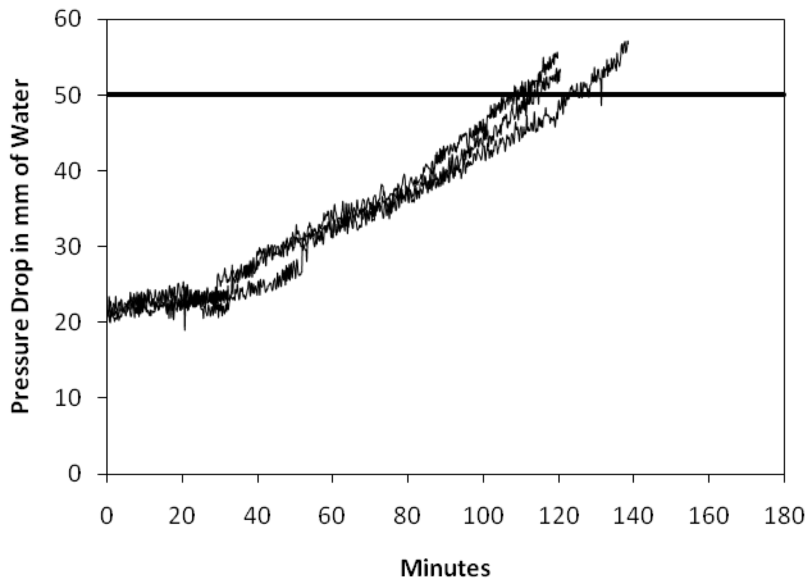

Figure 5 Pressure drop of the P-100 cloud without dust

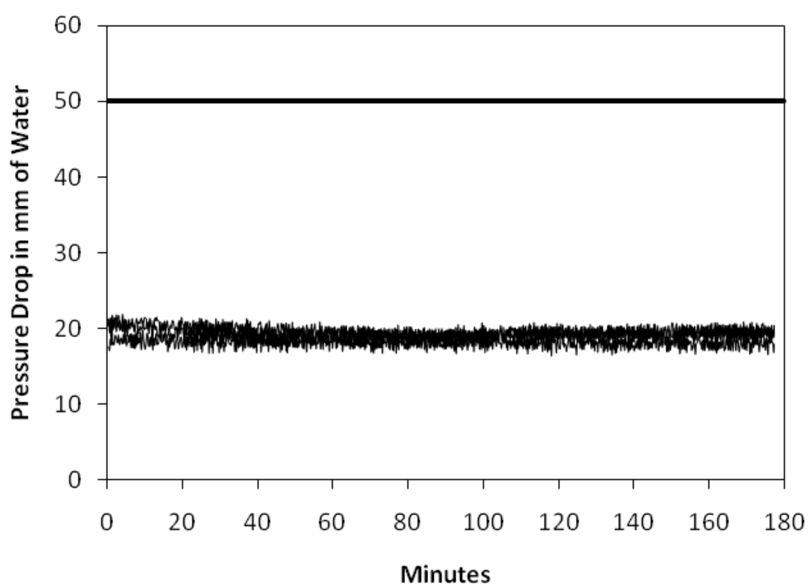

Figure 6 Pressure drop of the P-100 95% RH without dust

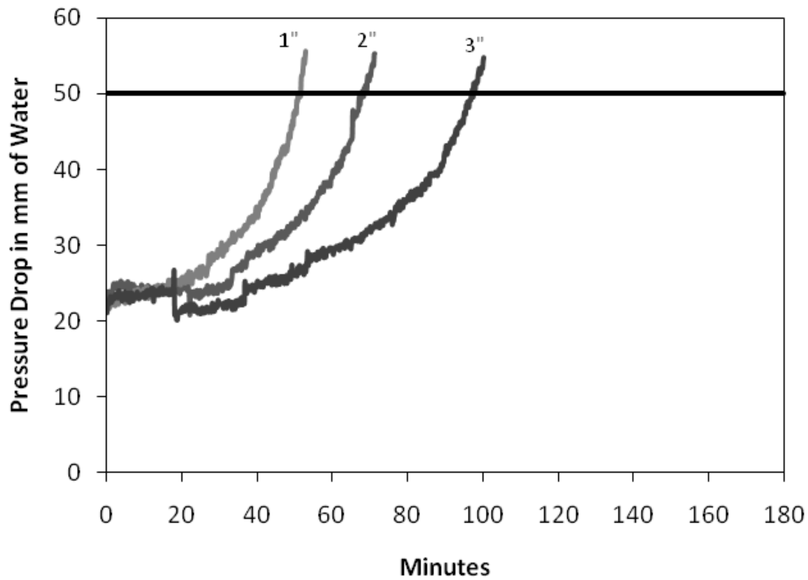

Figure 7. Pressure drop of the P-100 with foam prefilter in the cloud with dust condition.

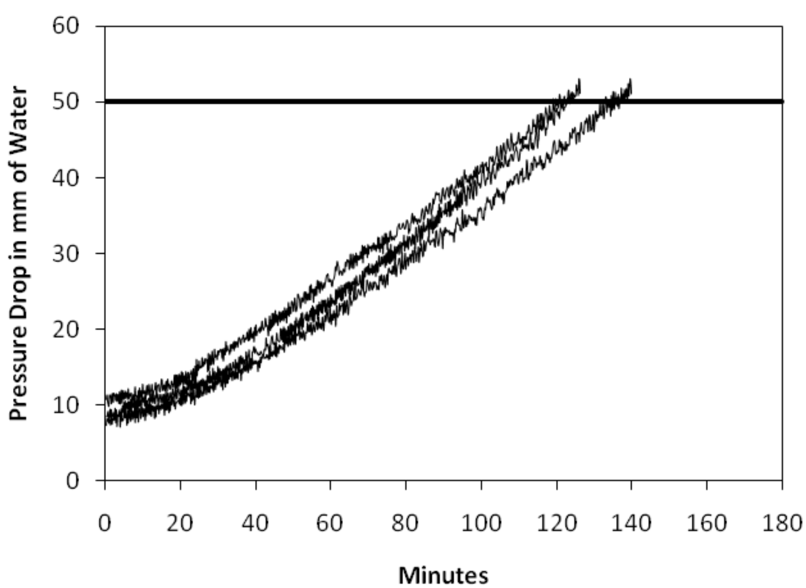

Figure 8. Pressure drop of the N-95 50% RH with dust

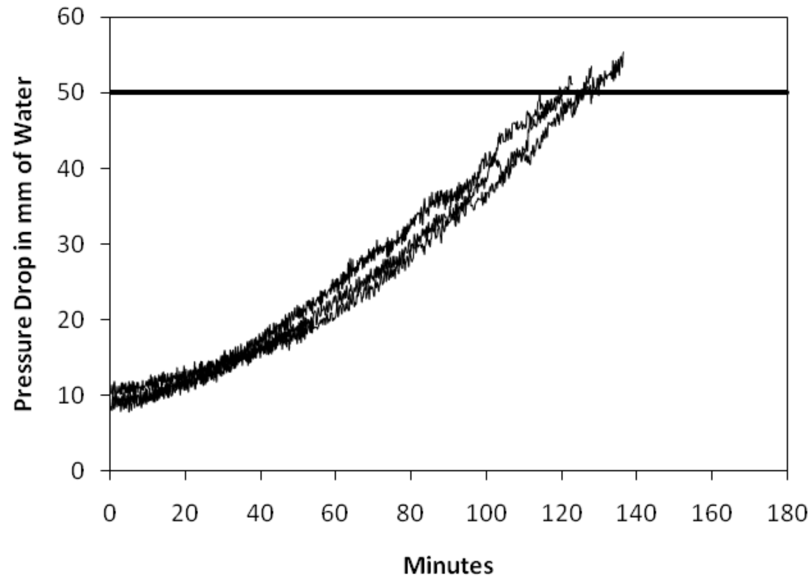

Figure 9. Pressure drop of the N-95 95% RH with dust

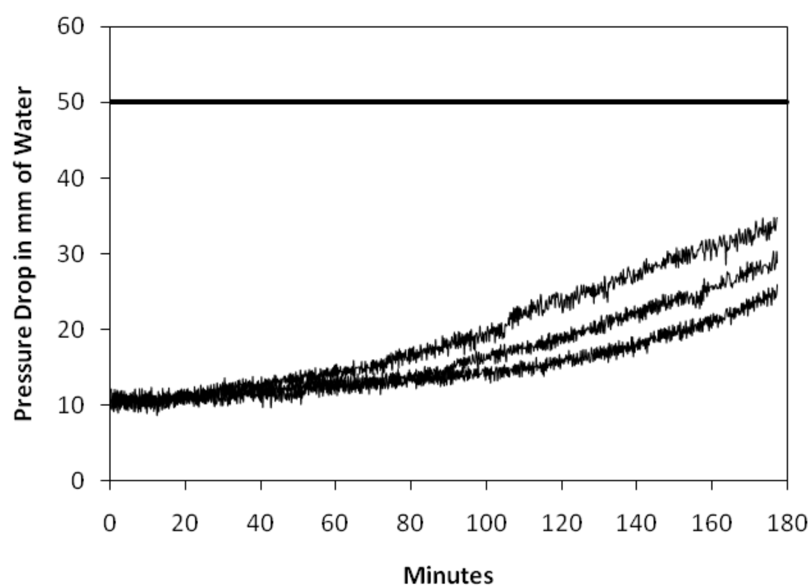

Figure 10. Pressure drop of the N-95 cloud with dust

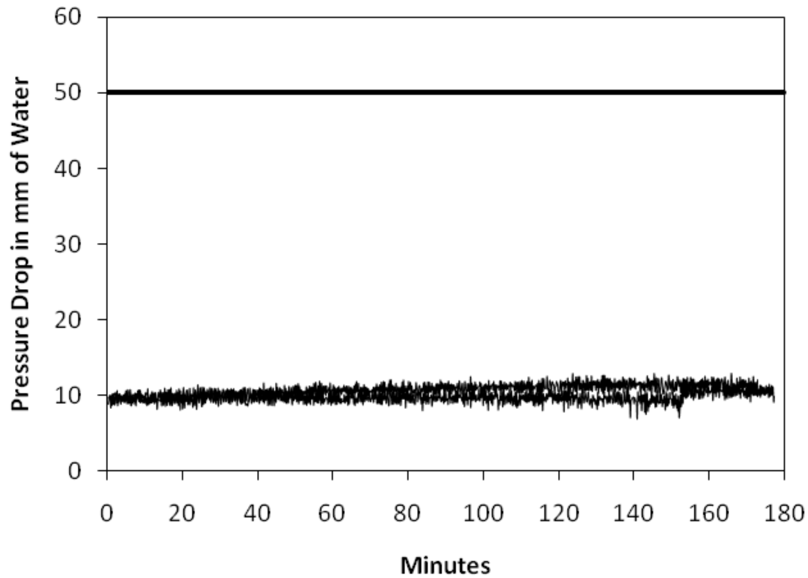

Figure 11. Pressure drop of the N-95 cloud without dust

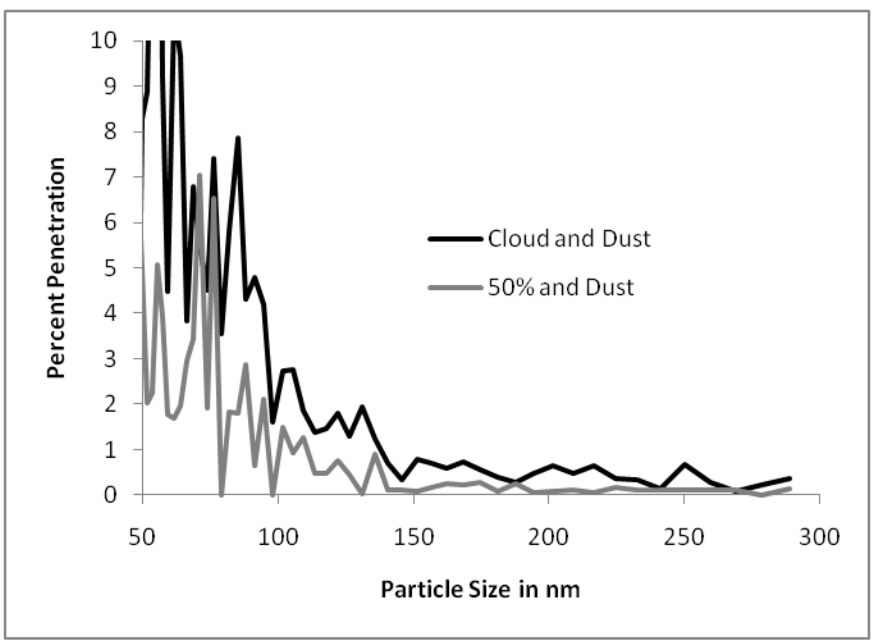

Figure 12. Comparison of penetration cloud with dust vs 50% RH with dust for the N-95

CHAPTER III
CONCLUSION

Respiratory illnesses affect a larger number of workers across a variety of industries. Exposures vary from large, course and dry particles to ultrafine particles in a mist. Though when protecting a worker from these hazards often little thought is given to the environmental conditions. These conditions can influence how the particles and the respirators will behave.

Workers in swine barns are known to be exposed to a wide range of chemicals, particulate matter and biological contaminants; that affect their respiratory health. The use of a respirator can help to alleviate respiratory symptoms in workers. In the pressure washing the exposure is not fully known. Though it can be assumed to be as bad as other areas of the barn if not worse since the pressure washing stirs particulate matter back into the air. Workers who carry out the cleaning process do not wear respirators as they complain that the respirator quickly becomes too difficult to breathe through. Though this is the opposite of what this study showed. The workers were wearing N-95 respirators which this study showed to last longer in cloud conditions. Because of this difference in results experiments need to be carried out in the field with workers to determine what else might be going on.

Wearing an N-95 mask in these situations should be fine as even with the increase in penetration it still meet NIOSH standards. The P-100 cartridge solves the penetration problem but the pressure drop across the filter increases rapidly in supersaturated environments. The best idea would be to use the P-100 with a prefilter that can remove the water droplets from the air.

This study does have its limitations though. One of which was determining how much water was present in the cloud condition. Without an accurate way of measuring how much water is in the chamber every time it has to be assumed that the water level did not varying between trials. It is also not known what amount of water was present in the swine barn during pressure washing. Another limitation was the dust. The dust levels used in this test were high when compared to the recommended values. This was done so the experiment would end with in a three-hour window. How smaller concentrations of dust would behave could be different from what was shown in this study. The dust is also non-hygroscopic while the dust in the swine barn is likely to be largely hygroscopic. This could cause vastly different results from what was seen in

More studies are needed to understand what is happening to the respirators in the given conditions. These studies need to observe what changes are occurring to the filter and the formation of the dust cake. Real world testing also needs to be done to see how pressure drop across the respirator affects workers. At what pressure drop workers find it too difficult to breathe through the respirator should be compared to NIOSHs test level. As the dust level in the test chamber was higher than those found in swine barns the increase in resistance that users feel may not be due to the formation of a dust cake on the filter. The use of foam as a prefilter gave promising results. Varying densities and thicknesses of foam should be studied to determine the optimal combination.

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