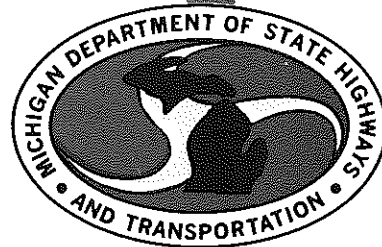


AIR QUALITY MEASUREMENTS OF
MOVABLE ASPHALT PLANTS FOR
RECYCLING PAVING ASPHALT



**TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION**

**AIR QUALITY MEASUREMENTS OF
MOVABLE ASPHALT PLANTS FOR
RECYCLING PAVING ASPHALT**

J. T. Ellis

**Research Laboratory Section
Testing and Research Division
Research Project 78 G-235
Research Report No. R-1099**

**Michigan State Highway Commission
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John P. Woodford, Director
Lansing, November 1978**

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INTRODUCTION

In April 1978, R. A. Welke, Supervisor of the Testing Laboratory's Bituminous Unit requested the Spectrochemistry Group's assistance in an experimental program involving movable asphalt plants for recycling asphalt paving. A program was outlined and approved for study by K. A. Allemeier, Engineer of Testing and Research. There was concern that particulate emissions from the asphalt plant stacks that were processing recycled asphalt paving would exceed Federal and Michigan emission standards. The experimental work plan was to use several mixtures of recycled mix and virgin material, varying from 90 percent to 50 percent recycled. Particulate measurements were to be performed for each mixture to determine the effect of mix ratio on particulate emissions. A total of five to six measurements were to be performed for the first project on M 57 near Greenville. Two projects were planned for 1978 with additional projects planned for 1979 and 1980.

The Spectrochemistry Group was requested to determine which Federal and Michigan standards applied and to determine what methods Michigan's Department of Natural Resources (DNR) and U. S. Environmental Protection Agency (EPA) specify for measuring stack emissions. Another task was to gather information as to possible methods for obtaining such measurements, such as:

- a) equipment required, cost, delivery time, personnel, and training required for performing measurements in-house,
- b) availability and cost to have measurements performed by a consultant, and
- c) cost and scheduling to have measurements performed by Michigan's DNR Stationary Source Unit.

Applicable Standards

Applicable standards for particulate emissions from asphalt paving plants are included in "Michigan Administration Rules for Air Pollution Control" and "U. S. EPA Regulations on Standards of Performance for New Stationary Sources." Michigan standards require that particulate matter shall not exceed 0.30 lb particulate per 1,000 lb of gas (approximately equivalent to 0.15 grains per dry standard cu ft, or gr/DSCF) and the plume shall exhibit not more than 20 percent opacity. Federal standards require that particulate matter shall not exceed 0.04 gr/DSCF (approximately equivalent to 0.08 lb per 1,000 lb of gas) and the plume shall not exhibit 20 percent or greater opacity.

Standard Measurement Methods

The "U. S. EPA Standards of Performance for New Stationary Sources" CFR, Volume 40, Part 60, requires Method 5 - 'Determination of Particulate Emission From Stationary Sources' be used as the reference method for compliance with the standard. Method 5 requires that particulate matter from the stack be withdrawn isokinetically (gas velocity entering the sampling nozzle equals the approaching gas velocity) and collected on a glass fiber filter. The filter is weighed before and after sampling. The difference in the filter weight, along with any condensed material in the sampling nozzle and probe, constitute the particulate mass. Michigan's DNR method for compliance with the standard is essentially Method 5 with minor procedural modifications.

Measurement Capabilities

Several alternatives for obtaining the stack emission measurements were found to be possible:

1) Michigan's DNR would perform the measurements if their time and schedule permitted. Cost would be about \$1,000 per measurement for a total cost of \$5,000 to \$6,000 per project.

2) Consulting firms would perform the measurements for about \$2,000 per measurement for a total cost of \$10,000 to \$12,000 per project.

3) The equipment could be purchased and the measurements performed by MDSHT personnel. The basic equipment required would cost approximately \$3,700. Required accessories would cost approximately \$1,200 to \$1,300 for a total equipment cost of about \$5,000. The work could be performed with existing personnel in the Spectrochemistry Group. A one-week EPA training course for one person to learn the instrument operation, sampling, and calibration procedures would also be required.

In a letter from J. T. Ellis to L. T. Oehler (April 21, 1978), it was recommended, with the concurrence of R. A. Welke, that the Department purchase the equipment and perform the measurements. L. T. Oehler transmitted the letter to K. A. Allemeier on April 24 for information and approval of the recommendation. The project was discussed at the Engineering Operations Committee meeting of May 3, 1978, and they agreed that the measurements should be performed by the Research Laboratory.

The instrument for performing the measurements was ordered from Western Precipitation Division of Joy Manufacturing Co. on May 18, and received on June 29.

Training Course

Permission was granted to attend the EPA Training Course No. 450 - 'Source Sampling for Particulate Pollutants' from May 22 to 26 in Detroit. The course presented the principles and techniques of performing isokinetic source sampling for particulates as required by EPA Methods 1 through 5 of the Federal New Source Performance Standards.¹ The theory and methodology of the various calibration and sampling operations such as pitot tube and dry gas meter calibration, sampling of stack emissions for moisture, gases, and particulates were discussed. Actual hands-on experience in performing many of the operations were included in laboratory sessions.

After the training course was completed and the instrumentation necessary for performing the measurements had been received, a training program for personnel to assist in the stack sampling was initiated. The training program included:

- 1) Reading and discussion of EPA Methods 1 through 5, EPA training manuals and instrument operations manuals,
- 2) Instrument operation, calibration, and maintenance procedures,
- 3) Observation of an actual stack sampling performed by a consultant at an asphalt plant near Dansville,
- 4) Practice in assembling and disassembling the sampling train, clean-up procedures (washing and collection of the washings from the sampling nozzle and probe, filter handling, and impinger water catch measurement), and analysis of the stack gases for carbon dioxide, oxygen, and carbon monoxide with an Orsat gas analyzer.

All necessary equipment for performing a stack test had been received, tested, and calibrated, personnel had been trained, and the procedures for planning and performing a stack test had been developed by July 20, 1978.

¹ Method 1 - Sampling and Velocity Traverses for Stationary Sources
Method 2 - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
Method 3 - Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight
Method 4 - Determination of Moisture Content of Stack Gases
Method 5 - Determination of Particulate Emissions from Stationary Sources

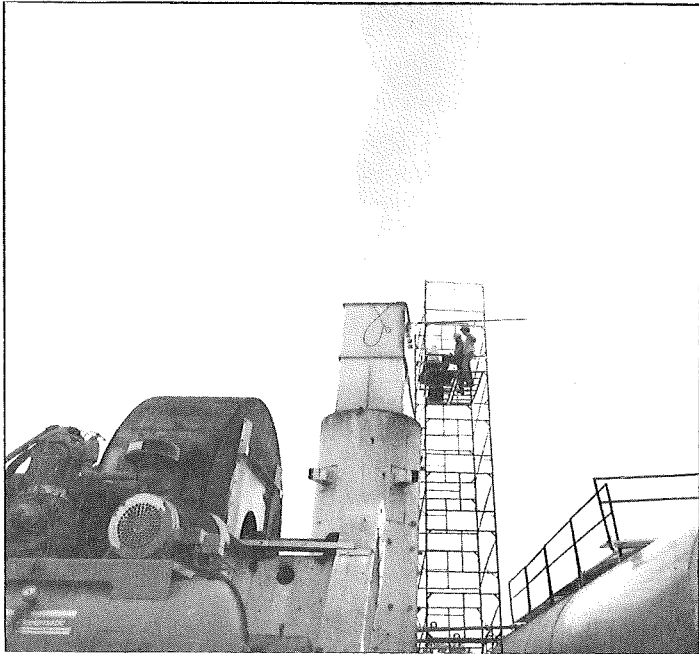


Figure 1. Spartan asphalt plant (above) on M 57 near Greenville. Scaffold with sampling set-up is shown at right.

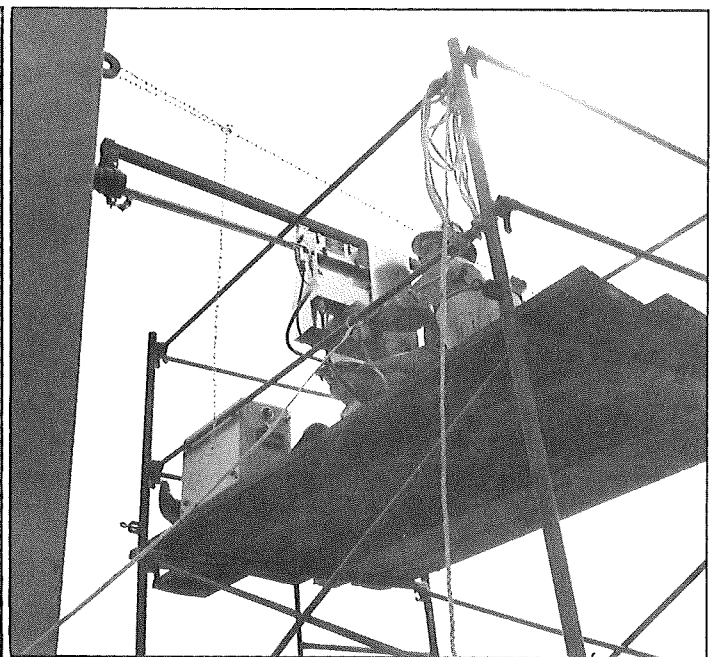
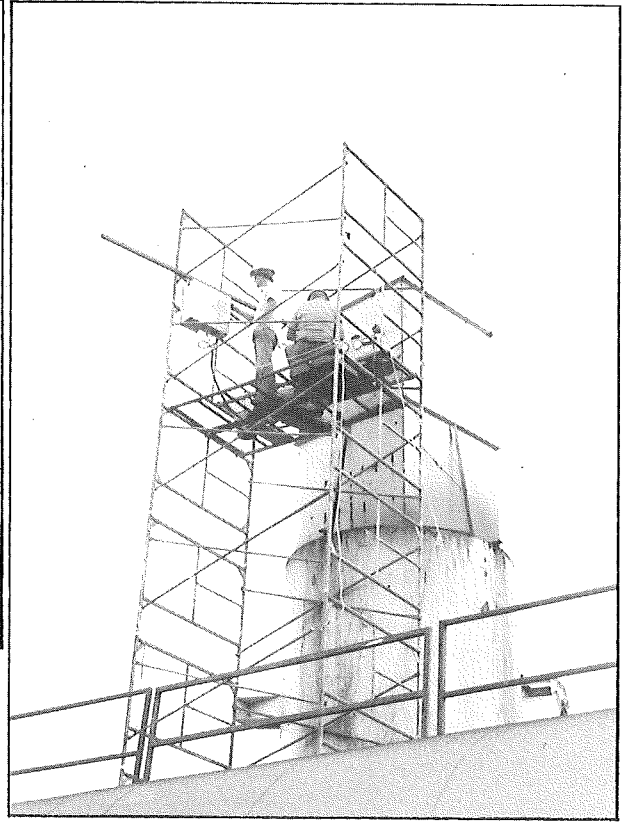


Figure 2. Stack samples (above) being taken at the Hicks asphalt plant (left) near Alma.

The procedure developed for planning a stack analysis and the procedure for performing the stack test follows guidelines in EPA Methods 1 through 5 and EPA manuals. These procedures are described in Appendix A.

PHASE I - M 57 RECONSTRUCTION

The first project where stack emission measurements were requested involved the reconstruction of M 57 from M 66 west to Greenville (approximately 9 miles), Construction Project Mb 59022. The contractor for the project was Spartan Asphalt Paving Company of Holt. The Spectrochemistry Group was requested to measure the particulate stack emissions over a several day period while mix ratios of recycled mix and virgin material were varied from 90 percent recycled and 10 percent virgin material to 60 percent recycled and 40 percent virgin material.

A survey of the project site and the asphalt plant was performed on July 25, 1978. The plant was located on the north side of M 57 about 1/2 mile west of M 66. It had been moved from Dansville several days earlier and was not fully operative, but the stack and scaffolding had been erected. The survey provided the following information.

- 1) The stack was not of uniform diameter. It consisted of a round 8-ft diameter by 18-ft high bottom section and a 5-ft square by 10-ft high top section (Fig. 1).
- 2) Four equally spaced 5-in. diameter ports were located 24 in. from the top on the south side of the stack.
- 3) Electrical power was available at the contractor's control trailer about 50 ft from the stack.
- 4) The scaffold was moderately sturdy, but not well secured to the stack; an additional cable for more support was added.
- 5) The plant used a wet scrubber system to remove solid particles before the plant emissions went up the stack.
- 6) The stack was emitting much water vapor and large solid particles. No blue smoke (an indication of hydrocarbons) was noted.

The stack's dimensions, the number and location of the ports, along with the distances to the nearest disturbances (8 ft downstream and 2 ft upstream) required that a minimum of 48 points be sampled when calculated in accordance with Method 1. Method 5 requires a minimum of two minutes sampling time at each point; therefore, a minimum total sampling time of 96 minutes was required.

The first stack sampling occurred on July 31, 1978. Upon arrival it was learned the plant was running an 80 percent recycled - 20 percent virgin mix. A preliminary traverse with the spare pitot tube and manometer measured the gas velocity pressure at each traverse point. The velocity pressure varied from 0.03 to 0.98 in. of water indicating a very turbulent stack. The moisture content and dry molecular weight of the stack gas as well as the other measurements (barometric pressure, stack pressure, stack temperature, and dry gas meter temperature) were taken and 'K' in the isokinetic rate equation was calculated. K is a constant necessary for setting the sampling rate. The isokinetic rate equation and the calculation procedures are shown in Appendix A.

After all apparatus had been hoisted to the scaffold, assembled, and heated to operating temperatures, sampling was begun. Mechanical difficulties shut the plant down earlier than normal so a complete sampling run was not accomplished. Only 19 of the planned 48 traverse points were sampled.

The next sampling of the stack occurred on August 1; the plant was again running the 80-20 mix and again shut down early. Sampling was accomplished at 29 traverse points. Several points could not be sampled because of zero and negative gas velocity pressures.

On August 3, the stack was again sampled. The plant was running a 90 percent recycled - 10 percent virgin mix. One complete sampling run plus a partial run was accomplished. Again several points could not be sampled because of zero or negative gas velocity pressures. On August 4, 1978 another partial sampling run of 24 points on an 80-20 mix was accomplished.

Sampling on the M 57 project was completed on August 10, as two complete sampling runs were performed. Run No. 1 was a 70 percent recycled - 30 percent virgin mix and Run No. 2 was a 60 percent recycled - 40 percent virgin mix. Several points in each run again could not be sampled because of zero or negative gas velocity pressures.

The particulate concentrations found for each mix on the days sampled are shown in Table 1. Two sets of particulate data (EPA and DNR) are included because of differences in determining the total particulate load. EPA Method 5 requires that only the filter catch plus any condensed material ahead of the filter (sample nozzle, probe liner, and associated glassware) be included in the total particulate load. The DNR also included any material that passes through the filter and condenses in the impinger water. The impinger water is evaporated, the residue oven dried and added to the particulate load, so that DNR particulate concentrations are usually slightly higher than EPA. All partial or incomplete samplings were calculated as if they were complete runs. Data from such runs would likely not be valid for compliance with EPA Method 5, but are useful in comparing the particulate emissions from the different mix ratios. Data from the abbreviated July 31 sampling are not included because of the small number of points sampled.

The data show that the Federal particulate emission standard of 0.04 gr/DSCF was exceeded for all mix ratios. The Michigan standard of 0.15 gr/DSCF when calculated by the EPA method was achieved for the 70-30 and 60-40 mixes. The 90-10 and 80-20 mixes appear to produce about the same amount of emissions. The 70-30 and 60-40 mixes produce considerably less emissions with the 60-40 mix producing the least.

TABLE 1
PARTICULATE CONCENTRATIONS
VERSUS MIX RATIOS

Date Sampled	Material Mix Ratio Recycled-Virgin	Particulate Concentration, gr/DSCF
August 1	80-20	0.20 (0.28)*
August 3 - Run No. 1	90-10	0.21 (0.26)
August 3 - Run No. 2	90-10	0.20 (0.29)
August 4	80-20	0.19 (0.27)
August 10 - Run No. 1	70-30	0.11 (0.18)
August 10 - Run No. 2	60-40	0.09 (0.15)

* Numbers in parentheses are those computed using the DNR method, resulting in higher values as noted in the text.

PHASE II - GRATIOT COUNTY

Particulate stack emission measurements were performed during September and October 1978, at an asphalt plant near Alma that was using recycled asphalt as part of its mix. The plant was a Barber-Greene owned by Hicks Construction Company of Alma. Hicks Construction was the contractor for resurfacing several county roads in the Alma area. This plant was sampled to obtain information on the particulate stack emissions produced by lower mix ratios (less recycled-to-virgin) than were encountered during Phase I.

A survey of the plant on September 5, 1978 showed the following:

- 1) The stack was rectangular with inside dimensions of 19-1/2 in. by 52-1/2 in. (Fig. 2).
- 2) Three equally spaced 3-in. diameter ports were located 48 in. from the top and 184 in. from the nearest disturbance (fan) below.
- 3) Electrical power was available at the contractor's control trailer about 75 ft from the stack.
- 4) The scaffold was moderately sturdy, but not secured to the stack.
- 5) The stack plume appeared very clean emitting only a small amount of water vapor and blue smoke.
- 6) The plant used a dry filtration system (bag house) to remove solid particles ahead of the stack.

Method 1 calculations indicated that a minimum of 24 points be sampled. Method 5 requires a minimum sampling time of 60 minutes, therefore, a three-minute sampling time at each point for a total sampling time of 72 minutes was used.

The first sampling occurred on September 15; the plant was running a 30 percent recycled - 70 percent virgin mix. They had planned to run a 50-50 mix but the high moisture content of the aggregate would not permit any ratio higher than 30-70. The preliminary traverse showed gas velocity pressure varying from 0.35 to 0.80 in. of water indicating a very stable stack. The moisture content and dry molecular weight of the stack gas as well as the other measurements (barometric pressure, stack pressure, stack temperature, and dry gas meter temperature) were taken and K in the isokinetic rate equation calculated as described in Appendix A. A complete sampling run of all traverse points was obtained, but we learned later that during the last one-third of the sampling run the plant had switched to a standard mix (no recycled material). Thus, information from this run is expected to be slightly biased toward low emissions.

The next sampling occurred on September 26 and again the high moisture content of the aggregate preempted the plant from running a 50-50 mix. The plant was having trouble with the bag house overheating. In trying to cope with the high moisture content of the aggregate, they had removed the flights (vanes) from the inside of the mixer drum the previous night to try to get higher temperatures and faster drying of the aggregate. However, the higher temperatures in the mixer resulted in excessively high temperatures in the bag house. They planned to reinstall the vanes after shutdown. They were able to run a 40 percent recycled - 60 percent virgin mix, however, and a complete sampling was obtained. The Barber-Greene engineer said he thought the high bag house temperatures would result in higher than normal particulate emissions.

Two complete sampling runs of a 50-50 mix were obtained on October 10. The aggregate was quite dry and the plant was operating steadily and at full capacity so data from these runs would be expected to present a true picture of the emissions from a 50-50 mix.

The particulate concentrations from all samplings are presented in Table 2. Data from the September 15 sampling are included for information only since it might be biased because part of the sample was from a standard mix.

The data show that compliance with the Federal standard of 0.04 gr/DSCF and the State standard of 0.15 gr/DSCF was achieved for the recycled mix ratios tested. The value calculated by the DNR method for September 26 was slightly higher than the Federal standard, but the EPA Method 5 value was easily in compliance.

TABLE 2
PARTICULATE CONCENTRATIONS
VERSUS MIX RATIOS

Date Sampled	Material Mix Ratio Recycled-Virgin	Particulate Concentration, gr/DSCF
September 15 ¹	30-70	0.09 (0.11) ²
September 26	40-60	0.04 (0.05)
October 10 - Run No. 1	50-50	0.02 (0.03)
October 10 - Run No. 2	50-50	0.01 (0.02)

¹ Included for information only.

² Numbers in parentheses are those computed using the DNR method, resulting in higher values as noted in the text.

SUMMARY

In response to R. A. Welke's request the following summarizes the items accomplished:

1) Information on Federal and Michigan emission standards for asphalt plants, specified methods for measuring the emissions, and alternatives (Michigan DNR or consultant) for obtaining the measurements were acquired.

2) Recommendations to perform the measurements in-house by the Spectrochemistry Group were approved, the instrumentation was purchased, the training and expertise to perform the measurements was developed, and two asphalt plants that were processing recycled paving asphalt were sampled.

The first plant sampled was processing recycled asphalt for the reconstruction of M 57 near Greenville. The plant used a wet scrubber system for filtering out solid particles before the gases entered the stack. Federal emission standards were exceeded for all recycled asphalt-virgin material mix ratios tested (90-10, 80-20, 70-30, and 60-40). Michigan standards were exceeded for the 90-10 and 80-20 mixes, but achieved for the 70-30 and 60-40 mixes.

The second plant sampled was processing recycled asphalt paving as part of its mix for resurfacing several Gratiot County roads in the Alma area. The plant used a dry filtration system (bag house) to remove solid particles from the gases ahead of the stack. Both Federal and Michigan standards were achieved for all recycled mix ratios tested (50-50 and 40-60).

CONCLUSIONS

1) Compliance with Federal and Michigan emission standards for asphalt plants processing recycled paving asphalt as part of its mix can be achieved.

2) There is a relationship between mix ratio (recycled to virgin) and emissions. The higher ratios generally result in greater concentrations of particulate matter.

3) The plant using the dry filtration (bag house) system was found to be more efficient in removing solid particles ahead of the stack than the plant with the wet scrubber system. Some wet filtration systems such as a high efficiency venturi scrubber are reported to approach the efficiency of a bag house system.

APPENDIX A
PROCEDURE FOR PLANNING AND
PERFORMING THE STACK TEST

PROCEDURE FOR PLANNING AND PERFORMING THE STACK TEST

A. Planning

- 1) Survey the sampling site to:
 - a) measure the stack diameter and height,
 - b) locate ports and measure diameter and distance from the nearest disturbance (both upstream and downstream). A disturbance is any bend, opening (including the top), baffle, blower, etc., which disturbs the normal flow of the gas stream.
 - c) locate available electrical power,
 - d) evaluate the safety of ladders and scaffolding,
 - e) obtain schedule of plant, if known.
- 2) Sketch the stack cross-section, locate traverse points (sampling points), divide into equal sampling areas, and calculate sampling time at each traverse point as required by EPA Methods 1 and 5.
- 3) Mark sampling probe at distances corresponding to the traverse points.
- 4) Place a dried and tared filter in the filter holder, add reagents to the impingers, and assemble the sampling train.

B. Performing

- 1) Transport equipment to sampling site.
- 2) Perform a preliminary traverse of the stack with a spare 'S' type pitot tube connected to a manometer to determine the stack gas velocity pressures.
- 3) Estimate the moisture content of the stack gas by measuring wet bulb and dry bulb temperatures and a psychrometric chart.
- 4) Collect a sample of the stack gases in a bag for analysis to determine the dry molecular weight of the stack gas.

- 5) Measure the atmospheric pressure at the site.
- 6) Calculate K in the isokinetic rate equation;

$$\Delta H = K\Delta P \text{ where } K = 846.72 D_N^4 \Delta H_{@} C_p^2 (1 - B_{ws})^2 \frac{M_d T_m P_s}{M_s T_s P_m}$$

where: ΔH = pressure drop across orifice meter in inches of water.
Calculated at each traverse point by multiplying $\Delta P \times K$.

ΔP = gas velocity pressure in inches of water. Read on velocity pressure gauge of console at each traverse point.

D_N = inside diameter of the sampling nozzle.

$\Delta H_{@}$ = pressure drop across orifice meter for 0.75 CFM flow rate at standard conditions.

C_p = 'S' type pitot tube coefficient.

B_{ws} = decimal fraction of moisture content of stack gas.

M_d = dry molecular weight of the stack gas.

M_s = wet molecular weight of the stack gas.

T_m = temperature at the dry gas meter.

P_s = pressure of the stack.

P_m = atmospheric pressure.

- 7) Fill the impinger compartment with ice, hoist apparatus to the scaffold, connect rail assembly to sample port, suspend sampling unit from the rail and attach sampling probe. Connect sampling unit to control module with umbilical cord, turn on power and turn oven and probe heater to maximum settings.
- 8) When the oven and probe have reached operating temperatures (250 \pm 25 F) perform leak check on assembled sampling train by plugging the sampling nozzle, turning on the vacuum pump and drawing 15 in. of Hg (mercury) vacuum. The leak rate shall not be more than 0.02 CFM.

- 9) Insert sampling probe to the first traverse point, note and record ΔP , and calculate ΔH from equation $\Delta H = K\Delta P$.
- 10) Start test by turning on vacuum pump and setting the sampling rate at the calculated ΔH with the fine adjustment of the vacuum pump. Record starting time and initial dry gas meter reading. Also record traverse point number, stack temperature, vacuum gage reading, probe temperature, inlet and outlet temperatures of dry gas meter, inlet and outlet temperatures of impinger compartment, and oven temperature. Start bag sampler to collect an integrated sample of the stack gas for Orsat analysis.
- 11) After sampling at point No. 1 for the desired time move probe to the next point; note and record ΔP , calculate ΔH and again set sampling rate. Record all data as before. Repeat for each traverse point. When changing ports turn off vacuum pump and record time and dry gas meter reading. When restarting in a new port turn on vacuum pump and again record time and dry gas meter reading.
- 12) When all traverse points have been sampled and the test is complete, turn off vacuum pump, record time and final dry gas meter reading. Turn off bag sampler. Again perform a leak check on the assembled sampling train at the highest vacuum achieved during the sampling run. If the leak rate exceeds 0.02 CFM the test is invalid.
- 13) If no further tests are planned for the day, disassemble sampling apparatus, lower to the ground and return all units to the laboratory for clean-up and analysis.
- 14) If additional tests are planned for the day, disconnect the probe from the sampling unit and the sampling unit from the rail. Lower the probe and sampling unit to the ground for clean-up and recharging with reagents. Remove the probe and sampling unit to a clean, quiet area away from the site, such as the back of the vehicle and clean as follows:
 - a) Disassemble the filter housing and place the filter in a clean identified petri dish. Also, carefully brush any particulate matter and/or filter fibers to the petri dish and seal. Wash the top half of the filter assembly with acetone collecting the washings in a beaker.

- b) Disconnect the sampling nozzle from the probe and carefully clean the inside by washing with acetone and brushing with a nylon bristle brush. Continue washing and brushing until washings are clean while collecting all washings in a beaker.
 - c) Wash and brush the inside of the sample probe while tilted and collect washings. Continue washing and brushing while rotating until washings are clear.
 - d) Combine washings from filter housing, nozzle, and probe and transfer to an identified plastic or glass bottle.
 - e) Measure and record the water in each impinger and transfer to an identified plastic or glass bottle.
 - f) Transfer expended silica gel to an identified plastic or glass bottle.
 - g) Return all plastic or glass bottles to the laboratory.
- 15) Place a tared filter paper in the filter holder, add reagents to the impingers, fill the impinger compartment with ice and reassemble the sampling train.
- 16) Hoist the probe and sampling unit to the scaffold, reconnect probe to the sampling unit, and the sampling unit to the rail, and repeat steps 7 through 12.

The procedures for laboratory analysis of the particulates, washings, and impinger catch, along with the calculation procedures are included in Appendices B and C.

APPENDIX B
SAMPLE RECOVERY

SAMPLE RECOVERY

1) Filter - transfer filter to a tared weighing dish, desiccate for 24 hours in a desiccator, and weigh to constant weight (nearest 0.1 mg) or oven dry at 105 C for two to three hours, cool in desiccator and weigh to constant weight (nearest 0.1 mg).

2)* Nozzle and Probe Wash Solution - transfer solution to a tared 250 ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to constant weight (nearest 0.1 mg).

3)* Impinger Water Catch - if water is cloudy or discolored transfer to a beaker with adequate capacity and evaporate to about 100 ml on a hot-plate. Transfer to a tared 250 ml beaker and continue evaporating to dryness. Oven dry at 250 C for one hour, desiccate and weigh to constant weight.

4) Add filter catch weight and nozzle and probe wash weight to get total particulate load for calculating EPA Method 5 particulate concentration. For calculating DNR particulate concentration add impinger water catch weight to the filter and nozzle and probe weights.

* Run Blanks on Reagents - acetone for the nozzle and probe wash and distilled water for the impinger water catch. Subtract blank weights from each.

APPENDIX C
SAMPLING DATA AND
PARTICULATE CALCULATIONS

SAMPLING DATA AND PARTICULATE CALCULATIONS

Data Required

- A. No. of traverse points _____ .
- B. Total test time (θ) _____ minutes.
- C. Water collected
 - 1) Impinger water (total) _____ ml.
 - 2) Silica gel _____ gm.
- D. Particulate weight (Mn) _____ gm.
- E. Volume metered (Vm)
 - $V_m = V_{\text{final}} - V_{\text{initial}} \times \text{DGMCF}^* \text{ _____ cu ft.}$
- F. Average $(\Delta P)^{1/2}$ _____ in. H₂O.
- G. Average ΔH _____ in. H₂O.
- H. Average meter temperature (Tm) _____ F + 460 = _____ R.
- I. Average stack temperature (Ts) _____ F + 460 = _____ R.
- J. Absolute stack pressure (Ps) _____ in. Hg.
- K. Barometric pressure (Pb) _____ in. Hg.
- L. CO₂ _____ %, O₂ _____ %, CO _____ %, N₂ _____ %.
- M. Area of stack (As) _____ sq ft.
- N. Area of nozzle (An) _____ sq ft.

* DGMCF - dry gas meter correction factor.

Calculations

- A. Standard volume metered. Vm (std).

$$V_m (\text{std}) = V_m Y \frac{T (\text{std})}{P (\text{std})} \times \frac{P_b + \frac{\Delta H}{13.6}}{T_m} = \text{_____ DSCF}$$

Y = dry gas meter calibration factor DSMCF

T (std) = 68 F + 460 = 528°F

P (std) = 29.92 in. Hg

- B. Moisture content of stack gas.

- 1) H₂O collected in impingers in standard cu ft (SCF)

$$V_{wc} (\text{std}) = K (V_{\text{final}} - V_{\text{initial}})$$

$$V_{wc} (\text{std}) = 0.04707 \text{ cu ft/ml (_____ ml) = _____ SCF}$$

2) H₂O collected in silica gel in standard cu ft (SCF)

$$V_{wsg}(\text{std}) = K (W_{\text{final}} - W_{\text{initial}})$$

$$V_{wsg}(\text{std}) = 0.04715 \text{ cu ft/gm} (\text{ ______ gm}) = \text{ ______ SCF}$$

3) Moisture content of stack gas (Bws)

$$B_{ws} = \frac{V_{wc}(\text{std}) + V_{wsg}(\text{std})}{V_{wc}(\text{std}) + V_{wsg}(\text{std}) + V_m(\text{std})}$$

$$B_{ws} = \frac{(\text{ ______ SCF}) + (\text{ ______ SCF})}{(\text{ ______ SCF}) + (\text{ ______ SCF}) + (\text{ ______ SCF})}$$

C. Molecular weight of stack gas (lb/lb-mole)

1) M_d (dry molecular weight) = $\sum M_x B_x$

$$M_d = (.44) \text{ ______ } \% \text{ CO}_2 + (.32) \text{ ______ } \% \text{ O}_2 + (.28) \text{ ______ } \% \text{ CO} + \\ (.28) \text{ ______ } \% \text{ N}_2 = \text{ ______ lb/lb-mole}$$

2) M_s (wet molecular weight) = M_d (1 - B_{ws}) + 18 B_{ws}

$$M_s = \text{ ______ } (1 - \text{ ______ }) + 18 (\text{ ______ }) = \text{ ______ lb/lb-mole}$$

D. Average stack gas velocity

$$V_s = K_p C_p \left[\frac{T_s}{P_s M_s} \right]^{1/2} \left[\Delta P \right]^{1/2}$$

$$K_p = 85.48$$

$$C_p = 0.837 \text{ pitot tube calibration factor}$$

$$V_s = (85.48)(0.837) \left[\frac{\text{ ______ }}{\text{ ______ }} \right]^{1/2} \left[\text{ ______ } \right]^{1/2}$$

E. Particulate concentration of stack gas, gr/DSCF

$$C_s = \frac{M_n}{V_m(\text{std})} (15.43 \text{ gr/gm})$$

$$C_s = \text{ ______ } (15.43) = \text{ ______ gr/DSCF}$$