FILE NAME: General Motors (GM)

DATE: 1980 Nov 6

DOC#: GM036

DOCUMENT DESCRIPTION: Internal Report - Gas and Particle Emission Rates from Asbestos Brake Linings

GMR-3434
ENV #91

Gas and Particle Emission Rates from Asbestos Brake Linings

by

Ronald L. Williams and Jean L. Muhlbaier

Environmental Science Department
General Motors Research Laboratories
Warren, Michigan 48090

Printed at
General Motors Research Laboratories
Warren, Michigan 48090
November 6, 1980

ABSTRACT

Brake emissions were measured on a specially constructed brake emission testing machine that confined the emissions so that a mass balance could be made. The particulate mass emitted from a single disc brake varied from 1.3 to 21 mg/stop over a normal range of simulated car velocities and deceleration rates, with a median level of 3.3 mg/stop. The airborne mass of 6.5 mg/vehicle/km is slightly greater than tire particulate emissions and about 40% of tailpipe particulate emissions from a car using unleaded gasoline. Median gaseous emissions of 1.4 mg C/brake/stop (6.7 mg/km) are emitted as CO_2, CO, and hydrocarbons.

Approximately half of the worn brake material becomes airborne with the remainder settling to the roadway or being entrained in the wheel. Because of the more open construction of disc brakes and the higher inertial load imposed on front-wheel brakes, about 50% more airborne particulate is emitted from front disc brakes than from rear drum brakes. It was found that there is no difference in the size distribution of particles emitted from disc or drum brakes. The mass median diameter is between 3 and 4 micrometers with 90% of the mass of particles greater than 1 micrometer. The composition of the particles will not be discussed in this paper.

As the wheel velocity increases, gaseous and particulate emissions during braking increase very rapidly. For example, fifteen times more airborne particulate is released at 88 km/h than at 40 km/h. Higher deceleration rates result in higher emissions although the increase is less pronounced than those observed with velocity changes.

INTRODUCTION

The drum linings and disc pads used in most of the cars on the road today consist of three basic components: chrysotile asbestos, friction modifiers, and binders. Approximately 50% of the brake lining consists of a chrysotile asbestos pad, used because of its friction and heat properties. Friction modifiers such as graphite and cashew resin are added to improve the friction properties; metal compounds are added to improve the wear properties of the asbestos. The materials are held together with phenolic binders.

During the lifetime of the brake lining (an estimated 40 000 miles for drum linings on rear wheels and 30 000 miles for disc pads on front wheels[1]), the brakes are worn away by abrasive and thermal wear. Particles worn from the brake lining become entrained in the wheel, settle to the roadway, or become airborne. The high surface temperatures reached during braking (up to 1000°C) also lead to gaseous hydrocarbon, carbon monoxide, and carbon dioxide emissions.[1]

Brake emission studies published to date have been limited by the experimental approaches taken. A variety of laboratory devices have been designed for evaluating and testing friction materials.[2,3] Emission studies from these devices cannot quantify the gaseous and particulate emissions from production brake components.[4] Brake-test dynamometers commonly use full-sized brake components, but it has proven difficult to confine the emissions. One open system for brake emission work has been demonstrated at the Ford Motor Company.[5] An on-board system designed by Bendix placed collection surfaces extremely close to the brake which may have reduced the amount of airborne wear debris.[1] To overcome these difficulties, we have built a unique brake-wear emission facility consisting of a brake-test dynamometer, an enclosure tube, and a sampling system. Brake emissions can be generated and collected under operating conditions that duplicate the usage range of automobile disc and drum brakes. This report quantifies the particulate and gaseous emissions and compares brake emissions as measured with our testing facility to other mobile-source emissions. The composition of the particulate emissions will not be discussed in this paper.

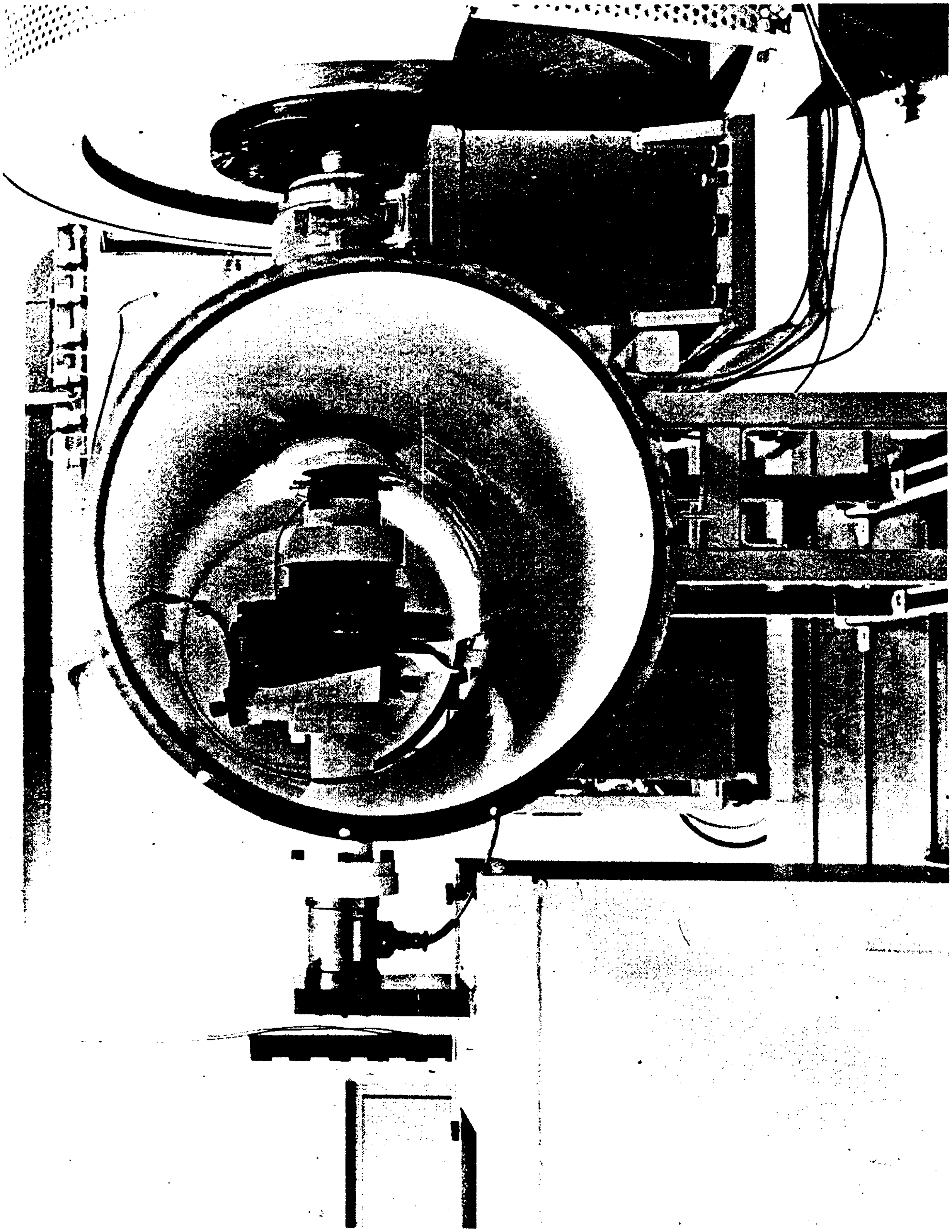

Figure 1. Disc Brake Assembly in Enclosure Tube

according to their aerodynamic diameter. Particulate materials are deposited on a set of impaction plates for mass measurements, microscopic examination, and chemical analysis.

The flow rate through each sample probe is adjusted to match the velocity at the probe inlet with the mainstream velocity in the collector tube. This isokinetic condition ensures that the sampling is indiscriminate with respect to particle size.

The fourth probe shown in Figure 2 was used to deliver a gas sample from the tube to a train of analyzers for continuous measurement of HC, CO, and CO_2. The analyzer signals were recorded on strip charts at the operator console. Brake-wear dust which fell out of the brake assembly during tests accumulated in the enclosure tube. This dust was collected in a polyethylene bottle through a short, Tygon inlet tube. The bottle was packed with glass wool and was attached to the inlet end of the hose to an industrial vacuum cleaner. This device was an efficient collector of brake-wear dust which tenaciously adhered to most surfaces. Most of the dust retained in the brake assembly was gently brushed into a tared vial. The vacuum device was used for final cleanup of the brake assembly, and the mass collected was added to the mass of dust in the vial to measure the total retained dust.

Selection of Test Brake Materials

The disc pads and drum linings for this test program were selected to represent high-volume production components. The disc-brake set and the drum linings used for most of the tests were new, OEM components. Two, used disc-brake sets were also tested . . . one set with 8000 km of use and one set with 60 000 km of use. All the disc-brake results will be presented as a single set since there were no measurable differences in emissions among the three sets. Both the disc and the drum brakes were manufacturer's equipment for standard-sized GM automobiles. The friction material used for testing consisted of about 60% asbestos, 22% inorganic modifiers, and 18% organic binder by weight. Overall, the

RESULTS

Test Results

The results of the disc and drum brake tests are shown in Tables I and II, respectively. All of the parameters were measured during the disc tests, but only the airborne particulate and gases were collected during the drum tests. The percent recovered is the ratio of the material collected to the loss in brake pad mass. The average percent recovered when all the parameters are measured is 90%. This is considered a good recovery since there is considerable difficulty in measuring small mass changes in the brake pads. Only 85% of the material from the drum tests was recovered. The remaining 15% is assumed to be due to sedimentary and retained particles.

Comparison of Front-Disc and Rear-Drum Brake Emissions

Average emissions for drum and disc brakes under two operating conditions are shown in Table III. Rear-drum brake emissions are always smaller than front-disc brake emissions. This is particularly true at the high velocities where disc temperatures rise quickly. This agrees with the trend found by Jacko and DuCharme and the fact that front-wheel disc brakes are known to wear out more quickly than rear-wheel drum brakes.[1] This can be attributed to the higher temperatures reached in disc brakes due to the smaller surface area at the disc-rotor interface and the higher inertial loads.

Table II. Results of Rear-Drum Brake Emission Tests[a,b]

Test	Velocity (km/h)	Deceleration (m/s^2)	Airborne Mass (mg/stop)	HC[c] (mg/stop)	CO_2[c] (mg/stop)	CO[c] (mg/stop)
58-60	40	1.85	0.72	0.06	0.04	0.03
61	40	1.85	1.10	0.05	0.07	0.02
54	40	1.85	0.60	0.21	0.73	0.18
51-53	40	4.9	3.01	0.06	0.18	0.05
62	40	4.9	2.5	0.03	0	0.02
48-50	64	1.2	0.75	0.29	0.84	0.23
42-44	64	1.85	1.04	0.67	0.55	0.44
55-57	64	1.85	1.12	0.36	0.66	0.21
45-47	64	2.5	1.12	0.85	2.4	0.56
63-65	64	4.9	1.63	0.46	0	0.27
66-68	88	1.85	2.18	1.2	0.73	0.11
69	88	1.85	3.25	0.53	1.8	0.6

[a] Tested using rear-wheel inertia of 53.4 $kg.m^2$.

[b] The total emission from the drum tests was 8.1 g which consisted of 4.2 g of airborne particles, 1.3 g of hydrocarbons, 1.9 g of CO_2 and 0.65 g of CO as C. The total brake loss was 9.5 g. Therefore, 85% of the brake loss material was recovered.

[c] CO, CO_2 and HC are reported as carbon mass.

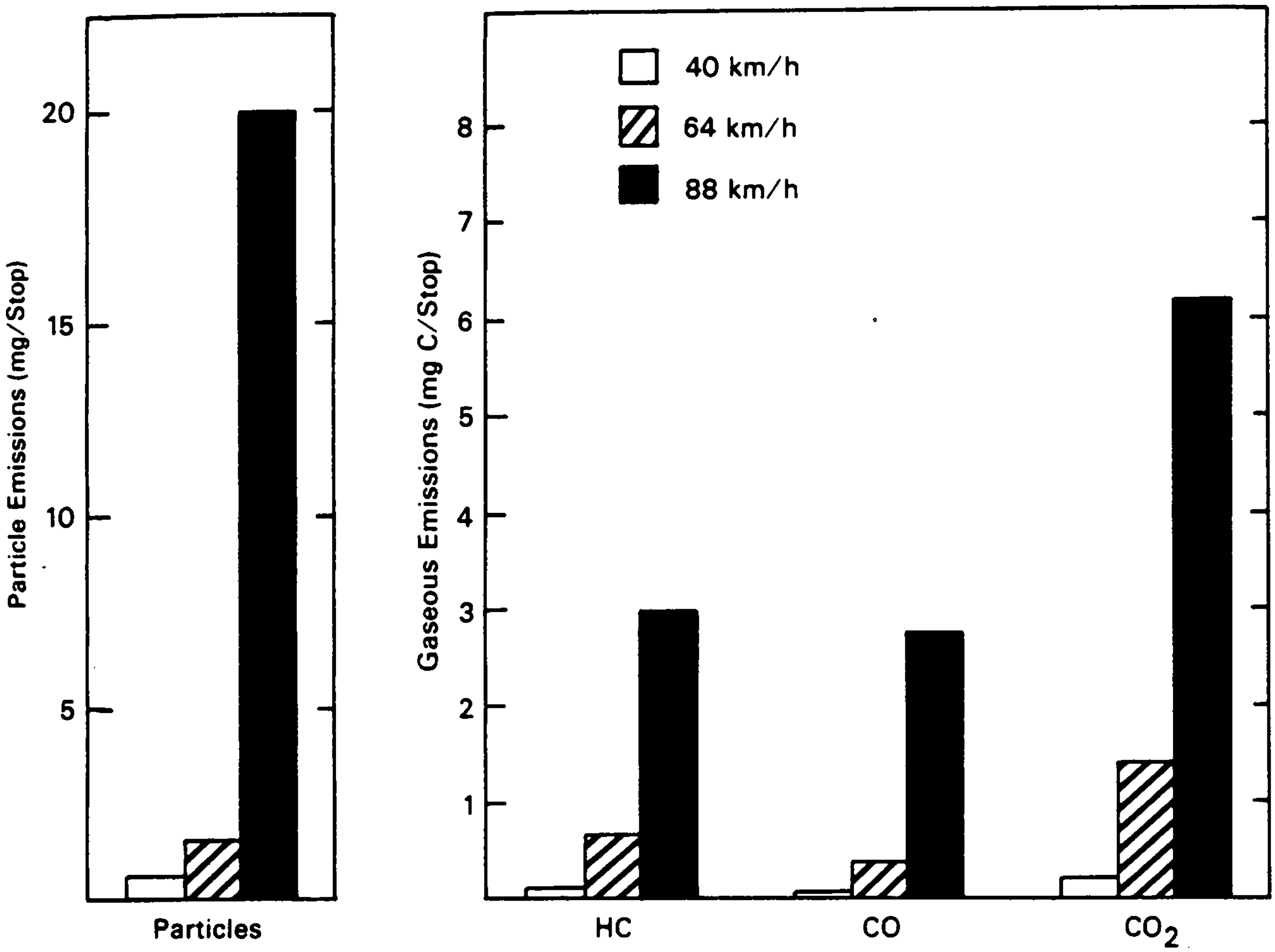

Figure 3. Disc Brake Emissions at Various Velocities.
Deceleration = 1.8 m/s^2.

Size Distribution

Several cascade-impactor runs were made to determine the size distribution of the airborne particulate. Particle size distributions for typical disc and drum tests are shown in Figure 5, using the manufacturer's cut-off diameter for the impactor stages. The disc and drum distributions are virtually the same, with the distribution peaking between 1 and 2 micrometers. The mass median aerodynamic diameter (MMAD) averages 3.1 micrometers for ten impactor runs and the submicrometer particles average only 10% of the total mass. This particulate distribution falls between the atmospheric bimodal distribution of secondary aerosols (centered around 0.3 micrometer) and mechanically generated aerosols (about 10 micrometers).[8] There is some evidence of a shift in particle size to smaller particles at higher wheel speeds. Thus, in a separate series of experiments, particles emitted at 40 km/h have an average MMAD of 4.0 micrometers compared to a 3.0 micrometers MMAD at 88 km/h.

Distribution of Emissions

For the purpose of calculations, the median levels of brake emissions were determined. The airborne particulate accounts for 1.6 mg/stop from front-disc brakes and 1.1 mg/stop from rear-drum brakes. Total emissions from one front-disc brake are 3.3 mg/stop particulate, 0.6 mg C/stop as hydrocarbons, 0.7 mg C/stop as CO_2, and 0.1 mg C/stop as CO. The average particulate is 55% airborne material, 12% sedimentary material, and 34% brake-entrained material. These values are quite different from those found by Jacko and DuCharme[1] of 7 to 15% airborne, 63 to 79% sedimentary, and 7 to 15% brake entrained. The values found in our study for brake-entrained material may be high since the brake was cleaned after each test. Over a longer running period, the available surfaces would be filled which would cause additional dust to settle to the roadway or become airborne. On the other hand, it is possible that the sedimentary portion found by Jacko and DuCharme may have been overestimated. The shroud surrounding their brake system created an artificial system with high surface areas for impacting material which might otherwise become airborne.

DISCUSSION

We have shown that approximately 3.3 mg of particles and 1.4 mg C as gaseous hydrocarbons, CO, and CO_2 are generated during a single disc brake application. The particulate was found to be 55% airborne, 12% sedimentary, and 34% brake-entrained. A front-disc brake emits 1.6 mg/stop airborne material compared to 1.1 mg/stop for a rear-drum brake. The larger emission for front-disc brakes is expected, due to the higher temperatures measured at the disc-rotor interface and the larger inertial load imposed on the front-wheel brakes. Brake emissions increase rapidly with increasing velocity, but deceleration rate has little effect. The airborne mass has a MMAD of 3.1 micrometers, with about 10% of the mass being in the submicrometer range.

Based on these results, total brake emissions can be estimated on a national basis. There were 144 million registered vehicles in the United States in 1977, each traveling an average of 15 800 km (9800 mi).[9] Brake applications per km range from 0.6-2.5, depending on the type of driving.[1] Assuming an average of 1.2 stops/km (2 stops/mile) and four brakes per vehicle, there would be 1.14×10^{13} brake applications yearly. The total emissions (based on data from disc brakes) would be 3.6×10^{10} g particles, 0.7×10^{10} g C as hydrocarbons, 0.8×10^{10} g C as CO_2, and 0.1×10^{10} g C as CO for a total emission of 5.2×10^{10} g/year. This agrees well with Jacko and DuCharme's[1] estimate of 5×10^{10} g of brake material worn away annually which was based on the number of brake linings installed.

The total airborne particulate emitted from brakes is about 6.5 mg/car/km ([2 discs at 1.6 mg/stop + 2 drums at 1.1 mg/stop] x 1.2 stops/km). This compares to particulate exhaust emissions for a car using unleaded gasoline of 16 mg/km (25 mg/mi)[10] and airborne tire-wear emissions of 2-5 mg/km.[11] Therefore, brake particulate emissions may be as much as 40% of exhaust particulate emissions, and comparable to tire emissions. Although brake particulate emissions are significant compared to tailpipe emissions, the total estimated brake emissions of 3.6×10^{10} g/year is extremely small compared to total U.S. anthropogenic particulate emissions of 1300×10^{10} g/year.[12] The gaseous emissions of approximately 7 mg/km from brakes are very small compared to tailpipe emissions.

ACKNOWLEDGEMENT

The authors thank A. E. Fincham for his assistance in this project.

REFERENCES

1. M. G. Jacko and R. T. DuCharme, "Brake Emissions: Emission Measurements from Brake and Clutch Linings from Selected Mobile Sources," Bendix Research Laboratories, Southfield, MI, Report 68-04-0020, March 1973.
2. S. K. Rhee, "Wear Equation for Polymers Sliding Against Metal Surfaces," Wear, 16, 431 (1970).
3. J. R. Lynch, "Brake Lining Decomposition Products," J. Air Pollut. Control Assoc., 18, 824 (1968).
4. D. M. Rowson, "The Chrysotile Content of the Wear Debris of Brake Linings," Wear, 47, 315 (1978).
5. A. E. Anderson, R. L. Gealer, R. C. McCune, and J. W. Sprys, "Asbestos Emissions from Brake Dynamometer Tests," Society of Automotive Engineers, Paper No. 730549, February 1973.
6. R. L. Williams, "Design and Construction of a Test Facility to Characterize Brake-Wear Emissions," General Motors Research Publication (submitted to Environmental Research).
7. S. K. Rhee, "Wear Mechanisms for Asbestos-Reinforced Automotive Friction Materials," Wear, 29, 391 (1974).
8. K. T. Whitby, R. B. Husar, and B. Y. H. Liu, "The Aerosol Size Distribution of Los Angeles Smog," J. of Colloid and Interface Science, 30, 177 (1972).
9. MVMA Motor Vehicle Facts and Figures, '78, Motor Vehicle Manufacturers Association (1978).
10. S. H. Cadle, G. J. Nebel, and R. L. Williams, "Measurements of Unregulated Emissions from General Motors Light-Duty Vehicles," Society of Automotive Engineers, Paper No. 790694, June 1979.
11. S. H. Cadle and R. L. Williams, "Gas and Particle Emissions from Automobile Tires in Laboratory and Field Studies," J. Air Pollut. Control Assoc., 5, 502 (1978).
12. National Air Pollutant Emission Estimates 1940-1976, U.S. EPA Report 450/1-78-003, July 1978.