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A dynamic aerosol flow chamber

Alan D. Hewitt

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A flow chamber has been developed for optically measuring the interaction between an aerosol cloud and falling snow. Analysis of aerosol clouds passing through the optical region of the chamber in the absence of precipitation resulted in an average ratio of 1.09 for transmission readings taken from two lines of sight 1.5 m apart. The ability to pass dynamic aerosol clouds of constant opacity through a chamber where they can be exposed to natural meteorological phenomena allows for the analysis of precipitation scavenging.

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PREFACE

This report was prepared by Alan D. Hewitt, Research Chemist, Geochemical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The author thanks James Cragin and Austin Hogan for helpful discussions concerning the design of the flow chamber, Gary Koh for taking snowfall replicas and developing a computer program to handle the data, Roger Berger for advice on laser systems, and Charles Zue for fabricating and repairing electronic equipment. Funding for this study was provided through DA Project 4A762730AT42, Task FS, Work Unit 004, *Scavenging of Obscurants by Falling Snow*.

CONTENTS

ILLUSTRATIONS

TABLES

A Dynamic Aerosol Flow Chamber

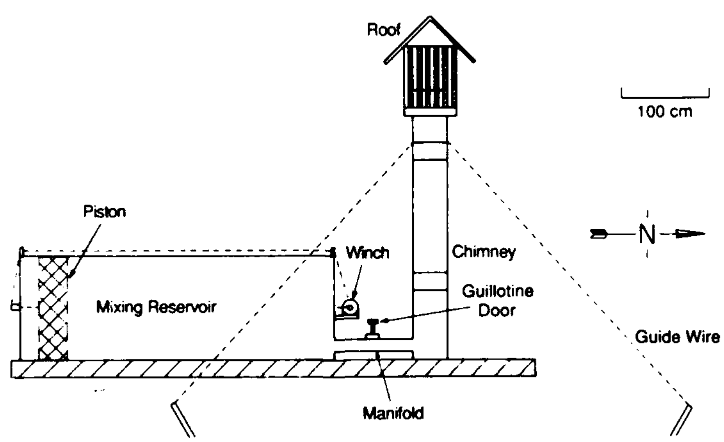
ALAN D. HEWITT

INTRODUCTION

The fate of brass infrared screener aerosol clouds coexisting with frozen precipitation has been under investigation at the Cold Regions Research and Engineering Laboratory (CRREL) as part of the Battlefield Obscuration program. Cragin and Hewitt (1987a,b) established a relationship between precipitation rate and snow surface concentrations of brass when cloud release coincided with snowfall, and they determined an average scavenging efficiency for a variety of snow crystal types passing through brass screener clouds. These findings support models predicting levels of increased transmission and expected lifetimes of airborne screeners when it is snowing (Cragin and Hewitt 1987b, Farmer et al., in prep., Hutt and Cragin, in prep.). To further substantiate these models, a smoke chamber was constructed to measure the influence of falling frozen hydrometeors on aerosol clouds as seen by a transmissometer. Obscurant clouds were exposed to falling snow by pushing an aerosol cloud from a production reservoir into a 3-m-high open chimney. This report describes the design and calibration of this aerosol chamber. Results and analysis of tests performed during snowfall are described elsewhere (Hewitt et al., in prep.).

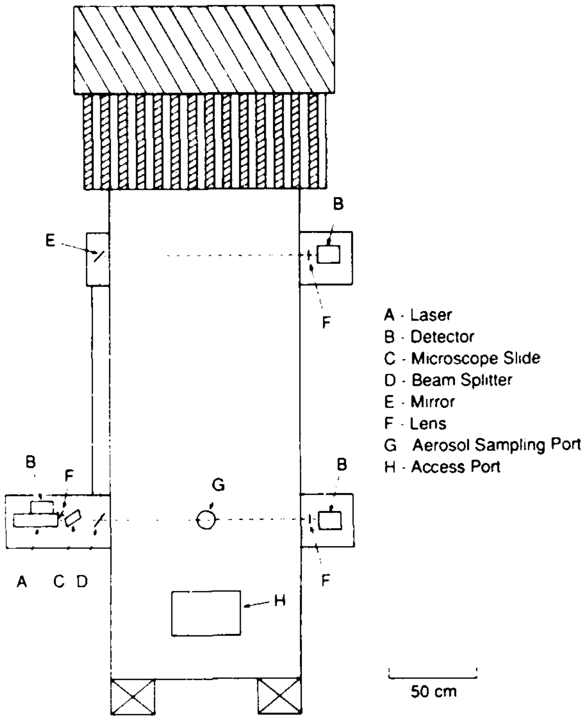
SMOKE CHAMBER DESIGN

The chamber was built to measure, by transmissometry, the influence of falling snow on screener aerosol cloud concentrations. The aerosol chamber shown in Figure 1 comprised a mixing reservoir, a manifold



a. Side view.

Figure 1. Aerosol chimney.



b. Front view.

Figure 1 (cont'd). Aerosol chimney.

and a chimney. Aerosol clouds were made by blowing obscurant particles into the mixing reservoir. After the mixing reservoir was filled, a manifold door was opened and the cloud was pushed out using a piston. The aerosol cloud next entered the bottom of the chimney, then traveled to the top where it exited to the atmosphere. When the roof was opened, the cloud passing upward through the chimney was exposed to the current weather conditions. The aerosol concentration of the obscurant cloud was monitored by a transmissometer mounted on opposite (east and west) sides of the chimney.

The aerosol chamber sat on a level frame of 10- x 20-cm timbers northwest of the Frost Effects Research Facility at CRREL. Most of the aerosol chamber components (reservoir, manifold and chimney) were made from rigid insulation glued to studs and then sealed with silicon caulking. The rectangular chimney was positioned on the north side of the mixing reservoir. The winch end of the mixing reservoir was adjacent to the chimney, with the piston wall to the south (Fig. 1a). This orientation was chosen so that the larger sides of the chimney were perpendicular to the prevailing storm wind direction.

Mixing reservoir

The mixing reservoir was a 4.5-m^3 box (interior dimensions 122 x 360 x 122 cm) built from 2-in.-thick Styrofoam solid insulation ("blueboard") with an exterior frame of wooden studs. The inner surface of the mixing reservoir was aligned with respect to the outer dimensions of the piston to allow for smooth passage. The hollow Styrofoam piston (112 x 30 x 121 cm) was covered with Teflon sheeting on the bottom and sides to reduce friction. At the end of the reservoir opposite the piston along the bottom was a 100- x 15-cm rectangular opening leading to the manifold.

In addition to the manifold hole, a small 8- x 0.2-cm slit was made in the center of the wall to allow for the passage of a 0.16-cm-diameter cable. This cable was attached to the middle of both sides of the piston and made a continuous loop, inside and around the outside of the reservoir including several turns on a 2.54-cm-diameter spool. The winding spool was driven by a 1:100 gear-reduction box coupled to a variable-speed motor. Together, they constituted a winch capable of moving the piston in either direction.

On the east side of the mixing reservoir (Fig. 1b), two holes were cut: one hole acted as the entrance port for obscurant aerosol discharged from The Green Machine crop duster (Model 4600LP, with duster conversion kit 46700), the other hole was made for taking aerosol mass concentration samples. Both holes were plugged when an aerosol cloud was moved from the reservoir into the chimney through the manifold.

The top of the mixing reservoir was covered with plywood for weather protection. The roof, along with three sets of braces attached to the frame on the long sides, held the structure rigid.

Manifold

The mixing reservoir and chimney were connected by a rectangular manifold with interior dimensions of 95 x 91 x 10 cm. The manifold was equipped with a vertically sliding guillotine door, which allowed the mixing chamber to be isolated from the chimney during cloud formation (Fig. 1a).

Chimney

An enclosed chimney with interior dimensions of 100 x 30 x 310 cm served to contain the vertically rising obscurant cloud. Attached to the chimney at various locations were parts of a transmissometer system consisting of mirrors, lenses, photo detectors and a laser (Fig. 1b). Guide wires were attached to the top of the chimney to stabilize it.

Light paths for the transmissometer were located at 93 and 243 cm above the floor, passing through 2.54-cm-diameter holes in the east and west walls. Two holes existed in the north wall, one 8.9-cm-diameter hole in the middle of the wall at a height of 91 cm for obtaining aerosol mass concentration samples, and a 40- x 25-cm rectangular access port near the bottom. Both of these ports were plugged during aerosol cloud passage.

Within the chimney body there were three features designed to create and maintain laminar aerosol cloud flow. At a height of 23 cm above the floor, a 5-cm-thick horizontal plate extended over the cross section of the chimney. This plate contained 108 evenly distributed 2.54-cm-diameter holes that helped disperse the cloud uniformly into the optical region of the tower. Above this plate, two vertical egg-crate dividers were hung, one (91 cm in height) between the two light paths and the other (30 cm in height) just below the top lip. These dividers broke the chimney up into twelve 25- x 10-cm rectangular tubes. The divider positioned between the two light paths was constructed from 0.08-cm-thick aluminum sheets, while the other was made from 0.24-cm-thick Lucite. By dividing the interior of the tower into 12 rectangular tubes at these two locations, obscurant clouds maintained a uniform mass distribution. Tests performed prior to installation of the vertical dividers indicated that the cloud moved to one side of the tower after passing the lower light beam.

Roof

A roof and vertical fence, designed to decrease the speed of air flowing across the chimney's mouth, added another 75 cm in height to this structure. The roof was made of 1-in. aluminum-faced urethane insulation fastened to a wood frame. The frame was split along the top ridge, making two roof sections. The roof halves were hinged so that they could be opened and shut by pulling ropes attached to the lower edge and the top ridge. Below the roof trestle (Fig. 1b) a fence consisting of offset 3.8-cm-wide wooden strips every 7.6 cm extended 30 cm above the chimney mouth. The interior dimensions of the fenced-in area were 138 x 60 cm. The combination of a larger mouth and a fence was designed to remove the influence of variable wind speeds and direction under light and moderate conditions (<2 m/s).

INSTRUMENTATION

Transmissometer system

A He-Ne 633-nm laser (Oriel, 0.5-mW minimum power output, Model 79255) was the light source for the transmissometer. The laser was coupled to a 40x diverging lens (Oriel, Model 15980) and visible beam expander-collimator (Oriel, Model 15920) making a 2-cm-diameter round light source. Three centimeters from the collimator front lens, an angled microscope slide intercepted the beam, reflecting approximately 10% of the intensity to a detector adjacent to the laser. The next device in the light path was a wheel holding three neutral-density filters (Oriel, Models G-66-22, G-66-24 and G-66-26) with absorbances at 600 nm of 0.295, 0.540 and 1.09. These filters were followed by a broad-band 50/50 beam splitter (Oriel, Model 38106) set at a 45° angle to the incident beam. The half-mirrored surface of the beam splitter divided the light into vertical and horizontal paths. The light removed from the incident path was focused on an angled mirror 1.5 m above the beam splitter. Both beams passed through 2.54-cm-diameter holes in the east wall, the chimney body, and then 2.54-cm-diameter holes in the west wall leading to the detectors. All three detectors were positioned behind plano-convex glass lenses (Ealing Electro-optics, Model 30-6928), which condensed the 2-cm-diameter beam to a 0.5-cm-diameter focal point on the surface of the silicon photocell detector. The detectors were all equipped with He-Ne laser line filters (Ealing Electro-optics, Model 35-4126), which limit the wavelengths of electromagnetic energy that are transmitted.

Alignment of the system involved maximizing the energy measured by the three photocell detectors. The silicon photovoltaic sensors have a reported 10% accuracy, a responsivity of 0.14 mA/mW at 0.45 mm, and a 1-V dc full-scale deflection. They were equipped with an amplifier, an attenuator (1000-0.001 mA), and a meter. The individual detectors were calibrated with neutral-density filters under laboratory and field conditions (Fig. 2, Table 1). The photocells whose responses most closely matched were chosen for monitoring the light intensity after passing through the chimney.

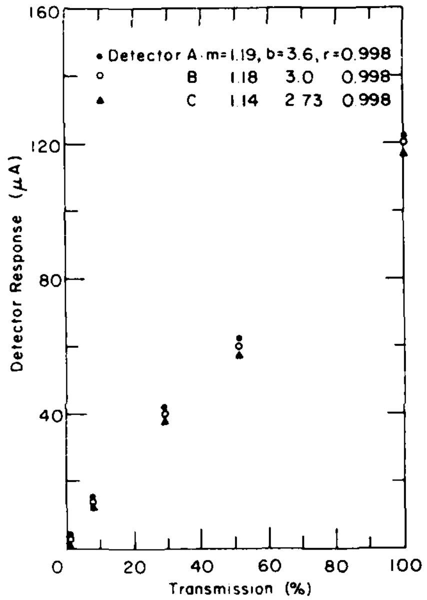


Figure 2. Detector calibration (m = slope; b = intercept; r = regression coefficient).

The detectors and laser used solid-state components. These were always left on to eliminate warm-up time between tests. A power supply (6 V dc at 15 mA) served as the external power source for the detectors. The power supply, along with a 33-m signal transfer cable, was made by CRREL's electronics staff. The laser also required a layer of Styrofoam insulation around the sides of the body (17.8 x 5.1 x 6.4 cm) to provide thermal stability. Small enclosures on the outside of the chimney housed all of the various transmissometer components (Fig. 1b). These weather-tight boxes were equipped with aluminum 1.27-cm-diameter rails for aligning the optics, the detectors and the laser.

Data acquisition system

The signal from the three detectors (the reference and two sample beams) was recorded by an Apple computer interfaced with an ISAAC 41A (Cyborg Corp.) data acquisition module. The acquisition system converted the analog signal to digital, and the computer integrated and normalized the responses. A computer program (Appendix A) processed the data and calculated an average transmission value after obtaining 30 discrete pulses from each of the three detectors. These values were recorded every 4 s in real time on a display screen and printer. To remove noise introduced by the laser's longitudinal sweeping (approximately 10%), the signals from the two sample beam detectors were normalized with respect to the reference detector. The program permitted the operator to choose multiplying factors so that the sample beam detectors would record 100% transmission at the beginning of each test.

Table 1. Comparison of silicon detector sensitivity.

Neutral-density filter (Absorbance)	*Transmittance (%)*	*Detector response (μA)*		
		A	*B*	*C*
0	100.0	122.0	121.0	117.0
0.295	50.7	62.1	60.0	58.0
0.540	28.8	41.2	39.8	37.8
1.09	8.13	14.5	14.3	13.9
2.03	0.93	1.8	1.7	1.6
2.90	0.12	0.6	0.5	0.4

CHAMBER TESTS

Before the system could be used in the field, both the tower's optical system and the chamber's ability to representatively sample meteorological phenomena, such as snowfall, required calibration. It was also necessary to analyze the travel time for obscurant particles passing between the two lines of sight and to consider the influence of dilution. A detailed procedure for operating the aerosol chamber is presented in Appendix B.

Calibration

The chamber's optical system was calibrated by measuring the obscurant mass collected on 0.01-mm glass fiber filters (General Metal Works, Model GMW-0232). Aerosol samples were taken simultaneously with transmission measurements to determine the correlation between aerosol mass concentration and photocell response (Fig. 3). The air mass sampling port was located at the same level as the bottom light path, so only this line of sight was used for calibration. Obscurant aerosol mass concentrations were determined by weighing the total particulate loading after a 30-s collection. A portable Handi-Vol 2000 air sampler (General Metal Works), regulated with a variable autotransformer to obtain flows around 65 L/min, was used to collect the samples.

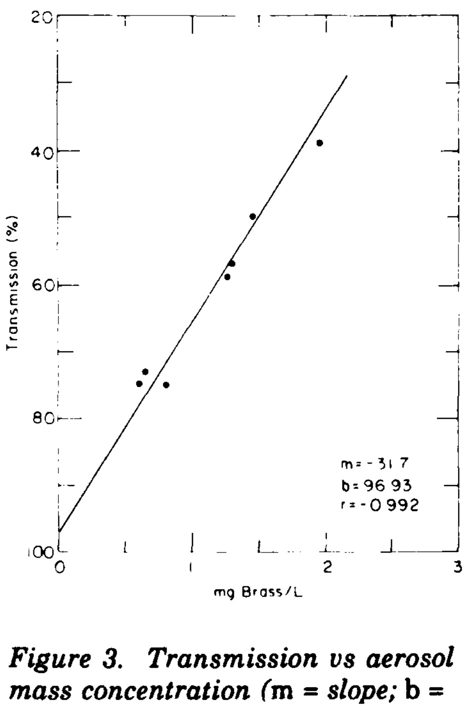


*Figure 3. Transmission vs aerosol mass concentration (*m *= slope;* b *= intercept;* r *= regression coefficient).*

When the chamber was being used for experiments, snowfall measurements had to be taken outside of the chimney. For this reason the smoke chamber's mouth had to be calibrated to make sure that the snow entering the chamber was representative of the snowfall rate outside the chamber. The mass precipitation rate was determined outside and adjacent to the chamber during snowfall events as described by Cragin and Hewitt (1987a). Square petri dishes (530 cm^2 in area) with pre-weighed pieces of aluminum foil were exposed for collection periods of 1–3 min. Weights of the aluminum foil and collected snowfall gave the mass precipitation rate. The configuration of the tower biased the precipitation that actually passed through the chimney. The lower precipitation rates measured inside the chimney were influenced by turbulence around the roof mouth. Thus, the precipitation rate inside and outside the chimney required correlation under a variety of meteorological conditions so that correction factors could be estimated. Snow crystal replicas were also made during tower tests for classification of habit and size.

Time shift

To compare the transmissions monitored at two lines of sight, an average time of travel for individual aerosol particles between these two points had to be determined. Establishing the time shift makes it possible to analyze the transmission through the same segment of the cloud as it passes the two lines of sight. Travel time was controlled mechanically by the speed of the piston. A piston speed of 34 cm/min was chosen based on the assumption that an exposure period of one minute for the rising cloud to pass between the two light paths was necessary for snowfall to remove a significant quantity of obscurant aerosols. The following is the theoretical argument and the variables characterizing snow used in making this assumption:

Snowflake mass = 0.2 mg (Locatelli and Hobbs 1974)

Snowflake diameter = 2 mm (Locatelli and Hobbs 1974)

Snowfall velocity = 1 m/s (Locatelli and Hobbs 1974)
Smoke rise velocity = 2.6 cm/s
Rise time between light paths = 58 s
Scavenging efficiency = 30% (Cragin and Hewitt 1987b)
Obscurant concentration = 1 mg/cm^3
Obscurant in block (1 x 100 x 30 cm) = 3000 mg.

Probable snow accumulation rates based on previous observations were 1.0, 2.5 and 5.0 mg/min-cm^2, which correspond to 0.083, 0.21 and 0.42 snowflakes/s-cm^2, respectively. This would make the number of snowflakes entering the 3000-cm^2 chimney for the three accumulation rates 250, 630 and 1260 snowflakes/s, respectively.

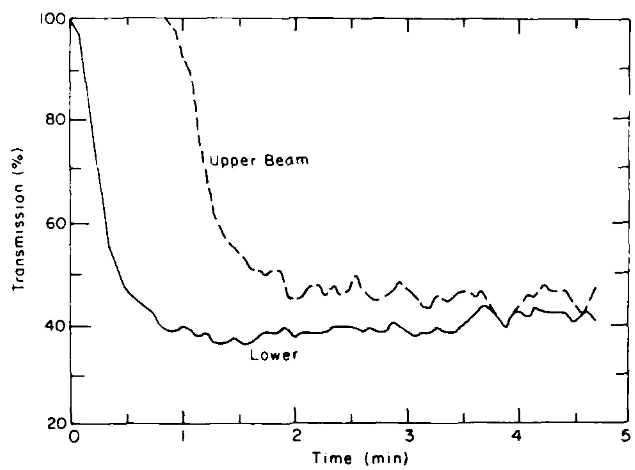
The amount of obscurant removed by snowflakes passing through a 1-cm-thick cloud is

3.1 mm^2 (area of snowflake) x 1 cm x 1 mg/cm^3 x 0.30 = 9.3 ng/snowflake.

Therefore, the amounts removed from the smoke block during a 58-s rise for the three accumulation rates would be 134, 340 and 680 mg, respectively (corresponding to percentages of 4.5, 11 and 23%). This evaluation shows that between 4.5 and 23% of the obscurant particles are removed under the range of conditions stated for a 2-mm-diameter snowflake that weighs 0.2 mg if the cloud rises at a rate of 2.6 cm/s (i.e. 58 s between light paths).

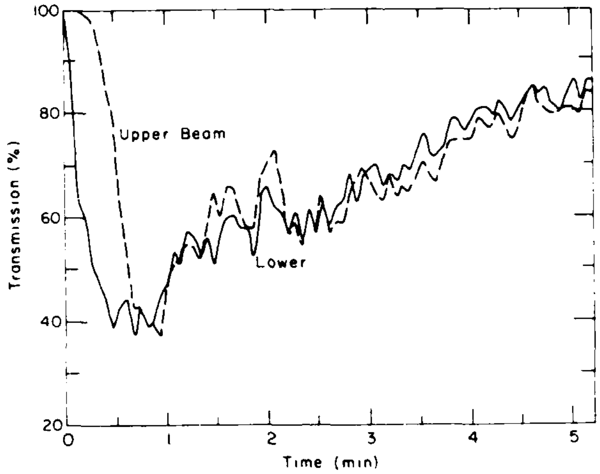
At this piston speed the particles were accelerated to around 500 cm/min as they passed through the manifold (95 x 10 cm). At the bottom of the chimney the cloud is pushed through a 5-cm-thick Styrofoam plate containing 108 holes, where the particles were further accelerated to velocities near 850 cm/min. After the obscurant particles pass through the plate, they enter the main body of the chimney (100 x 30 cm), where they were pushed or drawn out of the chimney. Typically it takes about one minute for the cloud to move from the mixing reservoir to the optical region of the tower. The velocity gained by passing through the distribution plate is lost within the first millimeter because of the physical inherent properties of the obscurant particles and the medium in which they were moving.* The particles were assumed to reach a steady velocity in the main chimney body corresponding to the speed of the piston. This terminal particle velocity set by the piston is on the order of 155 cm/min, making the travel time between the two laser beams approximately 58 s.

* Personal communication with J. Cragin, CRREL.



a. Test 1258802.

Figure 4. Real-time transmission through a brass obscurant cloud.



b. Test 1208804.

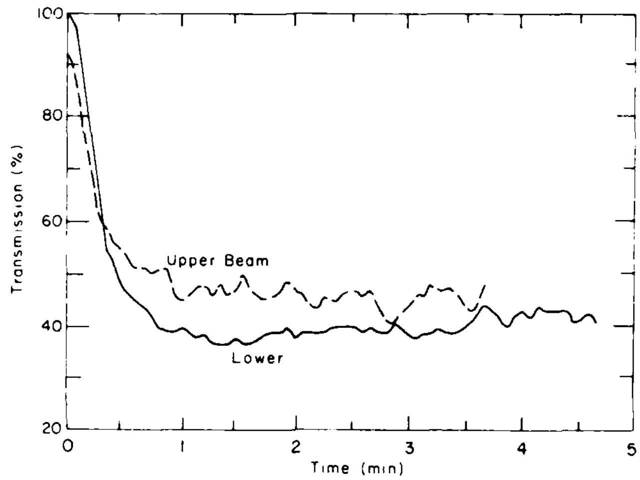
Figure 4 (cont'd).

Figure 4 shows two examples of how the chamber optical system monitors the passage of a brass obscurant cloud. These plots show the recordings from when the cloud initially intercepts the lower beam until the end of the experiments when the piston direction is reversed. In both cases the responses from the upper and lower sample detectors track one another.

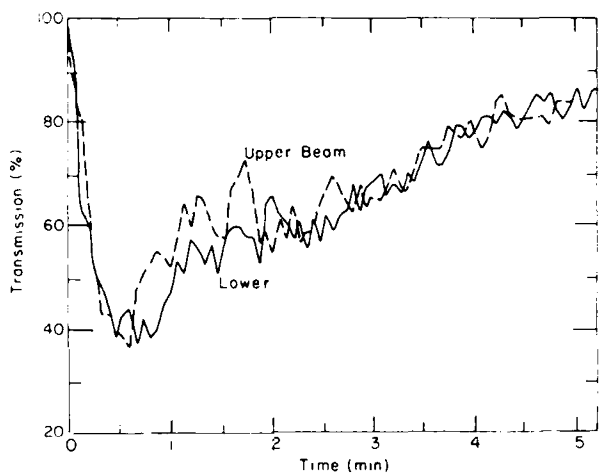
A time shift was determined by both a time series analysis of the transmission recordings and by employing the time corresponding to the flow rate set by the piston (i.e. mechanical default speed). The time series analysis was performed on those readings between the initial point where the aerosol cloud caused a decrease in transmission as monitored by the lower detector to the point where a maximum signal loss was first obtained by the upper detector. The time shift considered to be an estimate of cloud velocity was that which produced an average closest to one for the upper divided by the lower detector's transmission recordings. The flow rate established by the piston predicts a time shift of 60 s (more precisely 58 s, but since readings were taken every 4 s this was taken to be 60 s).

A time series analysis of test 1258802 results in a 60-s time shift (Fig. 5a). The time lapse for this cloud's traverse between the two light paths is identical to that predicted by the velocity of the piston. However, the time shift and the time it takes the cloud to reach the optical region of the chimney were not a function of piston speed alone. For example, test 1208804 (Fig. 5b) has a time shift on the order of 20 s based on a time series analysis. Both of these tests reach the same approximate maximum loss in transmittance due to the amount (10 gm) of brass obscurant employed in the cloud formation. The variation between the two tests is attributed to ambient wind speed. For test 1258802 the average wind speed taken at the chimney's mouth was <0.5 m/s, while an average of 2 m/s was observed during test 1208804. The rapid flow of air over the top of the open chimney is believed to cause aspiration, which is responsible for moving the aerosol through the chamber apparatus at rates greater than that set by the piston (Table 2). Fluctuations in the wind direction created many of the same features as the higher wind speeds.

A comparison of results obtained for the matched transmission ratios (T_{upper}/T_{lower}), based on time series analysis versus the time set by piston speed alone, appears in Table 2. The results show that, on the average, there is little difference in transmission ratios determined by the two techniques. The flow rate based on the mechanical properties of the aerosol chamber is less subjective and easier to use.



a. Test 1258802.



b. Test 1208804.

Figure 5. Time-shifted transmission through a brass obscurant cloud.

Dilution

Another consideration is dilution, since the difference in density between the obscurant cloud and the air it is displacing in the optical region of the chimney is less than 0.2%. To reduce the influence of this process it was necessary to approach steady state. With the present chamber system the void between the two laser beams was replenished twice. Thus, the first 120 s after the obscurant cloud intercepted the bottom beam was not included in the evaluation of the dynamic cloud properties with or without snowfall.

DISCUSSION AND CONCLUSIONS

A set of experiments performed to assess the response without precipitation (Table 3) shows that the same approximate value was obtained for six experiments. An average of 1.09 for this set represents the blank for the 1.09 for this set represents the blank for the system. Ideally if dynamic equilibria had been obtained, the average blank would be one. One third of the observed difference was attributed to the greater sensitivity of the upper detector (Table 1).

Table 2. Comparison of the average matched transmissions obtained when time shift is determined by time series vs the time set by piston speed. All of the time series analyses were normalized to a 60-s time shift.

Test no.	*Time shift (s)*	T_{upper}/T_{lower} *based on* *Piston speed*	*Time series*	*Difference (%)*
1138802	32	1.09	1.09	0.0
1138803	48	1.11	1.10	0.9
1208804	20	1.10	1.03	6.4
2088801	28	1.17	1.17	0.0
2198802	32	1.03	1.08	4.9
2198803	20	1.07	1.12	2.8
1048804	64	1.17	1.17	0.0
1048805	40	1.34	1.49	11.2
1048808	48	1.19	1.20	0.8
1088804	40	1.10	1.12	1.8
1088805	40	1.08	1.15	6.5
1088806	44	1.08	1.12	3.7
1088808	44	1.09	1.14	4.6
1088809	44	1.22	1.32	8.2
1088811	36	1.25	1.25	0.0
1208801	36	1.23	1.23	0.0
1208803	60	1.39	1.38	0.7
1258801	32	1.14	1.14	0.0
1258802	60	1.21	1.21	0.0
1258803	64	1.15	1.15	0.0
1258804	60	1.22	1.22	0.0
1258806	56	1.16	1.18	1.7
1258807	52	1.25	1.31	4.8
1258808	52	1.32	1.35	2.3
1258809	52	1.21	1.32	9.1
1258811	36	1.21	1.27	5.0
2048801	68	1.20	1.18	1.7
2048802	60	1.19	1.19	0.0
2048804	64	1.17	1.16	0.9
2048805	72	1.16	1.16	0.0
2048806	76	1.07	1.09	1.9
2048807	36	1.17	1.18	1.7
2048808	40	1.10	1.08	1.8
Average	47	—	—	2.6

Table 3. Transmission ratios for clear-air (blank) experiments.

Date	*Test no.*	T_{upper}/T_{lower}
13 Jan 88	113882	1.09
13 Jan 88	113883	1.11
20 Jan 88	120884	1.10
8 Feb 88	28881	1.17
19 Feb 88	219882	1.03
19 Feb 88	219883	1.07

Overall average = 1.09 ± 0.05

Tests performed with this aerosol chamber have demonstrated that relatively uniform obscurant clouds can be produced and passed through a tower, creating a dynamic setting for interaction between natural precipitation and man-made screeners. Analysis of a set of clear air tests shows that this device, under a range of meteorological conditions, is capable of producing a fairly homogeneous aerosol cloud. Systems of this type allow for direct optical measurement of scavenging of aerosol clouds by natural precipitation. The results of such experiments quantify increased levels of transmission and the expected lifetime of airborne screeners when released during snowfall, as presented elsewhere (Hewitt et al., in prep.).

The present system could be improved by increasing the exposure period between the lines of sight. This could be achieved by either increasing the distance between the light paths or slowing down the flow rate. A continuous supply of aerosol instead of the limited volume delivered by the mixing reservoir would be beneficial. More attention to the design of the chimney roof is necessary so that the aerosol cloud is less susceptible to wind speed and direction. And finally, real-time measurements of the aerosol flow rate in the optical region of the chimney should be made.

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APPENDIX A: COMPUTER PROGRAM FOR PROCESSING TRANSMISSION DATA

```
10   REM  DATA ACQUISITION PROGRAM TO COLLECT LASER TRANSMISSION
     THROUGH A SMOKE CHAMBER
30   HOME : REM CLEAR SCREEN
40   D$ = CHR$ (4)
50   PRINT "K1 AND K2"
60   INPUT K1,K2
100  REM
110  REM  READ THE DATE
120  REM
130  & DAY TO YR,MO,DT,DA
200  REM
210  REM  TURN PRINTER ON
220  REM
230  PRINT  D$;"PR#1"
240  PRINT "SMOKE CHAMBER TEST"
250  PRINT "            "MO"/"DT"/"YR
260  PRINT " "
270  PRINT "CH#1     CH#2     LASER    CH#1/2
280  PRINT " "
285  REM   TURN PRINTER OFF
290  PRINT  D$;"PR#0"
300  REM
310  REM   THREE CHANNELS
320  REM
400  & DAY TO YR,MO,DT,DA
410  & TIME TO HR,MN,SC
500  REM
510  REM SAMPLE DATA EVERY SECOND
520  REM
525  X = INT (SC / 2)
530  IF SC / 2 = X GOTO 600
540  GOTO 400
600  REM
610  REM  THREE CHANNELS
700  REM
710  REM  INITIALIZE THREE CHANNELS
720  REM
725  ACH = 0
730  BCH = 0
735  CCH = 0
750  REM
760  REM  READ 30 DATA POINTS
770  REM
800  FOR J = 1 TO 30
810  & AIN,(D#) = 0,(C#) = 0,(TV) = X
820  & AIN,(D#) = 0,(C#) = 1,(TV) = Y
825  & AIN,(D#) = 0,(C#) = 2,(TV) = Z
835  ACH = ACH + X / 409.6
840  BCH = BCH + Y / 409.6
842  CCH = CCH + Z / 409.6
850  NEXT J
900  REM
```

```
910  REM  DIVIDE BY 30
920  REM
940  ACH = INT ((ACH / CCH) * 333.33) / 10000 * K1
950  BCH = INT ((BCH / CCH) * 333.33) / 10000 * K2
960  CCH = INT (CCH * 333.33) / 10000
1000 REM
1010 REM  PRINTER ON
1020 REM
1030 PRINT  D$;"PR#1"
1040 PRINT HR":"MN":"SC"   "ACH"   "BCH"   "CCH"   " INT (ACH / BCH * 1000)
     / 1000
1050 PRINT " "
1060 PRINT  D$;"PR#0"
1070 GOTO 400
```

APPENDIX B: OPERATIONAL PROCEDURE

1. Load the crop duster hopper with 10 gm of brass, position it next to the mixing reservoir, and insert the discharge arm into the proper hole.
2. Open the chimney roof, turn on the data acquisition system, and obtain several readings. Stop the data acquisition system and determine the multiplying factors, setting transmittance at 100% for the two detectors monitoring the chimney interior.
3. Start the crop duster and set the engine on idle; then dispense the obscurant into the mixing reservoir by repeatedly moving the dispensing lever from the closed to the open position quickly. The hopper of the crop duster should also be shaken during this process to dislodge particles stuck to the walls. After 10-15 s turn off the motor, remove the discharge tube from the chamber, and plug the hole.
4. Turn on the data acquisition system and recorder.
5. Turn on the variable speed motor for the winch.
6. Once the piston begins to move, slide up the guillotine door, allowing the obscurant cloud to pass through the manifold into the chimney.
7. Two minutes after opening the manifold, measure the deposition rate or the aerosol concentration.
8. Reverse the direction of the piston and turn off the data acquisition system after the piston has traveled about 200 cm into the mixing reservoir (approximately 7 min after opening the manifold).
9. Close the roof, then open the 40- x 25-cm door on the north face of the chimney, allowing for the quick removal of the remaining obscurant aerosols in the optical region.
10. Turn off the winch motor when the piston is completely retracted, and close the guillotine door in the manifold. Plug the rectangular hole in the north face of the chimney after 98% of the original transmission monitored by the two chimney detectors has returned. Tests can be run about every 15 minutes.

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