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Dispersion of Pollutants Near Highways

Experimental Design and Data Acquisition Procedures

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DISPERSION OF POLLUTANTS NEAR HIGHWAYS
Experimental Design and Data Acquisition Procedures

by

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ABSTRACT

The major thrust of this investigation was the collection of data on particulate and gaseous pollutant concentrations, and detailed micrometeorological data in the vicinity of a major highway in a non-urban setting. A site on a relatively undeveloped section of the heavily travelled Long Island Expressway was selected for the collection of this data for the purpose of: (i) documentation of the distribution of sulfate, lead, total particulates and carbon monoxide at an array of sampling points adjacent to the highway; (ii) studying the micrometeorology associated with the highway, with special attention to those parameters important in the determination of atmospheric dispersion; (iii) reevaluating highway air pollutant emission factors from data gathered in tracer gas experiments; and (iv) examining the applicability of existing highway air pollutant dispersion models.

The location of the site and the experimental setup for collection of pollutant data are described. Details of the data acquisition procedures also are presented in this report.

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ACKNOWLEDGEMENTS

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SECTION 1

INTRODUCTION

The Environmental Protection Agency has developed national ambient air quality standards and oversees State enforcement of these standards. Before a permit is issued to construct a new highway or make major modifications to an existing highway, an air quality assessment must be made to ensure that the resulting vehicle emissions will not cause a violation of the national ambient air quality standards. In order to predict the air quality impact of motor vehicle traffic, mathematical modeling techniques are being employed in various forms to estimate ambient concentrations resulting from these vehicular emissions. A new national concern has lately arisen adding sulfate particulates from catalytic converter emission controls to the list of automotive pollutants.

In order to test the ability of any mathematical model to simulate the advective-diffusive transport of gaseous or particulate matter in the atmosphere, an extensive data base of meteorological conditions and highway-related pollutant concentrations must be collected. While there have been a number of mathematical models developed for the prediction of pollutant levels, only a few experimental programs have been undertaken for establishing a sufficiently detailed data base to be used for model verification. The objective of this investigation was the collection of such a data base at a highway site on the Long Island Expressway. This site has an average annual daily traffic count of 100,000 vehicles/day, and a relatively low background concentration of pollutants from sources other than the highway in question. Data on carbon monoxide, sulfate, lead and total particulates, traffic counts and meteorological variables were collected during the period October 1976 through May 1977.

This research was intended to cover all aspects of pollutant dispersion in the vicinity of a major highway. This report describes the experimental setup and design and the data acquisition and reduction techniques. The location of the site and preparations for the data collection are presented in Section 2. The carbon monoxide sampling procedures are described in Section 3. The ambient aerosol data collection is presented in Section 4. Techniques of measuring the traffic according to vehicle length and speed are described in Section 5. The various meteorological instrumentation used and the data collection procedures are presented in Section 6. In order to test the estimated pollutant emission rates, tracer gas release experiments were conducted and the details of these experiments are given in Section 7. Special micrometeorological measurements to study the turbulence characteristics in the vicinity of the highway are presented in Section 8. The logistics of the computer are presented in Section 9. The procedures of the laboratory analysis of the particulate filters are described in Section 10. Table 1 lists the various parameters measured at the site. All the data are being analyzed to examine the validity of various assumptions underlying mathematical modeling of highway dispersion and to determine the simulation capability of various mathematical dispersion models. The results of these studies will be presented in a subsequent report.

TABLE 1. DURATION OF DATA COLLECTION

Measurement	Sampling Length	Duration	Number of Sample Location
Sulfur Hexafluoride	1 hour	23 runs	16
Particulates	2 hour	236 runs	8
Carbon Monoxide	10 min.	3 months	8
Carbon Monoxide	10 min.	2 months	11
Traffic Counts	10 min.	8 months	6 lanes
Traffic Films	4 hour	32 films	1 direction
Gill UVW	10 min.	8 months	4
Climets	10 min.	8 months	6
Relative Humidity	10 min.	8 months	1
Precipitation	10 min.	8 months	1
Solar Radiation	10 min.	8 months	1
Temperature	10 min.	8 months	1
Temperature Gradient	10 min.	8 months	1
Sonic Anemometer	1 hour	36 runs	1
Temperature Fluctuation	1 hour	15 runs	1
Wind Profile A	15 min.	500 runs	6
Wind Profile B	15 min.	250 runs	4

SECTION 2

SITE DESCRIPTION AND INITIAL PREPARATION

The sampling plane (Fig. 1) was located several hundred meters east of Pinelawn Road near the Exit 49 interchange of the Long Island Expressway (Interstate Route 495). The road bed, oriented approximately east-west, is level for about one kilometer on either side of the sampling plane. The highway has 3 lanes in each direction with a 20m wide grass median. On the northern side, the shoulder bed rises gradually to a height of about 2m above grade at a distance of 21m from the road edge, beyond is a sod farm having a flat unobstructed fetch. Similar conditions are found on the southern side, except for a small grove of trees located directly 200m south and a few houses 500m southeast of the sampling plane. There are some commercial establishments to the west of the site about one kilometer away.

Since the site was within the Expressway's right-of-way, permission was given by the New York State Department of Transportation (NYS DOT) to clear the immediate environs of shrubs and small trees. This was done for 15m on either side of the sampling plane. From Pinelawn Road, NYS DOT constructed an access road about 100m south of the highway. Clinker from boilers at a nearby power station was used to provide an area for the trailer and a parking lot. This surface helped to control vegetative growth in the summer and provided traction during the winter months.

Coordinates of the area, as provided by the Federal Aeronautics Administration, are $40^{o}47'$-15" N, $73^{o}24'$-30" W, and the elevation is 66m above the mean sea level. No obstruction, lights or special painting were required for the towers.

Most construction and erection of sampling equipment was done by the Division of Air Resources personnel. A 70 ft x 40 ft x 10 ft high chain link fence was constructed in November, 1975, to provide security for a refurbished 40 ft long tractor trailer modified to include electrical power, heat and air conditioning, telephone service, work benches, instrument shelves and office space. Prior to obtaining the trailer, free of charge, the budget allowed for two aluminum sheds. The benefit of hindsight shows that such a course would have created very difficult working conditions. Table 2 lists the equipment used for the CO and meteorological data collection.

In January, 1976, the NYS DOT with its own rig and crew attempted to drive guy-wire anchors at the project site. However, snow, rain and thaws at different times thwarted these efforts. The final anchor was placed during the first week of March, 1976.

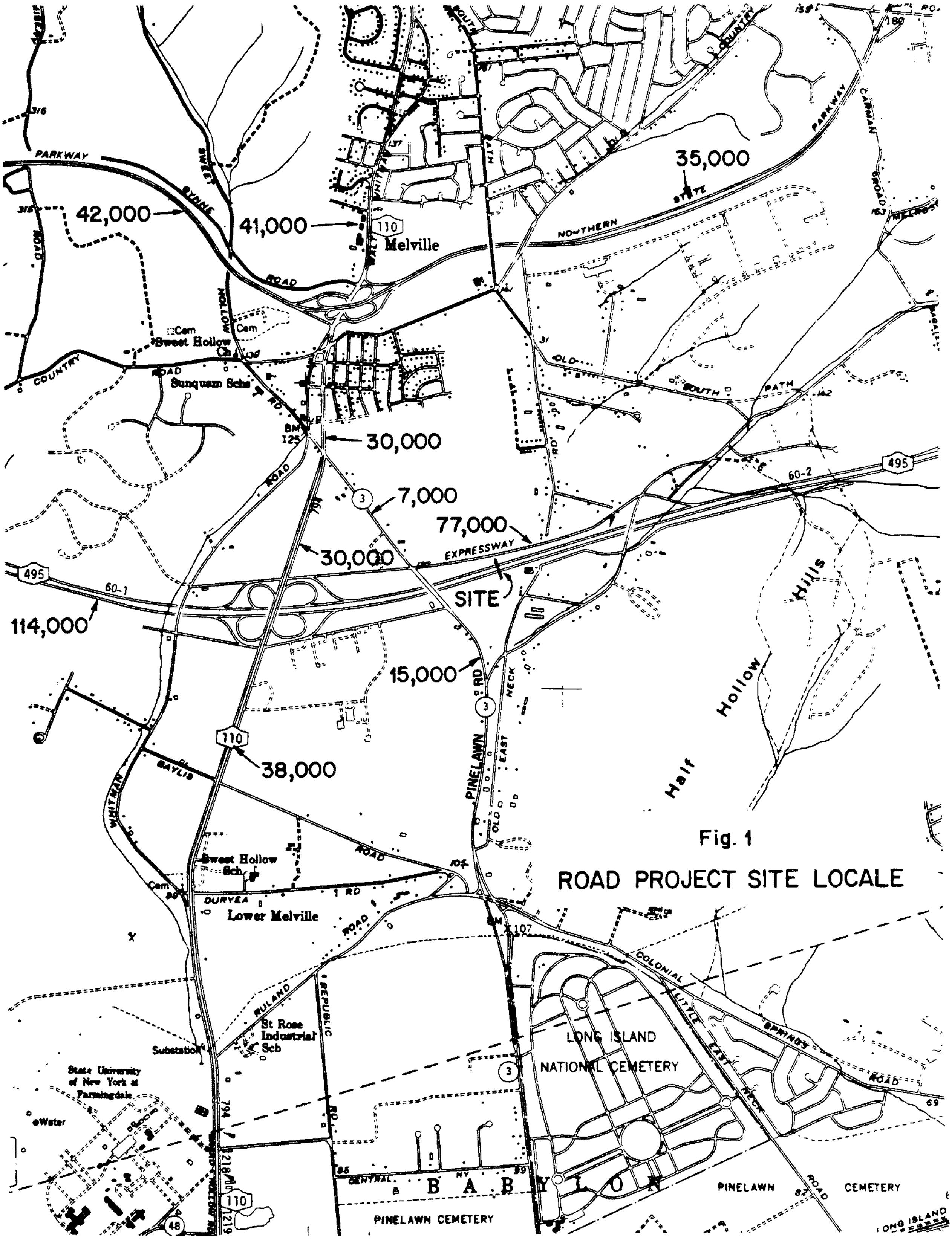


Fig. 1

ROAD PROJECT SITE LOCALE

TABLE 2. INSTRUMENTS USED IN THE PROJECT

Instrument	Measurement	Principle	Detection Range	Output To Computer
Beckman 865	CO	NDIR	0-50 ppm	0-5 VDC
Climet 011-1	Wind Speed	Anemometer Cup	0-20 m/s	0-5 VDC
Climet 012-1	Wind Direction	Vane	0-540^{o}	0-5 VDC
Climet 012-10	Wind Direction	Vane	0-540^{o}	0-5 VDC
Gill Anemometers	U, V W Wind	Propeller	0-20 m/s	0-5 VDC
Spectrosun Pyranometer	Sun and Sky Radiation	Thermopile	0-2 Langleys	0-5 VDC
MRI 840-1,840-2	Δ T	Thermistor	-3^{o}C to +3^{o}C	0-5 VDC
MRI 840-2	T	Therm./Resistor	-30^{o}C to +50^{o}C	0-5 VDC
MRI 840-7	Rel. Humidity	Crystals	0-100%	0-5 VDC
MRI 302	Precipitation	Tipping Bucket	0.01-1"	0-5 VDC

The following is a list of material used in erection of the towers:

1. Trylon, Inc. (defunct) STT-650H-40, STT-650H-80 tower sections. Each 10 ft section consisted of 3 (3/8") rods tied by a lattice of 1/8" rods to form an equilateral triangle cross section of 7 1/2" side. These are spot welded with tabs at either end for bolting.

2. Three telescopic towers mounted on trailers could be cranked up to a height of 65 feet. These towers were of sturdier design than those described in 1. Manufacturer unknown.

3. A third unmounted telescopic tower (70 ft), which proved to be the strongest, was used as the median tower. Manufacturer also unknown.

The three mounted towers were on loan from the U.S. Environmental Protection Agency (USEPA) and the others were from the State University of New York at Albany (SUNYA).

4. A.B. Chance Co. PISA-5 8-inch helix anchors with 3/4" rod driven to a depth of 5 to 10 ft, depending on number of wires attached.

5. 3/8" standard galvanized steel wire cable for guy wires, turn buckles and clips. 3/16" wire was also used to support the median towers horizontally to the shoulder ones.

6. 3' x 3' x 1/4" hot roll steel plates as bases for unmounted towers and two lightning rods for the 25 meter towers.

7. Climbing rope, harnesses and boots.

Placing of the median tower required help from the Suffolk County Police Department. Although the guy wires parallel to the longitudinal axis of the highway were tied to anchors in the median strip, those in the transverse plane posed a slight problem. The police were required to halt traffic in all three lanes on one side of the highway, until 3/16" guy wires could be strung from the already erect median tower and tied to the ones on the northern and southern shoulders. Three sets of wires on either side were placed at heights ranging from 25 ft to 45 feet. During this time, the median tower was held in the vertical position by means of a crane from NYS DOT. Figure 2 shows the initial setup at the site.

Tower 12 suffered structural damage when Hurricane Belle struck Long Island in August, 1976. The upper 16m sections were later removed for safety reasons. Therefore, the temperature difference measuring system was transferred to Tower 11. This new setup is shown in Fig. 3.

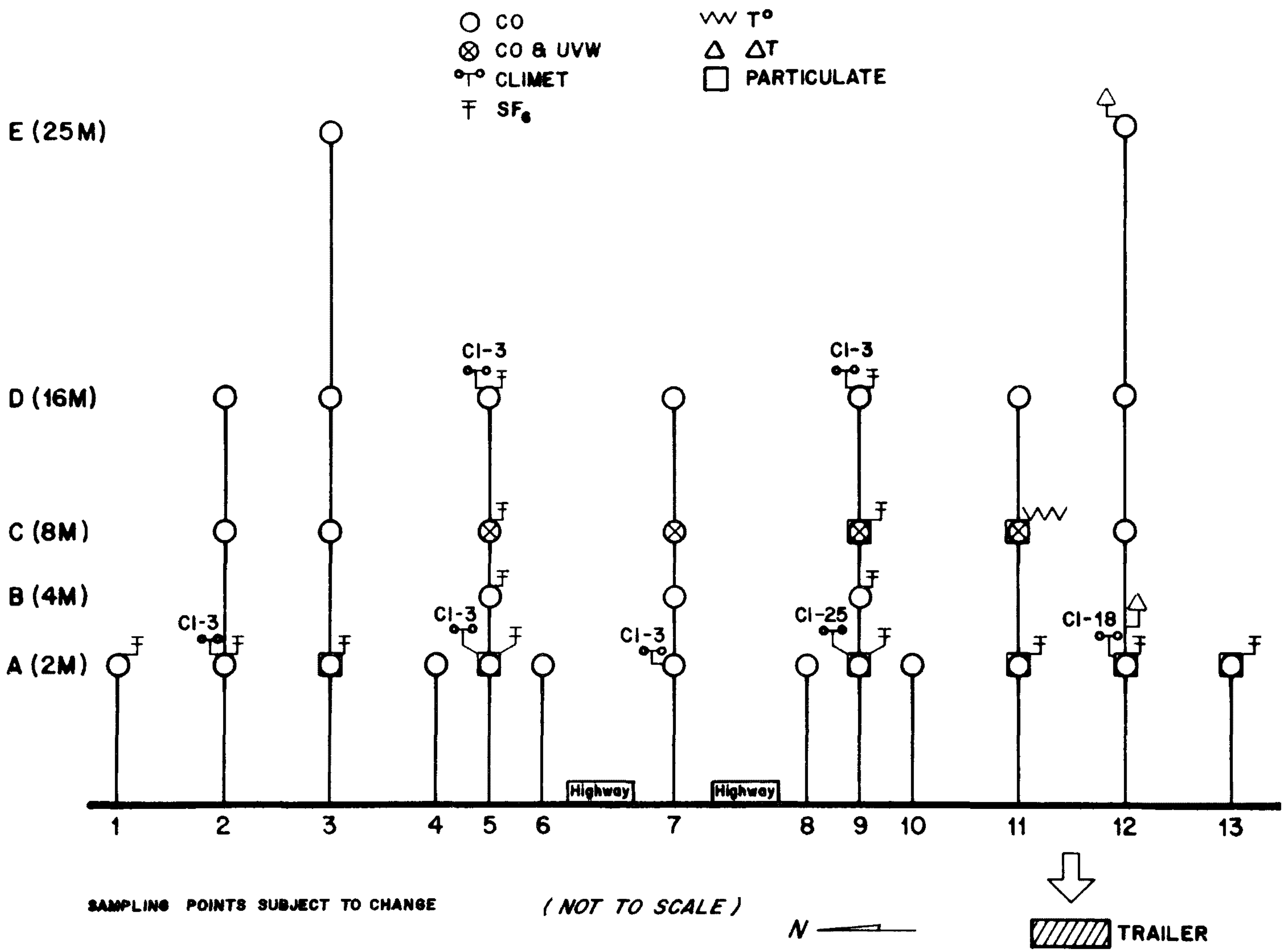
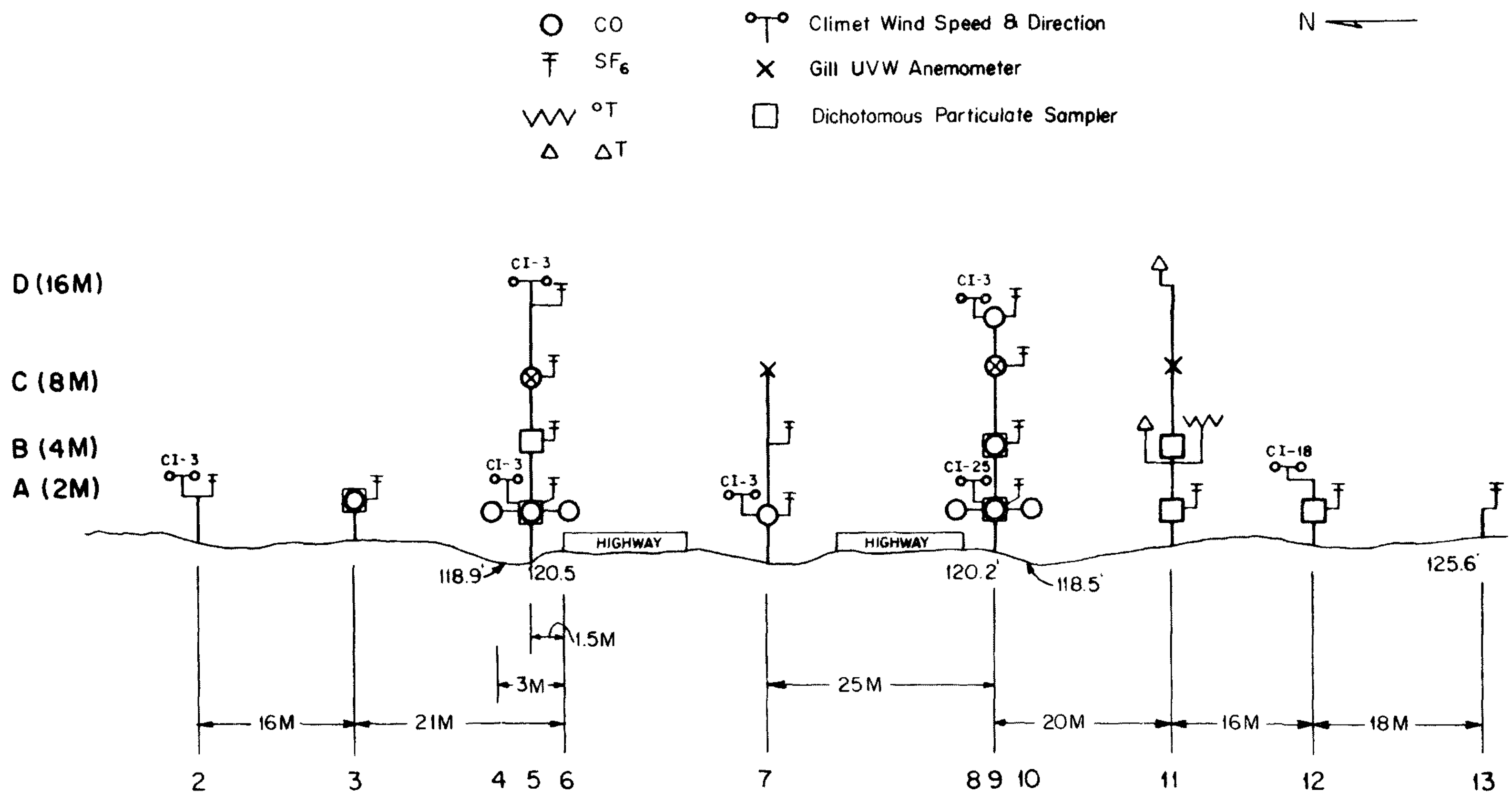


Fig. 2 Initial sampling set-up



Not to scale

Fig. 3 Modified sampling setup

SECTION 3

CARBON MONOXIDE DATA COLLECTION

GENERAL SET-UP

Teflon tubes, 7/16" inner diameter x 1/2" outer diameter, were strung from each assigned point in the array, shown in Figure 2, back to bulkheads in the wall of the trailer. Each tube continued from the bulkheads and terminated at one of three cylindrical collectors. All tubes between the bulkhead and collector included a Brooks Instrument Model #1355-8900-21-C-1-B-AA Sho-Rate "150" flowmeter, and a "T" section from which a sample could be diverted to a CO analyzer. Diversion of the sample was accomplished by means of electrically activated 2-way solenoid valves which were energized by signals from a mini-computer.

Each collector consisted of a 9" diameter x 2' long enclosed steel cylinder with 12 couplings on top at the periphery for the teflon tubes. Another coupling was placed in the center from which a 1/2" copper tube led to a high capacity pump. Internally, a 1" pipe went from the center coupling to 1" from the bottom of the cylinder. When in operation, the collector was exhausted by a high capacity pump via the copper tube and air from the sampling points entered continuously via the teflon lines. The purpose of the collectors was simply to maintain sample flows with only three pumps.

Each of the 32 teflon lines was fitted at its sampling point with a polyethylene funnel and mesh for water and insect protection. Within the trailer, the lines were divided into 8 groups of four. Sample flow to one of eight Beckman Model 865 non-dispersive infrared (NDIR) analyzers from each teflon tube was controlled by the normally closed solenoid valve referred to above. The on-board mini-computer was programmed to energize 8 solenoids (one from each group of 4) for 75 sec., allowing the sample from each of these 8 lines to be analyzed by the corresponding NDIR. At the end of this time the valves were deenergized and therefore returned to their normally closed position, thereby inhibiting any flow from those sample lines to the NDIR analyzers. Simultaneously, another 8 valves were energized by the computer for 75 sec. and analysis of these samples occurred. This procedure was repeated for the third and fourth valves in each group to complete analysis of all 32 lines. Since polling was done on a continuing basis, the computer then switched back to the first valve to repeat the cycle. For a ten-minute period, the computer routine averaged the first and fifth reading, second and sixth, etc. Thus, for each NDIR, the ten-minute printout had four values.

A change in the sampling set up was made in December, 1976 after tests showed that the 2-way solenoid valve system was inadequate. This was proven by introducing a known concentration of CO gas at a sampling point on the tower. Only 80% of that concentration was recorded using the 2-way valve system, which was allowing a back-flow from the collector to dilute the sample line flow. To overcome this problem, it was decided to convert from the 32 point sampling array to an 8 point array, which included points at the 2m level, (3A through 10A inclusive, see Fig. 4) or 1 point per analyzer. This was done with the NDIR analyzer pump sampling directly from the line.

It was determined that the basic, 32-point, system could have been retained by changing from 2-way to 3-way solenoid valves. However, the decision was made not to incorporate 3-way solenoid valves for the 32 sampling points because a deadline of March 31, 1977 to end the project had been agreed upon with the NYS DOT.

NDIR DESCRIPTION

The Beckman Model 865 non-dispersive infrared (NDIR) analyzer was used for measuring the carbon monoxide (CO) concentrations. There are two sources of infrared radiation as shown in Fig. 5. An optical chopper is placed directly in the path of radiation and interrupts it at 10 HZ. When in operation, a portion of the infrared energy is absorbed by carbon monoxide, with the percentage of infrared radiation absorption being proportional to the concentration of carbon monoxide. A flowing reference cell is incorporated in the analyzer and is designed to minimize the effect of water vapor interference and to eliminate the need for bottled zero gas. A catalyst scrubber is also placed upstream of the reference cell to remove carbon monoxide; the sample cell receives untreated air containing carbon monoxide. The resulting differential signal is exclusively due to carbon monoxide, since both cells receive the same gas stream except that carbon monoxide has been removed prior to entry in the reference cell. Because of the highway proximity, a 0-50 ppm range was selected for the analyzer corresponding to 0-5 VDC output to the computer. Tests performed at the site indicated a 60 sec. rise time to reach 100% concentration.

The NDIR analyzer also utilized an auto-zero/auto-span module during operation. This is an electronic device which at pre-selected times automatically gates zero gas to the analyzer and corrects the output from the recorder to zero; then gates a calibration gas to drive the analyzer upscale, correcting the output to the appropriate value. An out-of-range circuit is also included in the system and this activates indicator lights when the zero and span counters are at the limits of their count capability. The operator is then required to attend to the instrument.

All calibration gases used were in the range of 40 ppm CO in hydrocarbon-free air, doubly certified and purchased from Scott Environmental Technology Inc. Four intermediate ranges of CO concentrations were also used to ensure linear response of the NDIR analyzers.

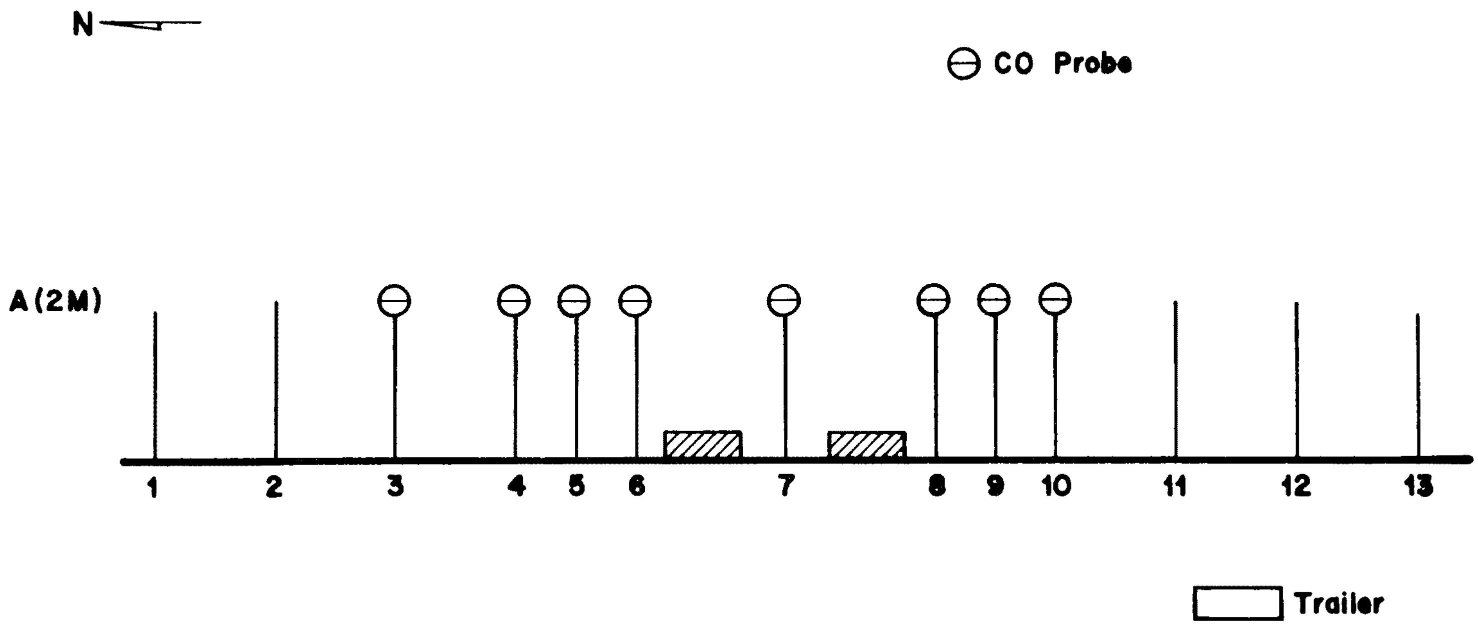


Fig. 4 Modified CO sampling set-up

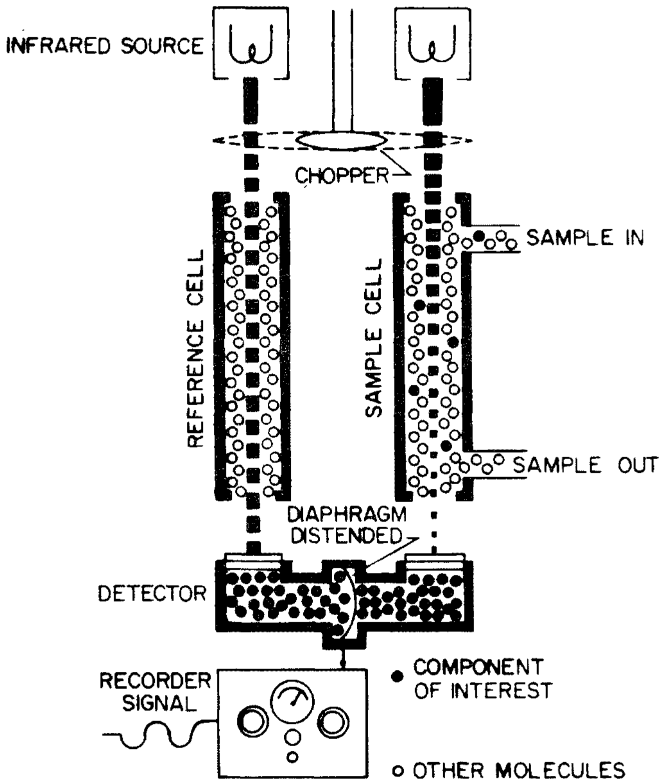


Fig. 5 Functional Diagram of a NDIR

NDIR MODIFICATIONS

During the zero mode, it was noticed that the output generally deviated from the original setting. This deviation occurred even with replacement of the detectors. The NDIRs, as originally configured, had a zero-span cycle time which lasted 25 min. Further, the computer routine did not have the capacity to record negative "zero" output from the NDIR. In order to account for the zero drift, two modifications to the zero-span module's circuitry were necessary.

The first alteration involved the inclusion of a potentiometer into the zero-mode circuitry of each NDIR. These were mounted external to the NDIRs. Each potentiometer was adjusted until a voltage of 250 mv was obtained across the circuit, which allowed the zero-mode output of each NDIR to be set initially to 250 mv. Thus, a downward decline, corresponding to -2.5 ppm, was still sent out as a positive signal. The span adjustment was also set 250 mv higher than before to obtain linearity throughout the range. Raising this zero setting allowed the measurement of zero drift below the set zero without increasing the computer memory storage space, which would have been required for negative voltages. Most zero drifts were confined to $\pm$ 0.5 ppm.

The second modification was also necessitated by the zero-span module and the computer recording scheme. Both the zero and span cycles consisted of two phases. During the first phase, the module monitors the current uncorrected value of either zero or span. The circuitry adjusts for any drift from the pre-set values during the second phase and outputs a corrected value. These values are necessary for data reduction in order to establish the true zero level for each of the detectors. An external switch which allowed the selection of either a short or long time interval was attached to the cycle time circuitry of the zero-span module. This facilitated manual adjustment of the NDIRs when needed.

The short zero-span cycle lasted a combined length of 5 min. and was used during correction of malfunctions of the analyzer. The longer zero-span cycle lasted 50 min., and required the insertion of additional resistors to the time constant circuitry. This position was the normal setting for the switch. By increasing each (zero and span) cycle time to approximately 25 min., the computer was able to record both the initial value and its final value, regardless of when either cycle started. The long time was required because of the averaging routine used for the vertical profile system. The design of the vertical profile system is described in this section.

All NDIRs were automatically set to zero and span three times daily at 4 a.m., noon, and 8 p.m. These times were selected so that monitoring during heavy traffic periods would not be interfered with. If a NDIR was not operating properly, it was run twice through the short cycles before manual adjustments were made. Normally the instrument corrected itself before manual adjustments were necessary. After using the short cycle, the switch was rethrown and the instrument was run through a long-cycle, so that the computer could record the outputs.

AVERAGING CHAMBERS

Rapid changes in CO concentrations were observed over short time periods which were not compatible with the computer monitoring system. Although these variations reflected the actual conditions, they caused inaccuracies in the ten minute averages. This problem was apparent when comparing the four reported values on the computer output for a common sampling point. The eight instantaneous readings were insufficient to reflect the true integrated average over the time period. To alleviate this problem, various size averaging chambers were tried. It was found that 1 gal. bottles produced the best results for the flowrate used. This volume was large enough to damp out spikes, and yet small enough not to mask longer changes. Therefore, averaging chambers were fabricated for all sampling points.

Averaging chambers were particularly useful for successful implementation of the vertical profile system, since only two readings per sampling point were taken in the 10 min. interval. The profile system incorporated sampling points: 9A, 9B, 9C, and 9D (Fig. 6). Using a single NDIR, which eliminated systematic differences between analyzers, consistent measurements of the small difference in concentration between points 9A and 9B were obtained using the averaging chambers.

Fig. 7 is a flow diagram of the profile system. The collector tank was used for the profile system. Each sampling line led to an averaging chamber. The destination of the flow from the exit port of each was controlled by a three-way solenoid. During any given time, only one solenoid was activated. Flow through this sample line was then drawn by the NDIR pump for analysis. Flow for the other three lines was drawn by the main pump through the collector. All flowmeters were set for a pressure corrected flowrate of 1.7 l/min. Therefore, whether the sample was being analyzed or not, the flow through the averaging chamber was maintained constant.

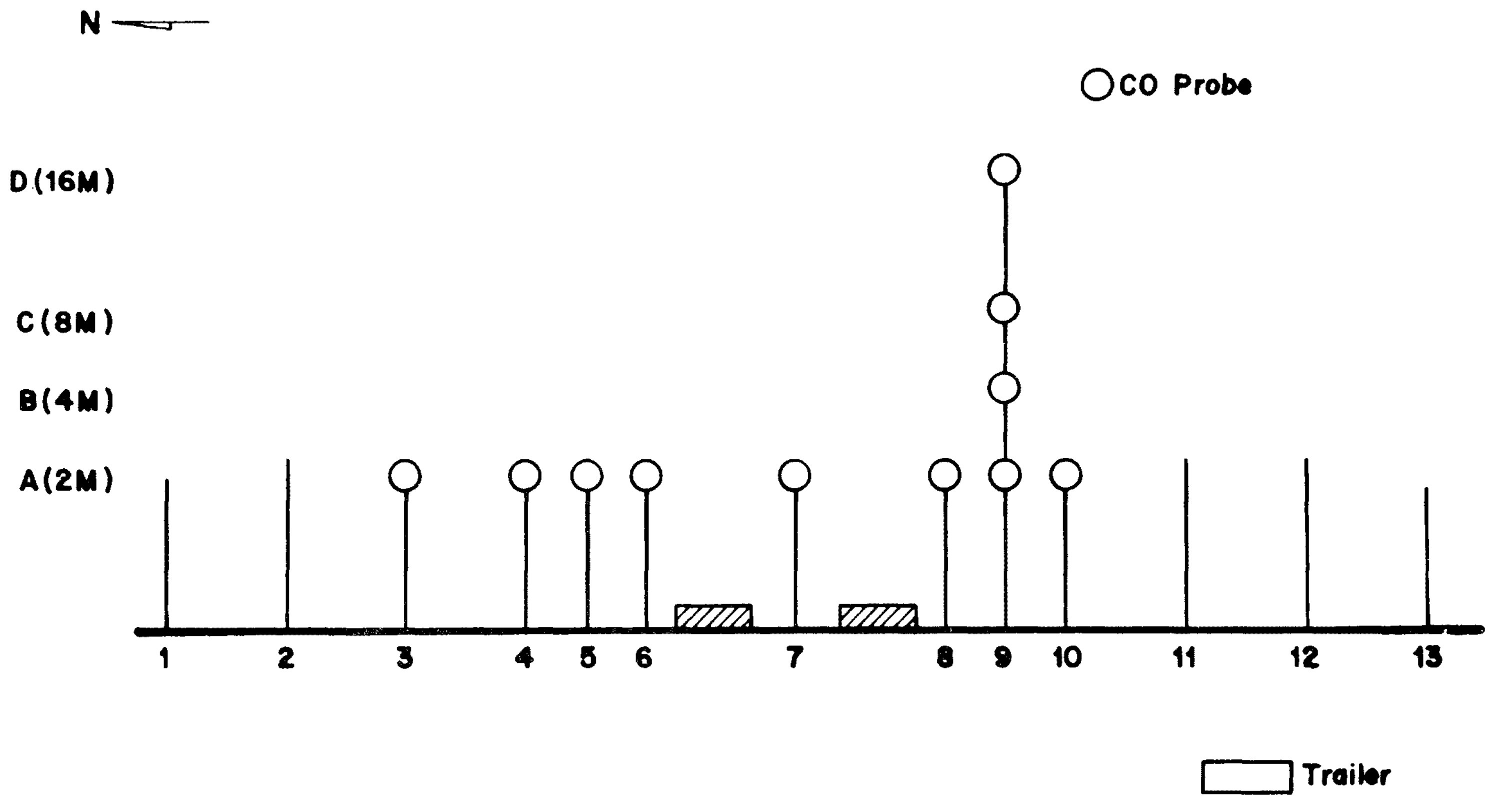


Fig. 6 CO Sampling system with the vertical profile system

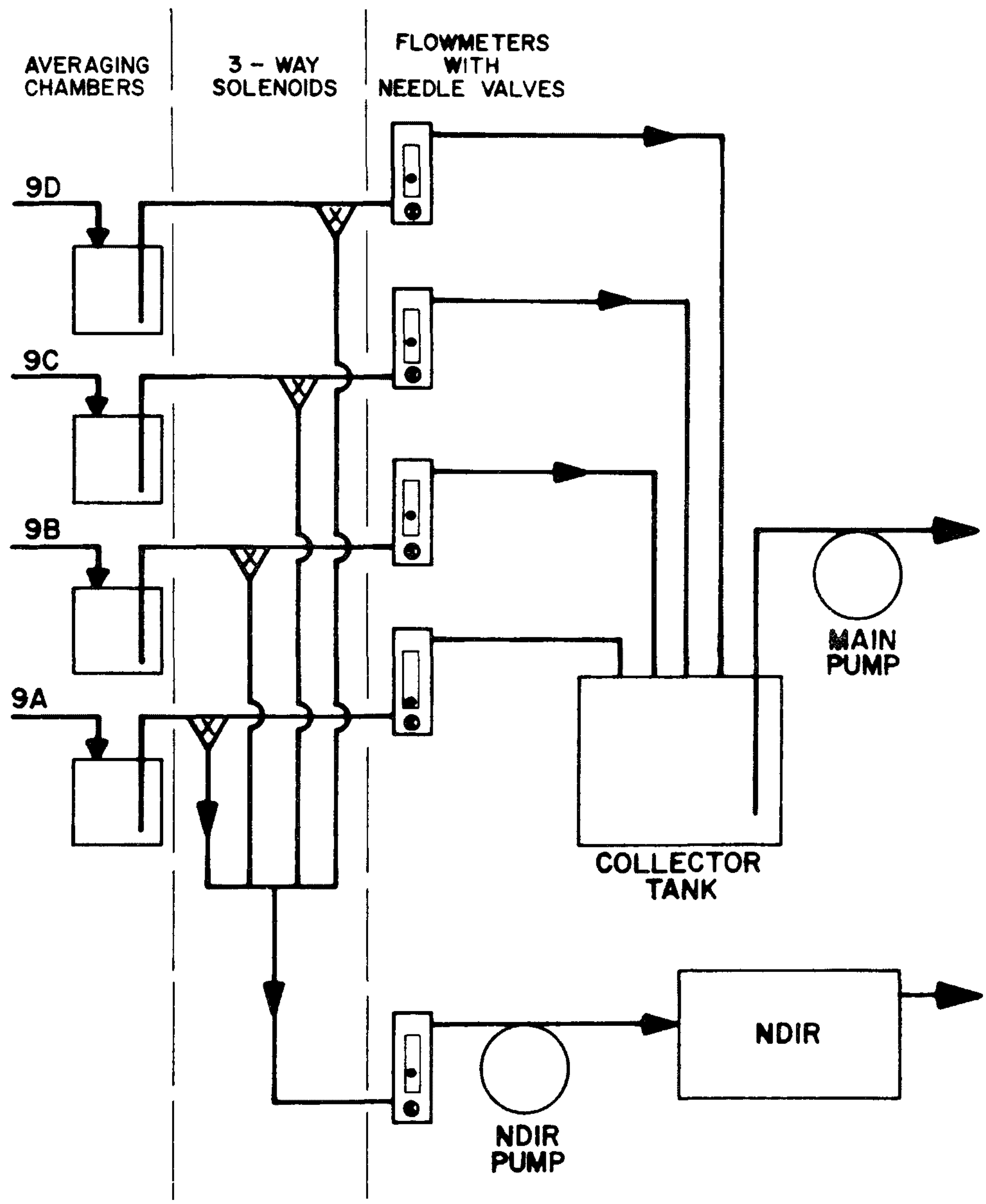


Fig. 7 The flow diagram for the vertical profile system.

SECTION 4

PARTICULATE DATA COLLECTION

DESCRIPTION OF THE SAMPLER

Eight dichotomous samplers were custom-designed for this study by the Environmental Research Corporation. The samplers had a nominal sampling rate of 50 l/min and were capable of sampling from a 2 to 8m height. Fig. 8 shows the location of samplers. The dichotomous samplers collect airborne particulates in two size ranges ($<3.3\mu m$ and $>3.3\mu m$) on separate filters. Fig. 9 is a schematic of the sampler flow system. Particle separation is achieved by means of a two-stage virtual impactor. The virtual impactor draws its sample isokinetically from a 200 l/min flow stream from which particles greater than 18μm have already been excluded. This removal is done via an auxiliary flow (20 l/min) around the perimeter of the sampling head. Particles above the cut-off point size (3.3μm) flow directly through the central nozzle of both stages of the impactor and are collected on the coarse particle filter. The major portion of air sample is deflected around these nozzles and contains the particles below the cut-off point which are subsequently deposited on the fine particle filter. Flow tubes after the virtual impactor create a uniform deposition across both filter faces. Flow through the sampler head and its auxiliary flow is produced by a standard hi-vol blower. Differential pressure gauges are used to monitor these flows. A retention filter covers the blower discharge so that these particulates and the carbon worn from the brushes will not bias the sample being collected. The top of the sampling head has a circular, lipped cover which prevents rain, snow, and road salt-sand from entering the sampling train. Flows through the virtual impactor are drawn by a carbon vane pump. These flows are monitored by rotameters, while needle valves are used to set the proper flowrates. The system is designed for flowmeter readings of 1.7 l/min for the coarse particle stream and 48.3 l/min for the fine particle stream. The coarse particle flow operates near atmospheric pressure, while the fine particle flow is at 7 psig vacuum. Therefore, the actual flow corrected for pressure for the fine particle stream is 35.3 l/min.

The sampler head, virtual impactor, filter assembly and blower are contained in a single unit which can be raised if a sampling height greater than two meters is desired. A metal plate with a ring welded to the upper surface was attached to the top of the sampling unit by three steel rods. The plate allows the sampler to be raised, as well as providing additional protection to the sampling head from rain and snow. The virtual impactor pump, flowmeters, gauges and elapsed time indicator are housed in a control box on which the collection unit normally rests.

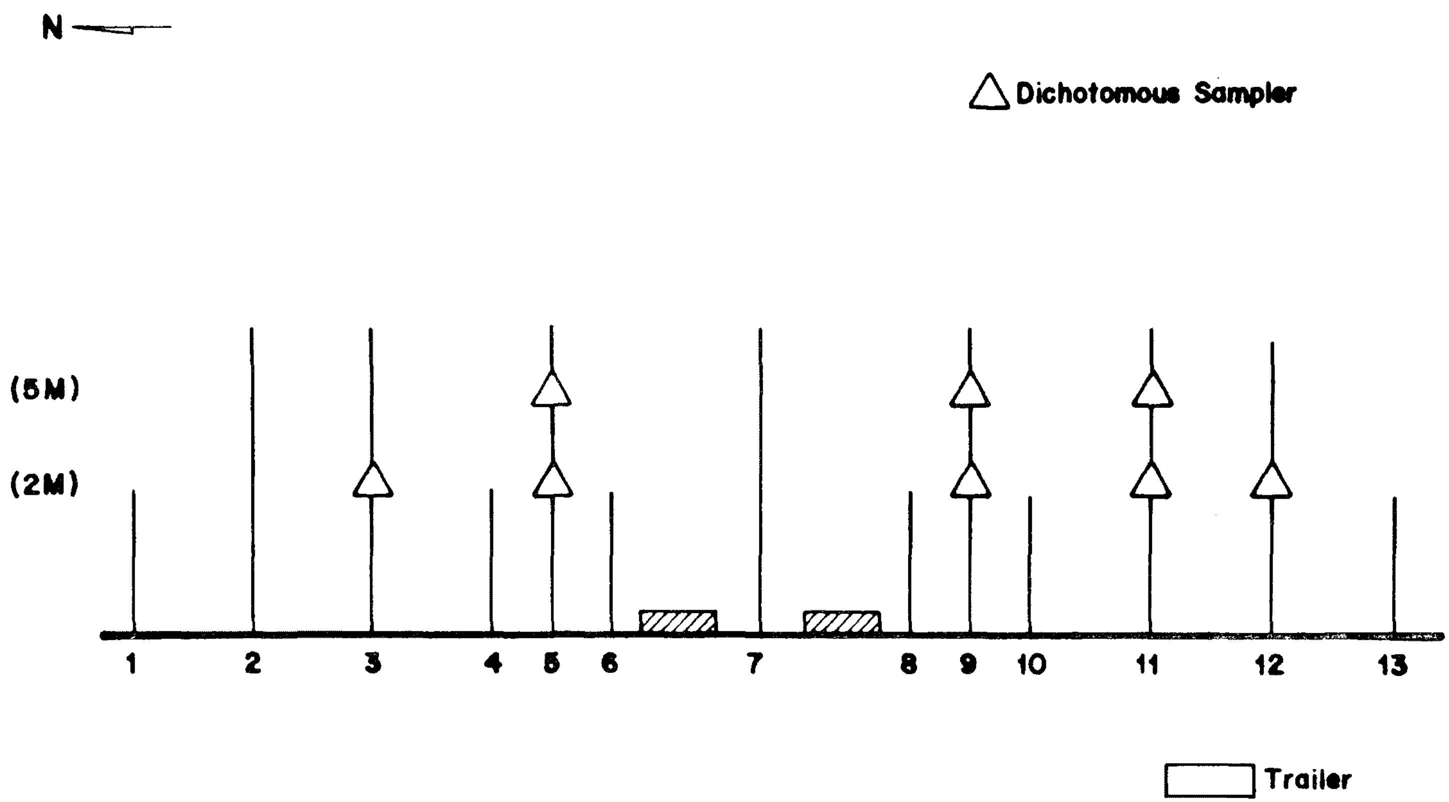


Fig. 8 Dichotomous sampler location in the sampling plane

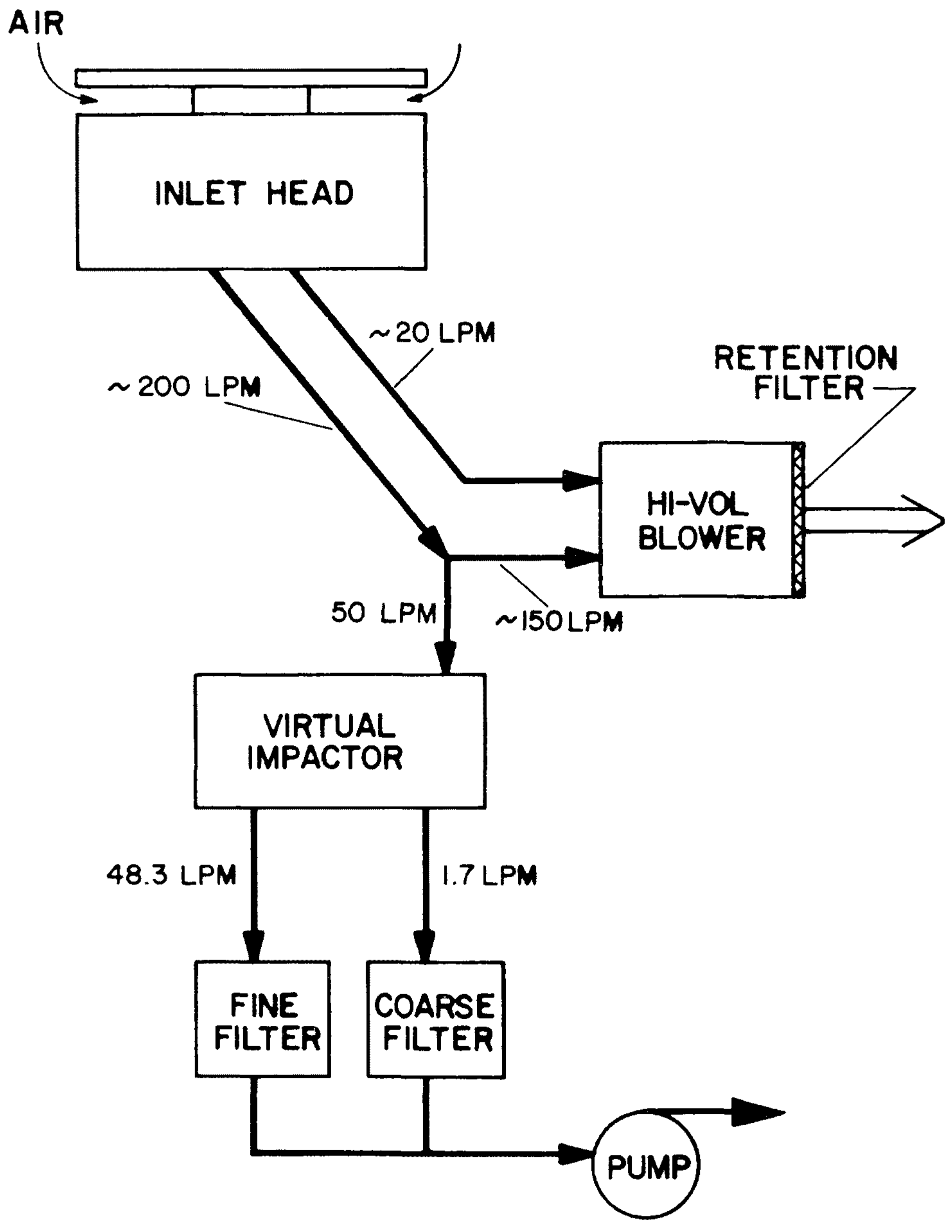


Fig. 9 Dichotomous sampler flow pattern

Millipore Fluoropore filters (0.5μm pore size, 47mm diameter) were used for sample collection. When enclosed in the sampling ring, the exposed diameter is 40mm. This gives an effective deposition area of 12.6 cm^2. An O-ring imbedded in this filter holder prevents both sideway leakage through the casing as well as cutting of the filter membrane.

The cut-off point of each sampler was determined by the manufacturer before delivery of the equipment. These tests were performed for aerosols of 2, 3, 4, and 5μm in diameter at a 50 l/min flowrate. The percent of aerosol concentration on each filter and the overall losses for each of these size particles was calculated. Fig. 10 is a composite diagram for all samplers. For individual samplers, the 50% cut-off point for coarse particles varies between 3.2μm and 3.35μm as determined by interpolation. As can be seen from this figure, losses are of the order of 5% for aerosols between 2 and 5μm diameter.

For two samplers, the cut-off point was estimated for flows of 40 and 60 l/min as well. Fig. 11 shows these results. As can be seen, collection efficiency decreases as the flow varies from the design rate. The cut-off point also shifts inversely with a change from design flow.

Preliminary Tests

Before the samplers were deployed along the sampling plane, all of them were stationed at Tower 11 to determine consistency of operation and comparability between the samples from different units. Ten runs were made with all samplers operating at approximately the same distance from the highway. Sample periods of 60 to 150 min. were tried.

The first five runs were made with all settings initially at manufacturer specifications. The fine particle air stream flow dropped 5 to 10% during the sampling period, while the coarse particle air stream flow sometimes rose by 6%. The sampler head flow varied ± 15%. These changes occur because the samplers have no flow controller to compensate for filter loading, or changes in ambient conditions.

Since the minimum flow rate through the sampling head is critical, the decision was made to set all the samplers at an initially high setting to ensure that the flow never went below the allowable limit. It was decided to set the fine particle flow 3 percent higher than the design flow, so that it would drift down through the design setting. Since the coarse particle flow remained the same or increased only slightly, the setting for the coarse particles was left at the design rate. Setting the fine particle flow initially high allows the sampler to operate usually within ± 3% of the design rate for the entire sampling period, while the average flow remains within ± 2% of the design flow. Referring back to Fig. 10, it is apparent that this operation minimizes cut-off point shift and particle losses.

The second set of five runs was performed with the above changes in initial flow settings. Flow readings were recorded every half hour during these runs. Sample air volumes computed by taking only the end-points were compared to the average volume computed from these and the intermediate values.

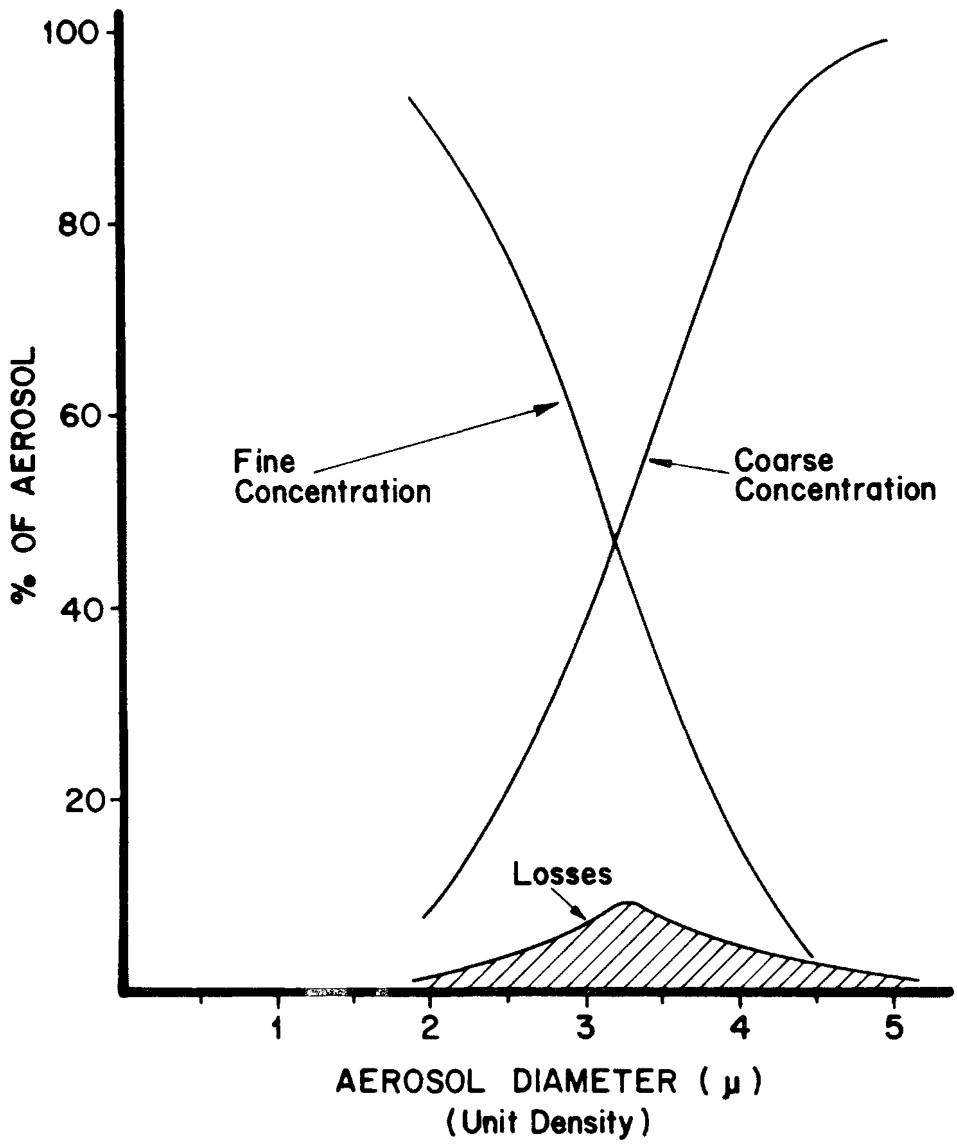


Fig. 10 % of aerosol concentration and overall losses

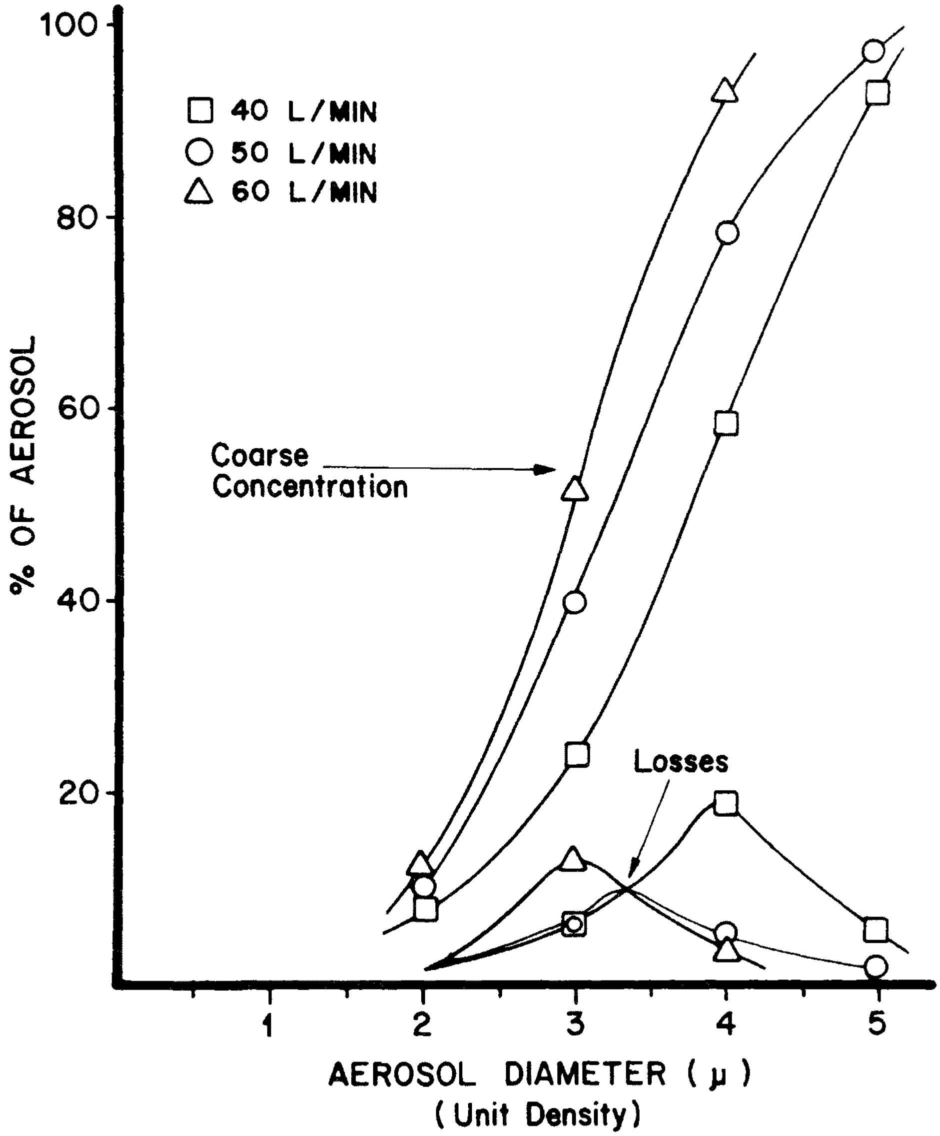


Fig. 11 % of aerosol concentration for different flow rates.

The largest difference between these two methods was 2%. Therefore, it was decided that taking start-up and shut-off readings would be satisfactory.

All filters were returned to Albany for laboratory analysis. Comparison of results between different sampling intervals led to the conclusion that a two-hour sampling period yielded overall the most satisfactory results. This was a compromise between the need to minimize the variation of traffic, wind, and flow rates during sampling, scheduling of other duties at the site, and collecting a satisfactory filter loading.

Iron pipe (2 1/2" OD) was used as booms for the three elevated sampling points. A pulley was attached to the boom 1m from the tower. The samplers were raised by means of nylon rope to a height of approximately 5m.

SAMPLING PROCEDURE

Table 3 is a copy of the log sheet used for sampling during the study. On this sheet, "S" stands for the "small" (fine) particle filter, while "L" denotes the "large" (coarse) particle filter. Each filter was pre-weighed in Albany and placed in a self-locking plastic petri dish. The shallow height of these dishes restricted the filters from curling and prevented the filter surface from touching the dish surface. Each dish was alpha-numerically labelled and sequentially packaged (e.g. 1A to 90A, 1B to 90B, etc.). The drawing in the upper right is a representation of the filter ring cassette. Even numbers were used exclusively for the coarse particle filters, while odd numbers were used for the fine particle filters. Filters were used sequentially. This convention was adopted as an aid in keeping track of the filter placements by the operator during sampling. Filters were mounted in and demounted from the filter rings inside the trailer. All filter placements and removals were done with the use of tweezers. If the filter was contaminated for any reason during these procedures, it was discarded.

All filter cassettes were put in the samplers and the elevated samplers raised into position before the first sampler was turned on. As each sampler was started, the flows were set at the values indicated on the sheet. "L Mag" refers to the differential pressure gauge on the left side on the control unit. This gauge measures the flow through the sampler head. "R Mag" is the differential pressure gauge on the right side, which measures the auxiliary flow. These flows were controlled by a common voltage control to the blower.

While all the samplers were in operation, each was rechecked to ascertain that all flows had their proper settings; if not, adjustments were made. Due to the distance between samplers and the need to cross the highway, most runs were done with an operator on each side. It usually took less than 5 min. between start-up of the first sampler and the last. If only one operator was present and traffic was heavy, this interval increased to about ten minutes.

During set-up, the date, weather condition, general wind direction, sampler locations, and time of day of start-up of the first sampler were noted. The elapsed time indicator was also reset to zero. At the conclusion of sampling all final flow readings were recorded as well as the duration of sampling. The samplers were shut off in the same order as they were started. The time

TABLE 3. LOG SHEET USED FOR THE DICHOTOMOUS SAMPLER

(L) EVEN
(S) ODD

DATE: ____________ WEATHER:

OPERATOR: ____________ TIME PERIOD: ________ TO ________

	Filters	Gauges	Initial	Final	Comments
1	S ( )	L Mag (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (SCFH)	105 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
2	S ( )	L Mag (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (SCFH)	105 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
3	S ( )	L Mag (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (SCFH)	105 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
4	S ( )	L Mag (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (SCFH)	105 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
5	S ( )	L Mag (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (SCFH)	105 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
6	S ( )	L Mag (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (SCFH)	105 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
7	S ( )	L Mag (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (SCFH)	105 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
8	S ( )	L Mag. (in. H_2O)	1.9 ( )		
	L ( )	R Mag (in. H_2O)			
	Position ( )	Sm. Flow (LPM)	50 ( )		
	Time ( )	Lg. Flow (LPM)	1.7 ( )		
	Wind Direction	2A			
		12A			
	Wind Speed	2A			
		12A			

of day when all sampling had ended was recorded. At this point, the elevated samplers were lowered and all filters were collected and returned to the trailer.

The sampling times were usually within the range of 120 ± 10 min. although intervals as low as 90 min. and as high as 150 min. occurred occasionally due to the necessity of performing other activities at the site. The difference in time between samplers in any particular run normally ranged no more than 5 min. between the longest and shortest period.

Field Sampling

Cross-plane sampling was divided into two phases. The first phase consisted of 71 runs, including the tracer study periods. All filters used during this phase were pre-weighed in Albany and returned for subsequent analyses. Generally, two runs per day were made. The first run in the morning began around 9 o'clock, while the second was started in the early afternoon about 2 o'clock.

The second phase of field sampling, consisting of 165 runs, differed from the first in two major ways. Because of the low concentrations being collected on the coarse particle filters, generally below the detection limit of the x-ray fluorescence analyzer, these filters were no longer analyzed after sampling. The second difference was the time scheduling of runs. Arrival times at the site by the field personnel varied from 6:30 a.m. to 9:30 a.m. An early arrival allowed the first sampling period to end before the morning rush hour traffic started to decline. Inversely, a late arrival allowed the second sampling period to start after the onset of the afternoon rush-hour traffic. Incidentally, the term "rush-hour" is a bit of a misnomer when applied to the site since it generally lasted three hours.

Five runs during the second phase were made for special studies by the New York State Department of Health. Sampling times of 30, 60, and 120 min. were used during one day, preceded and followed by overnight runs of 1,000 min. Nuclepore filters with a 0.4μm pore size were used during this period. These filters are being analyzed for trace metals and particle size.

Sixteen additional runs were made at the conclusion of the study with all the samplers again stationed at Tower 11. This was done to gather more data to be used for error analysis, as well as to ascertain whether the samplers had undergone any major changes in their sampling characteristics due to maintenance.

SECTION 5

TRAFFIC DATA COLLECTION

Vehicular counts by vehicle length and speed categories were obtained from each lane of the highway by means of induction loops and ancillary electronics. These were then stored in the computer and every 10 min an output typed out for each direction, containing the total number of vehicles according to speed/length category. Once a week, time-lapse movies of the traffic were made to determine the age composition of the vehicles as well as to provide a check on the electronic traffic monitor. Visual counts were carried out by field personnel when deemed necessary.

A pair of induction loops were imbedded in each lane of the expressway. The separation between the pair was 11 feet. A control box on each side of the roadway was used to house the loop detectors (Streeter Amet Model 740 with solid state output). The signal from the loops was carried to the trailer via multiple pair shielded cable. Line driver/receiver circuitry in the trailer served as an interface with the computer.

The computer polled each loop for vehicle presence every 16.7 milliseconds. If the up-stream loop indicated a vehicle was present, the computer measured the time interval until the second loop came on, as well as the total time the first was on. Since the distance between the loops is known, the vehicle speed can be calculated. Using this speed, the vehicle length can be calculated. This speed-length measurement was then stored in a 10 x 5 array as shown in Table 4.

Problems were encountered with the sensitivity setting of the loop detector. This was inferred when traffic counts printed out by the computer were suspected to be low or when one of the length categories had too many or too few vehicles. Then, adjustments of the detectors were made and visual traffic counts were undertaken to ensure that the corrections were in the right direction.

A total of 32 time-lapse movies of the traffic were taken during the study with a photographic system, manufactured by Time Lapse Incorporated. The camera was set at a speed of 4 sec a frame. The camera operates via a rechargeable battery with an internal clock and the film cassette used would run for 4 hr uninterrupted. The camera was mounted on the overpass bridge of Pinelawn Road (see Fig 1). Either direction of traffic flow could be photographed. Only days which were not cloudy, rainy, or foggy were useful for photography. Before each run, the first few frames of the film was exposed to a date and direction sheet; once the camera is started, with the internal clock set, it registers the time of the day on each of the frames. After the run was over, the camera was brought back to the trailer for recharging the battery and the film was sent out for professional development.

TABLE 4. LENGTH & SPEED CATEGORIES

Vehicle Length(s) (ft.)	Speed (mph)
< 11	Stalled
11 - 24	Stalled - 5
24 - 35	5 - 10
35 - 46	10 - 15
> 46	15 - 20
	20 - 30
	30 - 40
	40 - 50
	50 - 60
	> 60

SECTION 6

METEOROLOGICAL MEASUREMENTS

Meteorological data were collected from a total of 17 instruments. These are:

5 CI-3 wind system 1 CI-25 wind system 1 CI-18 wind system	manufactured by Climet Instruments Co.
4 Gill UVW's	manufactured by R. M. Young
2 Temperature difference sensors 1 Temperature sensor 1 Humidity sensor 1 Rain accumulator	manufactured by Meteorology Research, Incorporated
1 Pyranometer	manufactured by Spectrosun

The wind instruments were mounted on the tower by means of a 2 1/2" x 5' iron pipe clamped with U bolts. Attached to this was a 90° reducer to 1" from which a 1" x 2' pipe extended vertically to support the equipment. From each of the supporting beams a 2/0 copper wire was attached to a grounding rod driven at the base of the tower for removal of static charges, accumulated on the towers.

CLIMET INSTRUMENTS

The five CI-3 wind measuring systems with translators and Esterline-Angus chart recorders were obtained on loan from USEPA in Research Triangle Park, North Carolina. The CI-25 was purchased from the manufacturer to complement the CI-3's. Both models were designed by the manufacturer so that the anemometer and the vane are separated by a 3 1/2 ft bar. This bar was in turn mounted on the vertical 1" pipe. A four-lead shielded cable connected the wind speed measuring heads on the towers to the translators in the trailer, while a three-lead shielded cable was used for the directional heads. The principle of operation of the CI-3 and CI-25 is similar. The anemometer which measures the wind speed consists of a cylindrical slotted drum which alternately masks and exposes light from a lamp to a photo diode, producing pulses at a frequency proportional to the rate of rotation of the propeller. These signals are then sent to the translator for conversion to a D.C. analog. Horizontal wind direction is measured by the 0-360° wind vane system. The stem of the vane system is coupled to a 10K-100K high precision potentiometer, which produces an output corresponding to the attitude of the directional vane. The wind vane systems were calibrated to output 0-5VDC for a directional range of 0-360°. However, it was noted that this 0-360° capability of the CI-3's and CI-25 posed a problem of ambiguity and error when the vane fluctuates between the fourth and first quadrant. The analog output will be 5V for 360° but OV for <1°. On averaging this, the computer would yield 2.5V (180°) or a direction directly opposite that from which the wind came. One solution was to handle the problem via the computer program, but due to the limited core capacity it was decided to purchase a Wind Direction Translator from the Climatornics Corporation. Wind direction signals from the sensing vanes of all CI-3's and the CI-25 were diverted to this translator, which contained the logic for converting 0-360° transmission to a 0-540° signal at a low impedance output of 0-5 VDC. Data integrity of the wind vane systems was achieved by orienting the vane until a 0 VDC output was read. The vane was then taped and mounted on the tower receptacle pointing to geographic north. The orientation of the vane was done with a transit taking into account the declination angle of 12°15" and the known orientation of the line of sampling towers. Calibration of wind speed for both the models was done such that 0-5 VDC corresponded to 0-50 mph.

Model CI-18 was on loan from SUNYA. Because of its age and prior use, some of its components malfunctioned and it was returned to the factory for repairs on two occasions. Even with much expenditure of resources and man-time the instrument failed to perform satisfactorily. Eventually, all attempts to obtain data from point 12A with the CI-18 were abandoned.

GILL UVW INSTRUMENTS

The Gill UVW anemometer is a three component wind instrument designed for direct measurement of the 3 orthogonal wind components (east-west, "U"; north-south, "V"; and vertical, "W"). Three helicoid propeller sensors are mounted at right angles to each other on a common mast, with sufficient separation between propellers so that there is no significant effect of one upon another for all normal wind measurements.

Four Gill UVW's were used at the project site. When in operation, a miniature 2400 mv DC generator attached to each propeller shaft provides an analog voltage output which is directly proportional to wind speed (a signal of 5 VDC corresponds to 20 m/sec). A two conductor cable relayed data from each sensor to a custom made UVW translator in the trailer. This unit was capable of providing signal conditioning and filtering from the 4 UVW anemometers. The output signals were then fed into the back panel of the computer.

Bi-polarity is required since the anemometer measures forward and reverse air flows; when the propeller rotation reverses, the polarity of the generator also reverses. Response of the propeller as a function of its orientation to the wind vector closely approximates the cosine law. However, since this response is not exact, correction was made for all data points using an algorithm developed by Horst (1971).

Calibration of the UVW's was done by means of a unit with a calibrated 1800 rpm rotation connector shaft. The shaft was attached to the propeller mounting rod by means of a short tubing, and rotated in each direction in turn. At 1800 rpm's the trim potentiometer of the horizontal components were adjusted to 2.25 VDC to correspond to a 9 m/s wind and the vertical system set to 2.83 VDC for a 11.3 m/s wind.

OTHER INSTRUMENTATION

Temperature and Temperature Gradient

Temperature and temperature difference between two levels were measured with Meteorology Research, Inc. Model 840-2 and 840-1 instruments. The Model 840-2 placed at 4m on Tower 11 has two sensing elements, one for temperature and the other the lower half of a ΔT circuit; Model 840-1 containing the second element for ΔT was placed at 15m.

Each temperature sensor is comprised of a dual thermistor and resistor network, which provides a linear resistance change with an air temperature change. Two dual thermistors are used in the ΔT sensor heads and each works in a separate resistor network. The sensors are shielded by a power aspirated, reflective cylindrical housing which provides a high heat transfer from the ambient air to the sensing element, while at the same time affording protection from incoming short-wave radiation and outgoing long-wave radiation. The rate of air flow is approximately 15 f/sec.

Ranges for the sensors are -30^{o} to $+50^{o}C$ for temperature and -3^{o} to $+3^{o}C$ for ΔT. Signals from both ΔT elements were transferred via cables to the transmuter, where a circuit card converted the resistance difference to a proportional DC output. The transmuter output for both T and ΔT was 0-5 VDC corresponding to the ranges indicated above.

Relative Humidity

A Meteorology Research, Inc. Model 840-7 humidity sensor was placed on top of the trailer for measurement of relative humidity. The element, placed within a power aspirated, reflective cylindrical shield, is exposed to a constant flow of air. The sensor is made from an assembly of organic and inorganic crystals which detect moisture by the hydromechanical stress of cellulose crystallite structures acting on a pair of thermally matched, unbounded silicon strain gauges connected as half of a Wheatstone bridge. The signal from the sensor is fed into a transmuter via a cable. The analog output of the transmuter was connected to the computer back panel. Calibration was done such that 0-5 VDC output from the transmuter corresponded to 0-100% relative humidity.

Precipitation

A Meteorology Research, Inc. Model 302 rain gauge was placed on the roof of the trailer for measurement of precipitation. The instrument employs a 7.86" diameter collector tube whose funnel is 8" below the upper rim for maximum collection efficiency even during strong winds with high rainfall rates and a molded epoxy bucket pivoted on knife edges in Delrin wedges. A water guide over the center line of the bucket assures equal fill and eliminates splash loss.

In operation the rain gauge measures 7.95 cc of water when the bucket over-balances and swings to the other side. A magnet mounted under the bucket passes close to a magnetic switch during the tipping action causing a momentary closure of the switch. This pulse is then relayed directly to an MRI transmuter which, in turn, was connected to a recorder and the computer. Each bucket tip of 7.95 cc of water corresponds to 1/100" rainfall. The system was calibrated such that a 0-1" rainfall corresponded to 0-5 VDC output from the transmuter. The calibration procedure consists of manually tipping the bucket 100 times and accurately adjusting zero and span for outputs.

Solar Radiation

A Spectrosun Model SR-71 pyranometer, on loan from the EPA, was mounted on top of the trailer. Calibration of the instrument was achieved by comparing its output to that of a recently factory calibrated standard, a Model 8-48 Eppley pyranometer with a Model 1040 Transmation digital potentiometer. Both pyranometers were exposed to sunlight simultaneously and a digital potentiometer was used to measure their output in millivolts. To ensure proper calibration, several readings were taken during early afternoon. A calibration correction factor K is obtained from the following equation:

$$K = \frac{\text{mv (station sensor)}}{\text{mv (standard sensor)}} \times \frac{\text{calibration of standard sensor mvc}}{\text{present calibration of station sensor mvs}}$$

The objective was to calibrate the system for a full scale range of 0-2 Langleys. The calibration against the factory calibrated standard sensor showed that 2 Langleys corresponded to a sensor output of 10.16 millivolts. The sensor signal was connected directly to a strip chart recorder calibrated for a full scale sensitivity of 10.16 mv and a retransmitting slidewire stepped up the voltage range to 0-5 VDC before transmitting it to the computer.

SECTION 7

TRACER GAS EXPERIMENTS

One of the important variables in the dispersion models is the source strength. Since the gaseous and particulate emissions from the vehicles cannot be estimated accurately, measurements of source strength were made using sulfur hexafluoride, SF_6, as a tracer gas on the expressway. Knowing the source strength and concentrations of SF_6 and CO at various locations adjacent to the highway and assuming that the dispersion of SF_6 is similar to that of CO, one can estimate the source strength of CO. The experiments were conducted during three week-long periods during October and November, 1976. Altogether twenty-three runs were performed.

FIELD SET-UP

Sampling Train Set-up

The sampling train consisted of a battery operated pump connected to a five layer snout type mylar bag via an acrylic rubber tubing and a short length of tygon bubble tubing. The pumps, bags and the bubble tubing were manufactured by Calibrated Instruments, Inc. The pumps, having a flow rate of approximately 0.7 l/min, were mounted at the locations shown in Fig. 12. The wiring of the pump was modified so that the batteries and switch required for operation were external to the casing. Between the acrylic tubing coming down from the pump and the sample bag, the bubble tubing was inserted firmly and taped to ensure no leakage. This sample collection scheme is shown in Fig. 13. The sample bags were then placed in heavy duty garbage bags which were inside large plywood boxes. This was done to protect the sampling bags from the wind and other factors that could cause damage. Once all the bags were labelled and placed in position, the pumps could be turned ON/OFF by switches located on the ground. The capacity of the bags was 44 l which corresponds to about an hour of sampling. Once the run was over, the bags were separated from the bubble tubing and the snout was folded and taped. All the bags were then collected and brought back to the trailer for analysis.

Tracer Gas Release Set-up

Six 1976 Plymouth Fury station wagons were used in this experiment. A T-size cylinder containing 99.9% pure SF_6 gas was placed on the floor of each vehicle. The cylinder was blocked by wooden cradles with rubber trimmings so that no lateral movements were possible when the vehicle was in motion or came to an abrupt stop. A single stage regulator connected to the cylinder was used for 'coarse setting' of the SF_6 release rate and for monitoring the tank

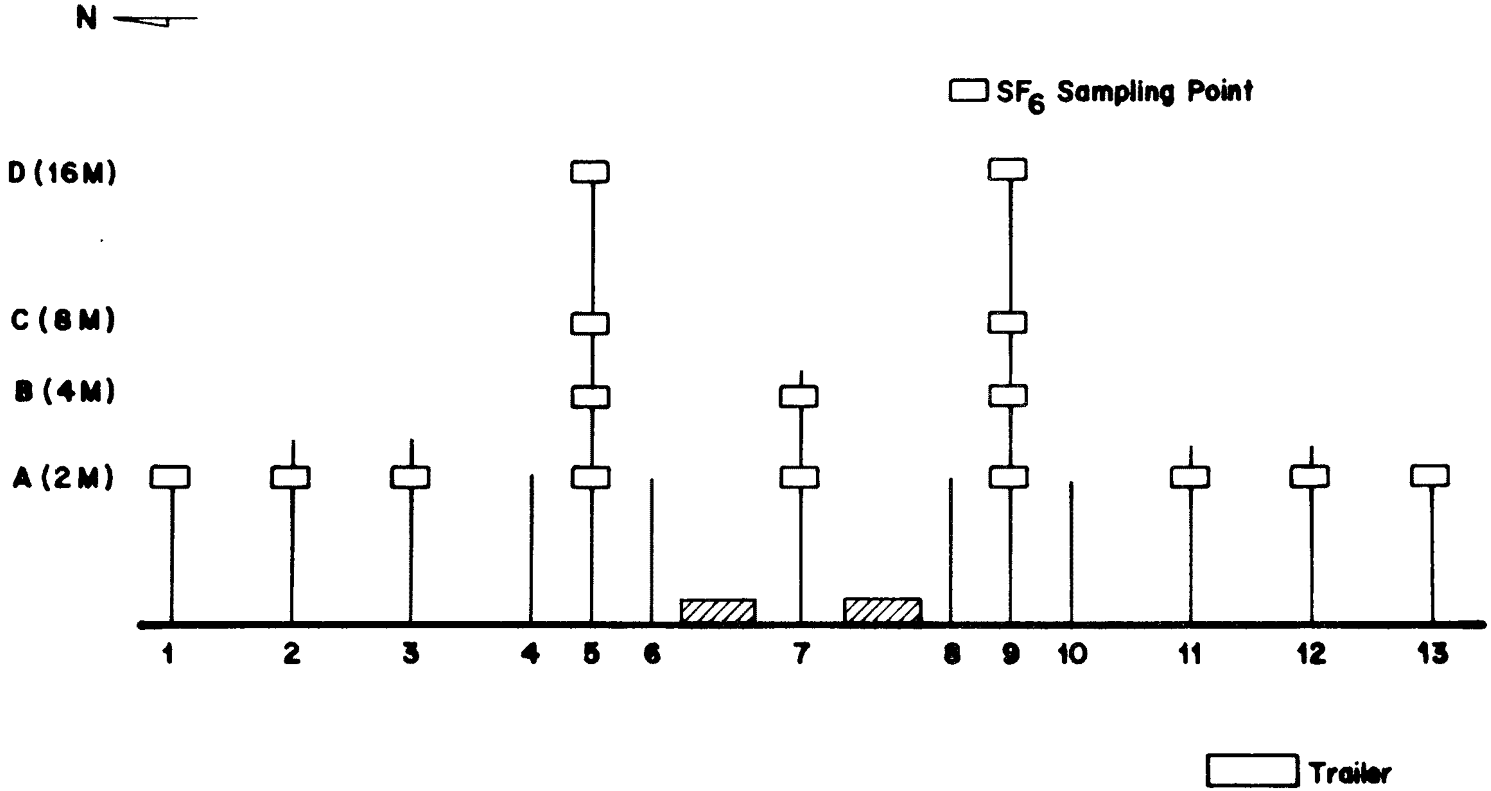


Fig. 12 Sampling locations for SF_6

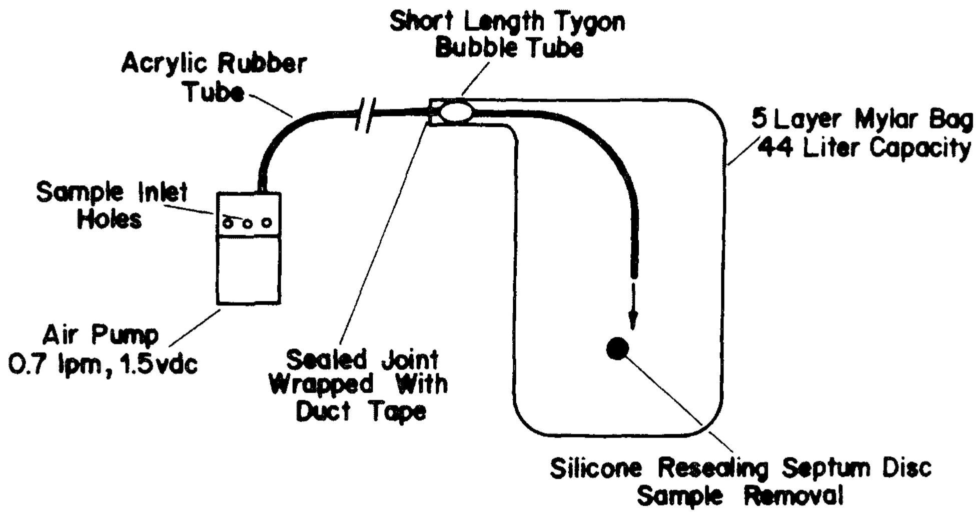


Fig. 13 SF_6 sample collection

pressure. This, in turn, was connected to a pressure gauge and flowmeter, which had been calibrated by Brook's Instruments, Inc., to operate at 75 PSIG. These units allowed 'fine setting' of the SF_6 release rate. One end of a 1/4" diameter copper tube was connected to the flowmeter and the other end was brought through the window of the vehicle to a point near the vehicle's exhaust pipe. The tubing was firmly taped to the vehicle's body. This is shown schematically in Fig. 14.

Procedure for Release of SF_6

The route of the tracer release vehicles is shown in Fig. 15. Two persons were assigned to each vehicle and the driver was instructed to drive at 55 mph in the middle lane while the second person released the tracer gas between the two bridges and recorded data in the log as shown in Table 5.

Prior to each run, the vehicles were lined up near the on-ramp at Exit 50 for leak checks and instructions on the flow rate setting. Once the calibrated pressure gauge and the flow meter readings were set at the prescribed level (3.6 SLPM), valve #3 was closed, and the vehicles were ready for the experiment. The vehicles departed at intervals of one-and-a-half minutes, and the tracer gas release controlled by opening or closing valve #3 (see Fig. 14). In the event the vehicles became bunched up due to heavy traffic, the vehicles would wait at the on-ramp of Exit 50 and restart to maintain the timed separation. This was done to ensure the creation of a constant line source between the release and end points on the roadway. At the start of the experiment, personnel were stationed on either side of the highway and the median strip to turn on the switches of the sampling pumps simultaneously when the second vehicle was abeam to the sampling plane on its return lap. This was done to ensure adequate dispersion of the SF_6 along the highway in both directions. The sampling was continued for one hour at the end of which one of the ground personnel signalled the shutting off of the pumps, and the end of the run to the vehicle personnel.

SULFUR HEXAFLUORIDE ANALYSIS

The analysis was performed with a portable electron capture Gas Chromatograph (A.I.D. Inc., model 511-06) in conjunction with a programmable Supergrator II integrator (Columbia Scientific Industries) and an Esterline-Angus millivolt chart recorder. The chromatograph was tested in the laboratory at Albany before it was taken down to the test site. The carrier gas used was argon with 5% methane, with a flow rate of 30 ml/min which corresponds to a head pressure of 13 PSIG on the G.C. The oven temperature was 55°C. The G.C. was switched on for at least 12 hours before it was used so as to establish thermal equilibrium between the oven, injection port and the detector.

A stainless steel 1 ml sample loop was used for the sample injection with the column size being 6' x 1/8" stainless steel molecular sieve 5A° and 45/60 mesh. The retention time for the sample was about 0.8 min. This was confirmed by injecting ultra pure N_2 gas.

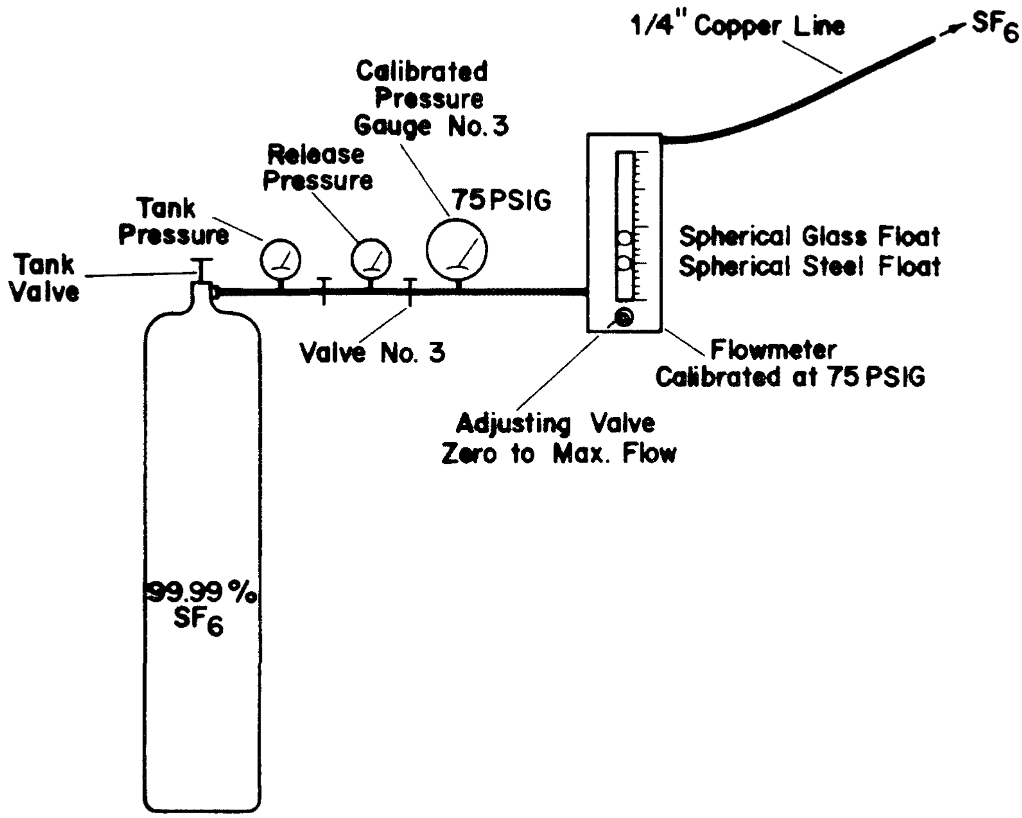


Fig. 14 Schematic of SF_6 gas release set-up

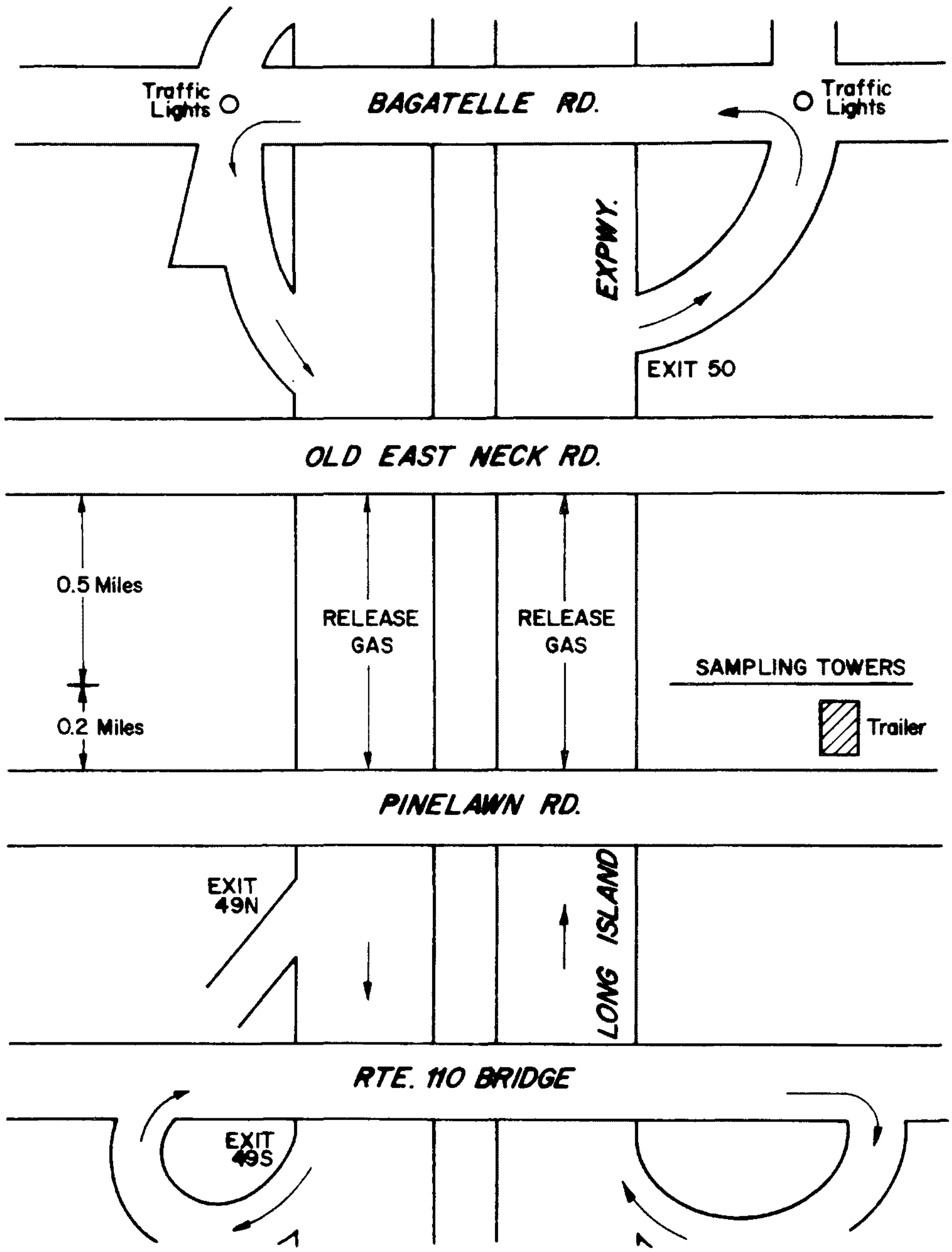


Fig. 15 Route for the tracer gas release

SHEET #___of___

TABLE 5. RESEARCH ON AUTOMOBILE POLLUTANT DISPERSION

SF6 TRACER STUDY

DRIVER____ OPERATOR____ CAR #___ DATE____ TEMPERATURE MAX____ (CAR) MIN____

TANK #____ RUN #____ FLOWMETER #____

TIME (LOCAL)	DIRECTION E/W	LANE	DURATION OF RELEASE	PRESSURE	FLOW METER		REMARKS
					TOP	BOTTOM	

Three standards, 0.1, 1.0, and 10.0 ppb SF_6 in ultra pure nitrogen, manufactured by Scott Environmental Laboratory, were used for calibration purposes. The base line as well as any instrument drift were established using samples of ultra pure nitrogen. The base line and calibration tests were performed each day before the samples from the bags were injected. It was found that the 10 ppb SF_6 standard when calibrated against 0.1 and 1.0 ppb yielded a reading of 7 ppb. When 10 ppb samples were diluted to half by volume with ultra pure N_2 and tested against 0.1 and 1.0 ppb standards, it was found that the linearity of the instrument extended to at least 5 ppb. Before each run fresh air samples in the vicinity of the highway as well as near the trailer were obtained with syringes and tested for the SF_6 concentration in the ambient air. Normally the SF_6 concentration was found to be zero. This was done to ensure that no leaks were present from the SF_6 tanks stationed near the trailer, and that the SF_6 released in the earlier experiment was completely dispersed from the vicinity of the roadway. This was necessary because at least two, one-hour release experiments were conducted per day and occasionally the sampled bags were purged in the vicinity of the trailer. Samples were taken from the bag, after it was thoroughly shaken, using syringes and injected into the G.C. The number of samples drawn to establish the concentration of the bag varied from a minimum of 3 to a maximum of 6. After each bag, either a standard was run or occasionally the system was purged with ultra pure N_2 and then the standards were run. The sampler bags were reused by flushing them with air three times and then ultra pure nitrogen. After the bags were flushed, samples taken from these bags indicated no measurable SF_6 concentration and that the bags were flushed properly.

SECTION 8

SPECIAL MICROMETEOROLOGICAL EXPERIMENTS

INSTRUMENTATION

In order to assess the effects of traffic on the turbulent structure of the atmospheric surface layer, time records of the turbulent wind components and temperature as well as wind profile data were collected on both sides of the Expressway.

Sonic Measurements

The three component wind fluctuations were measured by a sonic anemometer, Model PAT 311, constructed by Kaijo Denki Ltd. The design is a solid state pulse type with a 20cm path length. The instrument is based on the difference of arrival times of pulses emitted along and in the opposite directions of the wind. A detailed description of its development and usage can be found in the Japan - U.S. Joint Study Group Report (1971). Fluctuations greater than 20 HZ can be resolved with the help of the sonic anemometer. Before each run, the instrument was zeroed electronically by placing it in a "windless" box. Calibration was performed at least once every day using a Model 556 Tektronix oscilloscope with a time delay. Corrections for an apparent overestimation and zero drift were incorporated into the data reduction procedure.

The sonic head was mounted at a height of 3m on a sturdy boom extending 3m away from the tower to avoid any contamination due to sonic reflection. It was oriented such that the mean wind was centered between the two horizontal sonic paths. A total of 36 hourly runs were made during the fall of 1976 and late spring of 1977 with the anemometer mounted on either Tower 2, 9, or 11 (see Fig. 16). The runs were made over a variety of wind directions, stability, and traffic volumes and speed conditions. Each hourly run was then broken up into 15 min. segments to be used for processing and the average results of these four segments were used for analysis.

Temperature Fluctuation Measurements

Records of temperature fluctuations were obtained using a fast response copper-constantan thermocouple whose signal was amplified by using a Honeywell Accudata system with a gain of 5000. Fifteen runs were made and data was recorded on a Model 5600 Honeywell analog recorder. A zero reference voltage was recorded before each run to avoid playback problems.

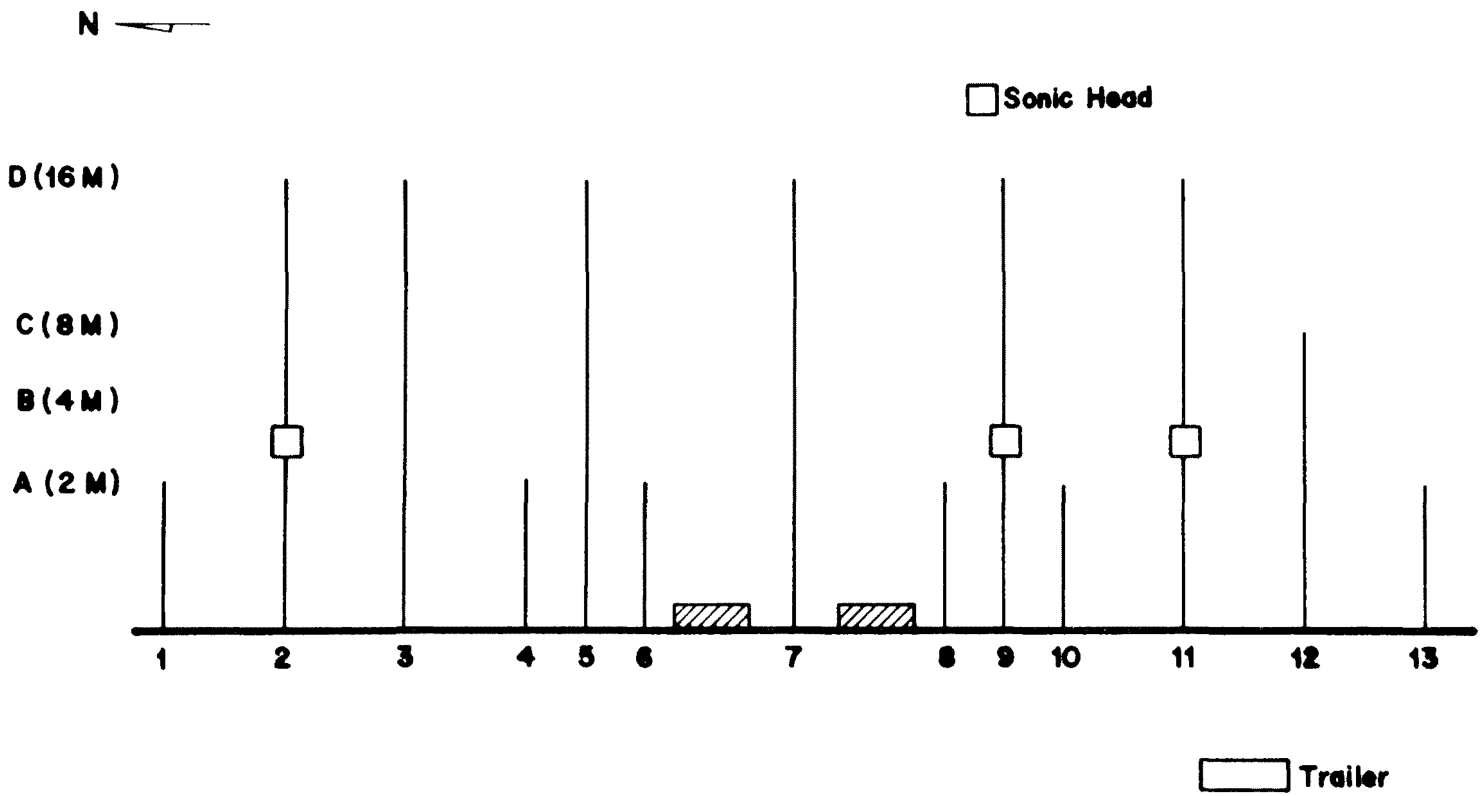


Fig. 16 Location of the Sonic Head

Wind Profile Measurement

Mean wind profiles were measured using two Thornthwaite Associates Inc. systems, equipped with digital readout. The matched cup anemometers were mounted on booms extending 1m away from the tower to minimize tower influence. A polaroid camera system was used to take pictures of the digital readout unit at intervals of 15 min. This allowed for automatic acquisition of continuous data for up to 12 hr. The new wind profile system was mounted on Tower 9 with the cups positioned at 1.5, 2, 3, 5, 8, and 11m levels, and the old system was mounted on Tower 3 with the cups at 2, 3, 5, and 8m levels. The runs were made in late spring of 1977 over a 14 day period of which only four days had both systems working simultaneously. Even with these limitations, simultaneous profiles under rather variable conditions were acquired.

DATA PROCESSING

To minimize aliasing in the spectra, the time records were played back through an active low pass filter. The cut-off frequency was chosen to be 10 Hertz to obtain maximum aliasing reduction for the sampling rate used, as suggested by Kaimal, et. al. (1968). The data were then digitized using a Hewlett-Packard Data Acquisition System at a rate of 20 samples/sec. The digital tapes were then decoded and analyzed on the UNIVAC 1110 computer. From these data, spectra and cospectra were computed using a fast Fourier Transform Technique (Cooley and Tuckey, 1965).

The wind profile data were organized according to (a) wind direction with respect to the highway, (b) traffic volume and speed, and (c) atmospheric stability. Profiles were drawn by averaging over at least 7 consecutive 15 min. runs. In this averaging process, checks were made to ensure consistency such that any changes at one level were accompanied by similar changes at all other levels. For a given situation, profiles from different days or times were also compared in order to check for the validity of the data. The atmospheric stability was determined by computing a parameter defined as

$$\frac{z}{L} = -zkg \frac{\overline{W^1T^1}}{\overline{T}U^{*3}}$$

where z is the height of observation, L is the Monin-Obukhov length, k Von-Karman constant, g acceleration of gravity, $\overline{T}$ mean ambient temperature, U^* friction velocity and $\overline{W^1T^1}$ heat flux. Further details on the data handling and reduction can be found in Sedefian (1977).

SECTION 9

COMPUTER DATA ACQUISITION & REDUCTION TECHNIQUES

COMPUTER SYSTEM

In this section details of the computer and its accessories necessary to collect and store data are presented. Necessary operations were:

a. collection of carbon monoxide data

b. collection of traffic data

c. collection of raw meteorological data (also perform some intermediate computations)

In order to carry out these tasks, the necessary hardware and software were built around a Data General Corporation (D.G.C.) NOVA 2 minicomputer having 8-K words of memory. The entire configuration is shown schematically in Fig. 17.

The accessory components are:

ASR 33 - Teletype
Dual Drive Diskette Unit from D.G.C.
Analog/Digital Interface from D.G.C.
Digital Interface from D.G.C.
and a Kiethley 10-channel Scanner.

Collection of CO Data

The output signals from the 8 NDIRs are fed into the back panel of the hardware cabinet and then routed to the first 8 channels on the Kiethley Scanner. The appropriate CO signal is selected by the scanner and passed to channel #31 of the A/D interface via the Cable C2. A 74 sec. cycle is used to sequence the 4-CO banks by which time all the 8 NDIR signals have been processed. Hence, during the 10 min. data collection period, each bank is cycled 2 times so that eight 74 sec. cycles occur, with an 8 sec. dead span. During the 74 sec. cycle, the CO samples flow through the NDIRs, which ensures purging the previously held samples. Between the 72nd and 74th sec., the NDIR is scanned by the Kiethley Scanner at 250 milliseconds interval and the signal passes on to channel #31 of the A/D interface.

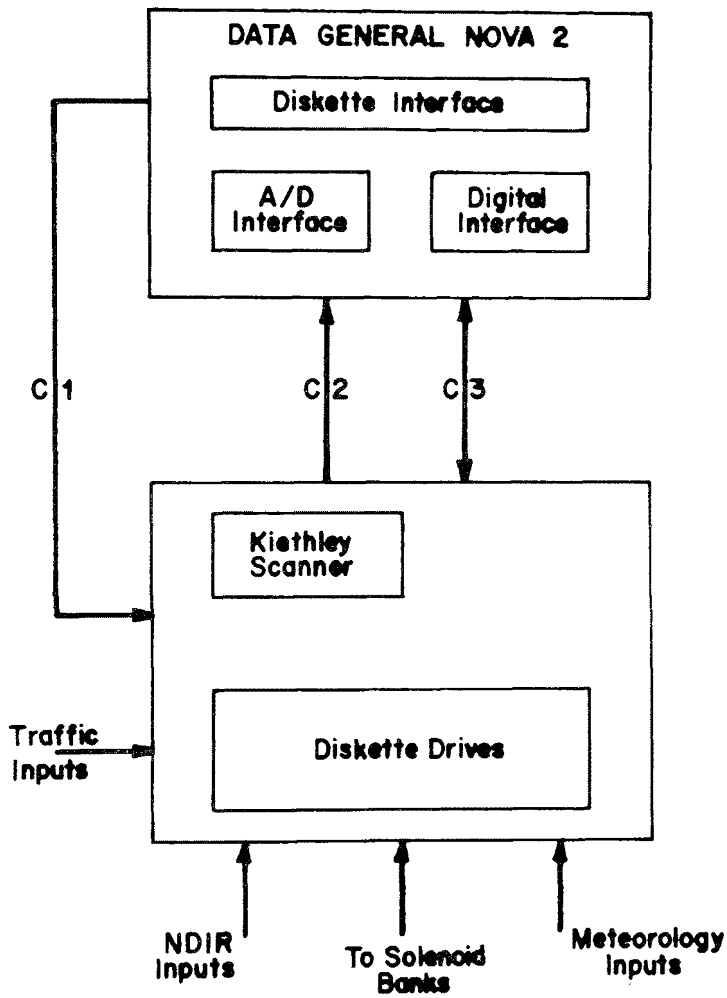


Fig. 17 Configuration of the computer and its accessories for data collection.

Traffic Data

Each lane on the expressway had a pair of induction loops imbedded in the pavement. The computer monitors the 12 loops every 16.7 milliseconds. The time interval between tripping loop A and loop B (which have a physical separation of 11 ft. on the roadway) is used by the computer program to determine the speed of the particular vehicle. The time interval for which loop A remains tripped due to the presence of the vehicle is then used to determine the length of the vehicle. Traffic signals are fed into the Hardware Cabinet and routed to the Digital Interface by Cable C3. Each of the 12 loops corresponds to one bit in a 16 bit digital word, which is processed by the Digital Interface. During the 10 min. sample period, the speeds and lengths of all the vehicles are stored in the computer memory. At the end of 10 min., this information is reported as number of vehicles for 5 length and 10 speed categories for the west bound as well as east bound lanes.

Meteorological Data

The output voltages of the 11 wind, temperature and temperature difference, solar radiation, and humidity sensors are fed into the hardware cabinet and routed to the A/D interface via the cable C2. The signals are collected every 250 milliseconds and block-averaged to obtain an effective sampling interval of 1 sec. The data from Gill anemometers were corrected for cosine response (Horst, 1971). The data from the precipitation sensor are acquired every 10 min.

COMPUTER PROGRAMS

The software as configured has three basic programs included in one master program. These include:

1. Data Acquisition Program
2. A/D Test Program
3. Debug 11 Program

Although the Data Acquisition Program is the prime program, the other two programs are useful utilities for testing and/or debugging hardware and software.

The Data Acquisition Program functions have been covered in earlier paragraphs. The A/D Test Program can be used to determine individual sensor data values. A variable number of data points (up to 200) at a variable time interval (10 milliseconds to 30 seconds) between each data point facilitates trouble-shooting of problems associated with particular groups of sensors. All 32 carbon monoxide channels, 31 meteorology channels, and the traffic work channel are accessible to this routine.

The Debug 11 Program has been imbedded into the program in order to provide on-site changes in program instructions and program constants.

Computer Output

Every 10 min., the data are averaged, manipulated, and stored on the floppy disk. The floppy disk has one recording surface divided into 77 tracks and each track contains 8 sectors. Data are transferred to the floppy disk from the computer memory in blocks of 256 16 bit words which corresponds to one data block per sector. Table 6 lists the arrangement of variables within a given block.

Since there are 144 10 min. periods in a day, a disk can accommodate four days worth of data. Hence, it contains four "Contiguous files" labelled DAY 1, DAT 2, etc. with each file being 144 blocks in length. The diskettes were changed every four days and brought back to the Central Office for further processing. A sample of the output for a 10 min. period is shown in Fig. 18 where the signal range 0-5V corresponds to 0-1024 A/D units.

Data Processing

The next stage of data processing is to read each block of data, and perform the following tasks:

a. Except for the traffic data, all the other variables are to be converted to their standard units.

b. Compute the necessary meteorological parameters.

c. Transferr the data from the mini-computer to Univac 1110.

The necessary hardware and software required are:

i. A NOVA 2/10 mini-computer with 24K word memory.

ii. A D.G.C. asynchronous line adapter module.

iii. An ASR-33 teletype

iv. A dual drive and a single diskette drive.

The entire configuration is shown schematically in Fig. 19. The 10 min. data are then transferred to Univac 1110 using the asynchronous line adapter module along with ancillary software and stored on a magnetic tape. Hourly averages are then obtained and stored on a magnetic tape.

TABLE 6. ARRANGEMENT OF DATA WITHIN A GIVEN BLOCK

Data	Word(s)
Year	1
Day	2
Hour	3
Minute	4
CO (32 channels)	5-36
Traffic (Lanes 1-3) West bound	37-86
Traffic (Lanes 4-6) East bound	87-136
Climet Wind Direction	137-143
Gill u	144-147
Gill v	148-151
Gill w	152-155
Temperature	156
Difference Temperature	157
Climet Wind Speeds	158-164
Humidity	165
Radiation	166
Vertical component of CI-25	167
Ground (Kiethley)	168
Precipitation	169
Blank	170-177
U	178-181
SQRT (ΣUH*wi/600)	182-185
SQRT (ΣU*wi/600)	186-189
SQRT (ΣV1*wi/600)	190-193
SQRT (ΣW1*T/600)	194-197
SQRT ($\Sigma U1^2/600$)	198-201
SQRT ($\Sigma V1^2/600$)	202-205
SQRT ($\Sigma W1^2/600$)	206-209
SQRT ($\Sigma U5^2/600$)	210-213
SQRT ($\Sigma V5^2/600$)	214-217
SQRT ($\Sigma W5^2/600$)	218-221
SQRT ($\Sigma U10^2/600$)	222-225
SQRT ($\Sigma V10^2/600$)	226-229
SQRT ($\Sigma W10^2/600$)	230-233
SQRT ($\Sigma U25^2/600$)	234-237
SQRT ($\Sigma V25^2/600$)	238-241
SQRT ($\Sigma W25^2/600$)	242-245
Blanks	246-256

```
1977      7      9     20             YEAR       J.D       HOUR         MIN
     CO VALUES
  22     69     36     86     58     51     68     97
  39     42     94     91    107     66     37     96
  36     49     36     58     27     41     73     41
  63     45     29     29     32     27     30     41
        WEST BOUND TRAFFIC
   0      0      0      0      0      0      1      0      0      0
   0      3      1      0      0      3    325    239     18      0
   0      0      0      0      0      0     15     18      2      0
   0      0      0      0      0      0      4      0      0      0
   0      0      0      0      0      0     22      7      0      0
        TOTAL WEST BOUND =      658
   0      0      0      0      0      0      0      0      0      0
   0      3      0      0      0      1     92     93     42      0
   0      0      0      0      0      0      4      7      6      0
   0      0      0      0      0      0      2      4      0      0
   0      0      0      0      0      0      0      9      1      1
        TOTAL EAST BOUND  =     265
 687    699    750    825   1024    619    598             WIND DIR.
  20     49     18     79    -91      0     59             WIND SPEED
  25      1     22      4                              GILL U
  67     75     64     61                              GILL V
   2     -1     -2     -1                              GILL W
 371    462   1013      2    582     -8     -9     TEMP   DELTA TEM  REL. HUM
                                                   SOL.RAD   GRND  PRECIP
  70     89     78     84                             GILL THETA
   1      0      1      4                             GILL PHI
  76     75     72     63                             UH
   7      0      5      2                             UHW1
  10      0      2      0                              SUHW1
   4      0      4      2                             U1W1
  24     19     26     23                              V1W1
  32      0     26      7                               W1T
U,V,W  SIGMAS FOR 1,5,10 25 SEC
  69     74     68     66      0      0      0      0     31      1     28      9
  69     75     68     67      1      0      1      0     30      0     27      8
  69     75     68     67      1      0      2      1     28      1     26      8
```

Figure 18. Typical Computer Output

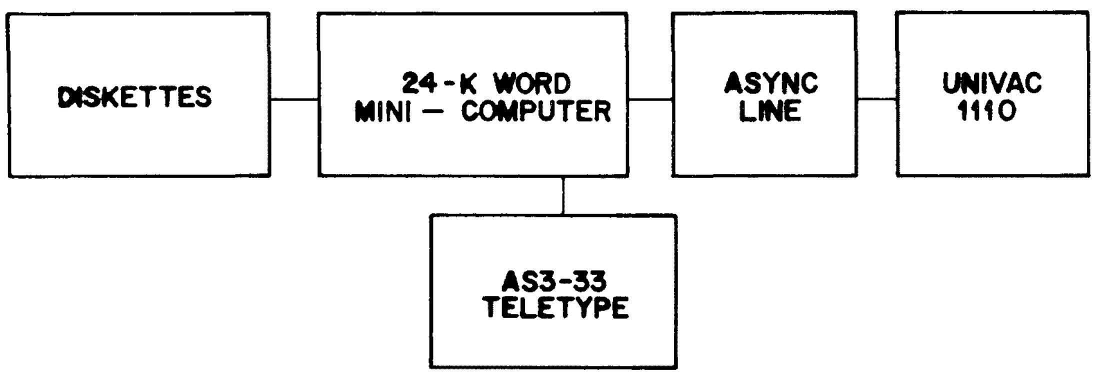


Fig. 19 Configuration of the computer and its accessories for data analysis.

SECTION 10

LABORATORY ANALYSIS

In order to determine the particulate weight of the samples collected by the dichotomous samplers, the millipore filters were weighed before and after the sampling. Techniques for their weighing as well as the analysis of these filters for sulfur and lead by x-ray fluorescence and for various anions are indicated below.

PARTICULATE WEIGHTS

The filter membranes which were used in this study were teflon (Millipore Fluoropore) with a pore size of 0.5 μm. The filter samples were weighed on a Mettler M-5 microbalance which had been enclosed in a glove-box for the purpose of maintaining constant humidity and temperature. Control of humidity was obtained through the use of saturated salt solutions which were exposed to the circulating air within the glove box. This relatively simple technique was adapted from the procedures described in ASTM, E 104-51 for maintaining constant humidity through the use of aqueous solutions. Calcium nitrate was used in this application and produced a relative humidity of 51% at 25°C. Weighing accuracies of ± 15 μg were obtained when a 10 millicurie krypton-85 beta source was positioned within the balance to neutralize any electrostatic charges on the filter membranes.

X-RAY FLUORESCENCE SPECTROMETRY

After the particulate weights had been determined, the filter membranes were analyzed for trace metals on a Siemens Model VRS wavelength-dispersive x-ray fluorescence (xrf) spectrometer. The Siemens xrf spectrometer has been modified to accept a ten position sample changer, and the entire system is interfaced to a Hewlett-Packard Model 9810 programmable calculator for the storing and processing of data on magnetic tape. Final data processing is performed on a Hewlett-Packard Model 9830 programmable calculator with a nine inch thermal printer. A molybdenum target tube powered by a K-4 generator was employed throughout this study; each particulate sample was analyzed for lead and total sulfur by use of lithium fluoride (200) and graphite crystals, respectively.

Because of the particular geometry employed by Siemens in the construction of their ten position sample changer, a significant amount of backscatter from the aluminum sample cup is able to reach the detector and cause a deterioration in the detection limits of the lighter elements, especially aluminum. Therefore, it became necessary to design and construct from

Plexiglas our own sample cups and mounting rings in order to present the samples to the spectrometer for analysis. This new design effectively reduced the amount of backscatter, improved the detection limits of the lighter elements such as sulfur, and permitted the analysis for aluminum in samples from other projects.

The calibration standards for this phase of the analysis were prepared according to the following procedure. The appropriate metal aerosol was produced by pumping an aqueous solution of an appropriate soluble metal salt into a May Spinning Disc Aerosol Generator. The resulting metal aerosol is subsequently deposited onto a 10 cm teflon filter membrane by use of a vacuum pump in much the same manner that the actual particulate samples were collected along the roadside. From the particular operating parameters which were used for the aerosol generator, the size of the resultant particles fell in the range 0-10 μm, with ninety percent of the particles less than five microns. Since the aerosol production was constant with time, the amount of particulates deposited on the filter membrane was linear with time. It was convenient to prepare samples with five different particulate loadings to cover the entire range of interest within this investigation. Three smaller discs (37 or 42 mm diameter) could be punched easily from each of the ten centimeter filters. Then the fifteen calibration samples were processed by xrf spectrometer and the net pulse counts were used to judge the uniformity of the deposit for each set of three discs as well as the suitability of each set in covering the appropriate concentration range. After this step was completed and all of the calibration samples were judged to be satisfactory, one particulate filter from each set of three was destructively analyzed for lead by atomic absorption methods while sulfur, in the form of sulfate, was determined by ion chromatography. Data from the resultant analyses were plotted against the initial xrf net pulse count to yield the required calibration curves. The curves for both lead and sulfur exhibited straight lines (correlation coefficients = 0.99) and the lower limits of detection were 170 ngm/cm^2 and 21 ngm/cm^2, respectively.

ANION ANALYSIS BY ION CHROMATOGRAPHY

After the completion of analysis by xrf techniques, particulate filters collected in the field were analyzed for anions of interest by ion chromatography. There are various methods currently available for analysis of sulfate and nitrate in ambient aerosols. Mulik et al (1976) showed the successful application of ion chromatograph to the analysis of aqueous sulfate and nitrate in ambient aerosols.

The principle involves separating the species of interest on an ion exchange separating column, followed by removal of the background ions in the eluent with a suppressor column leaving the sample ions undisturbed; they are monitored by a conductivity cell connected to a meter and recorder. For the analysis of sulfate and nitrate, the separation column contains a strong basic resin and the suppressor column contains a strong acid resin. A schematic of the flow system is shown in Fig. 20. The flow system consists of a separator or analytical column, suppressor column, four solvent reservoirs, injection valve with sample loop, two Milton Roy fluid pumps, conductivity meter and a

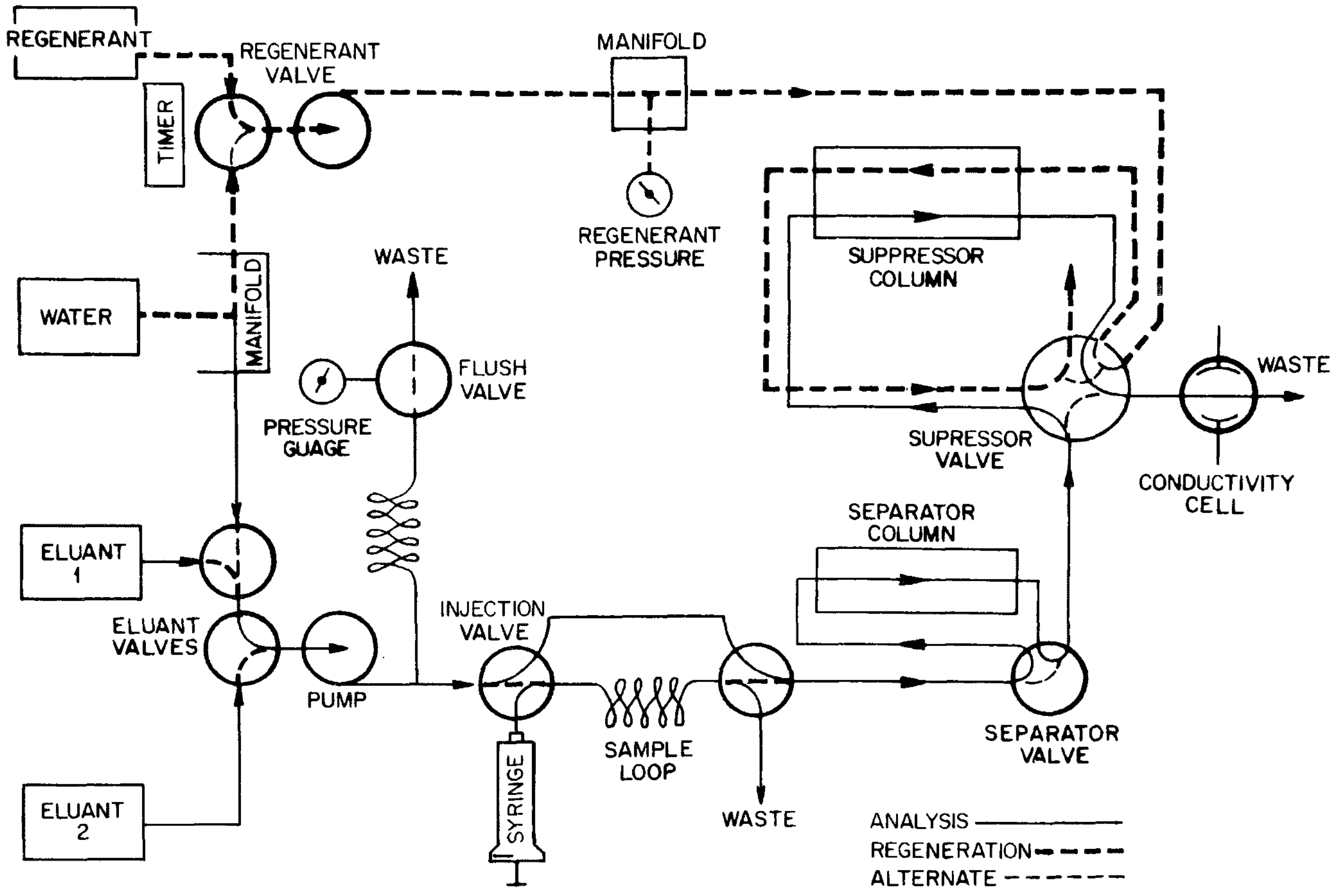


Fig. 20 Ion chromatograph flow system

valving system to direct the flow through various parts of the instrument. The system uses air activated teflon slider valves throughout.

The samples were extracted overnight on a laboratory shaker in 6 ml of a solution of 0.0030 M sodium bicarbonate and 0.0024 M sodium carbonate. The samples were then loaded into a sample tray for introduction into a Dionex Model 10 ion chromatograph for the general determination of chloride, fluoride, phosphate, bromide, nitrate, and sulfate anions. This equipment had been automated through use of a Technicon pump and Sampler IV and a Valco high pressure injection valve. The synchronization of the various pieces of equipment was accomplished through the use of a Columbia Scientific Industry Supergrator III integrator with programmable external contact switches. Each chromatogram was traced on a Hewlett-Packard recorder while the integrator printed all data in parts per million.

A standard solution of all five anions was made at 50 ppm in the carbonate/bicarbonate buffer solution. Portions of this solution were then diluted volumetrically to give solutions containing 25, 10, 5, and 1 ppm of all five anions. These solutions were processed through the ion chromatograph and the resultant data indicated that a linear response was obtained for chloride, fluoride, phosphate, bromide, nitrate, and sulfate over the concentration range 0-50 ppm. For the routine processing of normal samples, one of the above standard solutions was injected three times and the final data were averaged to obtain appropriate calibration constants before the unknown samples were injected. It was also routine to end the analysis late in the day with a single sample of the same standard solution. Review of this data with that from the morning would enable the operator to determine the amount of instrument drift through the day as well as the occurrence of an equipment malfunction. The precision of this method was better than 2% for a 500 ml sample loop.

It should be mentioned here that another analytical method has been in wide-spread use previously for the analysis of sulfates, especially for automotive exhaust applications. The specific method was referred to as the barium chloranilate procedure. Originally, this method was to be used in this study. However, from our own tests and from the General Motors Experiment (Cadle et al, 1976), the barium chloranilate procedure was found to suffer from many interfering ions, e.g., chloride, nitrate, bromide, phosphate, and carbonate. Since this project was a field study and sulfate levels were anticipated to be fairly low, low levels of interfering ions were also to be expected during analysis but could not be tolerated. Therefore, the relatively old technique of ion chromatography which employs the fairly recently developed ion chromatograph was chosen as the analytical method for this particular effort. For the specific analysis of sulfate in this study, there were no interferences.

REFERENCES

Cadle, S.H., D.P. Chock, J.M. Heuss, and P.R. Monson; "Results of the General Motors Sulfate Dispersion Experiment", Research publication, GMR-2107, General Motor Research Laboratories, Warren, MI, 1976

Horst, T.W.; "A Computer Algorithm for Correcting Non Cosine Response in the Gill Anemometer", Battelle, Pacific Northwest Laboratories, BNWL-1651-1, Richland, WA, 1971, (pp 183-186)

Japan - United States Joint Study Group Report; "Development of Sonic Anemometer and its Application to the Study of Atmospheric Surface Layers", Disaster Prevention Research Institute, Kyoto, Japan, 1971

Kaimal, J.C., J.C. Wyngaard, and D.A. Haugen; "Derived Power Spectra from a Three-Component Sonic Anemometer", J. Appl. Meteor., 7, 1968, (pp 827-836)

Mulik, J., R. Puckett, B. Williams, and E. Sawicki; "Ion Chromatographic Analysis of Sulphate and Nitrate in Ambient Aerosols", Analytical Letters, 9, 1976, (pp 653-663)

Sedefian, L.; "Some Characteristics of Turbulence Adjacent to a Major Highway", M.S. Thesis, State University at Albany, 1977, (pp 44)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The major emphasis of this investigation centered on the collection of particulate and gaseous pollutant data, and detailed micrometeorological data in a non-urban setting adjacent to the heavily travelled Long Island Expressway. The purposes for collecting the data were to (i) document the distribution of sulfate, lead, total particulates and carbon monoxide at an array of sampling points adjacent to the highway; (ii) study tne micrometeorology associated with the highway, with special attention to those parameters important in the determination of atmospheric dispersion, (iii) reevaluate highway air pollutant emission factors from data gathered in tracer gas experiments; and (iv) examine the applicability of existing highway air pollutant dispersion models. The location of the sites and the experimental setup for collecting pollutant data are described, and details of the data acquistion procedures are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Air pollution		13B
*Atmospheric diffusion		04A
*Limited access highways		04B
*Micrometeorology		14B
*Experimental design		
*Data acquisition		

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