Calibration Factors for Haze and Fog in the Film Industry

Submitted to:

IATSE

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Date: April 2018

Project No. IA170101

Report No. 1 Rev.1

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EXECUTIVE SUMMARY

Glycol and glycerin-based fog fluids have long been used in the entertainment industry to create atmospheric effects. Exposure to glycol and glycerin aerosols can cause a range of adverse health effects, including respiratory irritation. To help protect workers in the entertainment industry from overexposure to glycol and glycerin fogs, we examined whether aerosol measurements made with an easy to use instrument, the DustTrak DRX 8533, were comparable to those made using standard methods developed by the US National Institute for Occupational Safety and Health (NIOSH).

A total of seven fog machines were used with twelve fog fluids to create various concentrations of atmospheric fog. Side-by-side sampling with a real-time DustTrak DRX 8533 aerosol monitor and active sampling using NIOSH Methods 5523 and 0500 for glycol and glycerin aerosols, respectively, was conducted at the various fog concentrations. Calibration curves were then generated using linear regression to establish correction factors for converting DustTrak total aerosol measurements to glycol and glycerin aerosol concentrations. A total of eight correction factors were developed with glycol-based fog fluids, and two robust correction factors for glycerin-based fog fluids. Additional analysis was also performed to assess how bulk fog fluid composition affected maximum glycol and glycerin aerosol concentrations, and the various fog fluid correction factors.

The glycerin-based fog fluids had the lowest correction factors of all the tested fog fluids (i.e. below one). Correction factors for the glycol-based fog fluids ranged from approximately 0.75 to 7.6, with most correction factors falling between two and three. Both correction factors and maximum glycol aerosol concentrations were affected by the primary glycol compound in the fog fluid. Propylene glycol-based fog fluids generated the highest maximum glycol aerosol concentrations and had the highest correction factors of all the fog fluids tested. If no correction factor is available, consideration should be given to the chemical composition of the fog fluid, to help protect workers from overexposure to glycol and glycerin aerosols.

1.0 STUDY OBJECTIVES

With the increased use of fog-based products in the entertainment industry, interest in the health effects of fog exposures among workers in the industry has also grown. The International Alliance of Theatrical Stage Employees (IATSE) requested Aura Health and Safety Corporation (Aura) in collaboration with the University of British Columbia (UBC) to conduct air monitoring of fog aerosol exposures. Since fog special effects used in film and theatrical productions typically use organic-based fog products, the focus of the study involves examining glycol and glycerin-based fogs.

The aim of the study is to address the following objectives:

1) Develop correction factors that can be used with a direct-reading instrument for assessing exposures released by fog fluid products containing propylene glycol, triethylene glycol, dipropylene glycol, butylene glycol, and glycerin.

DustTrak aerosol monitors are used on various production sets, along with fog machines, to monitor total aerosol concentrations. By developing correction factors for converting these DustTrak total aerosol measurements to glycol/glycerin aerosol concentrations, it will be possible to track the glycol/glycerin exposures of workers in real-time.

2) Evaluate parameters that affect the correction factors, such as product chemical composition and aerosol particle size.

Assessing how fog fluid chemical composition affects fog fluid correction factors, and in turn glycol/glycerin aerosol concentrations, will help inform decisions as to what fog fluids should be used in the entertainment industry for minimizing worker exposure to glycol/glycerin aerosols.

2.0 INTRODUCTION

2.1 Artificial Fog

Artificial fogs and smokes are commonly used in the entertainment industry to produce atmospheric special effects (Varughese, et al*.,* 2005). Historically, a range of products have been used to generate artificial fog, including dry ice, mineral oil, and various organic compounds. Theatrical performances and film/TV show productions regularly use specialized fog machines which use heat to aerosolize fog fluids to generate the desired special effects. Artificial fogs are used to generate these effects for a range of durations, varying from brief periods to entire work shifts (Sataloff, 2006). Artificial fogs and smokes are divided into two broad categories: fog fluid products that contain organic compounds and fog fluid products that contain inorganic compounds. Examples of organic-based fog products are fluids that contain mineral oil, glycerin, and/or glycols, whereas inorganic fog products make use of liquid or solid gases (eg., dry ice and liquid nitrogen) and water mists. This study focuses on the use of glycol and glycerin-based fog products, which are two of the most commonly used fog fluid products in the entertainment industry.

Glycols are aliphatic alcohols with a hydrocarbon backbone and two hydroxyl functional groups. Several types of glycols have been used in fog fluids, including ethylene glycol, propylene glycol, diethylene glycol, butylene glycol, triethylene glycol, and dipropylene glycol. In contrast to glycols, which are a group of compounds, glycerin is the name given to a three-carbon compound with hydroxyl groups on each carbon atom. Glycerin-based fog products are composed of glycerin and water, whereas glycol-based products feature more variation in their composition, with some containing three or more different glycols and water. A recent study found that among commonly used fog products, glycol-based compositions largely contain a variation of propylene glycol, dipropylene glycol, triethylene glycol and 1,3-butylene glycol (Ramboll ENVIRON, 2015). Ethylene glycol was historically a common component in glycol-based fog fluids; however, it is currently prohibited from theatrical fog products because of the toxicity of its particulate form (Sataloff, 2006). Fog products containing this and other compounds were not examined for this study.

Artificial fog can be generated using specialized fog machines that heat the fog fluid and condense the resulting vapor. The fog machines examined in this study use this common heating-based method to generate and disperse the fog aerosol. In general, the fog effect is achieved when the fog fluid products are heated to temperatures ranging from 350°F to 700°F, depending on the specific fog machines (Sataloff, 2006). The aerosolized fog can contain particles with an aerodynamic diameter ranging from 0.5 µm to 60 µm in size as it cools and condenses (Sataloff, 2006). Other fog generation and dispersion methods include atomizers that force air through small holes, and ultrasonic techniques, that vibrate the fog solutions into droplets (Teschke, et al., 2005).

Artificial fog is used at varying concentrations in the entertainment industry, depending on the desired effect. A common special effect used in the entertainment industry is the use of haze effects, whereby an ambient fine mist is maintained in an environment that would accent lighting without obscuring the performer (Moody et al., 2017:2016). To achieve this effect, fog machines regularly run for the entire duration of a performance or filming process.

2.2 Health Effects

Several epidemiological studies have assessed potential associations between artificial fog exposure and adverse health effects in the entertainment industry. A 2000 cross-sectional study by Moline et al. (2000) used a health survey, medical evaluations, and exposure assessments to evaluate these associations in actors performing in musical performances (Moline, Golden, Highland, Wilmarth, & Kao, 2000). The authors found no significant acute changes between pre- and post-performance measures of lung function, voice quality, or vocal cord appearance. However, performers with exposures to elevated glycol levels reported more symptoms than those with less exposure. Additionally, longer exposures to peak glycol levels was associated with an increase in certain inflammation indicators of the throat or vocal cords, whereas no association was seen for mineral oil exposure.

A more recent study by Teschke et al. (2005) examined a variety of production types and determined that general fog effects in the air had aerosol concentrations upwards of 4 mg/m^3 (Teschke et al., 2005). Furthermore, it was noted that over 60% of the overall aerosol mass concentration had an aerodynamic diameter less than 3.5 microns, which suggests the possibility of entry into the alveolar regions of the respiratory system. The complimentary study by Varughese et al. (2005), used health surveys, pulmonary function testing, and exposure monitoring to assess associations between glycol and mineral oil fog exposure and health effects in a range of production types (Varughese et al., 2005). Average lung function parameters were significantly lower in the study participants from the entertainment industry compared to the control group. One measure of lung function, forced vital capacity, decreased significantly with increasing cumulative exposure. The study found an increased prevalence of chronic work-related wheezing and chest tightness with increased combined glycol and mineral oil fog exposure. Total fog aerosol concentration, regardless of aerosol type, was associated with acute upper airway and voice symptoms. Dryness and systemic symptoms were associated with glycol-based fog exposure and not with overall aerosol concentration. No studies were found that assessed glycerin fog exposure and health effects. To date, most studies examining associations between theatrical fog exposure and health effects have focused on live productions, where the duration of worker exposure is relatively brief compared with film production workers. More studies are needed to examine the effects of the more prolonged exposures for this latter group of workers, for whom shift lengths and therefore exposures can, on occasion, exceed 14-hours.

The toxicity of the most commonly used glycols in fog products has been reviewed extensively (BIBRA, 1990, 1993a, 1993b, 1996; Moline et al., 2000). There is limited evidence of reproductive effects and genotoxicity, as well as carcinogenicity. A low degree of acute toxicity and irritation in both animal and human studies has been seen among all glycols. Evidence of adverse effects on the central nervous system and kidney damage, among other health effects, were present for exposures to triethylene glycol.

3.0 EXPOSURE GUIDELINES

3.1 Occupational Exposure Limits

WorkSafeBC sets Occupational Exposure Limits (OELs) for protection of worker health in Part 5 of the *Occupational Health and Safety Regulation* (OHSR). Section 5.48 of the OHSR contains the Table of OELs for Chemical and Biological Substances (Table of Exposure Limits for Chemicals and Biological Substances). OELs for respirable glycerin mist are provided in Table 1, below. However, the American Conference of Governmental Industrial Hygienists (ACGIH) has recently removed the threshold limit value (TLV) for glycerin, and WorkSafeBC proposes to also remove the OEL for glycerin mist.

WorkSafeBC does not have OELs for the various glycol compounds, aside from ethylene glycol, which is already prohibited from use. However, the American Industrial Hygiene Association (AIHA) has developed Workplace Environmental Exposure Limits (WEELs) for propylene glycol, which is one of the most common compounds found in the glycol-based fog products. In addition, both the American National Standards Institute, and a study conducted by Environ International Corporation made recommendations for overall glycol exposure limits. While the recommendations from the three organizations are not regulatory limits, the proposed guidance levels can provide a point of reference when examining compounds that do not have OELs.

Table 1. WorkSafeBC Occupational Exposure Limits & Alternative Guidance Limits

Compound Name	CAS #	WorkSafeBC	AIHA WEELS	ANSI E1.5-2009
Glycerin Mist	56-81-5	3 mg/m^3 (Respirable TWA) 10 mg/m^3 (Total TWA)	-	10 mg/m^3 (Total TWA) 50 mg/m^3 (Total C)
Propylene Glycol (Total)	57-55-6	-	10 mg/m^3 (TWA)	-
Glycols (Total)	-	-	-	10 mg/m^3 (TWA) 40 mg/m^3 (C)

Notes:

mg/m^3	Milligrams per cubic meter
TWA	Time Weighted Average – 8 Hour Occupational Exposure Limit/Guidance Level
C	Peak concentration that should not be exceeded at any point during shift
AIHA WEELS	American Industrial Hygiene Association Workplace Environmental Exposure Limits
ANSI	American National Standards Institute

3.2 Extended Work Shifts

The regulatory limits and guidance levels proposed in the prior section are based on 8-hour work shifts, but because work shifts in the entertainment industry can be as long as 12+ hours, the limits need to be adjusted to reflect the extended work shift exposures. Section 5.50 of the OHSR contains the TWA limit factors for work periods beyond the 8-hour TWA limit and the updated OEL values are detailed in Table 2 below.

Table 2. Extended Work Shift-Adjusted Exposure Limits

Shift Duration (Hours)	Total Glycols/Total Glycerin	Respirable Glycerin Mist *
8	10 mg/m^3	3 mg/m^3
8-10	7 mg/m^3	2.1 mg/m^3
10-12	5 mg/ m^3	1.5 mg/m^3
12-16	2.5 mg/ m^3	0.75 mg/m^3
16+	1 mg/ m^3	0.3 mg/m^3

Notes:
mg/m^3 Milligrams per cubic meter
* WorkSafeBC 8-Hour TWA for respirable glycerin mist

4.0 METHODOLOGY

4.1 Bulk Fog Fluid Composition Analysis

Bulk samples for all the glycol and glycerin-based fog fluid products used in this study were analyzed for relative abundance of propylene glycol, dipropylene glycol, triethylene glycol, 1,3-butylene glycol, and glycerin at the Occupational and Environmental Hygiene Laboratory at the University of British Columbia. Briefly, samples were diluted in methanol and analyzed through Gas Chromatography/Mass Spectrometry. A calibration curve was run containing each identified compound, which was then used to quantify the unknown concentrations in the bulk samples. The actual concentrations were then calculated using the original dilution factor with the detected concentrations.

4.2 Glycol and Glycerin Air Sampling Experiments

Air sampling experiments for establishing correction factors for all fog fluids were conducted in a controlled indoor setting. A total of seven different fog machines and 12 fog fluids were used to attempt to create a correction factor for each fog fluid (Table 4). A fog machine was placed on one end of a table and a DustTrak™ DRX Aerosol Monitor 8533 (TSI Inc.) and air sampling equipment were placed adjacent to it to perform side-by-side monitoring for glycol and glycerin aerosol in the room. At the start of each sample process, the area was first ventilated, and then the DustTrak aerosol sampler was started to measure and record mass concentration of total aerosol, PM10, PM4, PM2.5, and PM1 at 1-second intervals. The fog machine was then used to maintain a total aerosol concentration in the room at concentrations ranging from 5 mg/m^3 up to 140 mg/m^3, as measured by the DustTrak. Once the desired concentration was reached, the sampling pump was used to collect glycol and glycerin aerosol samples in accordance with National Institute of Safety and Health (NIOSH) Method 5523 and Method 0500, respectively, at sampling times ranging from one to ten minutes and flow rates from one to four liters per minute. Relative humidity and air temperature measurements were also taken for each experiment.

For glycol aerosol measurements, an XAD-7 OVS charcoal sorbent sampling head was attached to the air sampling pump, and for glycerin-based fog fluids an open cassette containing a pre-weighed 37-mm, 5-micron PVC filter was used as the sampling head. In order to ensure that the DustTrak and the glycol and glycerin sampling heads were collecting air samples which contained homogenous glycol and glycerin concentrations, a sampling hose was attached to the sample outlet of the DustTrak and positioned directly adjacent to glycol and glycerin sampling heads. Air samples were sent for analysis to SGS Galson Laboratories, East Syracuse, New York, Scientific Analytical Institute in North Carolina and ALS Environmental in Utah to determine aerosol propylene glycol, dipropylene glycol, triethylene glycol, and 1,3-butylene glycol concentrations in accordance with NIOSH Method 5523 - Glycols, and total aerosol concentrations for glycerin samples following NIOSH Method 0500 – Particles Not Otherwise Regulated (National Institute for Occupational Safety and Health, 1994, 1996). General observations were also collected regarding the visual characteristics of the fog, including colour/shade, relative thickness, persistence in air (hang time), and odour during the experiments.

4.3 Data Analysis

4.3.1 Developing Calibration Factors

In order to develop calibration curves for each of the fog fluids, both data from the direct-reading instrument and active-sampling lab results were used for the analysis. Data values logged by the

DustTrak included mass concentrations for size fractions ranging from PM1 to PM10; however, total mass concentrations were used for determining the correction factors, expressed in mg/m^3, by averaging over the same sampling period as the active pump start-end times. Active-sampling lab results were analyzed for analyte mass and total concentration was calculated using known sampling duration and pump flow-rates. Next, simple linear regression was run in Excel (Version 15.32) using the measured DustTrak and active-sampling concentrations for each fog fluid. The number of air measurement points used for generating each calibration curve ranged from 3-11 (see Appendix I for the calibration curves). For all fog fluids, the correction factor was reported as the slope of the line with the X,Y-intercept set to 0,0, with the exception of CITC 15-Second Fog Fluid. For this particular fluid, fixing the intercept in this manner significantly decreased the Coefficient of Determination (R^2) and altered the correction factor, and so the Y-axis intercept was reported along with the slope. For each calibration curve, the Coefficient of Determination was also reported as the trend line's goodness of fit. Samples with glycol or glycerin concentrations below the analytical limit of detection were not included in the calibration curves.

4.3.2 Statistical Analysis

DustTrak and active sample concentration measurements, alongside bulk sampling data, were used for analyses in JMP (Version 13.0) to assess for associations between bulk fog fluid composition and total glycol/glycerin aerosol concentrations. Analyses were also performed to assess the effect of bulk fog fluid composition on the various correction factors of the fog fluids. For active sampling concentration measurements below the limit of detection (LOD), the LOD value was used.

Fog fluids were categorized by the majority glycerin or glycol compound in the fluids as determined by bulk analysis, and aerosol concentrations were visualized with box plots. Using this same categorization, the effect of fog fluid composition on correction factors was also visualized. Analysis of variance and Tukey's Honest Significant Difference tests were performed to determine whether bulk fog fluid composition had a significant effect on both total glycol/glycerin aerosol concentrations and the fog fluid correction factors. Various multiple regressions were also run using fog fluid type, fog fluid composition, and fog fluid machine manufacturer as independent variables to predict total glycol/glycerin aerosol concentrations, although those results are not reported here.

5.0 RESULTS

5.1 Bulk Fog Fluid Compositions

A total of 11 fog fluids were assessed for glycol and glycerin composition by bulk analysis (Table 3). Three fog fluids, Luminous 7 Haze, Organic Haze, and Regular Haze, contained glycerin in concentrations ranging from 12% to 76%. Propylene glycol was the most common glycol compound in the fog fluids, detected in eight of the 11 fog fluids analyzed. Four fog fluids, Rosco Stage & Studio, Ultratec Molecular Fog, Quick Dissipating CITC 15-second Fog, had propylene glycol as the primary glycol compound in concentrations ranging from 41% to 76%. Quick Dissipating fog fluid was not available for bulk analysis, however the Safety Data Sheet indicated propylene glycol was the primary glycol compound present. Dipropylene glycol was detected in very low concentrations (<1%) in two fog fluids, and was the majority glycol compound in one fog fluid, Ultratec Director's choice, at a concentration of 49%. Triethylene glycol was present in five of the fog fluids, and the majority glycol compound in four fluids at concentrations ranging from 21% to 35%. Butylene glycol was detected in low concentrations (<10%) in two fog fluids.

Table 3. Bulk Fog Fluid Compositions

Fog Fluid Commercial Name	Propylene Glycol	Dipropylene Glycol	Triethylene Glycol	1,3-Butylene Glycol	Glycerin
Look Solutions Regular Fog	25%	0.03%	27%	-	-
Rosco Stage & Studio	51%	0.05%	1.3%	-	-
Rosco V-Hazer	14%	-	21%	-	-
Ultratec Molecular Fog	76%	-	-	-	-
CITC 15-Second Fog	41%	-	-	-	-
Ultratec Director's Choice	-	49%	-	-	-
Luminous 7 Haze	0.063%	-	-	-	76%
Rosco Clear Fog Fluid	20%	-	31%	7%	-
CITC Organic Haze	-	-	-	-	12%
Rosco Fog Fluid	14%	-	35%	5%	-
C-Beam Regular Haze Fluid	-	-	-	-	19%

NOTE: Blue shading indicates the majority glycol or glycerin compound detected in the fluid.

5.2 Fog Fluid Correction Factors

Correction factors for two glycerin-based and eight glycol-based fog fluids were determined (Table 4 and Appendix I). A correction factor represents the multiplicative value for adjusting DustTrak total aerosol concentrations to reflect aerosol glycol or glycerin concentrations. With the exception of the Rosco V-Hazer fog fluid, all glycol-based fog fluids had correction factors greater than one, with approximately half of the fluids having a correction factor of approximately two. The Quick Dissipating and Stage and Studio fog fluids had the highest correction factors, 4.0 and 7.63, respectively. In contrast, the correction factors for both glycerin-based fog fluids were less than one. The goodness-of-fit values, expressed as the R^2

value, of all calibration factors was greater than 0.9, with the exception of Quick Dissipating Fog Fluid, which was 0.69.

Correction factors for two fog fluids, C-Beam Regular Haze Fluid and Rosco Clear Fog Fluid could not be determined. For C-Beam Regular Haze fluid, when the Dust Trak values indicated 50 mg/m^3 or less, the active sampling results were at or below detection limits, meaning a viable curve could not be produced. For two single point calibration points when the Dustrak value indicated 100 mg/m^3, the active glycerin sampling results were 15 and 28 mg/m^3 for two trials.

A representative standard curve for Ultratec Director's Choice, a glycol-based fog fluid, is shown in Figure 1. See Appendix I for the calibration curves for all correction factors shown in Table 4. Figure 2 below gives a visualization of each fog fluid's correction factor, stratified by majority glycol/glycerin compound.

Table 4. Correction Factors for Glycol and Glycerin-Based Fog Fluids

Fluid Manufacturer	Machine	Fluid Name	Fluid Type	Calibration Factor	R^2 Value
Looks Solutions	Viper NT	Regular Fog Fluid	Glycol	1.81	0.96
Ultratec Special Effects	G300 (Le Maitre)	Director's Choice	Glycol	2.38	0.98
		Molecular Low-Lying Fog Fluid	Glycol	2.64	0.94
		15-sec Fog Fluid (CITC)	Glycol	2.84*	0.96
	Radiance Hazer	Luminous 7 Haze	Glycerin	0.78	0.99
Le Maitre	G150	Quick Dissipating	Glycol	4.0	0.69
Rosco	V-Hazer	V-Hazer	Glycol	0.77	0.94
	Vapor Plus	Stage and Studio Fog Fluid	Glycol	7.63	0.94
		Rosco Fog Fluid	Glycol	1.03	0.95
CITC	Aquamax Organic Haze	Organic Haze Fluid	Glycerin	0.44	0.94
LeMaitre	Le Maitre G300	C-Beam Regular Haze	Glycerin	<0.3**	-

* Standard curve does not pass through 0,0 point on graph. Full equation is: [Aerosol Glycol] = [DustTrak] X 2.84 + 363

** For C-Beam Regular Haze, multiple attempts were made to achieve a curve, but many active sample results were non-detect. The highest single point calibration factor achieved was 0.28. The value in the table is based on one data point and is subject to limitations.

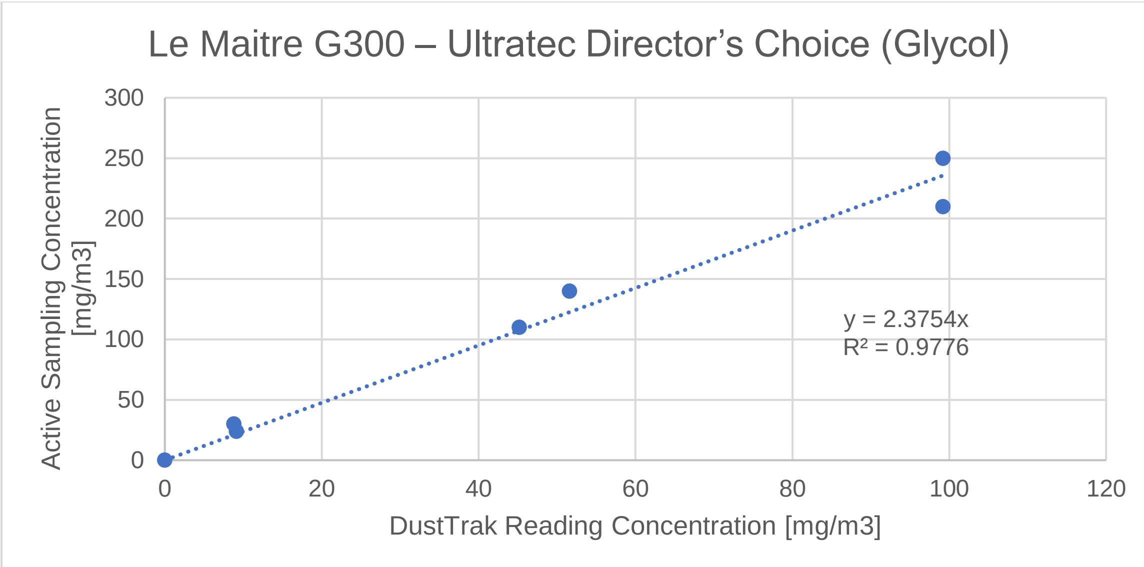


Figure 1. Standard Curve for Ultratec Director's Choice Fog Fluid Correction Factor

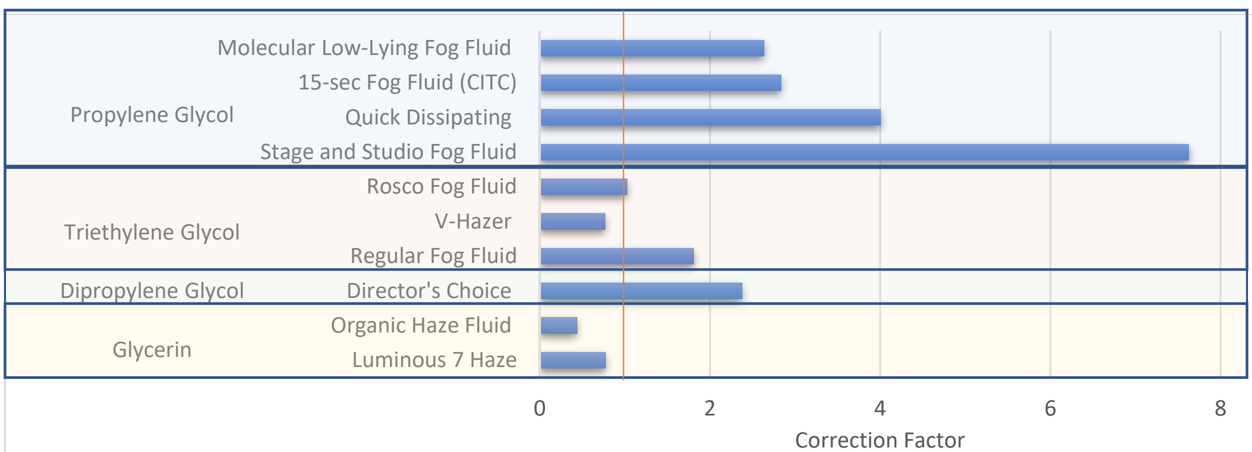


Figure 2. Correction Factors by Fog Fluid Name and Major Glycol Compound or Glycerin
Vertical orange line indicates a correction factor value of one.

5.3 Observations

Observations were made to determine if a particular fog effect could be visually examined in order to estimate the approximate fog concentration in the environment. However, the fog concentrations could not be reliably predicted; the visual difference between the 10 mg/m^3 to 50 mg/m^3 range from the DustTrak measurements in most cases was indistinguishable. Readings above 100 mg/m^3 dramatically reduced visibility.

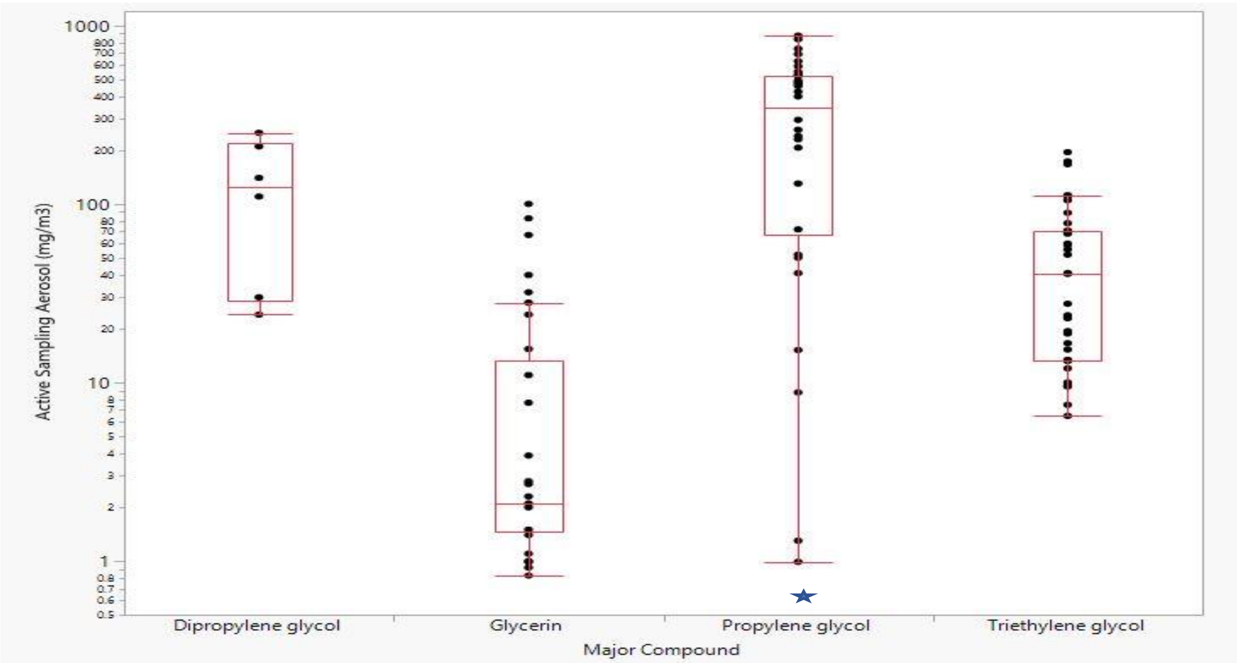
A general observation with regards to the differences between glycol-based and glycerin-based fog fluid products is that the glycerin-based fluids tended to produce a longer-lasting haze effect in the environment. It generally took longer for the glycerin-based fog fluids to achieve the same effect compared with other glycol-based products, and overall it was more difficult to ventilate the room when glycerin-based fogs were used. However, each fog fluid product had subtle characteristics, making the effect they generate vary from one another. Specific observations are noted in Table 5 below and photographs of the different fogs at varying concentrations are included in Appendix II.

Table 5. Fog Fluid Observations

Manufacturer	Fog Fluid	Fluid Type	Observations
Looks Solutions	Regular fog fluid	Glycol	Regular dissipating fog fluid
Ultratec	Molecular low-lying fog fluid	Glycol	Thick, white fog, dissipates quickly.
	Director's choice fog fluid	Glycol	Odorless, medium hang time, leaves residue (as evident on surfaces).
	Luminous 7 Haze	Glycerin	Creates an evenly dispersed, dry and long-lasting haze.
Le Maitre	Regular haze fluid	Glycerin	Long-lasting haze effect, takes long duration to clear out the room.
	Quick Dissipating	Glycol	The fog fluid dissipated quickly
Rosco	V-hazer	Glycol	It achieves maximum hang time, evident by the longer duration to dissipate. Resembles natural fog in the outdoors.
Rosco Vapour Plus	Rosco Stage and Studio	Glycol	It creates a low-lying effect and dissipates quickly. Looks similar to exhaust smoke.
	Rosco Fog Fluid	Glycol	Persists in the air for a prolonged period of time.
	Rosco Clear Fog	Glycol	Effects are similar to Rosco Fog Fluid.
CITC	Aquamax Organic Haze	Glycerin	Odorless, persists in the air.
	15-second Fog Fluid	Glycol	In comparison to the molecular low-lying fluid, the fog dissipates quicker and is cleared out of the room faster.

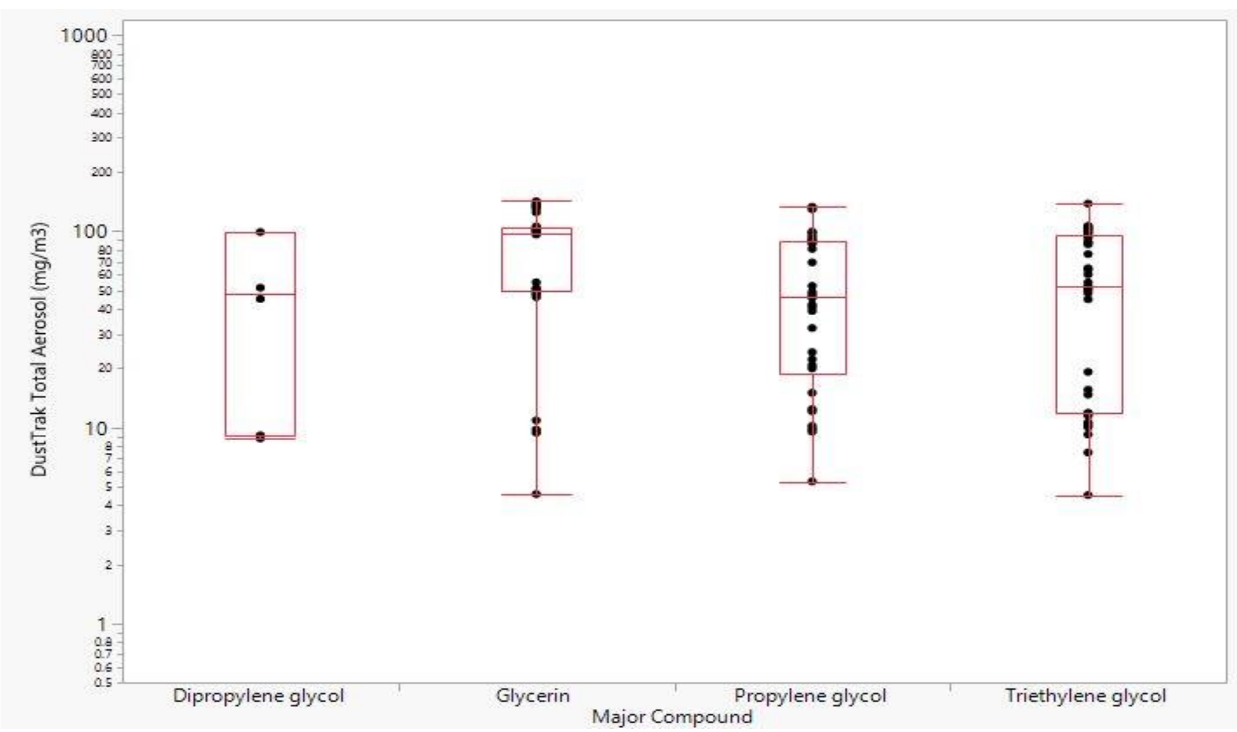
5.4 Effect of Majority Glycol or Glycerin Compounds on Aerosol Concentrations

Box plots were generated to assess if the majority glycerin or glycol compound in the fog fluids had an effect on aerosol concentrations (Figure 3). There was no difference in total aerosol concentrations measured by the DustTrak for the different fog fluids, stratified by majority compound. However, for active sampling, the majority glycerin or glycol compound did have an effect on airborne glycerin/glycol concentrations in air. Fog fluids with propylene glycol as the major glycol constituent had significantly higher maximum airborne glycol concentrations compared with fog fluids containing primarily glycerin or triethylene glycol. Airborne glycol concentrations exceeded 800 mg/m^3 when propylene glycol was the major glycol compounds in the fluid. Glycerin-based fog fluids generated the lowest total aerosol concentrations as measured by active sampling, despite similar DustTrak concentrations compared with all other fluids.



★Indicates a significant difference with glycerin and triethylene glycol at P<0.0001

A) Active Sampling



B) DustTrak

Figure 3. DustTrak Total Aerosol and Active Sampling Aerosol by Fog Fluid Major Compound

Lower, middle, and upper lines of the box indicate the 25th, 50th, and 75th percentiles, respectively. The upper and lower whiskers represent plus and minus 1.5X the interquartile range, respectively.

5.5 Effect of Majority Glycol or Glycerin Compounds in Fog Fluids on Correction Factors

Lastly, plots were generated and ANOVA and Tukey's Honest Significant Difference tests were run to assess if the majority compound in the fog fluids was associated with the correction factors for each fluid (Figure 4). Propylene glycol-based fluids had significantly higher correction factors compared with all other fluids. Correction factors for these fluids ranged from approximately 2.5 to 8. In contrast, there was no significant difference between the correction factors of all other fluids. Correction factor values ranged from 0.4 to less than 2.5 for non-propylene glycol-based fog fluids, with glycerin having the lowest correction factors.

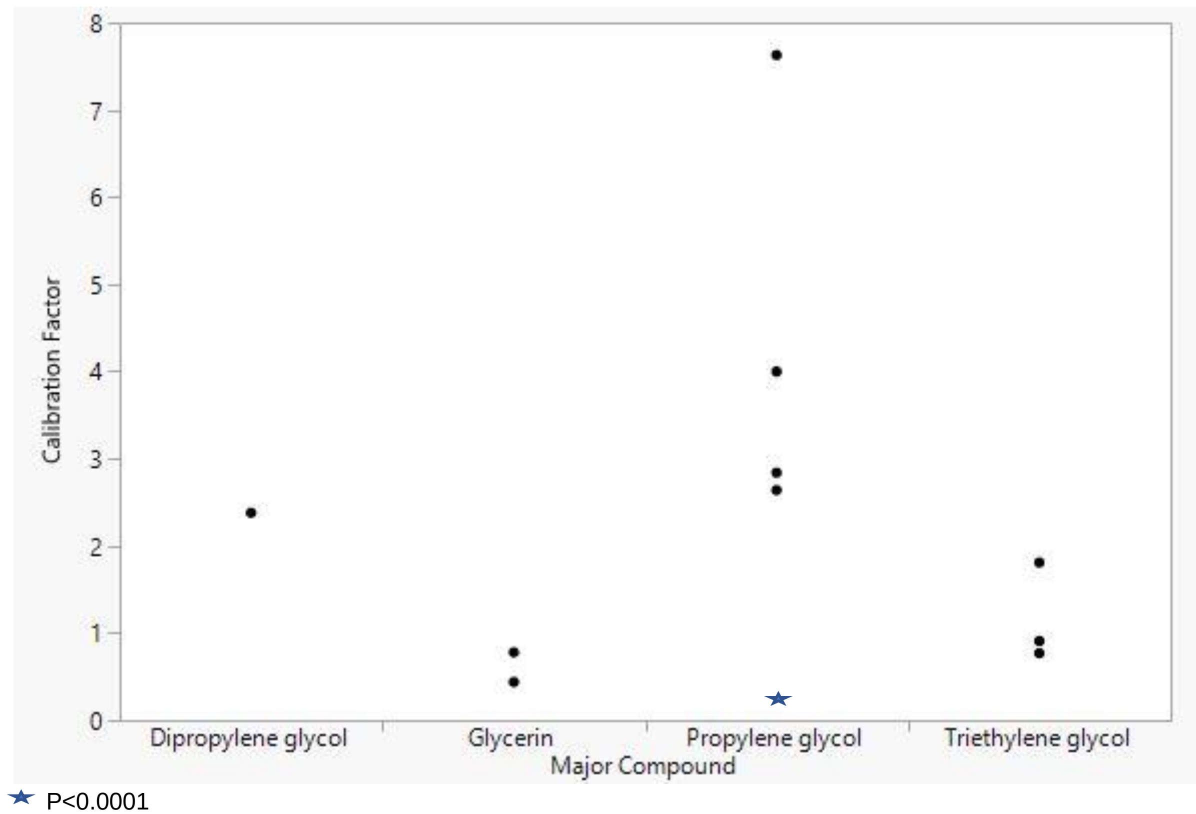


Figure 4. Effect of Majority Glycol or Glycerin Compound in Fog Fluids on Correction Factors

6.0 DISCUSSION

6.1 Major Findings

A total of ten correction factors for fog fluids were determined. The correction factor values ranged from 0.44 to 7.63. Correction factors for two fog fluids could not be determined because no identifiable trend between DustTrak total aerosol measurements and active sampling measurements was observed. The correction factors for glycerin-based fog fluids were all below one, indicating that DustTrak total aerosol measurements over estimate concentrations compared with active sampling. In contrast, all glycol-based fog fluids, with the exception of Rosco V Hazer fog fluid, had correction factors greater than one (Figure 2), indicating that DustTrak measurements underestimate the total glycol aerosol concentrations.
The majority of glycol-based fluids had a correction factor greater than two, with two fog fluids exceeding four and seven.

The calibration curves for all fog fluids had relatively high goodness-of-fit values, expressed as the R^2 value. The goodness-of-fit value effectively measures how closely the determined calibration factor is in agreement with the measured concentrations from both the DustTrak and active sampling methods for each fog fluid. A value of one indicates perfect agreement, while a value of zero means there is no agreement. Nine of the ten fog fluids had greater than 90% goodness-of-fit between the calibration factors and the measured concentrations, indicating very strong agreement.

Interestingly, the specific glycol compounds in the fog fluid significantly affected the amount of glycol aerosol present, reflected by the different correction factors. Triethylene glycol-based fluids had the lowest correction factors (Figure 2 and 4) of the glycol-based fluids, at less than two. The dipropylene glycol-based fog fluid had a correction factor slightly higher, at just over two. In contrast, propylene glycol-based fog fluids had the highest correction factors observed, with values ranging from 2.5 to approximately eight. One possible explanation for propylene glycol having consistently higher correction factors may be due to its higher vapour pressure compared to all the other glycols studied. A higher vapour pressure may indicate that propylene glycol vapourizes more readily than the other glycols possibly causing the DustTrak (which only measures aerosols) to underestimate the actual levels of proplylene glycol because much of it is in a vapour phase. The rank order of vapour pressures of the three different glycols from highest to lowest mirrors the correction factors from highest to lowest: propylene glycol, dipropylene glycol, and triethylene glycol.

6.2 Previous Findings

A 2001 report by Environ International Corporation also determined fog fluid correction factors for a number of fog fluids used in the entertainment industry (Environ International Corporation, 2001c). Table 6 shows correction factors for four fog fluids assessed both in our study and from the Environ study. There is good agreement for three of the four correction factors in common between the two studies. There is, however, a notable difference between the correction factor for Rosco Stage and Studio Fog Fluid between the studies. However, the two real-time monitors used in the studies for developing the correction factors are different – in our study we corrected for a DustTrak DRX aerosol monitor, while the Environ study used a pDR 1000 aerosol monitor. Both use light scattering technology, but some discrepancy would be expected between correction factors generated using the different aerosol monitors. Interestingly R^2 values were not reported in their study, so there is no quantitative value for how reliable the correction factors are for predicting glycol aerosol concentrations. However, looking at the calibration curves in their report, for some fog fluids there is a large discrepancy between the measured concentrations and the fitted line. In our study as well, not all experiments produced useable calibration curves. It is possible that there is not always a strong linear relationship between DustTrak measurements and active sampling glycol/glycerin aerosol concentrations under all conditions.

Table 6. Comparison of Previously Determined Correction Factors with Current Study

Fog Fluid Type	Environ (2001) Correction Factors	Current Study Correction Factors
Le Maitre Quick Dissipating	3.45	4.01
Le Maitre Molecular Fog Fluid	2.58	2.64
Rosco Stage & Studio Fog Fluid	1.56	7.63
Rosco Fog Fluid	1.27	1.03

6.3 Aerosol Particle Size and Vapour Interactions

The Dustrak showed that small particles (PM1), constituted over 90% of the total aerosol concentration (data not shown). Interestingly, this proportion of smaller particles to total particles changed as total aerosol concentration changed. At lower DustTrak total aerosol concentrations, PM1 constituted a higher percentage of total particles, often exceeding 98%. At higher total aerosol concentrations, this proportion dropped to around 90%. Thus, at higher total aerosol concentrations, the proportion of larger particles increased. Although the precise mechanism behind this phenomenon is unclear, it may play a role in aerosol-vapour interactions of the fog fluids. It is possible that smaller glycol aerosol particles more readily vapourize to form glycol vapour than larger particles, which may explain some of the larger discrepancies seen between DustTrak total aerosol measurements and active sampling measurements at lower concentrations. The DustTrak only measures aerosolized particles in air, while the active sampling procedure, NIOSH Method 5523, measures both glycol aerosol and vapour. Some of the active samples collected at lower DustTrak concentrations had proportionately higher glycol levels than at the higher DustTrak concentrations. One explanation for this phenomenon could be that during the longer sampling times required for these lower concentrations, some of the highly abundant smaller particles could have vapourized to form glycol vapour. This glycol vapour would not be measured by the DustTrak but would be detected by the active sampling method. Future research helping to elucidate the effect of total aerosol concentration on aerosol-vapour interactions could help ensure that worker exposures are not being underestimated while DustTrak monitors are used to estimate glycol aerosol exposures.

6.4 Considerations for Exposure Limits

There are currently no WorkSafeBC occupational exposure limits for the glycols found in the tested fog fluids. However, the AIHA WEELs recommend the nuisance dust standard of 10 mg/m^3 for propylene glycol over an 8-hour work shift. This 8-hour limit of 10 mg/m^3 is also recommended in the ANSI Standard, ANSI E1.5 – 2009 (R2014), and both ANSI and the Environ (2001) report recommend that total glycol concentrations in air should never exceed 40 mg/m^3, and that total glycerin aerosol concentrations should never exceed 50 mg/m^3. If a production decides to use glycol products to produce a consistent fog effect throughout the day, it is important to be aware of the possibility that these recommended limits may be exceeded, especially for fog products with high calibration factor values. For example, Rosco Stage and Studio Fog Fluid has an estimated correction factor of 7.6. Maintaining 8-hour TWA total glycol aerosol concentrations below 10 mg/m^3 would entail maintaining average DustTrak readings below 1.3 mg/m^3 while this fluid is used. However, as mentioned above, these exposure limits would need to be adjusted for shift-lengths which exceed 8-hours, which is often the case for film production workers.

6.5 Thermal Decomposition Products

One potential health hazard not considered in this report are the byproducts from the thermal breakdown of fog fluid compounds. Various decomposition products such as aldehydes (e.g., formaldehyde and acrolein), carbon monoxide, carbon dioxide, nitrogen oxides (i.e., NO_2), and hydrogen cyanide (HCN) are created by heating organic compounds to high temperatures. A number of these compounds cause respiratory irritation at lower concentrations and are asphyxiants. A 2003 study showed heating fog fluids at temperatures within the operating range of fog machines resulted in the release of formaldehyde and acetaldehydes, both of which are mucous membrane irritants and possibly carcinogenic (Teschke et al., 2003). However, it is unclear whether the above aldehydes were generated as a result of thermal breakdown of fog fluid constituents, or they were originally present in the fog fluids. Further research is needed to determine i) the extent to which these compounds may be present in artificial fogs used in the entertainment industry and ii) if workers are being exposed.

7.0 LIMITATIONS

One of the limitations of this study was that glycerin aerosol concentrations could not be measured directly, as there is currently no available method for doing so. Rather, the standard method for measuring glycerin aerosol concentrations is a non-specific measure of total aerosol mass. Although the authors have confidence that glycerin aerosol particulate was the primary aerosol compound being measured, it could not be definitively shown.

Another limitation of this study was the variability in results between some experiments with the same fog fluid. Presented here are the results from experiments which yielded the highest coefficient of determination for the calibration curves. However, we observed notable variability between some of the calibration curves from experiments utilizing the same fog fluid. Similarly, the 2001 Environ International Corp. report showed that not all fog fluids produced calibration curves with high goodness-of-fit. It is possible that other factors not assessed in their report, and in our study, affect the agreement between DustTrak measurements and active sampling using two NIOSH methods. This possibility should be considered when applying correction factors to assess worker exposures.

Another limitation of this study was that information regarding the operating temperatures of the fog machines could not be obtained. The temperature at which the fog fluids are heated would expectedly affect aerosol formation and the fate of the aerosol particles. Also, whether the temperature of the fog machines stays constant, or changes with time, would also potentially affect glycol/glycerin aerosol concentrations in air. Additionally, knowing the temperature of the machines would provide information as to the risk of thermal breakdown of fog fluid products.

Another potential limitation of this study was the use of a sampling hose attached to the DustTrak monitor. It is possible that glycol or glycerin aerosol drawn in through the hose may have settled on the inner lining of the hose, and thus not have been measured by the DustTrak monitor. During active sampling, glycol and glycerin aerosol was drawn directly from the air onto the sampling media, and so this settling phenomenon would not have occurred. Therefore, it is possible that the DustTrak monitor underestimated the aerosol concentration, compared with active sampling, which may have contributed to higher calibration factors if this phenomenon occurred to greater extent at higher aerosol concentrations.

Lastly, some of the fog concentrations used for the calibration curves were higher than those normally used in productions. Although, measurements were also taken at lower concentrations, the increased sampling time required was believed to contribute to some variability in the observed measurements. Despite the calibration curves for all of the fog fluids having a linear relationship through the 0,0 intercept (with the exception of CITC 15-Second Fog Fluid), continuing to measure aerosol glycol/glycerin concentrations at the lower fog concentrations when developing future correction factors will be important for capturing conditions frequently encountered in work environments within the entertainment industry.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the literature review and the findings reported in this study:

- There is some evidence of negative human health outcomes, namely irritation, from exposure to aerosols from glycol and glycerin fog fluid products;
- Calibration factors developed for the DustTrak Model 8533 can be used to approximate glycol and glycerin aerosol exposures for eight glycol-based and two glycerin-based fog fluids analyzed in this study;
- Correction factors and maximum aerosol concentrations are lower for glycerin-based fog fluids compared with glycol-based fog fluids assessed in this report;
- The propylene glycol-based fog fluids assessed in this report are associated with higher correction factors and higher maximum glycol aerosol concentrations than other glycol fog fluids;
- The correction factor for a given fog fluid may be affected by additional factors not evaluated here, and so correction factors may vary across settings. This limitation should be considered when applying correction factors to assess worker exposures.

Recommendation:

- When choosing a fog fluid for use, consider the glycerin/glycol compounds in the fluid and their effect on correction factors reported in this study; and
- Visually distinguishing between low fog concentrations, specifically DustTrak readings between 10 and 50 mg/m^3, is difficult and may not be reliable. To gain a more accurate measure of aerosol concentrations in this range, consider having fog technicians perform aerosol monitoring.

9.0 CLOSURE

This report has been funded exclusively by IATSE Local 891. No other warranty, expressed or implied, is made. Any use that a third party makes of this report, or any reliance on or decisions to be made based upon it, are the responsibility of such third parties. Aura accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. Please see Aura's Statement of Limitations included in Appendix III.

Yours truly,

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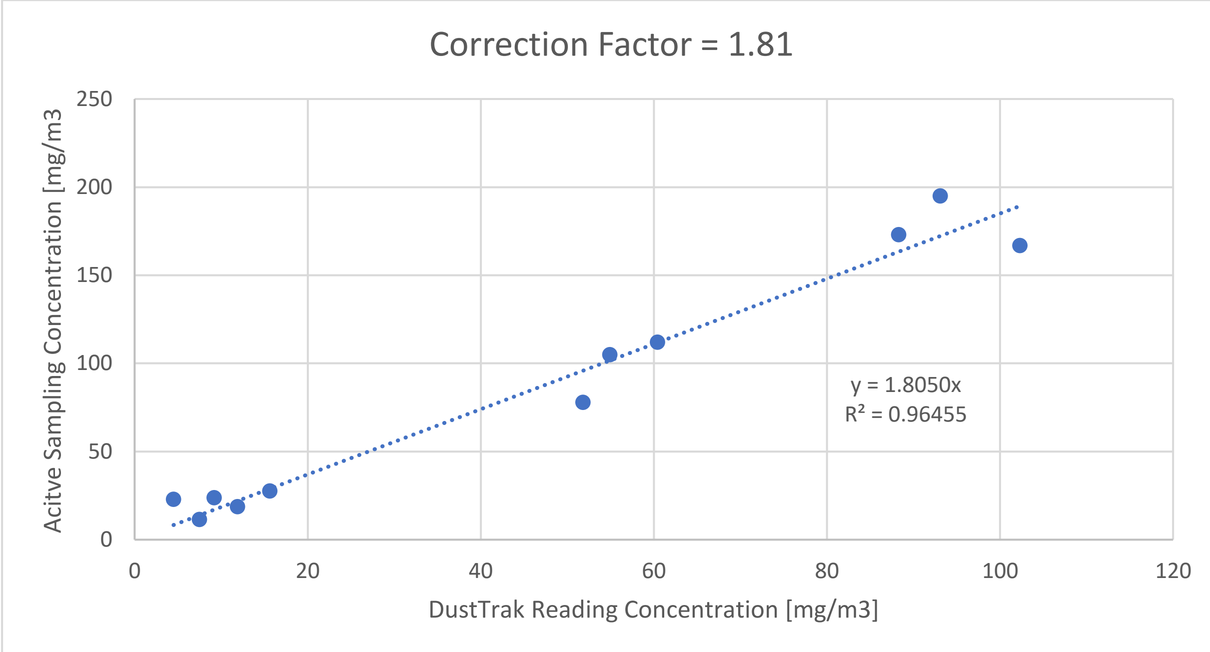
11.0 ACKNOWLEDGEMENTS

We would like to acknowledge the following individuals without whom this study would never have been possible:

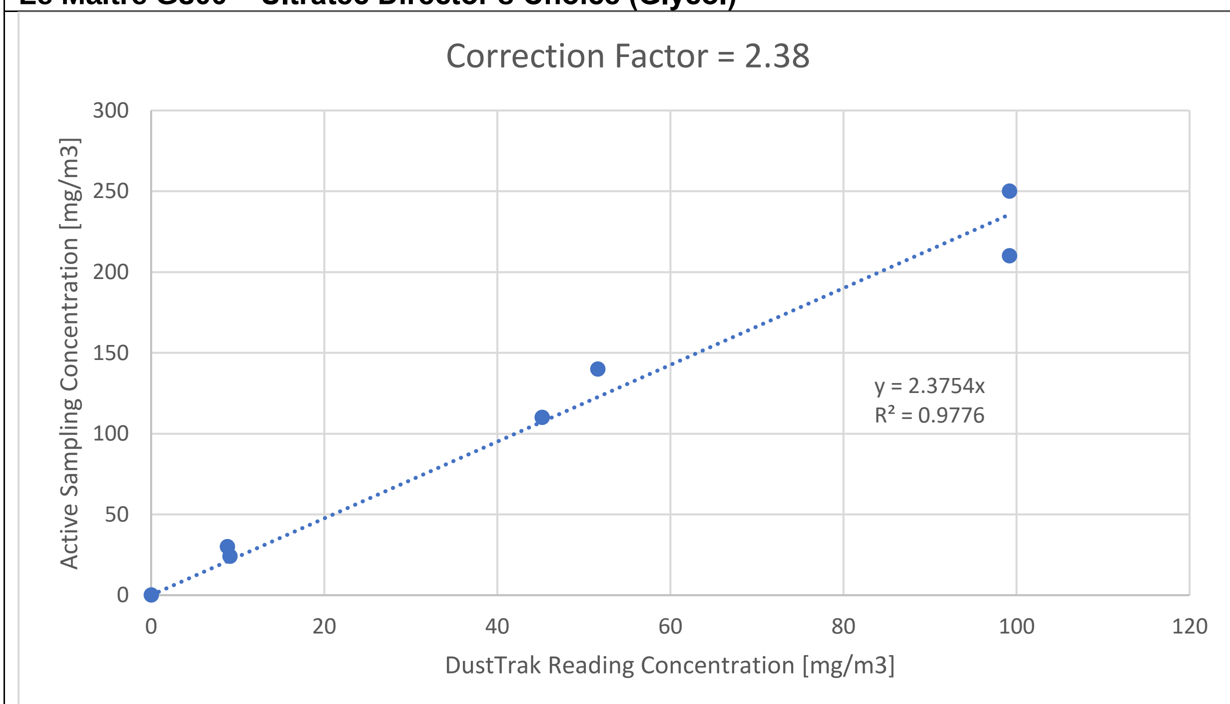
- IATSE Local 891 for funding this research.
- James Paradis (Fog Technician) for providing us with a room and fog machines for our sampling.
- Mike Kaern (owner of the Holly North Production Supplies) for providing us with multiple fog machines and various fog fluids free of charge.
- Stephan Baeuml (production director of Arts Club Theatre on Granville Island) for allowing us to use the theatre and fog machines.
- Scott Lombardi & Sreenath Avula (TSI Incorporated) for providing us the Dusttrak.
- Dave Garrett (WorkSafeBC) and Dr. Kay Teschke (UBC) for providing us guidance as part of our Technical Committee.
- Dr. Michael Brauer and Dr. Karen Bartlett (UBC) for providing guidance to our students.
- Our students, Kiana Kajbafzadeh and Raymond Wang, for conducting the literature review and field work throughout the summer.

Appendix I – Calibration Curves for Correction Factors

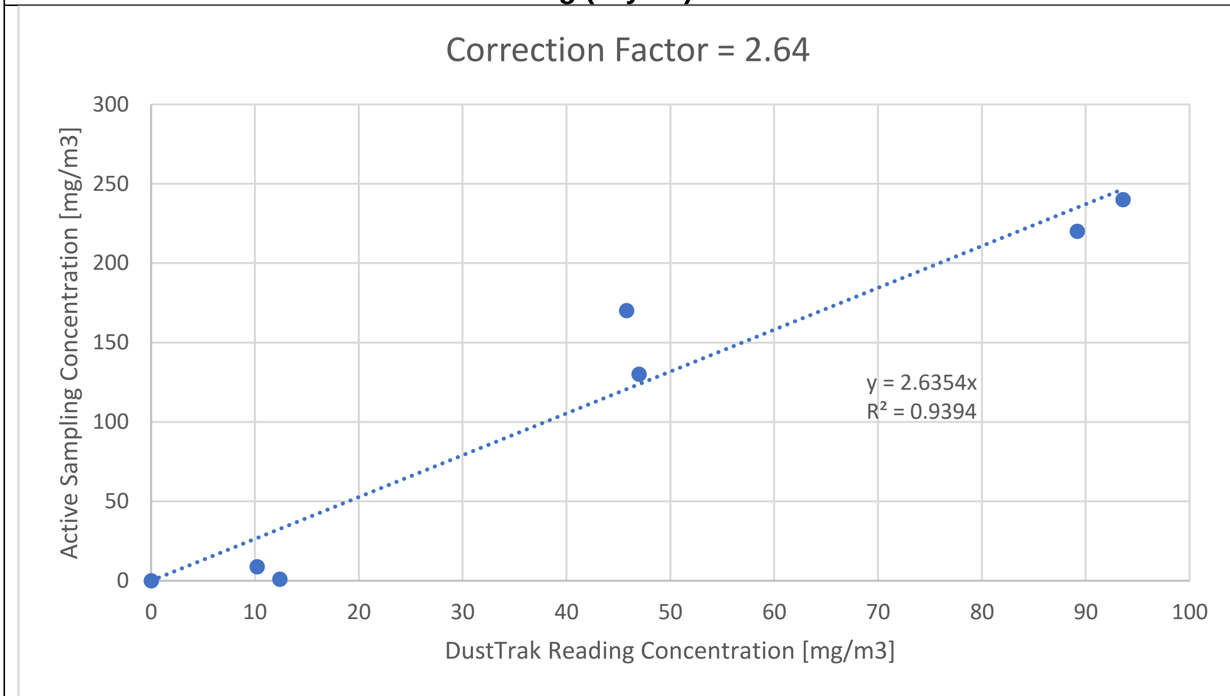
Look Solutions Viper NT – Regular Fog (Glycol)



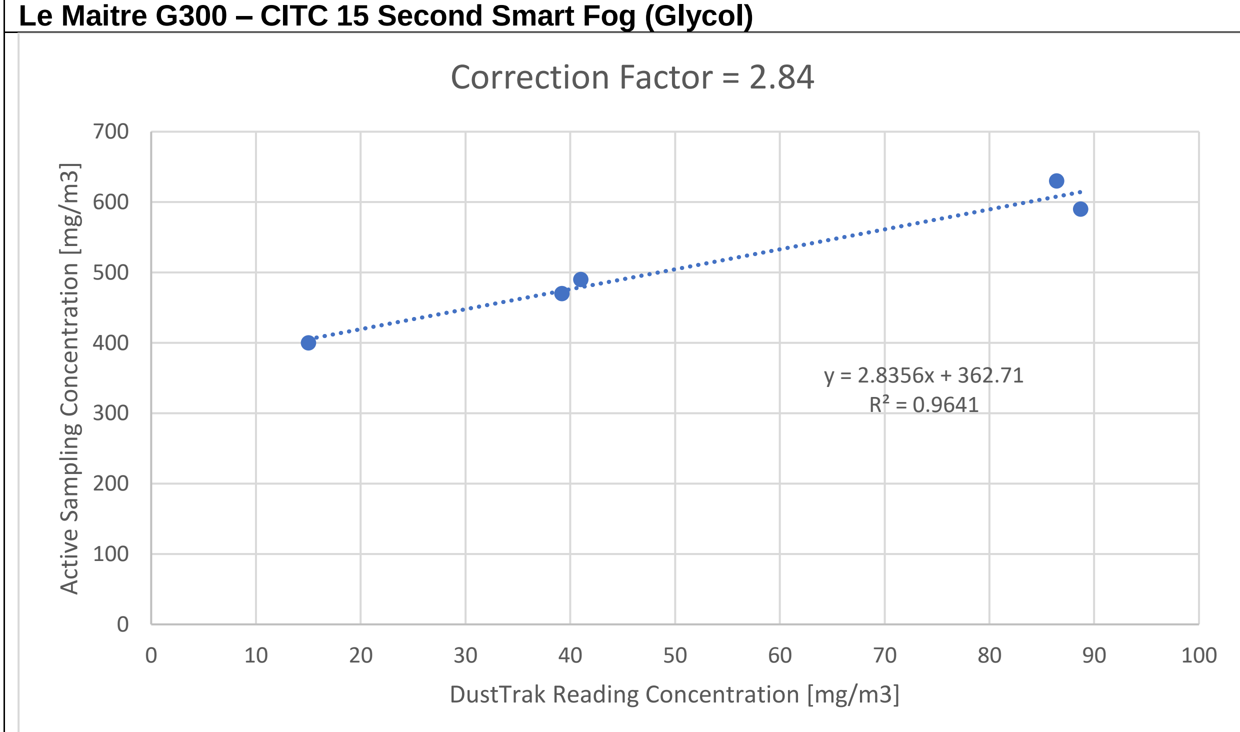
Le Maitre G300 – Ultratec Director's Choice (Glycol)



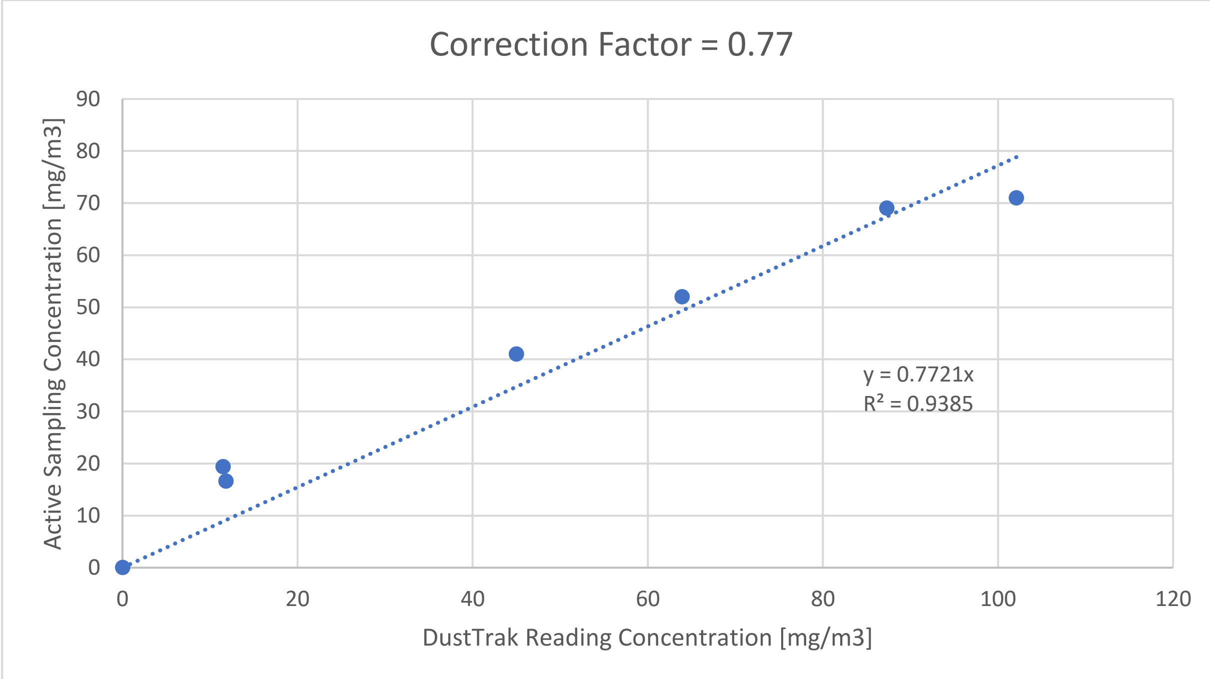
Le Maitre G300 – Ultratec Molecular Fog (Glycol)



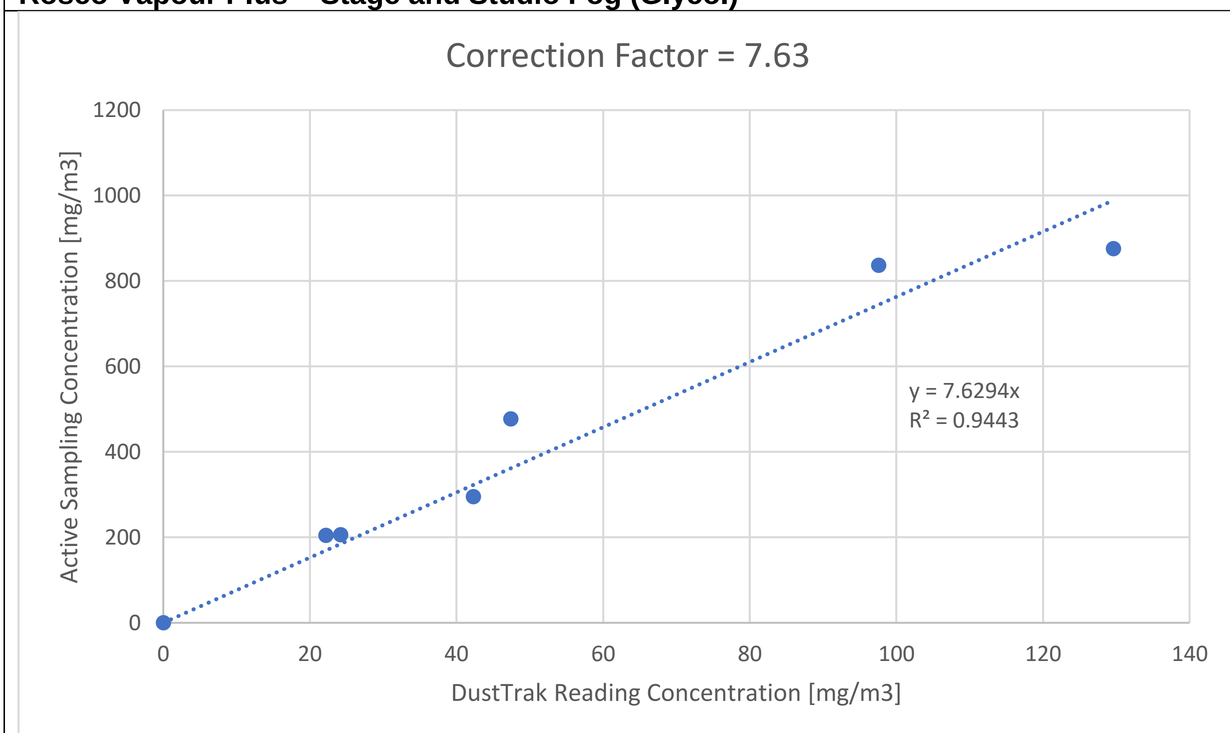
Le Maitre G300 – CITC 15 Second Smart Fog (Glycol)



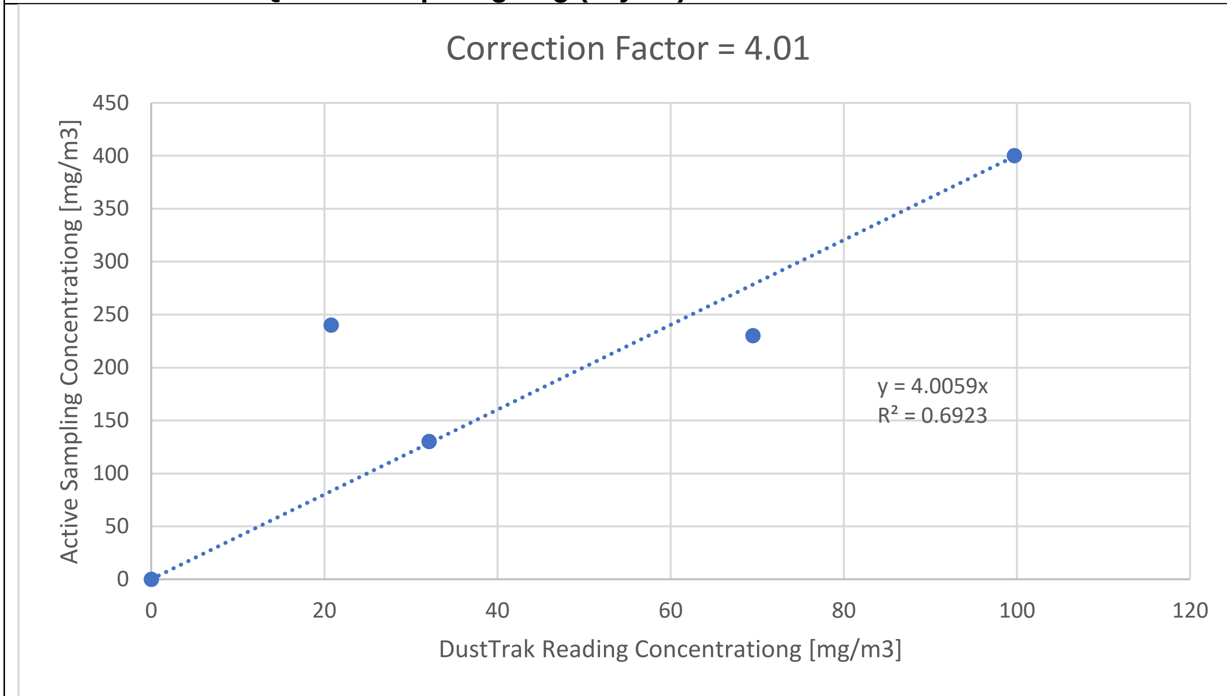
Rosco V-Hazer – V-Hazer Fog (Glycol)



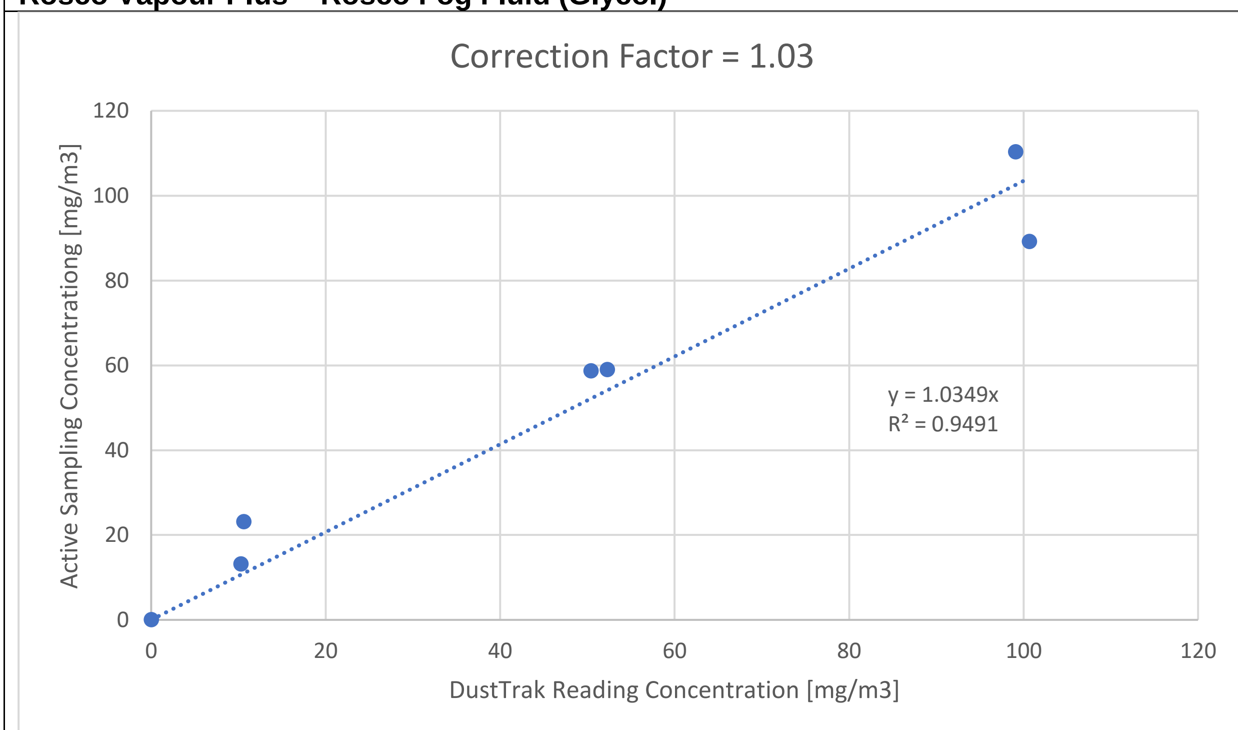
Rosco Vapour Plus – Stage and Studio Fog (Glycol)



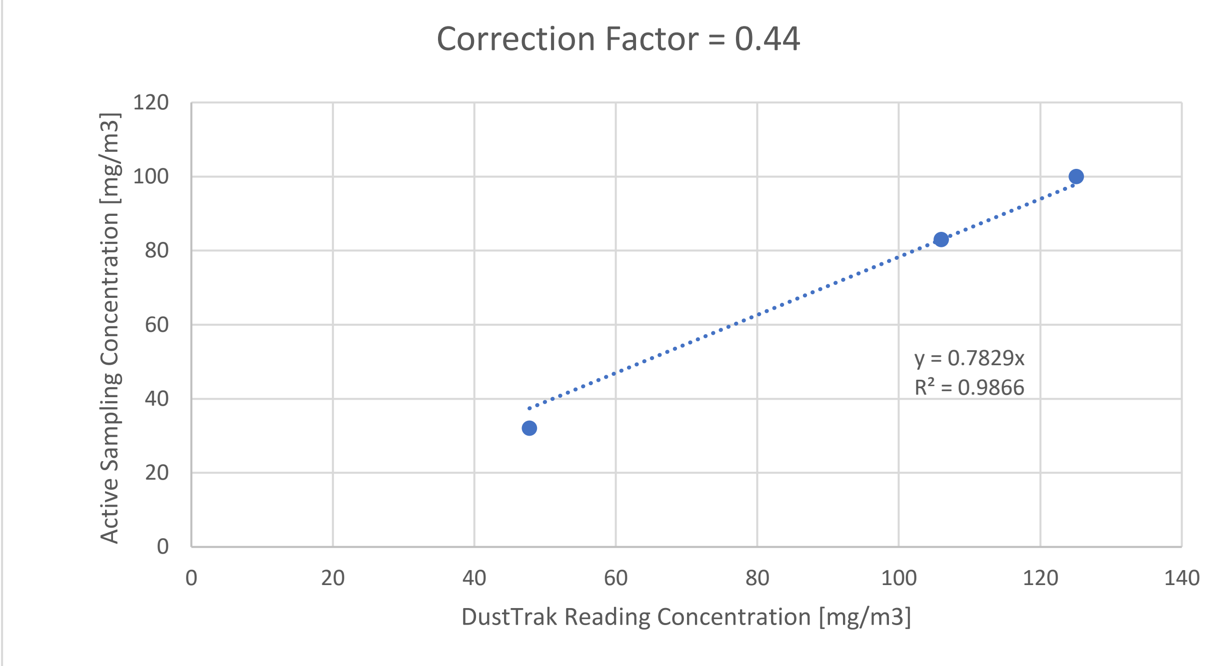
Le Maitre G150 – Quick Dissipating Fog (Glycol)



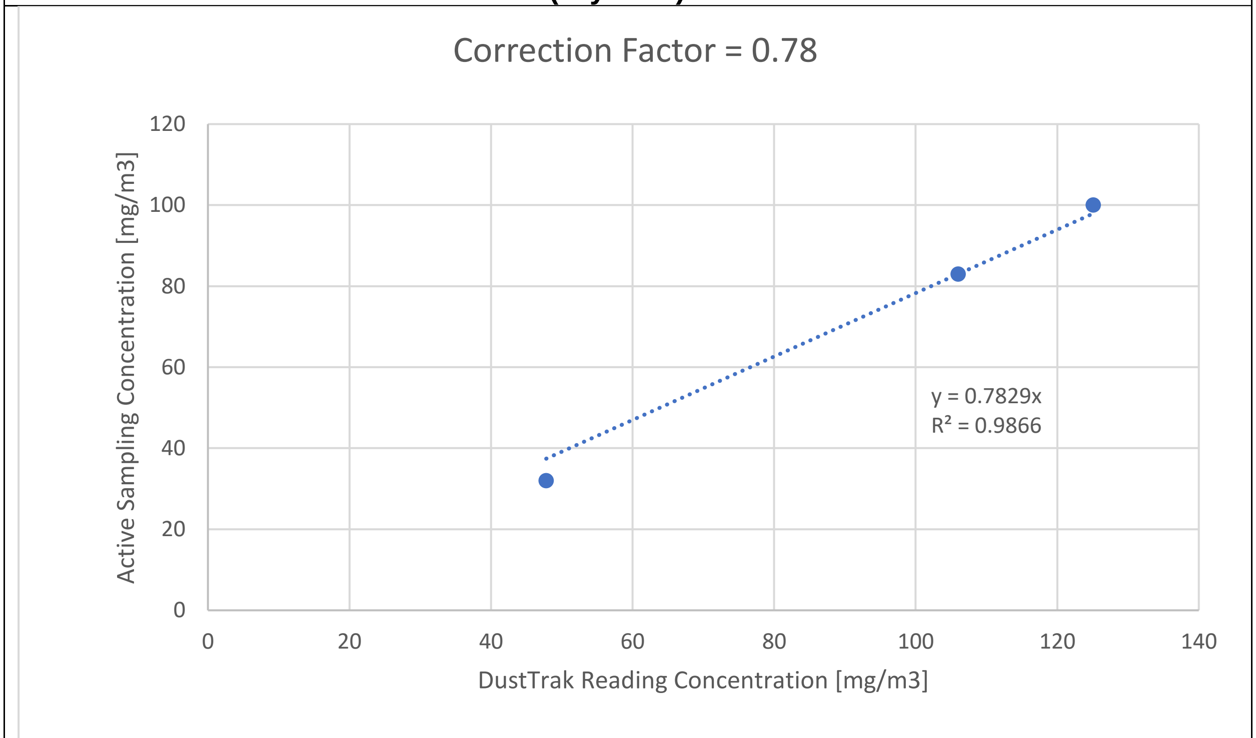
Rosco Vapour Plus – Rosco Fog Fluid (Glycol)



CITC Aquamax – Organic Haze (Glycerin)



Ultratec Radiance – Luminous 7 Haze (Glycerin)



Appendix II - Photos

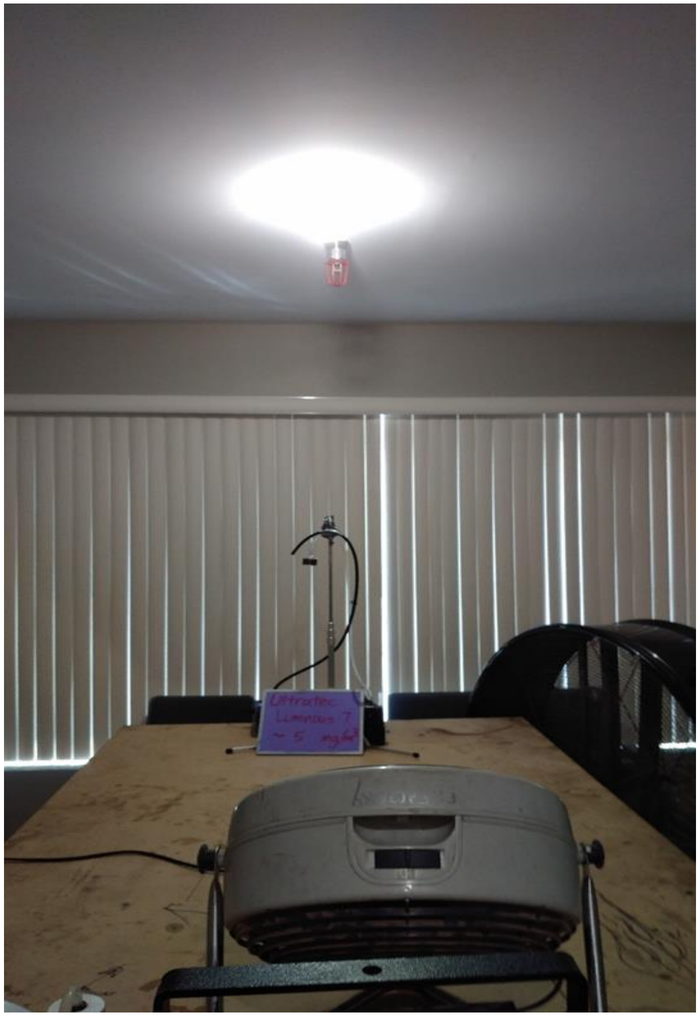


Photo 1. Ultratec Luminous 7 Haze Fluid **-** DustTrak Concentration ~ 5 mg/m^3

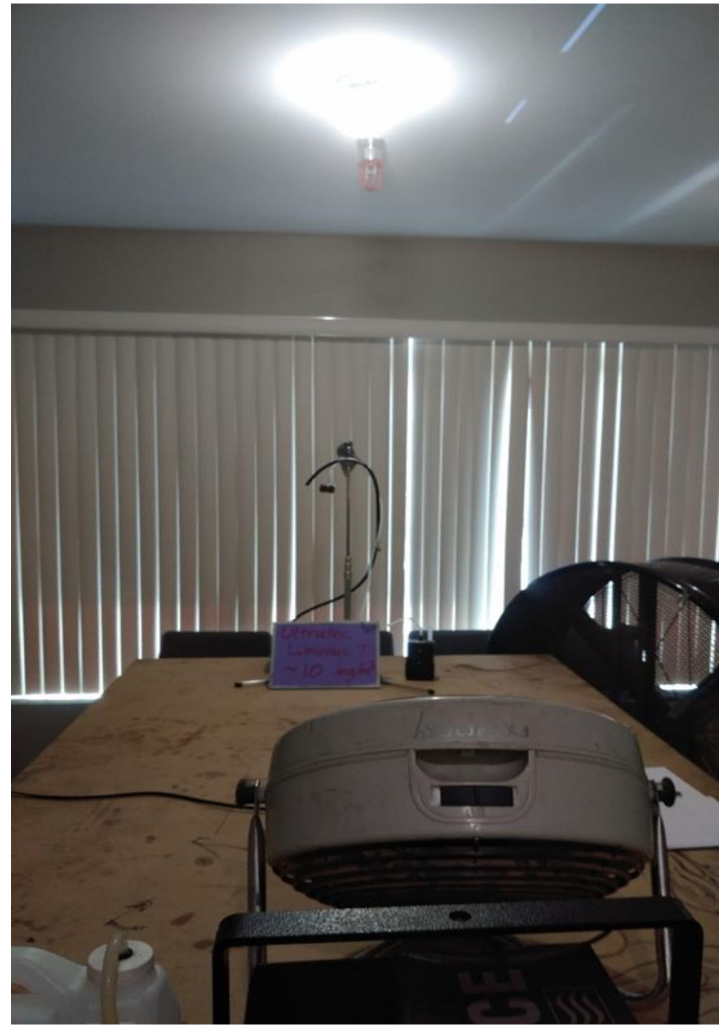


Photo 2. Ultratec Luminous 7 Haze Fluid **-** DustTrak Concentration ~ 10 mg/m^3

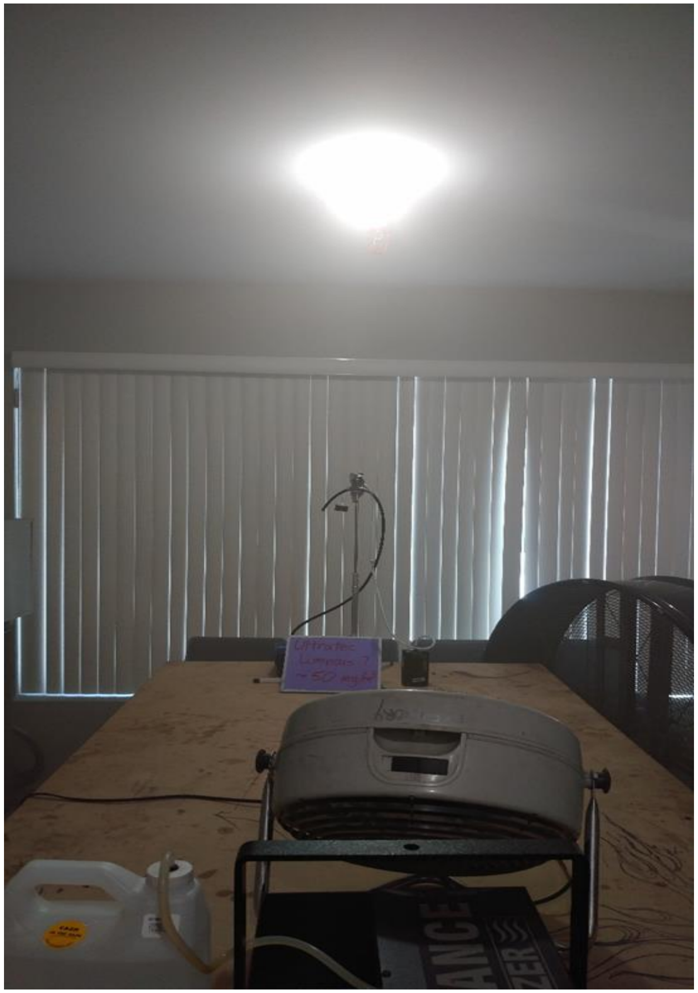
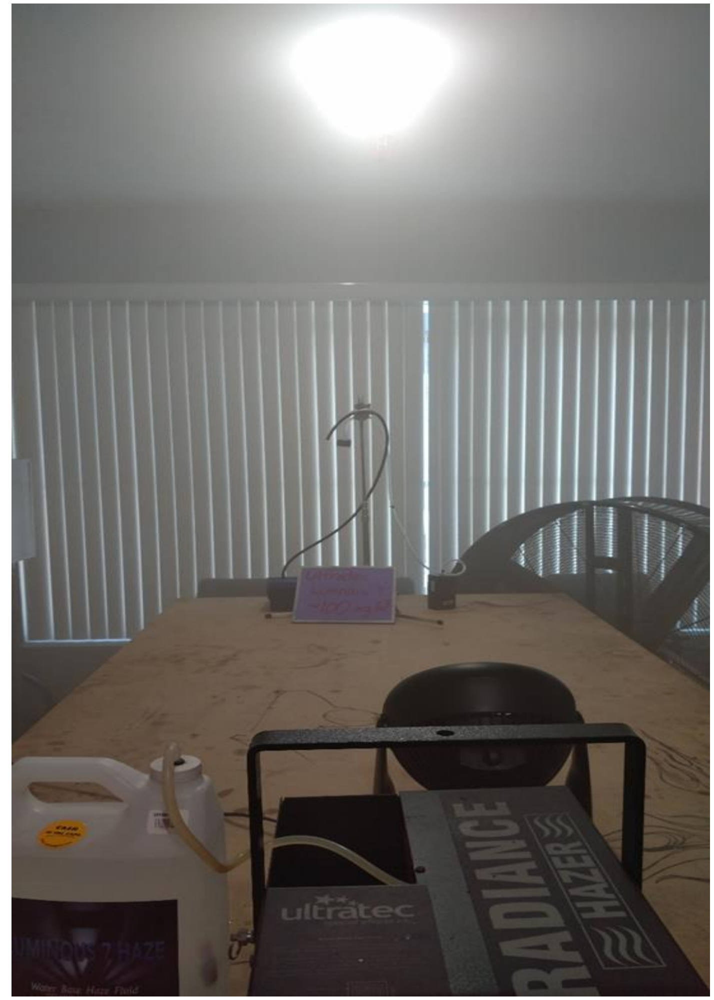
	

Photo 3. Ultratec Luminous 7 Haze Fluid **-** DustTrak Concentration ~ 50 mg/m^3	**Photo 4.** Ultratec Luminous 7 Haze Fluid - DustTrak Concentration ~ 100 mg/m3

Photo 5. Look Solutions Regular Fog Fluid - DustTrak Concentration ~5 mg/m^3

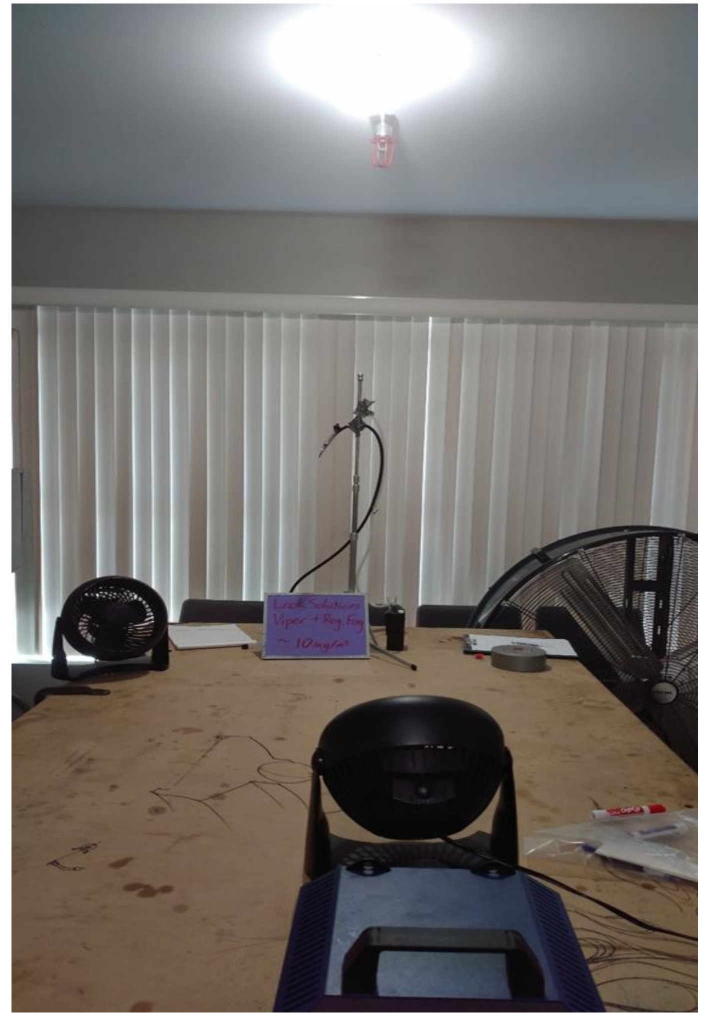


Photo 6. Look Solutions Regular Fog Fluid - DustTrak Concentration ~10 mg/m^3

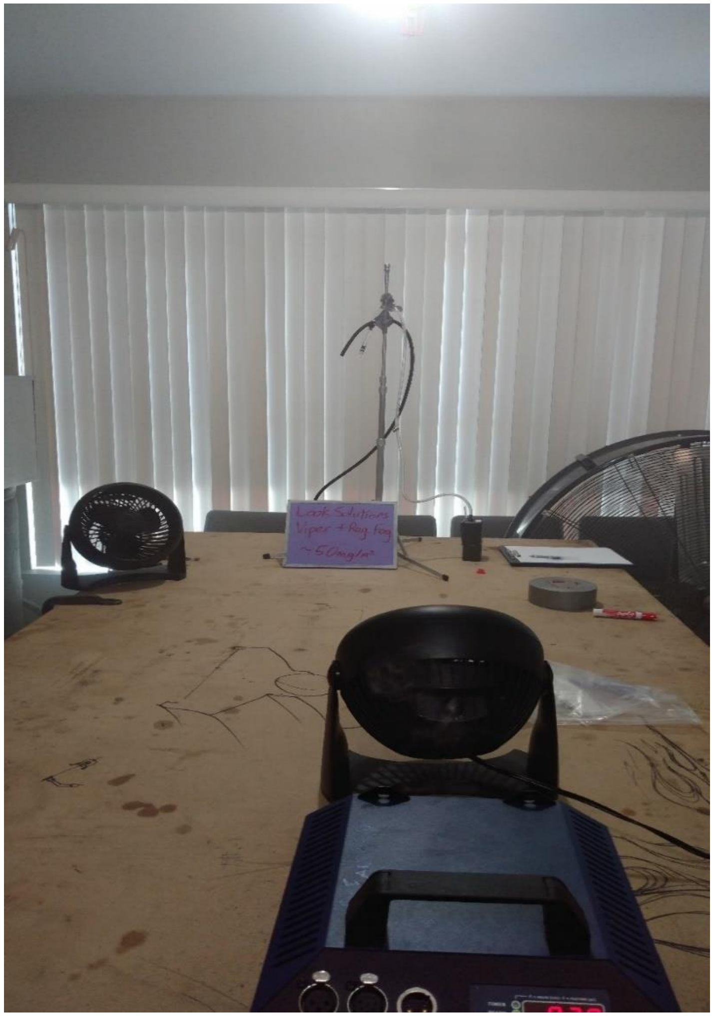


Photo 7. Look Solutions Regular Fog Fluid - DustTrak Concentration ~50 mg/m^3

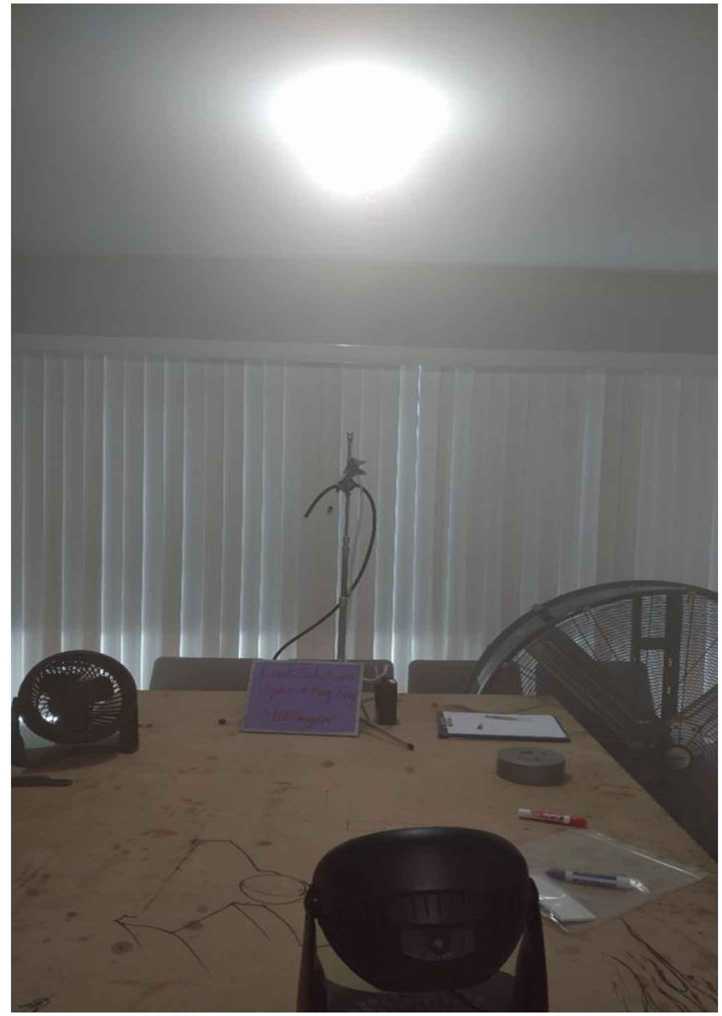


Photo 8. Look Solutions Regular Fog Fluid - DustTrak Concentration ~100 mg/m^3

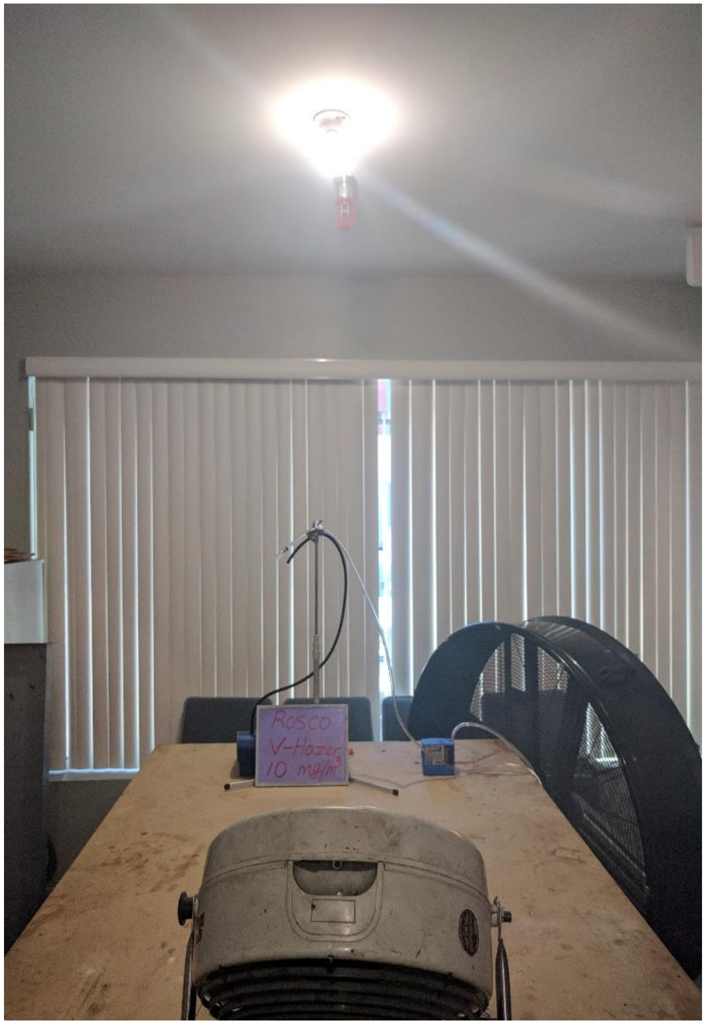


Photo 9. Rosco V-hazer Fog Fluid - DustTrak Concentration ~10 mg/m^3

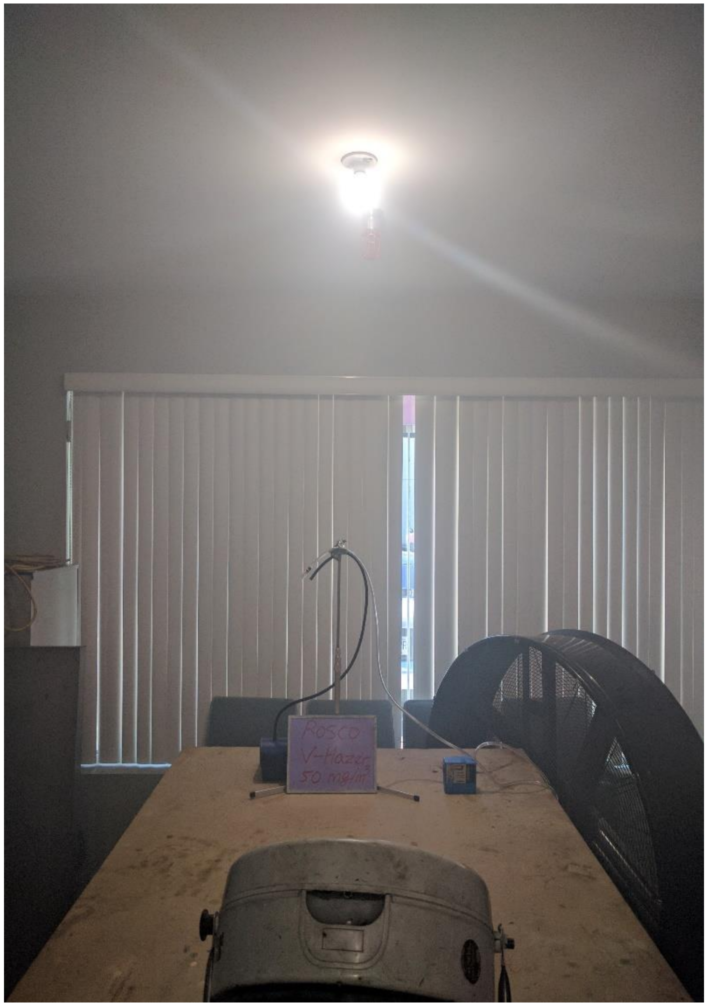


Photo 10. Rosco V-hazer Fog Fluid - DustTrak Concentration ~50 mg/m^3

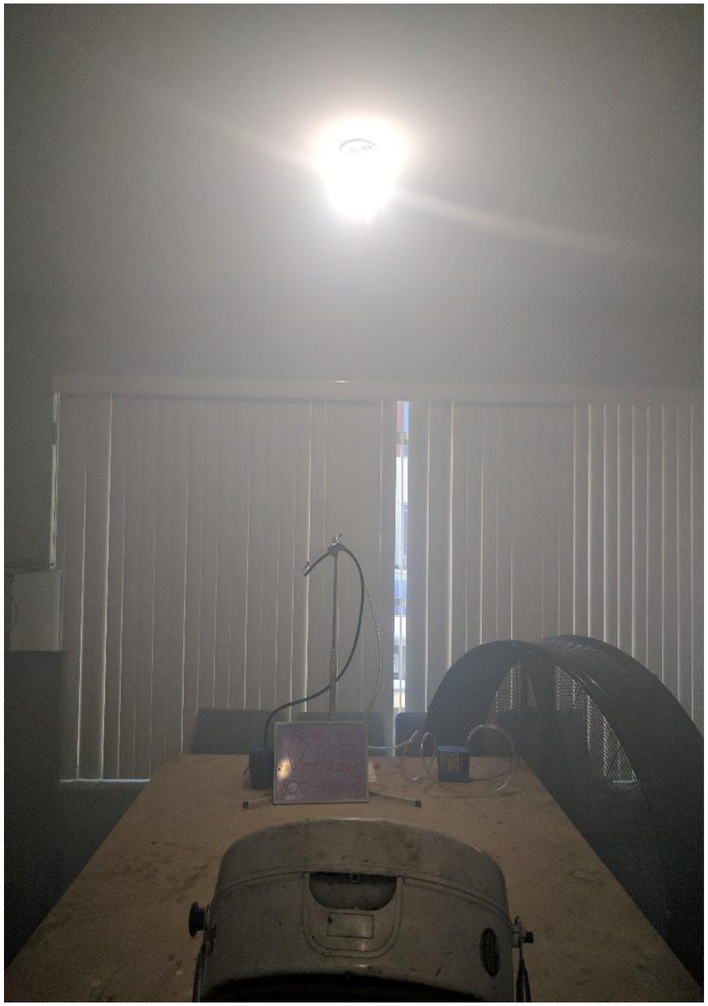
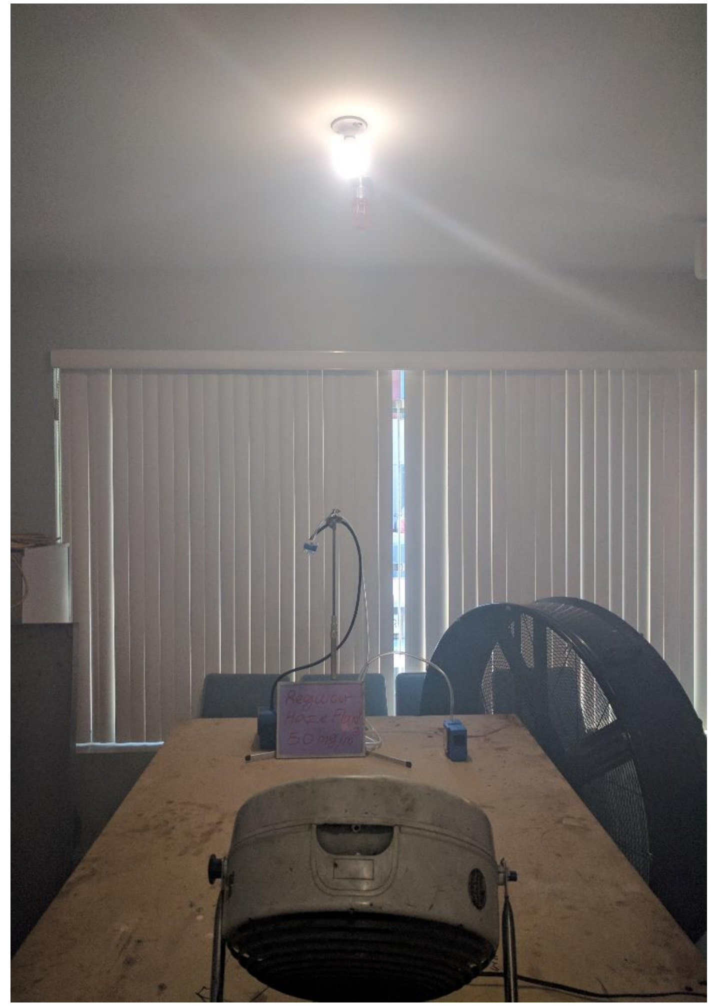
	

Photo 11. Rosco V-hazer Fog Fluid - DustTrak Concentration ~100mg/m^3	**Photo 12.** Regular Haze Fluid - DustTrak Concentration ~50mg/m^3

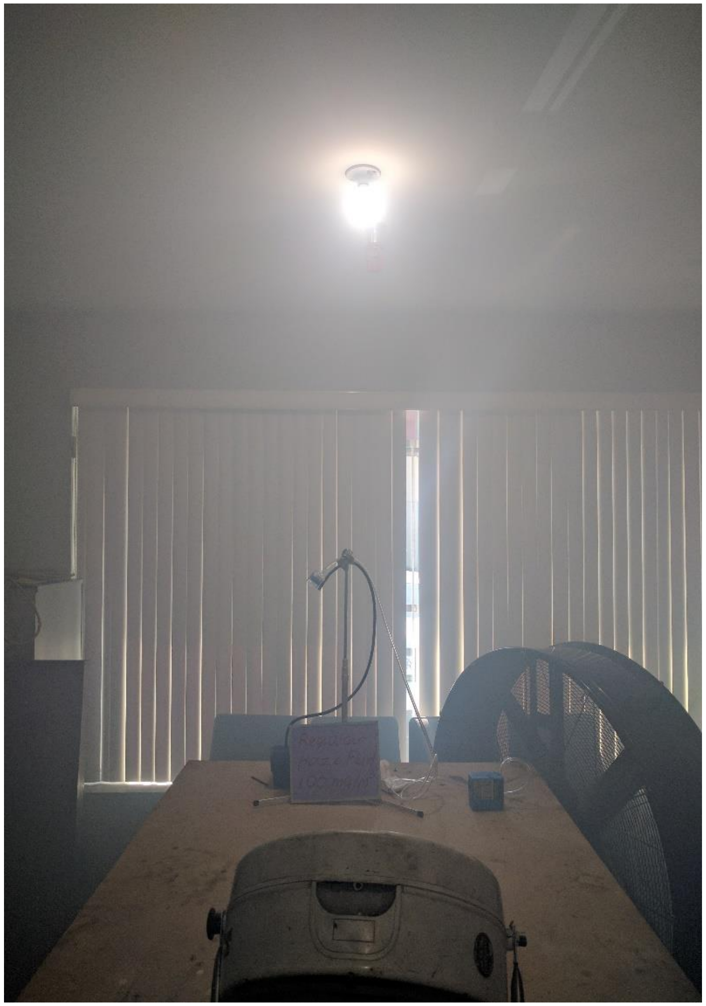


Photo 13. Regular Haze Fluid - DustTrak Concentration ~100 mg/m^3

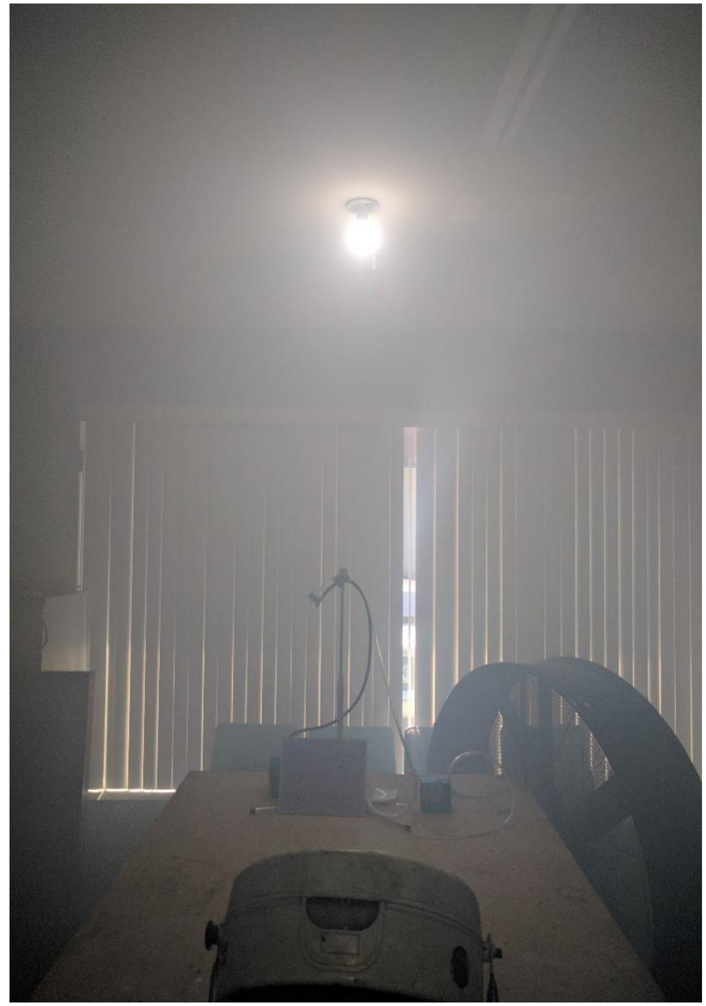


Photo 14. Regular Haze Fluid - DustTrak Concentration ~140 mg/m^3

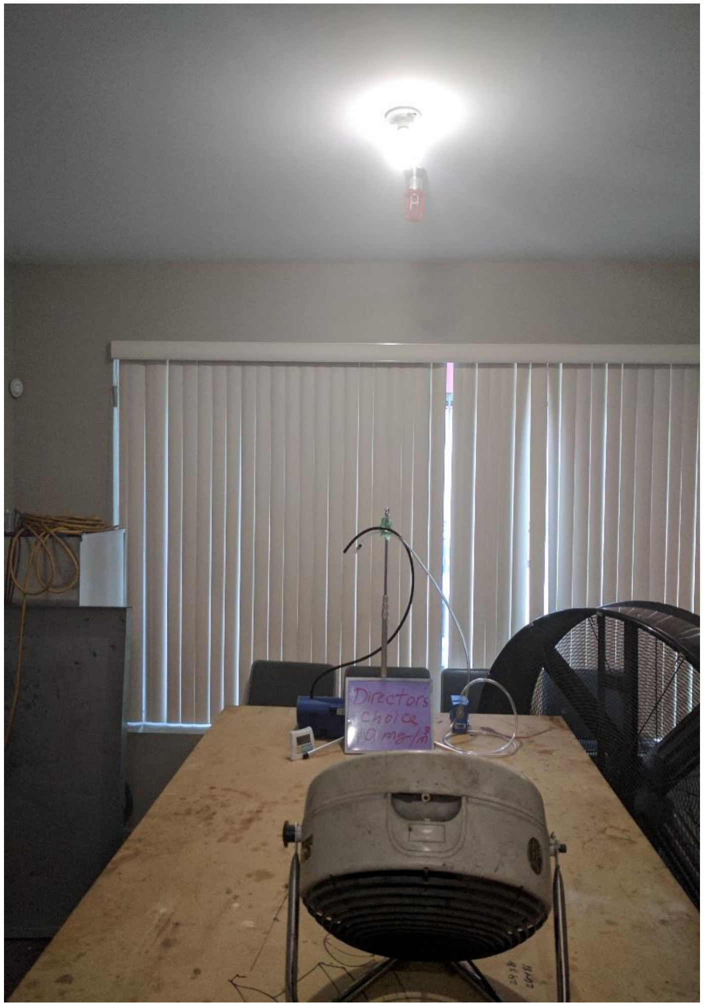


Photo 15. Director's Choice Fog Fluid - DustTrak Concentration ~10 mg/m^3

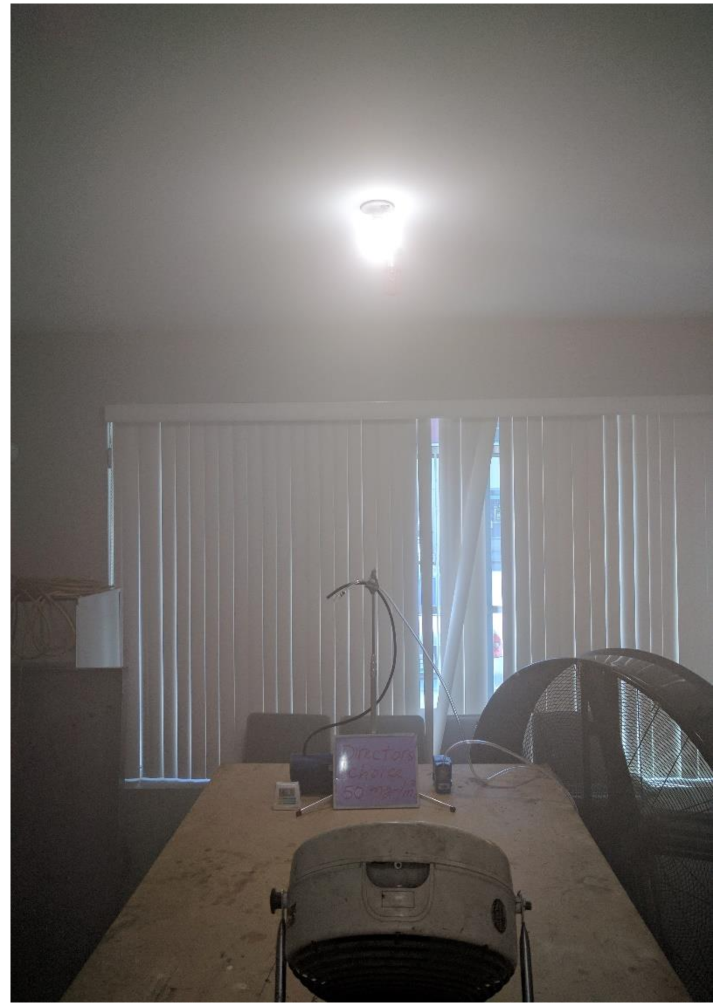


Photo 16. Director's Choice Fog Fluid - DustTrak Concentration ~50 mg/m^3

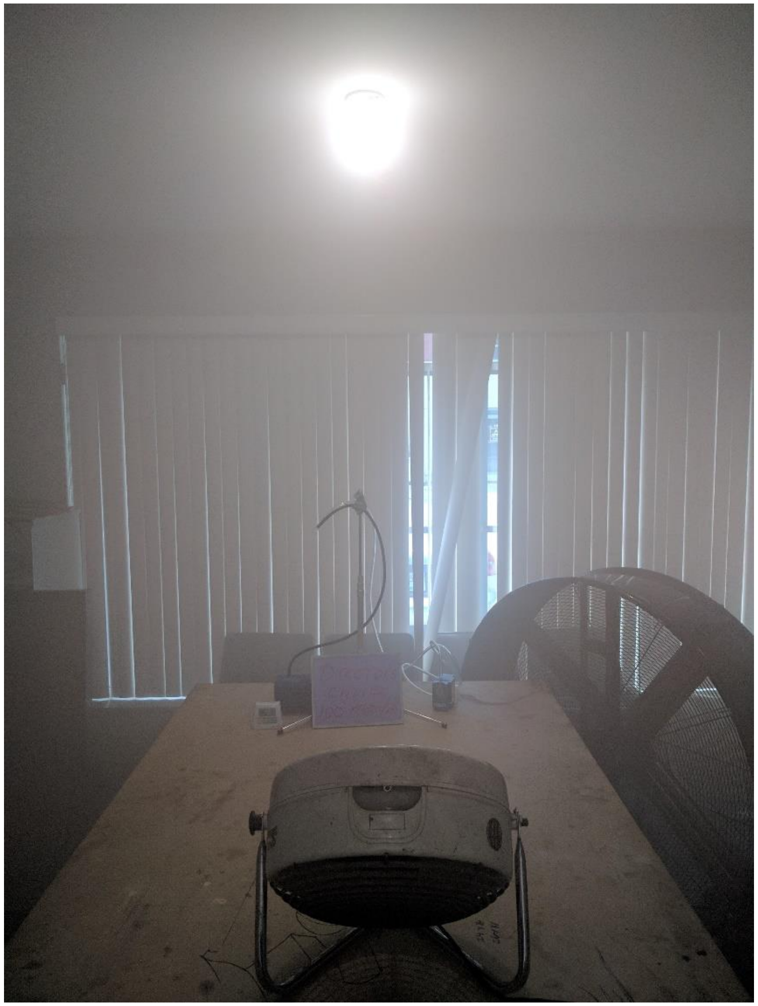


Photo 17. Director's Choice Fog Fluid - DustTrak Concentration ~100 mg/m^3

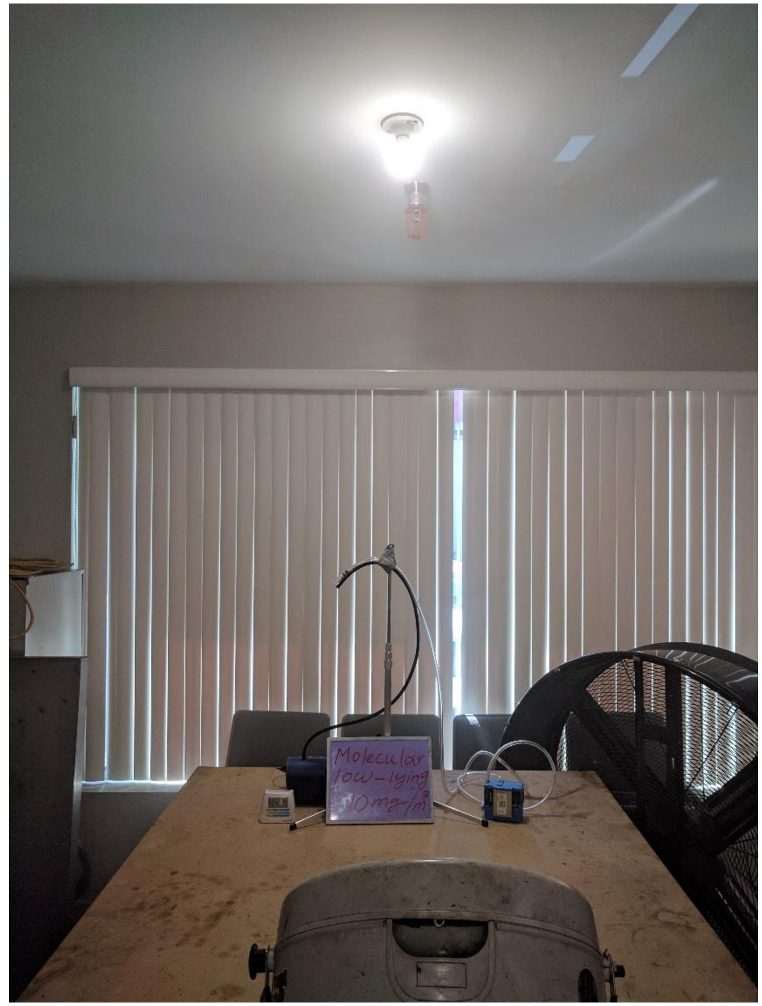


Photo 18. Molecular Low-Lying Fog Fluid - DustTrak Concentration ~10 mg/m^3

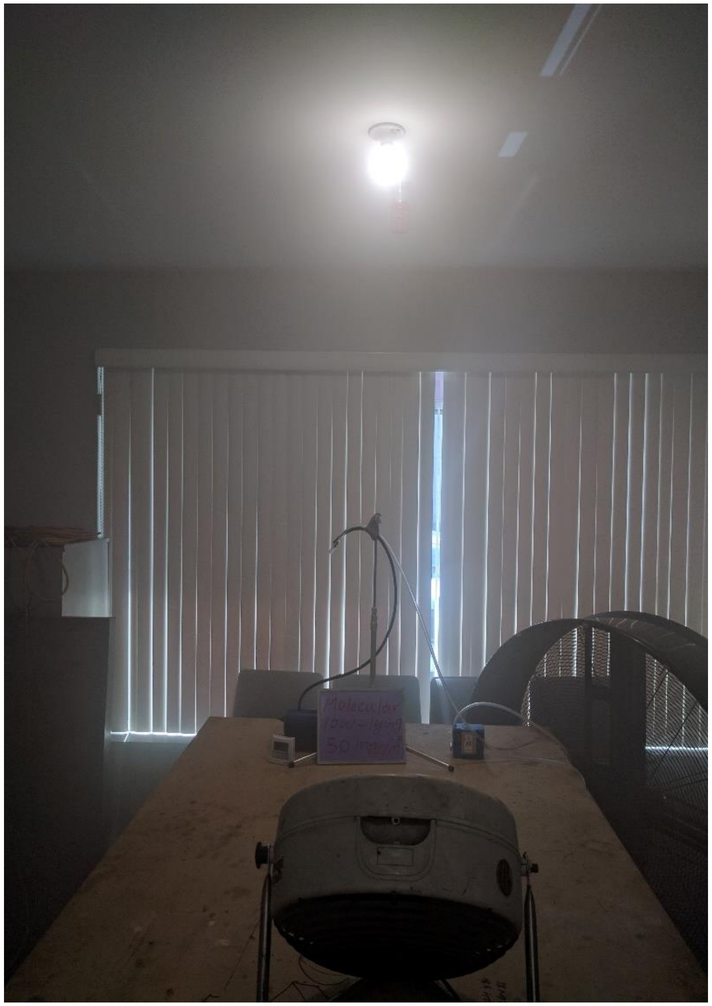
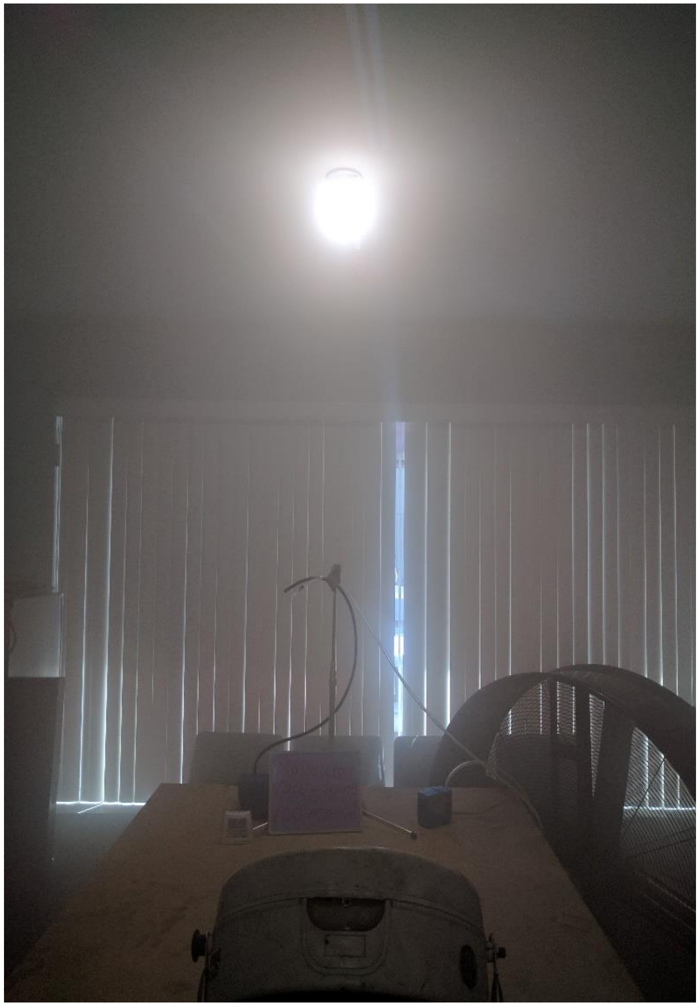
	

Photo 19. Molecular Low-Lying Fog Fluid - DustTrak Concentration ~50 mg/m^3	**Photo 20.** Molecular Low-Lying Fog Fluid - DustTrak Concentration ~100 mg/m^3

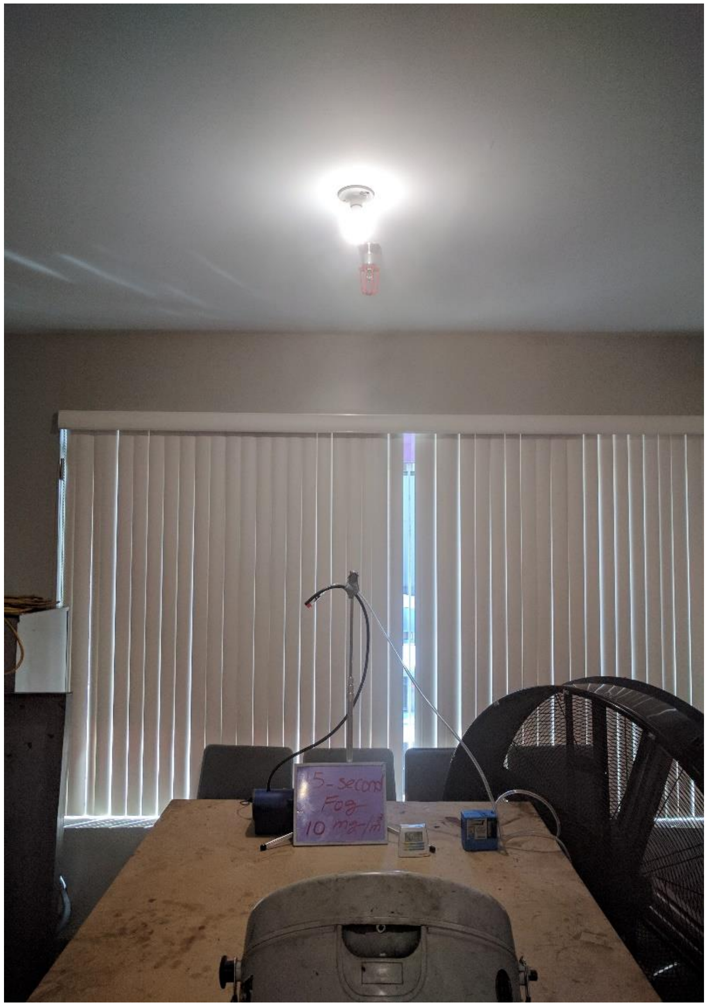


Photo 21. 15-Sec Fog Fluid - DustTrak Concentration ~10 mg/m^3

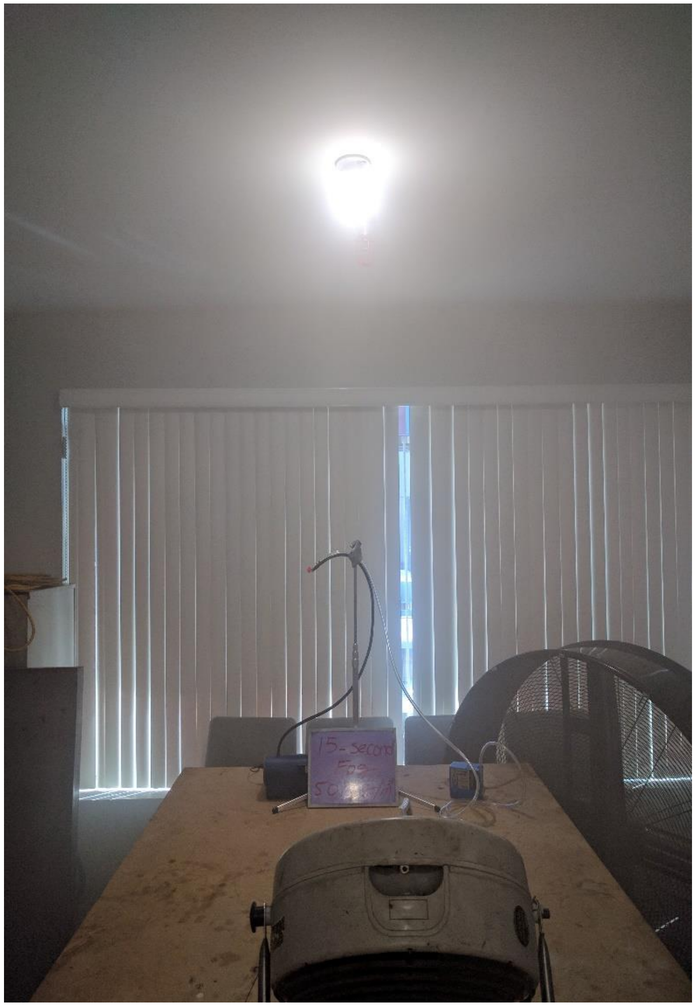


Photo 22. 15-Sec Fog Fluid - DustTrak Concentration ~50 mg/m^3

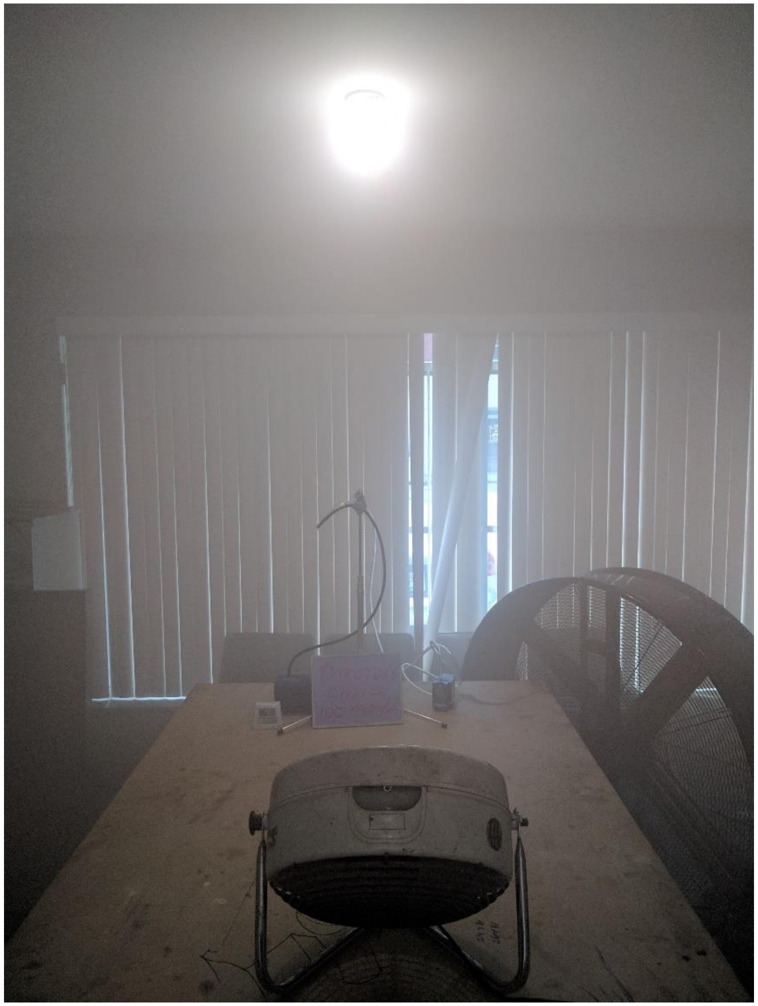


Photo 23. 15-sec Fog Fluid - DustTrak Concentration ~100 mg/m^3	**Photo 24.** Le Maitre Quick Dissipating Fluid – Varied concentrations

fasdfasdfasdf

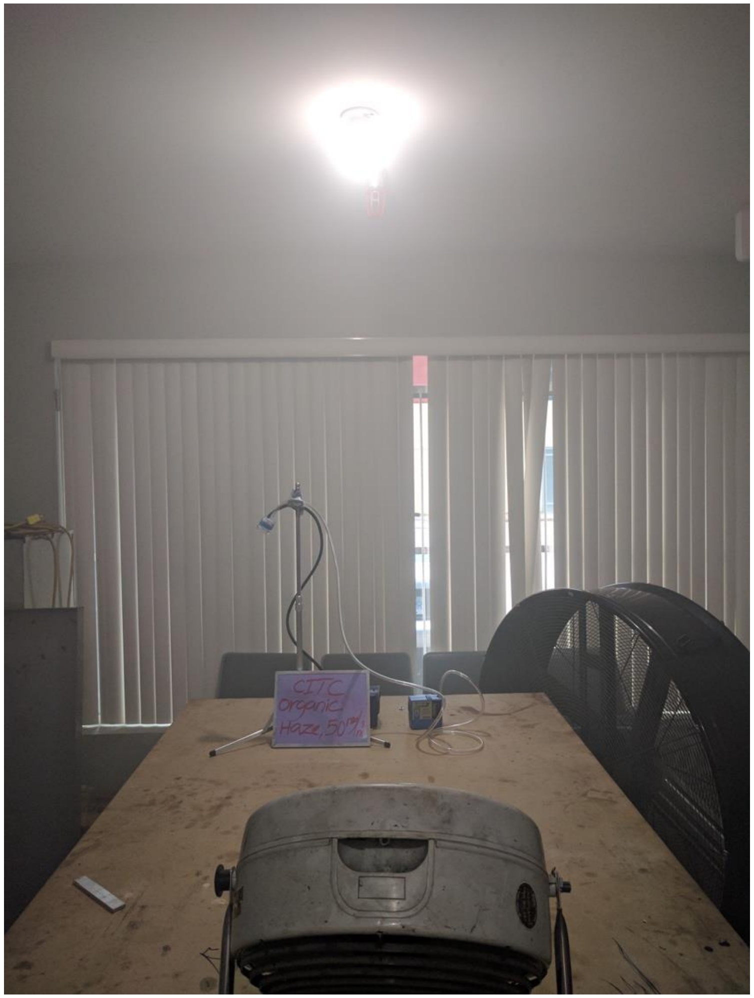
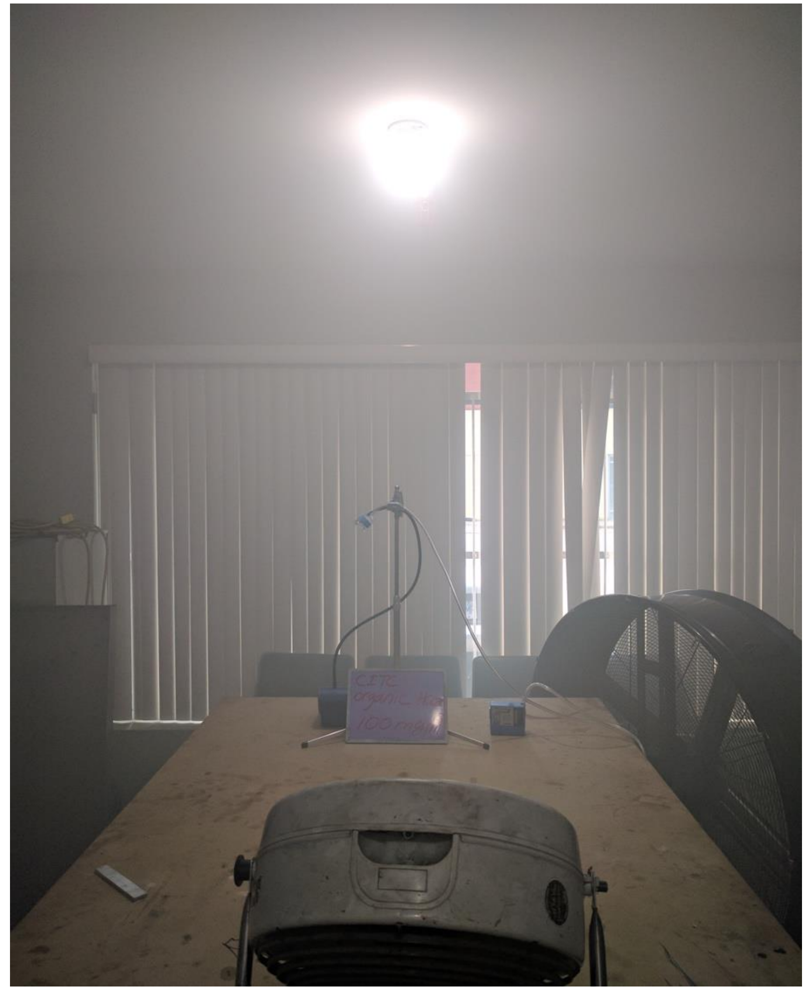
	

Photo 25. CITC Organic Haze Fluid - DustTrak Concentration ~50 mg/m^3	**Photo 26.** CITC Organic Haze Fluid - DustTrak Concentration ~100 mg/m^3

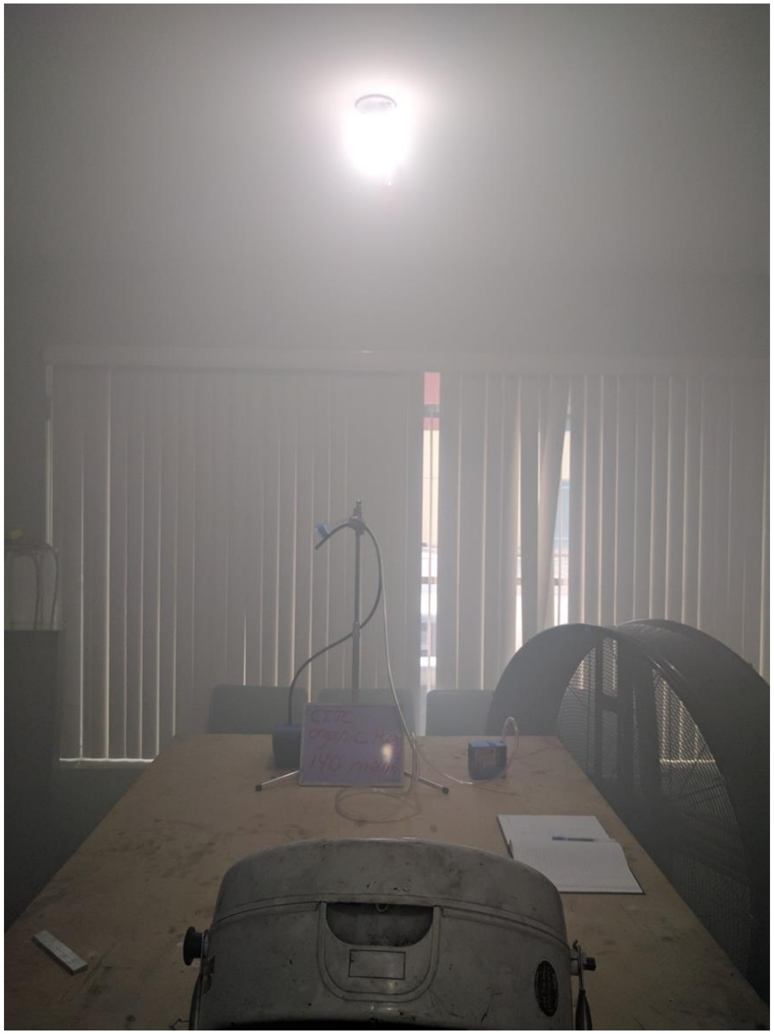


Photo 27. CITC Organic Haze Fluid - DustTrak Concentration ~10 mg/m^3

Photo 28. Stage & Studio Fog Fluid – Varied concentration

Appendix III – Statement of Limitations

STATEMENT OF LIMITATIONS

The work performed in this report was carried out in accordance with the Standard Terms of Conditions made part of our contract. The conclusions presented herein are based solely upon the scope of services and time and budgetary limitations described by this contract.

The report has been prepared in accordance with generally accepted industrial hygiene and/or health and safety practices. No other warranties, either expressed or implied, are made as to the professional services provided under the terms of our contract and included in this report.

The correction factors and other results presented here are based on the experimental work under the conditions described in this study. Results may vary under different experimental conditions, which should be considered when applying the correction factors reported here to estimate glycol/glycerin aerosol concentrations.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it are the responsibility of such third parties. Aura Health and Safety accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.