COVID-19 Implications of the Physical Interaction of Artificial Fog on Respiratory Aerosols

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Abstract

Introduction Artificial fog is used in the film, television, and live entertainment industries to enhance lighting, as a visual effect, and to create a specific sense of mood or atmosphere. This study investigated whether the suspension time of respiratory aerosols spiked with tagged DNA tracers would change in the presence of glycerin- or glycol-containing artificial fogs.

Methods & Materials Respiratory aerosols with tagged DNA tracers were sprayed into a closed environment without and with glycerin- or glycol-containing artificial fog, with air samples taken at regular intervals to determine the decay of tagged DNA tracer over time. The study treatments included Control (no fog), Glycerin Low (3 mg/m^3), Glycerin High (~15 mg/m^3), Glycol Low (~5 mg/m^3), and Glycol High (~40 mg/m^3).

Results All artificial fog treatments had lower mean log reduction curves compared to the Control treatment. Compared to the Control and Glycerin Low treatments, the differences in mean log reduction for nearly all other artificial fog treatments were statistically significant ($p<0.001$); the difference between Control and Glycerin Low treatments was not statistically significant ($p=0.087$). The differences in mean log reduction between treatments using the same artificial fog type were not statistically significant.

Conclusion Artificial fog use does not increase suspension time of respiratory aerosols, and therefore does not appear to increase the risk of airborne transmission of diseases from respiratory aerosols, such as COVID-19. Of the two types of artificial fogs investigated, that containing glycol decreased suspension time more than that containing glycerin. In practice, the additional reduction in suspension time provided by the physical interaction of respiratory aerosols with artificial fog does not suggest any practical benefit for using artificial fog as a control measure.

Keywords: Aerosols, Artificial Fog, Atmospheric Fog, COVID-19, Entertainment, Exposure, Film, Physical Interaction, Respirable, Respiratory Aerosols, SARS-CoV-2, Suspension, Television, Theatrical Fog, Transmission

1 Introduction

Artificial fog is used most often for creating special effects in the film, television, and live entertainment industries to make lighting or lighting effects visible, and to create a specific sense of mood or atmosphere. Devices, referred to as fog machines, work by either condensing vapor generated by heating liquid fogging fluid, or by mechanically generating aerosols directly from liquids. The fog consists of small liquid aerosols suspended in air. The aerosols include the same ingredients as the fluids used in the machines, which are water-based, but often combined with a percentage of glycerin, glycols, or highly-refined mineral oils. The fog is not real smoke, soot, or char. It is not generated by thermal decomposition or burning of fluid ingredients, although a small amount of thermal decomposition byproducts may be produced during the process of heating the fluid prior to condensation.

With the onset of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic, now termed as Coronavirus Disease 2019 (COVID-19), there has been a concern expressed within these entertainment industries regarding the interaction of artificial fog and respiratory aerosols, which may contain and transmit COVID-19. The aerosol transmission of COVID-19, in the absence of artificial fog, in well-ventilated indoor spaces is not an efficient route of transmission for the virus based on modeling of the COVID-19 aerosol (Smith et al., 2020), as COVID-19 microdroplets, owing to their small size, contain less virus than the larger droplets, known as respiratory aerosols. Respiratory aerosols, generated by coughing, sneezing, or speaking, tend to fall to the ground within approximately three feet (one meter) of the generating source. The question arises whether the physical interaction of artificial fog on respiratory aerosols could increase suspension of these larger aerosols containing more virus and thus increase the likelihood of COVID-19 transmission and subsequent infection. Specifically, this current study investigated whether the suspension time of respiratory aerosols spiked with tagged DNA tracers would change in the presence of glycerin- or glycol-containing artificial fogs.

2 Methods and Materials

2.1 DNA Tracers

The tagged DNA tracers, supplied by SafeTraces Inc., were housed in and sprayed by Flairosol spray bottles. The DNA tracer solutions were approximately 1% solids to mimic saliva. The tagged DNA tracers used by SafeTraces are generally recognized as safe (GRAS) by qualified experts when aerosolized in this type of application, and when aerosolized, they are well below the U.S. Occupational Safety and Health Administration's exposure limit for particulates not otherwise regulated. The Flairosol spray bottle produced a median particle size (D50) of 87.27 micrometers (µm) (+/- 1.62 µm) with a distribution ranging from 43.25 µm on the 10th percentile to 191.36 µm on the 90th percentile; the volume mean diameter (if all particles were the same sized spheres) was on average 103.87 µm (+/- 1.92 µm). Therefore, the spray bottle reproduced respirable aerosols and droplets that are similar in size and distribution compared to those generated by sneezing, coughing, and talking (Xie et al., 2007; Xie et al., 2009). Due to these factors, and the

83 low detection limit achievable, SafeTraces Inc. and their tagged DNA tracers were deemed safe
84 and adequate in simulating respiratory aerosols.

85

86 2.2 Study Design Summary

87

88 Respiratory aerosols with tagged DNA tracers were sprayed into a closed environment with and
89 without artificial fog, where air samples of aerosols were taken at regular intervals to determine
90 the decay of tagged DNA tracer over time. A small office boardroom measuring 545 cubic feet
91 (8'11" long by 8' 4" wide by 7' 5" high), occupied with one table and two chairs, was sealed along
92 the walls, door, window, supply air diffuser, and ceiling with one millimeter-thick poly sheeting
93 (HDX, Canada). This poly sheeting created a closed environment where airflow in or out of the
94 room was minimized, thereby limiting tagged DNA tracer decay due to natural settling processes
95 only. Five treatments were completed: one control treatment, two glycerin-containing artificial fog
96 treatments, and two glycol-containing artificial fog treatments. The two glycerin-containing
97 artificial fog treatments aimed to maintain airborne glycerin concentrations at approximately 1.5
98 milligrams per cubic meter (mg/m^3) or 15 mg/m^3; the two glycol-containing artificial fog treatments
99 aimed to maintain airborne glycol concentrations at approximately 5 mg/m^3 or 40 mg/m^3. These
100 glycerin and glycol concentrations aligned with regulatory or guideline limits commonly used for
101 workplaces in North America (i.e., for 12-hour time-weighted average and ceiling limits,
102 respectively). For each treatment, six trials were completed; each trial consisted of spraying a
103 unique tagged DNA tracer into the room and collecting one five-minute sample every five minutes
104 from the time of spray until thirty-minutes had elapsed, for a total of six samples collected per trial
105 and 36 samples per treatment.

106

107 2.3 Air Sampling

108

109 Two Pilot Studies were conducted to refine the method to ensure proper set-up of equipment and
110 capture of the decay of tagged DNA tracer (Figure 1). Each sample consisted of a Grade A-E 25-
111 millimeter (mm) glass fiber filter (Sterlitech Corporation, USA) housed in a 50 mm long, three-
112 piece conductive black polypropylene cassette housing cowl with a backing pad (Zefon
113 International, USA) attached to a Leland Legacy Pump via Tygon® tubing (Saint-Gobain
114 Performance Plastics Corp., USA). The Leland Legacy Pump was pre-calibrated to draw air at
115 approximately 8 liters per minute using a Defender 510 (Mesa Labs, USA) with the first sample.
116 The cowl was angled downward at approximately 45 degrees and suspended approximately five
117 feet above the ground in the middle of the room by an aluminum tripod (Environmental Monitoring
118 Systems, USA). The cassette angle helped minimize collection of aerosols through deposition
119 and mimicked the human nose more accurately when used in conjunction with the cowl. Once
120 the first sample was ready, the tagged DNA tracer fluid was sprayed five times from a Flairosol
121 spray bottle, distributing the aerosols into each corner and center of the room; the different
122 directions of each spray assisted in homogenizing the aerosol in the room quickly. Immediately
123 after spraying, the Leland Legacy Pump was turned on to begin the first sample; the first sample
124 started after the sprays owing to Researcher limitations. Once this first sample started, a table
125 fan with a blade diameter of twelve inches (GD Midea Environment Appliance Mfg. Co., Ltd,
126 China) located in the Southeast corner was turned on to its lowest speed (660 feet per minute

127   (ft/min) at the face, 275 ft/min at a distance five feet away) and oscillated over a 90 degree range
128   from the Southwest to Northeast corners; operation of the fan began after the sprays to ensure it
129   did not disrupt the initial natural dispersion of aerosols but helped homogenize the aerosols in the
130   room afterwards. After a sample duration of five minutes, the Leland Legacy Pump was paused,
131   sampled cassette was removed, a new cassette was attached to the Tygon® tubing, and then the
132   Leland Legacy Pump was restarted; it took approximately ten seconds to complete sample
133   swapping. The same Leland Legacy Pump was used to ensure the flow rates and pump
134   parameters were consistent between each sample. This process was repeated for each
135   subsequent sampling time (interval): 5 to 10 minutes, 10 to 15 minutes, 15 to 20 minutes, 20 to
136   25 minutes, and 25 to 30 minutes. After all six samples were completed for a given trial, the last
137   sample was used to post-calibrate the Leland Legacy Pump.
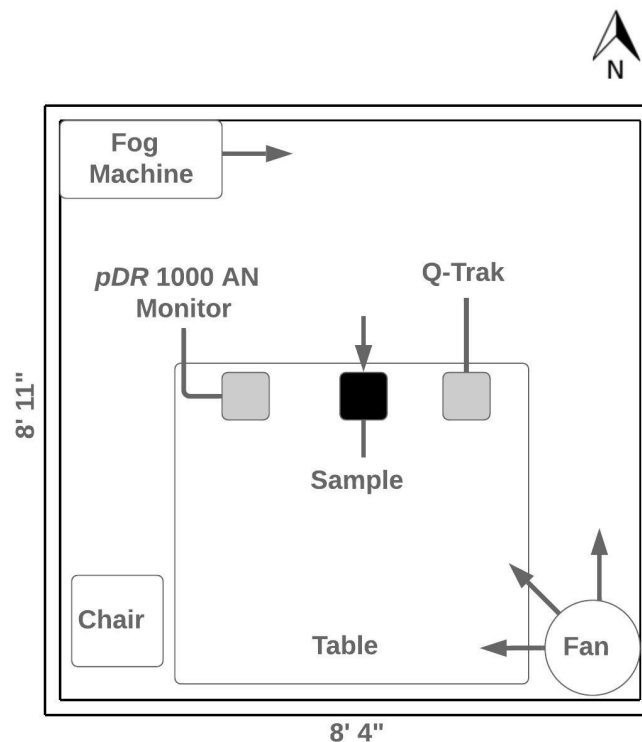
138
139   **Figure 1. Study design physical layout for performing air sampling.** The arrows indicate the
140   direction of air movement away from the fan and fog machine, and the direction of air movement
141   when collecting air samples.
142
143   2.4 Artificial Fog
144
145   Water-Vapor Haze™ (CITC, USA) was used in a Haze Max machine (CITC, USA) to generate
146   the glycerin-containing artificial fog treatments. SmartFog™ Fogging Fluid: 3 Minute Low-Ground
147   Fog (CITC, USA) was used in a Fog Max machine (CITC, USA) to generate the glycol-containing
148   artificial fog treatments. The fog machines were turned on and dispensed fog until the desired
149   airborne glycerin or glycol concentration was reached. A personal DataRAM™ pDR-1000AN
150   Monitor (Thermo Fisher Scientific Inc., USA) placed next to the samples was adjusted using a
151   calibration factor of 1.87 (Environ International Corporation, 2014) to measure glycerin aerosols

4

152 and 0.66 (Environ International Corporation, 2002) to measure glycol aerosols; calibration factors
153 adjusted the instrument's sensors to specifically measure glycerin or glycol aerosols. This
154 instrument was moved around the room periodically to ensure homogeneous glycerin and glycol
155 concentrations. Before each treatment, the instrument was zero calibrated and programmed to
156 record every ten second average concentration throughout the treatment. The *p*DR-1000AN
157 Monitor has an aerodynamic particle cut point range at 10 μm and a concentration measurement
158 range from 0.001 to 400 mg/m^3. The Researcher inside the room encouraged dispersion of the
159 artificial fog by manually fanning the air with a clipboard. When fanning, care was taken to not fan
160 air upwards towards the sample being collected. Once the desired concentration was reached,
161 the tagged DNA tracer and sample collection process started. Periodically throughout the
162 sampling period, the fog machine dispensed artificial fog in 0.5 to 1.5 second bursts, followed by
163 dispersion via fanning, to maintain a consistent glycerin or glycol concentration in the air. The
164 same process and actions were repeated with the Control treatment, except distilled water was
165 used in the fog machine instead of a glycerin- or glycol-containing artificial fog.
166
167 2.5 Temperature and Relative Humidity
168
169 Temperature in Celsius (°C) and relative humidity in percentage (%) were measured continuously
170 during every sample using a Q-Trak Model 7565 with Probe 982 (TSI, USA), with every ten
171 second average reading recorded. The instrument probe was located next to the samples in the
172 middle of the room.
173
174 2.6 Sampling Shipment
175
176 All trials for a treatment were completed in the same day. A unique tagged DNA tracer was used
177 for each trial to eliminate possible cross-contamination between trials. At the end of each
178 treatment, each sampled filter was removed from its cowl using clean plastic tweezers and placed
179 into a 2 milliliter (mL) DNA LoBind Tube (Eppendorf AG, Germany), then placed into a 2-millimeter
180 thick plastic bag. All samples were shipped to SafeTraces Inc. (Pleasanton, California, USA) for
181 laboratory analysis. Bulk liquid samples of each tagged DNA tracer used were collected by
182 pouring 2 mL of the fluid into a 2 mL DNA LoBind Tube and placing into a 2-millimeter thick plastic
183 bag. The floor, walls, ceiling, table, and chairs of the closed environment and plastic tweezers
184 were cleaned with a 10% bleach solution at the end of each treatment.
185
186 2.7 Quality Control
187
188 An OmniAire 1200PAC Portable Air Cleaner (Omnitech Design, USA) was operated overnight for
189 approximately sixteen hours at medium speed to filter the air between treatments to minimize
190 cross-contamination between different treatments, because the same set of tagged DNA tracers
191 were used for each treatment. Approximately three field blanks per treatment were collected for
192 quality assurance and quality control purposes to evaluate sample handling and potential routes
193 of contamination. Each field blank was treated the same as samples, except no air was drawn
194 through them.
195

196　2.8 Laboratory Analysis
197
198　Filter samples contained inside 2 mL DNA LoBind Eppendorf Tubes were stored at SafeTraces
199　Inc. in a -20°C freezer prior to starting the DNA extraction protocol. Samples were then taken out
200　of the freezer and allowed to equilibrate for approximately 10 minutes to room temperature (21°C).
201　A volume of 0.5 mL of elution buffer was added into the 2 mL tube containing the filter samples,
202　vortexed at full speed for 2 minutes using a VortexGennie2, then centrifuged using a minifuge at
203　10,000 revolutions per minute (rpm) for 10 seconds to pool the eluate at the bottom of the tube.
204　A 4 microliter (μL) sample of the eluate was transferred to the corresponding reaction well of a
205　0.2 fast 96-well non-skirted PCR plate which contained 16 μL of master mix reagents (IDT prime
206　time gene expression master mix, water, primers, and SYBR green) per well. The 96-well was
207　sealed using a MicroAmp Optical Adhesive Film, centrifuged using an Eppendorf centrifuge 5810
208　at 4,000 rpm for 1 minute. The qPCR plate containing a 20 μL total reaction volume per well (4
209　μL sample with 16 μL master mix) was then loaded into a QuantStudio3 or QuantStudio5 qPCR
210　instrument operated following these thermal cycling parameters: activation step of 95°C for 1
211　minute, then 40 cycles of 95°C for 0.1 second and 60°C for 20 seconds of annealing time using
212　the standard FAM 2-step fast qPCR protocol. Readings were collected at the end of the
213　annealing/extension step. The QuantStudio platform generated a quantification cycle (Cq) value
214　associated with the input DNA concentration. The Cq value was then used to estimate the number
215　of DNA copies in the reaction well using a standard curve.
216
217　2.9 DNA Tracer Quantification
218
219　The number of DNA copies aerosolized were calculated and adjusted based on the concentration
220　of DNA measured in each bulk liquid sample (Equation 1). This value was also adjusted based
221　on an aerosol fraction, which synchronizes the Flairosol spray bottle aerosol fraction to that
222　generated from sneezing, talking, and coughing. Given the described distribution of aerosol sizes
223　generated from sneezing, talking, and coughing, and the potential for partial or total evaporation
224　of liquid aerosols between 60 to 100 μm (Xie et al, 2007), an aerosol diameter cut-off point of
225　73.56 μm was selected. This cut-point corresponded to 37.35% volume of the distribution of
226　aerosols released by the Flairosol spray bottle.
227
228　$$DA = D * V * AF \qquad\qquad\qquad \text{(Eq. 1)}$$
229
230　DA = number of DNA copies aerosolized
231　D = number of DNA copies per milliliter
232　V = sprayed volume in milliliters
233　AF = aerosol fraction, assumed to be 37.35 percent (0.3735)
234
235　The logarithmic (log) reduction was calculated for each sample using base ten (Equation 2). In
236　addition to log reduction, the number of copies per million copies aerosolized was calculated for
237　each sample (Equation 3).
238
239　$$Log_{10}reduction = Log_{10}(DA/DD) \qquad\qquad \text{(Eq. 2)}$$
240

241   DA = number of DNA copies aerosolized
242   DD = number of DNA copies detected
243

$$DNA\ copies\ per\ million\ sprayed\ =\ 10^{(6 - Log_{10}reduction)} \qquad \text{(Eq. 3)}$$

246   2.10 Mean Log Reductions
247
248   For each treatment, the mean log reduction, standard deviation, sample size, and 95% confidence
249   interval were calculated for each sampling time. This analysis was repeated for the number of
250   DNA copies per million sprayed. For each treatment, the mean log reduction and 95% confidence
251   interval were plotted against the sampling time, with the x-axis for sampling time and y-axis on a
252   log scale for log reduction and number of DNA copies per million sprayed, yielding a mean log
253   reduction curve for each treatment.
254
255   2.11 Temperature and Relative Humidity Analysis
256
257   The mean temperature, relative humidity, and artificial fog concentration were calculated for each
258   sample, sampling time, trial, and treatment. The mean differences in these variables were
259   calculated and compared between all treatments, between all sampling times, and between trials
260   within each treatment.
261
262   2.12 Statistical Analysis
263
264   All data were organized using Microsoft Excel (Microsoft Corporation, 2018); statistical analyses
265   and figures for log reductions were conducted and produced in R version 4.0.3 (R Core Team,
266   2021) using packages contained in Tidyverse (Wickham et al., 2019).
267
268   The assumption of normality for the treatments was qualitatively assessed, because the sample
269   size was too small for formal statistical tests. The assumption of homogeneity of variance was
270   tested using a Bartlett Test of Homogeneity of Variance (Bartlett, 1937), applied to the combined
271   levels of the variables "Treatment - Interval". A two-way analysis of variance (ANOVA) (Chambers
272   & Hastie, 1992) was performed with the levels of the variables "Treatment" and "Interval" to
273   determine if there was any significant interaction between the two variables. An ANOVA and
274   Tukey Honest Significant Differences test (Miller, 1981; Yandell, 1997) was performed for
275   "Treatment" and "Interval" to determine if mean differences in overall log reductions were
276   statistically significant. For all statistical analyses, a significance level of 5% was used to reject
277   the null hypothesis (α = 0.05).
278
279   **3 Results**
280
281   3.1 Summary
282
283   Sampling was completed between November 2020 and January 2021 in Burnaby, British
284   Columbia, Canada. All treatments were completed by the same Researcher, in the same office

285 space, under similar environmental conditions. The maximum mean difference in temperature
286 and relative humidity between treatments was 3.6°C and 12.4%. Two trials were excluded from
287 the analysis: one was a calibration trial to refine the methodology (Glycerin Low, Trial 1) and the
288 other was analyzed for the incorrectly tagged DNA tracer (Glycol Low, Trial 3). Nearly all
289 treatments with artificial fog maintained glycerin or glycol concentrations near the desired
290 concentration. One exception is the Glycerin Low treatment, where the glycerin concentration was
291 higher (Table 1).
292

293 **Table 1. Summary of Sampling Completed**

Treatment	Condition	Trials	Samples
Control	No artificial Fog	6	36
Glycerin Low	Glycerin Concentration 3.0mg/m^3	5*	30
Glycerin High	Glycerin Concentration 15.6 mg/m^3	6	36
Glycol Low	Glycol Concentration 5.2 mg/m^3	5**	30
Glycol High	Glycol Concentration 38.8 mg/m^3	6	36
Total		28	168

294 *Notes.* mg/m^3 = milligrams per cubic meter, * Trial #1 was a calibration trial to refine the methodology and was removed
295 as an outlier, ** Trial #3 was analyzed for the incorrect tagged DNA tracer and was removed
296

297 3.2 Suspension Time
298

299 All artificial fog treatments had lower mean log reduction curves compared to the Control
300 treatment, indicating the tagged DNA tracers in air decayed at a faster rate, and their suspension
301 time in air was shorter (Figure 2). The Glycol High mean log reduction curve was the lowest, with
302 the shortest suspension time of tagged DNA tracers in air. The glycol-containing fog treatments
303 had lower mean log reduction curves compared to the glycerin-containing fog treatments. The
304 Glycerin High mean log reduction curve was lower than the Glycerin Low mean log reduction
305 curve.
306

307 The overall mean log reduction, from the time of spray until 30 minutes had elapsed, ranged from
308 6.4 logs for the Control treatment to 7.5 logs for the Glycol High treatment. Within the first and
309 last measured sampling times (intervals), the total log reduction measured for the Control
310 treatment was 2.6 logs. The artificial fog treatments resulted in reductions ranging from 2.8 to 3.4

311   logs, with Glycol High yielding the largest overall log reduction. In general, with each successive

312   sampling interval, the magnitude of reduction decreased for all treatments. The largest mean log

313   reductions for all treatments occurred during the first three sampling times, which were the first

314   15 minutes after spraying. Between 15 to 30 minutes, the total mean log reduction was 1.1 logs

315   or less for all treatments.
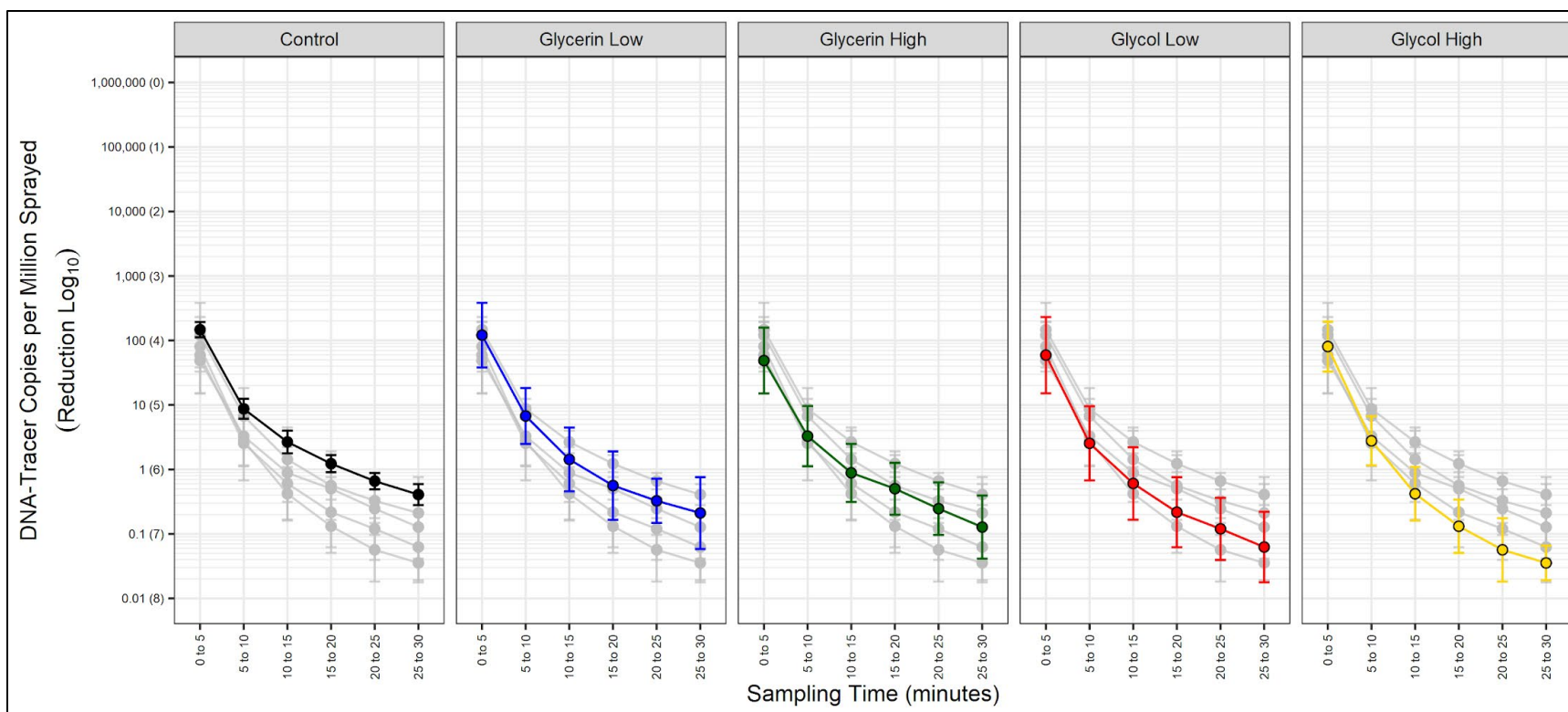
Figure 2. Mean log reduction of tagged DNA tracers in air over time with and without artificial fog. For each treatment, the mean log reduction (mean ± 95% CI) was calculated and plotted at each sampling time (interval). The solid point represents the mean and the bar and whiskers represent the 95% confidence interval around the mean. Within a treatment panel, the colored line represents that treatment's mean log reduction curve while the grey curves represent all other treatment mean log reduction curves.

320 Given the sample size, no formal statistical test was applied to test the assumption of normality
321 for the log reductions. Based on a qualitative assessment of the individual data points, the data
322 follows a central trend; therefore, this assumption is moderately accurate. The test for
323 homogeneity of variance applied to the combined levels of the variables "Treatment-Interval"
324 yielded no statistically significant differences (p = 0.11, K-squared = 38.37). The two-way ANOVA
325 determined the interaction between the variables "Treatment" and "Interval" was not statistically
326 significant (p = 0.633), indicating that there is no interaction between the variables, and their
327 effects on mean log reduction are independent of each other. When analyzed independently, the
328 effect of "Treatment" was statistically significant (p<0.001), and the effect of "Interval" was also
329 statistically significant (p<0.001).
330
331 Compared to the Control and Glycerin Low treatments, the differences in mean log reduction for
332 nearly all other artificial fog treatments were statistically significant (p<0.001) (Table 2). The
333 difference in mean log reduction between Control and Glycerin Low treatments was not
334 statistically significant (p = 0.087). The differences in mean log reduction between treatments
335 using the same artificial fog type were not statistically significant.
336
337 **Table 2. Tukey Honest Significant Difference Comparing Treatment Mean Log Reductions**

Treatment Comparison	Mean Difference in Log Reduction	95% CI of the Mean Difference		p-value
		Low	High	
Glycerin Low vs Control	0.23	-0.02	0.49	0.087
Glycerin High vs Control*	0.45	0.21	0.69	<0.001
Glycol Low vs Control*	0.65	0.39	0.90	<0.001
Glycol High vs Control*	0.78	0.53	1.02	<0.001
Glycerin High vs Glycerin Low	0.22	-0.04	0.47	0.129
Glycol Low vs Glycerin Low*	0.41	0.15	0.68	<0.001
Glycol High vs Glycerin Low*	0.54	0.29	0.80	<0.001
Glycol Low vs Glycerin High	0.20	-0.06	0.45	0.209
Glycol High vs Glycerin High*	0.33	0.08	0.57	0.003

11

Treatment Comparison	Mean Difference in Log Reduction	95% CI of the Mean Difference		p-value
		Low	High	
Glycol High vs Glycol Low	0.13	-0.12	0.38	0.617

338   *Notes*. * statistically significant, CI = confidence interval

340   The differences in mean log reduction between nearly each sampling time were statistically
341   significant (p<0.05); the exception is between sampling times "20 to 25" and "25 to 30", where the
342   difference in mean log reduction was not statistically significant (p = 0.18).

344   **4 Discussion**

346   It was shown that artificial fog appears to decrease suspension time to varying degrees depending
347   on the chemical composition and airborne concentration. The largest decrease in suspension time
348   was observed after the first five minutes, where all treatments had at least a four-log reduction.
349   The log reduction observed in the artificial fog treatments was, in general, statistically significant
350   compared to the Control treatment. The magnitude of reduction past four logs became
351   exponentially smaller with each additional log reduction. A change from four to five logs is
352   equivalent to a reduction of an additional 0.009%, and a change from five to six logs is equivalent
353   to a reduction of an additional 0.0009%. Although artificial fog treatments were observed to have
354   lower mean reduction curves, the amount of additional reduction yielded from the physical
355   interaction of artificial fogs does not appear to be practically significant as a control measure for
356   reducing airborne aerosols.

358   The natural decay of artificial fog in air was semi-quantitatively assessed by bringing up fog levels
359   to both high and low levels and observing the decay with the *p*DR-1000AN Monitor. To decay
360   90% from a starting concentration that matched the "High" treatment, it took the glycerin-
361   containing artificial fog approximately one hour and seventeen minutes and the glycol-containing
362   artificial fog approximately ten minutes. The presence of the tagged DNA tracer in air did not
363   appear to drastically alter this decay duration. The intended use of these two artificial fogs were
364   different, where the glycerin-containing artificial fog was designed to stay suspended in air to
365   create a haze effect, while the glycol-containing artificial fog was designed to be a low-lying fog.
366   The different purposes of each artificial fog may have contributed to their effect on respiratory
367   aerosol suspension time. If the artificial fog physically interacts with respiratory aerosols, artificial
368   fogs that are designed to fall more quickly out of air, or be low-lying, may physically remove
369   respiratory aerosols and shorten suspension time compared to artificial fogs designed to remain
370   in air longer. The opposite does not appear to be true, as the artificial fogs designed to stay in air
371   did not increase respiratory aerosol suspension time in air compared to no artificial fog.

373   The relative humidity during the Glycol High treatment had a mean difference of -12.4% compared
374   to the Control treatment, noticeably lower than the other artificial fog treatments. Lower relative

12

375 humidity promotes increased desiccation of aerosols in air. One previous study identified that with
376 decreasing relative humidity, the total mass of aerosols with a mean aerodynamic diameter of 2.5
377 micrometer in air increases, meaning the suspension time increases (Zhaou et al., 2020). Given
378 the mean differences in temperature and relative humidity between the Glycol High treatment
379 (22.0°C and 64.1%) and Control treatment (21.7°C and 76.6%), the aerosol suspension time
380 during the Glycerin High treatment is estimated to increase by approximately less than 1% based
381 on the work performed by Zhaou et al. (2020). Additionally, Chen and Zhao (2010) determined
382 that the influence of temperature and relative humidity on the dispersion of droplets with an initial
383 diameter range of 0.1 to 200 μm was negligible. It is possible the differences in temperature and
384 relative humidity may have affected the Glycol High treatment mean log reduction curve, but the
385 impact is not expected to meaningfully alter its relationship with the Control treatment mean log
386 reduction curve. The same is true for the other artificial fog treatments.
387
388 The limitations of this study are noteworthy. The small sample size for each treatment was limited,
389 which impacted the resolution of mean log reduction curves and reduced the power to detect
390 statistically significant differences in mean log reductions. Despite this limitation, there was
391 consistency within each treatment and sampling interval, with all mean standard deviations being
392 less than 0.50. The samplers used were not size selective, thereby may have captured all aerosol
393 size fractions and potentially captured larger aerosols outside the respiratory size range. This
394 limitation was partially controlled for by adjusting the calculated number of DNA copies to align
395 the Flairosol spray bottle aerosol distribution with the distribution of aerosols generated by
396 sneezing, talking, and coughing and which partially or totally evaporated. This study did not
397 investigate how artificial fog may affect the propagation distance of respirable aerosols, nor the
398 disinfection properties of glycerin or glycol on tagged DNA tracers. Only one type of each glycerin-
399 containing and glycol-containing artificial fog fluid was used for this study. There are a large range
400 of manufacturers and fluid types available, each with slightly different liquid compositions and
401 percentages of glycerin or glycol. The impact of different liquid compositions and percentages of
402 glycerin or glycol were outside the scope of this study.
403
404 **5 Conclusion**
405
406 This study supports that artificial fog does not increase the suspension time of respiratory aerosols
407 in air, but rather has no effect or decreases the suspension time. Of the two types of artificial fogs
408 investigated, artificial fog containing glycol decreased suspension time more than that containing
409 glycerin. Regardless of the type of artificial fog used, suspension time decreased more with
410 increasing artificial fog concentration, albeit not statistically significantly. In practice, the additional
411 reduction in suspension time provided by the physical interaction of respiratory aerosols with
412 artificial fog does not suggest any practical benefit for using artificial fog as a control measure.
413 The principal outcome supported by this study was that artificial fog use does not increase
414 suspension time of respiratory aerosols, and therefore does not appear to increase the risk of
415 airborne transmission of diseases from respiratory aerosols, such as COVID-19.

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