

Report On The Determination  
Of  
Mass Emissions From Two-Cycle  
Engine Operated Vehicles

Prepared for  
Department of Health, Education & Welfare

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#### ABSTRACT:

Two-cycle spark ignited motorcycle engines are evaluated for exhaust emissions from the standpoint of both concentration (percent) and mass (gms/mile) according to current and projected Federal Testing Procedures for light duty vehicles (under 6,000 pound GVW). Seven two-cycle and one four-cycle motorcycle were tested for Carbon Monoxide, Carbon Dioxide, Hydrocarbons, Nitrogen Oxide and Dioxide using Non-Dispersive Infrared, Non-Dispersive Ultra-violet, flame ionization and gas chromatographic analytical techniques. The inconsistencies in the test method as applied to motorcycles are pointed out and suggestions are made for further studies.

#### CONCLUSION:

The seven two-cycle motorcycles tested per the current Federal test cycle for light duty vehicles under this contract averaged 4429 ppm Hydrocarbon (HC) as Hexane equivalent and 4.34 percent Carbon Monoxide (CO). The corresponding mass figures calculated per those 1970 Federal procedures are 3.59 and 6.81 gms/mile respectively. Calculated per the proposed 1972 procedures (proportional bag sample) the figures are 11.8 and 26.85 grams per mile. A rationale for the discrepancies is suggested, and it is also the author's opinion that of the two test methods employed the precision and accuracy of the 1970 analytical procedures are considerably superior to those of the proposed 1972 method because of long experience with the former

and the converse with the latter.

Although one would suspect a priori that the average Carbon number of the exhaust Hydrocarbons from two-cycle engines would be higher than that of four-cycle engines because of the different types of engine lubrication the gas chromatographic data shows a Carbon number well within the expected range for the latter class. This limited data would suggest only a most modest contribution to atmospheric hydrocarbon loading as a lubricating oil contribution.

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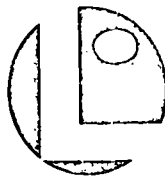
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## INTRODUCTION:

The purpose of this project was to gain a preliminary estimate of both the concentrations and mass emissions from a group of two-cycle motorcycles comprising the most popular makes and displacements. To provide a frame of reference a popular four-cycle engine powered machine was also tested.

Two-cycle engines have been suspect from the standpoint of a high emission potential because of the nature of their combustion process. Appendix C describes two-cycle SI combustion as compared to four-cycle SI engines.

The eight motorcycles tested during this project are described in Table 1. The oldest machine was a 1967 model, the next oldest a 1968, with the balance being 1969's. No formal inspection or tune-up procedures were employed on any of the 'cycles, although they were all road and dynamometer evaluated for proper operation before being tested. All the motorcycles were obtained from either rental agencies or private owners. Within the constraints of sample size it is believed that the 'cycles tested are representative of currently sold and owner operated two-cycle motorcycle engines.

All the machines with the exception of the Yamaha 250 Enduro were tested with Indolene 30 gasoline. Inadvertently the latter 'cycle was tested for both emissions and GC analysis with tank fuel as received. Determination of either the grade or brand of the fuel could not be made on that cycle.

It is of interest to consider the method of lubricating the engines tested in this program. As is generally known the conventional method of lubricating two-cycle engines is simply to add oil to the fuel and intimately mix immediately prior to pouring the fuel into the tank. Alternately one can place the oil in the tank either prior to or subsequent to tank filling with gasoline. The possibilities for gross error in oil to fuel ratios as compared to recommended ratios either way this procedure is carried out are obvious. In the engines that were tested in this program lubrication was supplied from an oil reservoir through a proportioning pump which introduced oil into the engine.

Attached as appendix D is a section from a Yamaha Service Manual which describes in very general terms the operation of their "Autolube" system. Such a system generally adds one quart of oil to every 10 gallons of fuel which represents a 40:1 fuel-oil ratio.

#### INSTRUMENTATION:

All the 'cycles were tested using the following instrumentation:

1. Beckman Model 315 Low HC analyzer.
2. Beckman Model 315 High HC analyzer.
3. Beckman Model 315 CO analyzer.
4. Beckman Model 315 CO<sub>2</sub> analyzer.
5. Beckman Model 315A NO analyzer.
6. Horiba Model UVA-1 NO<sub>2</sub> analyzer.
7. MSA Flame Ionization analyzer.
8. Clayton Model CT-200 Chassis Dynamometer.
9. Olson Laboratories Variable Volume Constant Mass Sampler

Analyzers numbered 1-5 are all Non-Dispersive Infrared while number 6 is Non-Dispersive Ultra-violet.

#### TEST PROCEDURES:

All of the motorcycles were tested over the seven-mode HEW cycle. It was recognized that in all probability that the typical motorcycle driving pattern bore little resemblance to the seven-mode cycle, but lacking information on such a driving pattern, the use of the seven-mode cycle would at least allow a comparison of the emissions from the motorcycles to those of motor vehicles now subject to Federal Standards.

The criterion for determining the success of each run was whether or not the acceleration modes could be completed within the times specified by the Federal Register. To accomplish this, the Clayton dynamometer was altered by removing the fixed 2000 pound inertia wheel. As indicated in Table 1, a 500 pound inertia



wheel was used for the larger motorcycles to simulate acceleration performance, while inherent system inertia was sufficient for the smaller motorcycles. In all cases the power absorption unit was not used. This practice is commonly adopted in the testing of lightweight, foreign automobiles. Since it has been observed that four-cycle engine exhaust concentration emissions vary little within the broad constraints of horsepower and inertia settings, it is believed that similar results apply to two-cycle vehicles.

The exhaust gas analysis system, as shown schematically in Figure 2, incorporates an Olson Laboratories Variable Volume Constant Mass Sampler. Samples for both the continuous and bag analysis were diluted using the Constant Mass Sampler. This was done to avoid insofar as possible any "wall" effects in the analytical train in view of the expected high Hydrocarbon concentrations. The calibration curve for the Constant Mass Sampler appears in Figure 3 and the method used for calibration of the sampler is described in Appendix E. The desired dilution range was selected as an approximate 10:1 air/exhaust ratio. To achieve this ratio the air delivery was varied in 40 CFM increments until the proper mix was achieved. Figure 4, the calculation sheet for one run on the Yamaha 180, illustrates the dilution ranges encountered. The mass sampler heat exchanger was not cooled, but was actually used as a heat sink to average out the diluted exhaust at temperatures of 46-52° C which further reduces the possibility of condensation of the high molecular weight Hydrocarbons (from the oil) peculiar to this study.

From the diluted exhaust samples continuous analyses were made for

HC, CO, CO<sub>2</sub> and NO over the HEW test cycles. NO<sub>2</sub> and Flame Ionization Hydrocarbons were measured only on the bag samples with the Flame Ionization instrument using a fuel of 60% N<sub>2</sub>-40% H<sub>2</sub> with air as the oxidizer. The bag samples were also tested for NDIR HC, CO, NO, and CO<sub>2</sub> concentrations. Samples for the gas chromatographic analysis were drawn from the bag sample into two-liter glass flasks. These samples were packed in dry ice and immediately transported to the subcontractor for analysis. Before introducing the samples to the G.C. the flasks were heated to 70% C by means of a heating mantel.

#### DISCUSSION OF RESULTS:

The seven-mode cycle "Hot Start" data appears in Table 2. The data was calculated according to the Federal procedures for the 1968 emission standards. The carbon dioxide (CO<sub>2</sub>) corrected value also appears in this table. The Hydrocarbon value was added to the total Carbon correction on all modes. The high concentrations of Hydrocarbons encountered significantly affected the correction factors and would have given higher emissions if this factor was only used on the decel modes as prescribed by the Federal Register. In all cases the data shows the engine operating with a rich mixture which is probably characteristic of a two-cycle motorcycle as well as the baseline four-cycle engine. As was mentioned earlier no attempt was made to make adjustments on these motorcycles.

Table 3 is a summary of the diluted bag sample analysis. In

comparing the corrected values for Hydrocarbon (HC) and Carbon Monoxide (CO) in Table 3 with those from Table 2, we find an average difference of about 10 per cent. The average Hydrocarbon value obtained for all 8 motorcycles by the 7-mode analysis was 4404 as compared to 3948 for the bag analysis. The respective Carbon Monoxide values were 4.61 and 4.12.

Considering we are comparing a closed verses an open cycle this agreement could be considered quite good. This close agreement however was not shown in the mass emission calculations by the two different methods.

The oxides of nitrogen determined by bag sample analysis were much higher than the seven-mode cycle data. The seven-mode cycle data is the more logical and probably the correct value. The bag samples were probably contaminated from previous tests due to moisture in the system and hang-up. These bags were carefully flushed with clean air between samples but it is obvious from the data that the interference of moisture and NO<sub>2</sub> hang-up was probably contributing greatly to the response.

Mass emissions as determined from these two sets of data appear in Tables 4 & 5. There is a noticeable difference in the mass emissions as determined by these two methods. The oxides of Nitrogen differences are readily explainable by the large concentration differences determined by the two methods. The differences seen between the values for Hydrocarbon and Carbon Monoxide are less easily explained.

The greatest influence on this calculation is the exhaust volume per mile as determined by the two different methods. If one for example takes the V mix calculated in Table 5 for the Yamaha 180 and divides by the correction factor we obtain a corrected exhaust volume per mile of 19.2 which compares to 4.8 as determined by the empirical formulae from the Federal Register (45 CFR § 85.97).

Another difference which affected the results was that the flame ionization data was used to calculate Hydrocarbon emissions in Table 5 (bag samples) and the NDIR multiplied by a factor of 1.8 was used for Table 4. This factor as can be seen by Figure 1 was incorrect as the actual ratio came out 1.33.

Other factors which affected the comparison were the different methods used to determine the correction factors, and inherent errors involved in measurement of temperatures, pressure, and mass flow rates.

Mass emissions calculated by the seven-mode data cannot be expected to agree with the Variable Volume Mass Sampler data. It is obvious from the difference in the calculations and sampling techniques that were used that we really are trying to compare two different things. As to which method is correct, we believe that both methods suffer from inadequacies as these methods were specifically designed for a four-cycle passenger car. This data is presented only as a comparison of emissions based on present sampling procedures.

The large differences between the two methods of calculations

shows a need for the development of more appropriate driving cycles and sampling procedures. We can only conclude that the actual emissions found by newer methods will be within the ranges reported.

Table 6 is a summary of the Gas Chromatography data and the complete data by compound appears in Appendix F.

In addition to the actual concentrations of individual compounds the reactivity of each compound has been computed using the G.M. reactivity index<sup>1</sup>. Individual compounds were identified using the data of McEwen<sup>2</sup> and Jackson<sup>3</sup>.

The Hydrocarbon names have been abbreviated on the data sheets and the identifications are given in Appendix A. The reactivity of the Hydrocarbons is a measure of its smog forming potential. The higher the reactivity number the faster the Hydrocarbon will react in the smog forming photooxidation reaction.

Appendix B is a typical automobile exhaust calculation of individual Hydrocarbons and reactivity. In comparing this set of data with that determined from the two-cycle emissions we see an order of magnitude difference in both concentration of Hydrocarbons and reactivity. However, the higher emissions from the two-cycle engines should be weighted on a grams per mile basis rather than a per cent or ppm basis as reported. The data does show that the overall reactivity when compared on the basis of Hydrocarbon concentration is nearly equivalent to a typical automobile exhaust. The total Hydrocarbons determined by gas chromatography are very close to the flame ionization data obtained although less in each

case. This G.C. data is, however, representative of greater than 90% of the total Hydrocarbons. McEwen<sup>2</sup> reports average Carbon numbers in the range of 3.40 to 5.95. Since the highest average Carbon number reported (5.9) falls within this range and since this particular cycle (Suzuki 250) has oil pumped directly to the main bearings and rod lower end rather than being pre-mixed or injected with the fuel, the contribution of the oil to the Hydrocarbon measured could be considered slight for these two-cycle engines. If the oil were actually contributing to the overall Hydrocarbon measurement we would expect higher average Carbon numbers for the other two cycles.

It should be noted that the Yamaha 250 was not run on the same fuel as the other two motorcycles.

Also, because of the small volume of the tanks and the difficulty of completely draining the tank before filling with the test fuel it would be possible for this residual fuel to affect the overall composition. However, we feel the data as presented is valid for the purpose of obtaining typical emissions of individual Hydrocarbons especially those formed primarily in the engine such as acetylenes and the lower Carbon number paraffins and acetylenes.

#### CONTRIBUTION TO OVERALL POLLUTION

The U.S. Department of Transportation shows that in 1966 passenger cars traveled a total of 744,844 million miles, motorcycles traveled a total of 6,396 million miles. According to the latest

information the two-cycle motorcycles account for 39% of the motorcycle sales.

Using the overall average mass emissions from Table 4 for two-cycle motorcycles and assuming that all passenger cars meet the standards of 2.2 grams per mile of Hydrocarbon and 23 grams per mile of Carbon Monoxide we arrive at the following information:

1. Two-cycle motorcycles emit 0.65 of the passenger car Hydrocarbon emissions and 0.11 of the Carbon Monoxide emissions.
2. This amounts to approximately 11,300 tons per year of Hydrocarbons and 20,100 tons per year of Carbon Monoxide.

Figure 5 is a graph comparing the range of Hydrocarbons experienced on a single device equipped passenger car as compared with the motorcycle emissions on a grams per mile basis as determined from Table 4. The Carbon Monoxide emissions are significantly lower than the passenger car but the Hydrocarbon range is greater by approximately a factor of 3. Therefore, even though the motorcycles at present represent a small percentage of the total overall vehicle emissions as the cycle becomes more popular it could be a significant contributor to air pollution in the near future.

According to the U.S.D.T. study there was an increase in sales of motorcycles of 32.4 percent from 1965 - 1966. More up-to-date information on 'cycle population and other two-cycle engine machines such as boats, lawn-mowers, chain saws and ski-mobiles

would most likely show an even more significant contribution to air pollution than we can presently estimate.

SUGGESTIONS FOR FURTHER STUDY

Before a more accurate picture of overall two-cycle emissions can be determined a study of actual population types and numbers should be made of all two-cycle engine machines. Also, a study should be made of driving or operating conditions peculiar to the various types. With this type of information and equipment designed around these operating parameters and using the most advanced types of instrumentation available a study should be made which would give us a more accurate index of the contribution the two-cycle engine is making to air pollution.



REFERENCES:

1. C.S. Tuesday and W.A. Glasson, "Hydrocarbon Reactivity in the Atmospheric Photo-oxidation of Nitric Oxide". Paper presented at ACS Meeting, Atlantic City, September 1965.
2. D.J. McEwen "Automobile Exhaust Hydrocarbon Analysis by Gas Chromatography", Anal. Chem. Vol. 38 (1966) page 1047.
3. M.W. Jackson "Effects of Some Engine Variables and Control Systems on Composition and Reactivity of Exhaust Hydrocarbons". SAE Transaction Vol. 75, 1967, page 114, SAE publication #660404.

Table 1

Vehicle Identification

Manufacturer	Displacement CC	Vehicle Weight Pounds	Model Year	Mileage	Dyno Inertia <sup>3</sup> Pounds
Honda <sup>1</sup>	350	325	1969	New	500
Yamaha	180	300	1968	6282	Rolls only
Yamaha	100	212	1969	736	Rolls only
Yamaha	50	174	1969	1292	Rolls only
Yamaha	80	185	1967	11916	Rolls only
Yamaha	305	384	1969	1249	500
Suzuki	250	325	1969	28	500
Yamaha Endura <sup>2</sup>	250	275	1969	No Odometer	500

1. Four-cycle engine.
2. Used premixed fuel-oil mixture of 40:1
3. Horsepower absorption unit not used.

TABLE 2

SUMMARY OF CONTINUOUS 7-MODE CYCLE  
NON-DISPERSIVE INFRARED ANALYSIS

Vehicle	HC/NDIR	CO %	NO ppm	CO <sub>2</sub> %
<u>Honda 350 4-cycle</u>				
Run #1	602 ppm	6.43 %		8.18 %
Run #2	558 ppm	6.63 %	292 ppm	8.04 %
Run #3	585 ppm	6.50 %	297 ppm	8.14 %
Average	582 ppm	6.52 %	294 ppm	8.13 %
<u>Yamaha 180 2-cycle</u>				
Run #1	4260 ppm	2.79 %	171 ppm	9.63 %
Run #2	4785 ppm	1.92 %	242 ppm	10.20 %
Run #3	4632 ppm	2.84 %	297 ppm	9.39 %
Average	4560 ppm	2.52 %	237 ppm	9.74 %
<u>Yamaha 100 2-cycle</u>				
Run #1	3585 ppm	4.26 %	208 ppm	8.59 %
Run #2	3963 ppm	3.73 %	185 ppm	8.89 %
Run #3	3600 ppm	4.53 %	84 ppm	8.22 %
Average	3716 ppm	4.19 %	159 ppm	8.57 %
<u>Yamaha 50 2-cycle</u>				
Run #1	3299 ppm	3.68 %	319 ppm	9.34 %
Run #2	4204 ppm	3.14 %	369 ppm	9.22 %
Run #3	3993 ppm	3.64 %	450 ppm	8.93 %
Average	3832 ppm	3.49 %	379 ppm	9.13 %

TABLE 2 Cont'd

SUMMARY OF CONTINUOUS 7-MODE CYCLE  
NON-DISPERSIVE INFRARED ANALYSIS

Vehicle	HC/NDIR	CO %	NO ppm	CO <sub>2</sub> %
<u>Yamaha 30 2-cycle</u>				
Run #1	2407 ppm	1.65 %	368 ppm	11.90 %
Run #2	2232 ppm	1.76 %	244 ppm	11.86 %
Average	2345 ppm	1.70 %	306 ppm	11.82 %
<u>Yamaha 305 2-cycle</u>				
Run #1	5840 ppm	6.62 %	100 ppm	4.61 %
Run #2	6166 ppm	6.55 %	159 ppm	5.34 %
Run #3	5996 ppm	6.58 %	114 ppm	4.82 %
Run #4	6447 ppm	3.19 %	546 ppm	7.95 %
Average	6112 ppm	5.73 %	230 ppm	5.68 %
<u>Suzuki 250 2-cycle</u>				
Run #1	5155 ppm	6.10 %	130 ppm	6.17 %
Run #2	4248 ppm	5.83 %	158 ppm	6.61 %
Run #3	4483 ppm	6.59 %	126 ppm	5.71 %
Run #4	4628 ppm	7.46 %	434 ppm	4.76 %
Average	4629 ppm	6.50 %	212 ppm	5.81 %
<u>Yamaha 250 2-cycle</u>				
Run #1	5603 ppm	6.54 %	94 ppm	5.10 %
Run #2	5674 ppm	6.22 %	168 ppm	5.37 %
Run #3	6141 ppm	6.19 %	137 ppm	5.10 %
Average	5806 ppm	6.31 %	133 ppm	5.19 %

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Table 3

Summary Of Corrected & Uncorrected  
Bag Sample Data (NDIR, NDUV & FI)

Vehicle & Test No.	HC/NDIR ppm Hexane	HC/FID ppm Hexane	CO %	NO ppm	NO <sub>2</sub> ppm	NO <sub>x</sub> ppm	CO <sub>2</sub> ppm
<u>Honda 350</u>							
Run #1	455	750	2.30				3.10
Run #2	365	750	2.20	125	36	161	2.75
Run #3	375	750	2.05	100	14	114	2.65
Average	398	750	2.18	113	25	138	2.83
Correction Factor: 2.73							
Average Corrected:	1,087	2,048	5.95	308	68	377	7.73
<u>Yamaha 180</u>							
Run #1	490	595	.35	25	74	99	.87
Run #2	490	595	.28	25	109	134	.85
Run #3	490	690	.26	37	138	175	.80
Average	490	627	.30	29	107	136	.84
Correction Factor: 10							
Average Corrected:	4,900	6,265	3.0	290	1,070	1,360	8.40
<u>Yamaha 100</u>							
Run #1	350	525	.40	37	81	118	.62
Run #2	375	550	.41	25	92	117	.62
Run #3	390	550	.46	12	97	109	.62
Average	372	542	.44	25	90	115	.62
Correction Factor: 11.03							
Average Corrected	4,103	5,973	4.85	276	993	1268	6.84

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Table 3 - Cont'd

Summary Of Corrected & Uncorrected  
Bag Sample Data (NDIR, NDUV & FI)

Vehicle & Test No.	HC/NDIR ppm Hexane	HC/FID ppm Hexane	CO %	NO ppm	NO <sub>2</sub> ppm	NO <sub>x</sub> ppm	CO <sub>2</sub> ppm
<u>Yamaha 50</u>							
Run #1	220	300	.21	50	90	140	.55
Run #2	275	410	.18	75	102	177	.55
Run #3	240	390	.18	62	76	138	.55
Average	245	367	.19	62	89	152	.55
Correction Factor: 15.31							
Average Corrected	3,751	5,611	2.91	949	1,363	2327	8.42
<u>Yamaha 80</u>							
Run #1	150	250	.07	50	56	106	.67
Run #2	145	250	.08	75	56	131	.62
Average Uncorrected	148	250	.08	63	56	119	.65
Correction Factor: 16.48							
Average Corrected:	2,439	4,120	1.32	1038	923	1961	10.71
<u>Yamaha 305</u>							
Run #1	630	920	.48	25	169	194	.60
Run #2	630	900	.49	37	187	224	.46
Run #3	640	900	.52	50	187	237	.67
Run #4	685	920	.44	12	156	168	.62
Average	646	910	.48	31	175	206	.59
Correction Factor: 9.32							
Average Corrected:	6,021	8,481	4.47	289	1631	1920	5.50

Table 3 - Cont'd

Summary Of Corrected & Uncorrected  
Bag Sample Data (NDIR, NDUV & FI)

Vehicle & Test No.	HC/NDIR ppm Hexane	HC/FID ppm Hexane	CO %	NO ppm	NO <sub>2</sub> ppm	NO <sub>x</sub> ppm	CO <sub>2</sub> ppm
<u>Suzuki 250</u>							
Run #1	1000	1355	.83	37	200	237	.70
Run #2	815	1210	.76	37	66	103	.71
Run #3	860	1210	.80	37	80	117	.65
Run #4	1325	2030	.93	175	95	270	.55
Average	1000	1452	.83	72	110	182	.65
Correction Factor: 6.38							
Average Corrected:	6380	9261	5.30	459	702	1161	4.15
<u>Yamaha 250</u>							
Run #1	790	950	.63	50	102	152	.60
Run #2	845	970	.66	12	124	136	.67
Run #3	780	1020	.59	37	86	123	.60
Average	805	980	.63	33	104	137	.62
Correction Factor: 8.15							
Average Corrected:	6561	7987	5.13	269	848	1117	5.05

TABLE 4

MASS EMISSIONS AS DETERMINED FROM 7-MODE CYCLE DATA <sup>1</sup>

	Inertia <sup>2</sup>	Exhaust Volume Cu.Ft.Per Mile <sup>3</sup>	HC g/mi	CO g/mi	NO <sub>x</sub> g/mi
Honda 350	500	6.0	0.62	12.95	0.096
Yamaha 180	450	4.8	3.86	4.0	0.062
Yamaha 100	350	2.5	1.64	3.47	0.022
Yamaha 50	325	1.9	1.28	2.2	0.039
Yamaha 80	335	2.14	.88	1.20	0.036
Yamaha 305	500	6.0	6.48	11.38	.075
Suzuki 250	500	6.0	4.9	12.91	.069
Yamaha 250	500	6.0	6.14	12.53	0.043
Average 2-cycle only			3.59	6.81	0.049

1. Average values from Table 2 used for calculations.
2. Determined either by dynamometer loading or by the vehicle weight plus 150 pounds.
3. Calculated per 45 CFR § 85.87

Mass Emission Equations:

$$\text{HC Mass} = \frac{\text{ppm Hexane}}{10^6} \times 1.8 \times 6 \times \frac{\text{Exhaust Volume}}{\text{Mile}} \times \text{Density HC}$$

$$\text{CO Mass} = \frac{\% \text{ CO}}{100} \times \frac{\text{Exhaust Volume}}{\text{Mile}} \times \text{Density CO}$$

$$\text{NO Mass} = \frac{\text{ppm NO}}{10^6} \times \frac{\text{Exhaust Volume}}{\text{Mile}} \times \text{Density NO}_2$$



Table 5

Mass Emission As Determined  
From Variable Dilution Bag Sampler Data <sup>1</sup>

	$V_{mix}$ Cu.Ft./Mile <sup>3</sup>	HC g/m <sup>2</sup>	CO g/m	NO <sub>x</sub> g/m
Honda 350	91.8	6.75	66.0	0.69
Yamaha 180	192.0	11.8	19.1	1.42
Yamaha 100	91.0	4.83	13.3	0.57
Yamaha 50	91.5	3.28	5.76	0.76
Yamaha 80	92.3	2.26	2.45	0.60
Yamaha 305	185.0	16.5	29.4	1.76
Yamaha 250	186.0	26.5	51.2	1.84
Yamaha 250	185.0	17.8	38.6	1.39
Average For 2-cycle engines		11.8	26.85	1.19

1 Average values from Table 3 were used for these calculations.

2 As determined by Flame Ionization.

3  $V_{mix}$  = Diluted exhaust volume in cubic feet per mile, corrected to standard conditions.

Mass Emission Equations:

$$\text{HC Mass} = \frac{\text{ppm Propane}}{10^6} \times 3 \times V_{mix} \times \text{Density HC}$$

$$\text{CO Mass} = \frac{\% \text{ CO}}{100} \times V_{mix} \times \text{Density CO}$$

$$\text{NO Mass} = \frac{\text{ppm NO}}{10^6} \times V_{mix} \times \text{Density NO}_2.$$

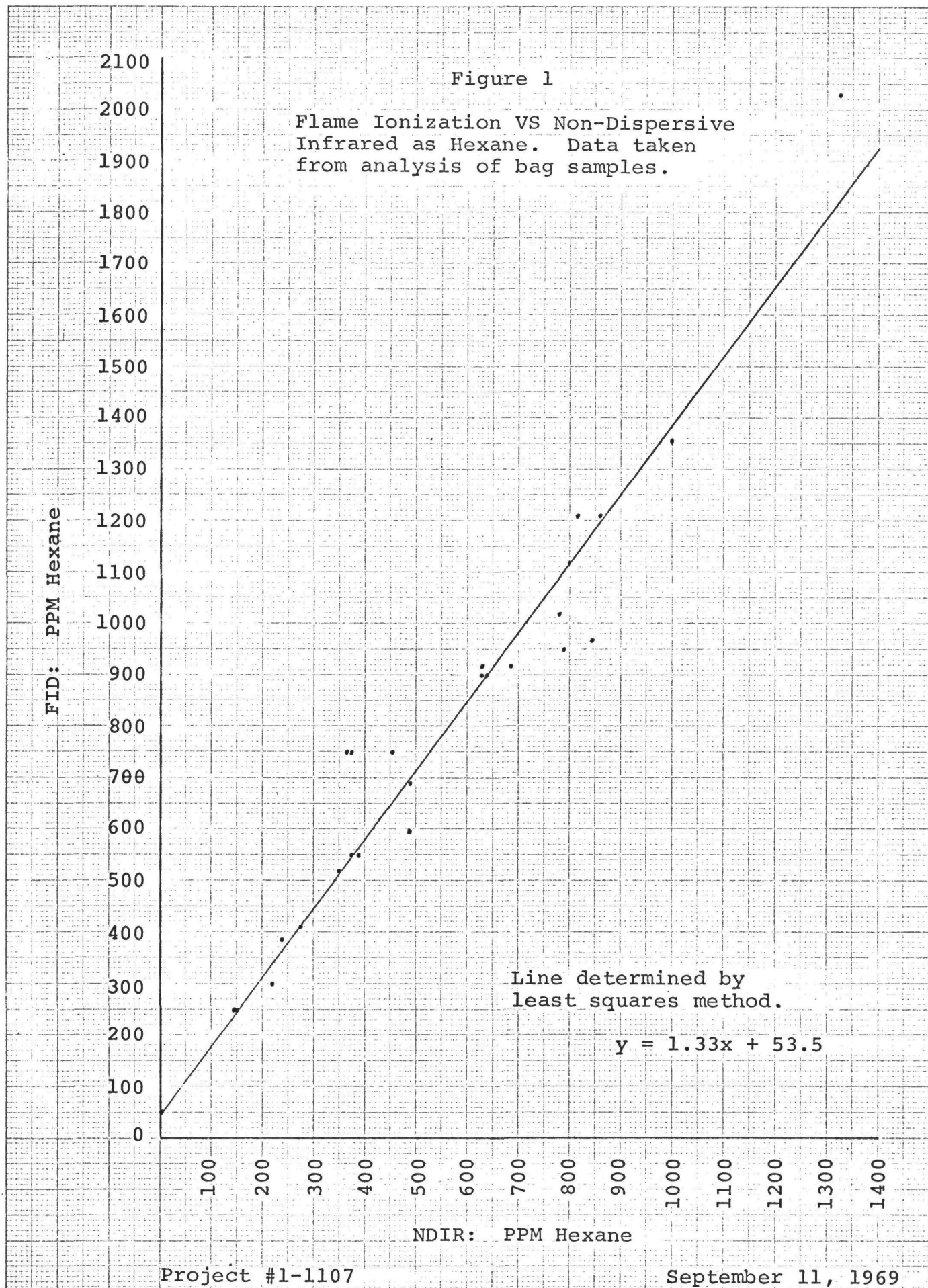
Table 6  
Summary Of Gas Chromatography Data <sup>1</sup>

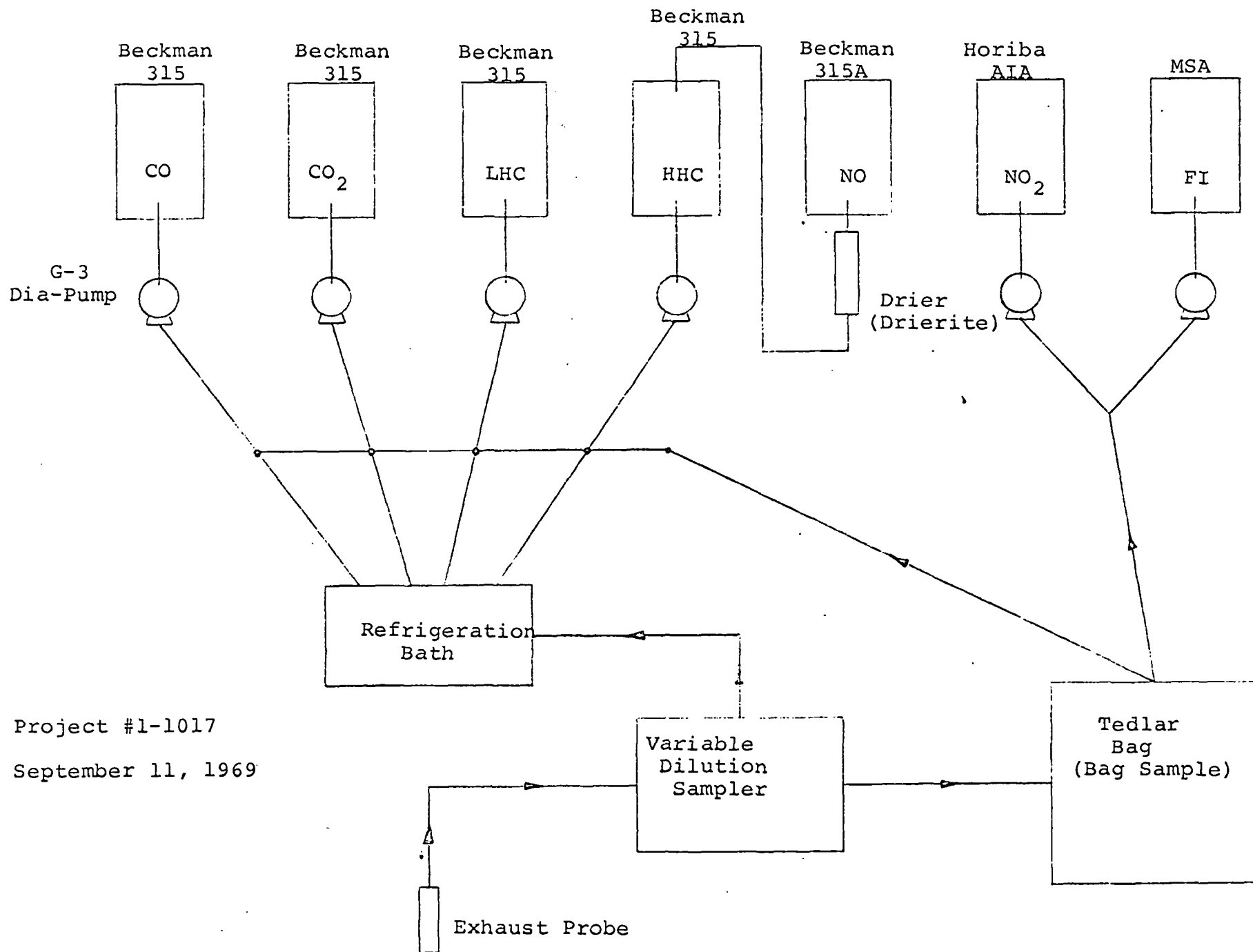
	Test #1 Yamaha 250	Test #2 Yamaha 305	Test #3 Suzuki 250
Total Paraffins PPM Carbon	25239.91	21414.2	25698.69
Average Carbon Number	5.01	5.41	5.69
Total Paraffins PPM	5038.97	3958.61	4514.7
Percent Paraffins	56.79	45.83	57.02
Reactivity (G.M.)	6044.73	5053.94	5880.47
Total Olefins PPM Carbon	8397.21	8990.99	4270.41
Average Carbon Number	4.08	4.48	4.74
Total Olefins PPM	2059.82	2007.28	900.23
Percent Olefins	23.21	23.24	11.37
Reactivity (G.M.)	16785.9	18998.6	9247.14
Total Aromatic PPM Carbon	9579.73	18777.27	15922.49
Average Carbon Number	7.77	8.13	7.59
Total Aromatics PPM	1232.29	2309.94	2098.32
Percent Aromatics	13.89	26.74	26.50
Reactivity (G.M.)	3883.32	7540.09	5834.11

Table 6 Continued  
Summary Of Gas Chromatography Data <sup>1</sup>

	Test #1 Yamaha 250	Test #2 Yamaha 305	Test #3 Suzuki 250
Total Acetylenes PPM Carbon	1090.34	728.57	811.57
Average Carbon Number	2.01	2.02	2.01
Total Acetylenes PPM	542.18	361.19	404.41
Percent Acetylenes	6.11	4.18	5.11
Reactivity (G.M.)	23.28	24.18	10.72
<u>Grand Totals:</u>			
PPM Carbon	44307.07	49911.03	46702.89
PPM Hexane	7384.523	8318.5	7783.844
PPM Compound	8873.133	8636.875	7917.52
Reactivity (G.M.)	26737.24	31616.88	20972.5
Maga Index	0.625	0.723	0.674
G.M. Index	3.013	3.661	2.649
Average Carbon Number	4.993	5.779	5.899

1 All data corrected by the factor  $\frac{15}{\text{CO} + \text{CO}_2 + 6 \text{ HC}}$



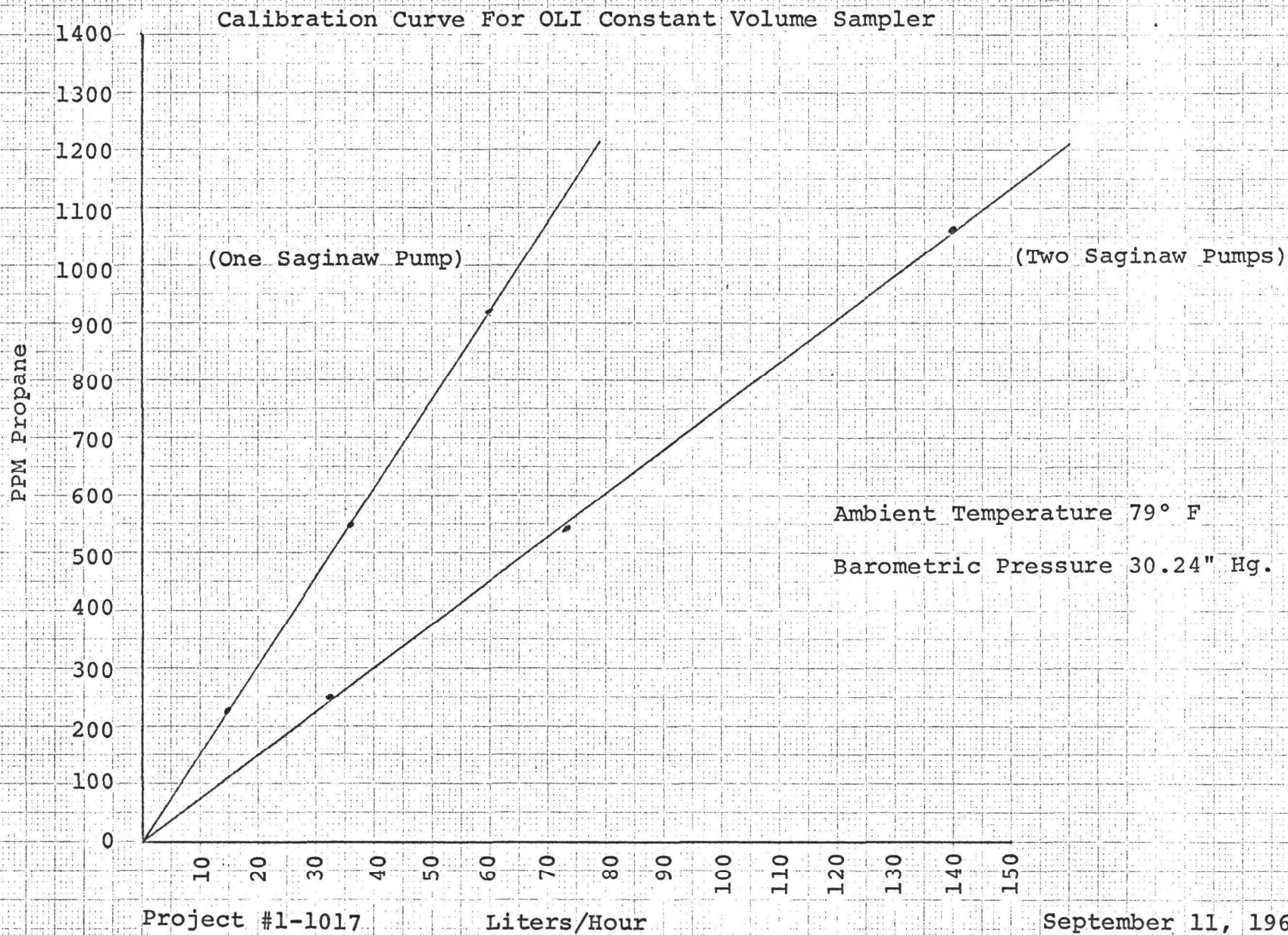


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(Figure 2) Flow Schematic for Exhaust Gas Analysis System

Figure 3



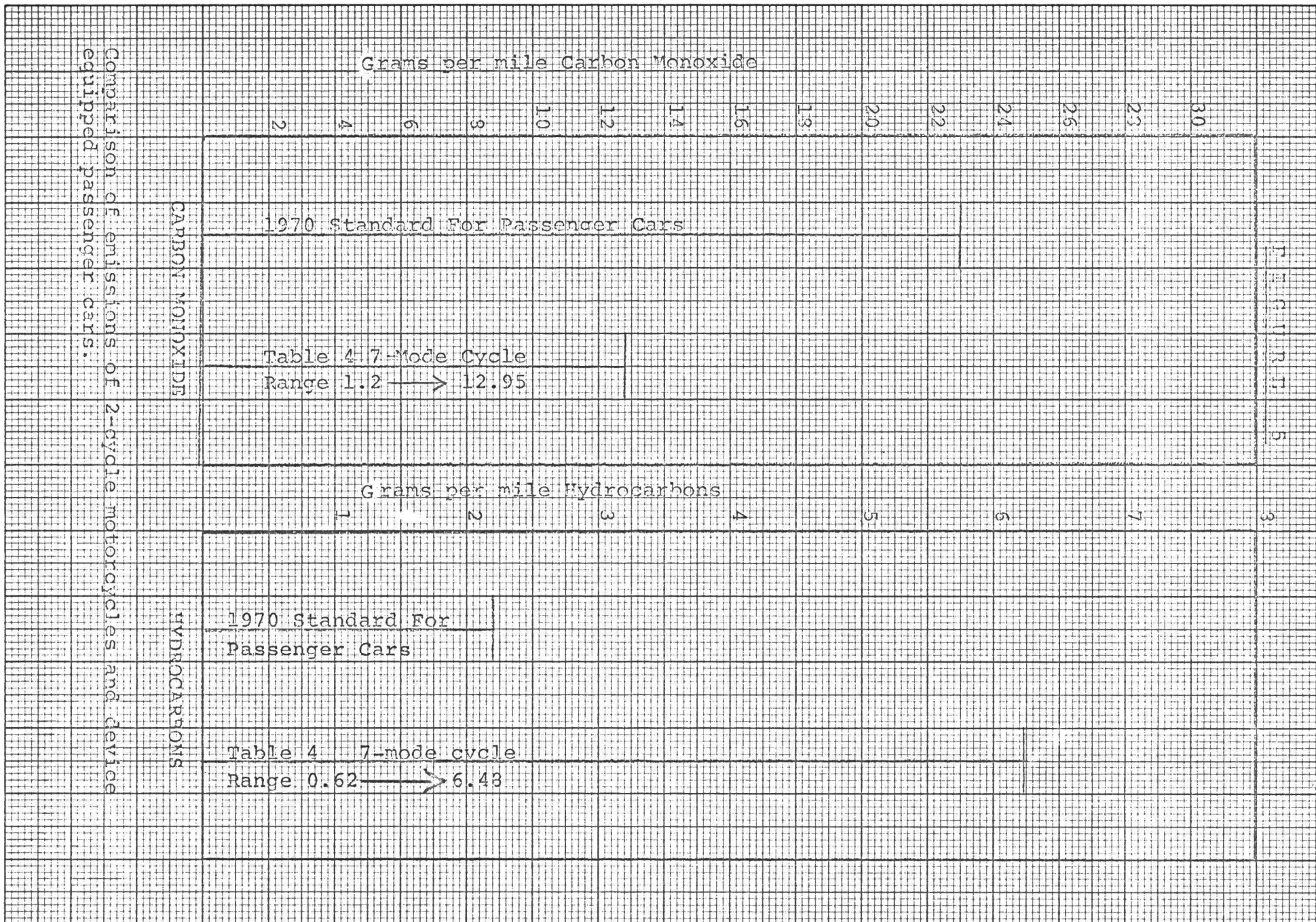
**Figure 4**  
**EXHAUST CONCENTRATION DATA**

Date 7-25-69 Project No. 1-1107 Vehicle Yamaha 180 Run No. 319  
Odometer \_\_\_\_\_  
Device \_\_\_\_\_

Cycle	MODE	HC		CO		CO <sub>2</sub>		15	CORRECTED		Weight Factor			TOTAL WEIGHT VALUE
		Meter	ppm	Meter	%	Meter	%	CO-CO <sub>2</sub> Factor	HC	CO		HC	CO	
1	Idle		198		.08		.17	40.67	8053	3.25	.042	338	.14	
	0-25		565		.58		1.12	7.36	4156	4.27	.244	1014	1.04	
	30		375		.25		1.35	8.22	3082	2.05	.118	364	.24	ppm HC
	30-15		286		.11		.50	19.19	5488	2.11	.062	340	.13	4315
	15		405		.08		.74	14.11	5714	1.13	.050	286	.06	
	15-30		450		.29		1.25	8.29	3729	2.40	.455	1697	1.09	% CO
	50-20		450		.15		.29	21.13	9508	3.17	.029	276	.09	2.79
	Idle		187		.07		.17	42.59	7964	2.98	.042	334	.12	
2	0-25		385		.26		1.07	9.61	3699	2.50	.244	902	.61	
	30		425		.45		1.37	7.23	3072	3.25	.118	362	.38	ppm HC
	30-15		315		.15		.50	17.88	5632	2.68	.062	349	.17	4204
	15		385		.05		.72	14.98	5767	.75	.050	288	.04	
	15-30		475		.38		1.25	7.81	3709	2.97	.455	1688	1.35	% CO
	50-20		475		.21		.24	20.41	9695	4.29	.029	281	.12	2.79
	Idle										.042			
	0-25										.244			
3	30										.118			ppm HC
	30-15					HC =	4260 PPM				.062			
	15					CO =	2.79%				.050			
	15-30										.455			% CO
	50-20	Bag Sample									.029			
	Idle										.042			
	0-25		490		.35		.87	9.91	4855	3.47	.244			
	30										.118			ppm HC
4	30-15					HC =	4855 PPM				.062			
	15					CO =	3.47%				.050			
	15-30										.455			% CO
	50-20	FID 1190 propane									.029			
	Idle										.042			
	0-25										.244			
	30										.118			ppm HC
	30-15										.062			
6	15										.050			
	15-30										.455			% CO
	50-20										.029			
	Idle										.042			
	0-25										.244			
	30										.118			ppm HC
	30-15										.062			
	15										.050			
7	15-30										.455			% CO
	50-20										.029			
	Idle										.042			
	0-25										.244			
	30										.118			ppm HC
	30-15										.062			
	15										.050			
	15-30										.455			% CO

NO ppm \_\_\_\_\_ 4260 HC ppm \_\_\_\_\_ 2.79 CO







## APPENDIX

Final Report  
Project # 1017

APPENDIX A  
HYDROCARBON CODE IDENTIFICATION

PARAFFINS		AROMATICS CONTINUED	
---	METHANE	13DEBZ	1,3-DIETHYLBENZENE
---	ETHANE	1M3NPRBZ	1-METHYL-3-N-PROPYLBENZENE
---	PROPANE	1M4NPRBZ	1-METHYL-4-N-PROPYLBENZENE
1B	1-BUTANE	NBBZ	N-BUTYLBENZENE
NB	N-BUTANE	12DEBZ	1,2-DIETHYLBENZENE
1P	1-PENTANE	13DM5EBZ	1,3-DIMETHYL-5-ETHYLBENZENE
NP	N-PENTANE	14DEBZ	1,4-DIETHYLBENZENE
22DMB	2,2-DIMETHYLBUTANE		
CP	CYCLOPENTANE		
23DMB	2,3-DIMETHYLBUTANE		
2MP	2-METHYLPENTANE		
3MP	3-METHYLPENTANE		
NHX	N-HEXANE		
MCP	METHYLCYCLOPENTANE		
22DMP	2,2-DIMETHYLPENTANE		
24DMP	2,4-DIMETHYLPENTANE		
223TM3	2,2,3-TRIMETHYLBUTANE		
33DMP	3,3-DIMETHYLPENTANE		
CHX	CYCLOHEXANE		
23DMP	2,3-DIMETHYLPENTANE		
2MHX	2-METHYLHEXANE		
3MHX	3-METHYLHEXANE		
UNK 3	UNKNOWN 3		
3EP	3-ETHYLPENTANE		
224TMP	2,2,4-TRIMETHYLPENTANE		
NHP	N-HEPTANE		
MCHX	METHYLCYCLOHEXANE		
22DMHX	2,2-DIMETHYLHEXANE		
223TMP	2,2,3-TRIMETHYLPENTANE		
25DMHX	2,5-DIMETHYLHEXANE		
24DMHX	2,4-DIMETHYLHEXANE		
33DMHX	3,3-DIMETHYLHEXANE		
234TMP	2,3,4-TRIMETHYLPENTANE		
233TMP	2,3,3-TRIMETHYLPENTANE		
23DMHX	2,3-DIMETHYLHEXANE		
3MP	3-METHYLHEPTANE		
225TMHX	2,2,5-TRIMETHYLHEXANE		
T12DMCHX	TRANS-1,2-DIMETHYLCYCLOHEXANE		
NOC	N-OCTANE		
C12DMCHX	CIS-1,2-DIMETHYLCYCLOHEXANE		
NV	N-NONANE		
ND	N-DECANE		
ACETYLENES		OLEFINS	
---	ACETYLENE	---	ETHYLENE
MA	METHYLACETYLENE	---	PROPYLENE
		---	PROPADIENE
		1B	1-BUTENE
		1BE	1-BUTENE
		13B	1,3-BUTADIENE
		T2B	TRANS-2-BUTENE
		C2B	CIS-2-BUTENE
		UNK 1	UNKNOWN 1
		3M1B	3-METHYL-1-BUTENE
		1P	1-PENTENE
		2M1B	2-METHYL-1-BUTENE
		2M13B	2-METHYL-1,3-BUTADIENE
		T2P	TRANS-2-PENTENE
		C2P	CIS-2-PENTENE
		2M2B	2-METHYL-2-BUTENE
		T13P	TRANS-1,3-PENTADIENE
		33DM1B	3,3-DIMETHYL-1-BUTENE
		C13P	CIS-1,3-PENTADIENE
		CPE	CYCLOPENTENE
		4M1P	4-METHYL-1-PENTENE
		23DM1B	2,3-DIMETHYL-1-BUTENE
		4MC2P	4-METHYL-CIS-2-PENTENE
		4MT2P	4-METHYL-TRANS-2-PENTENE
		2M1P	2-METHYL-1-PENTENE
		1HX	1-HEXENE
		2E1B	2-ETHYL-1-BUTENE
		C3HX	CIS-3-HEXENE
		T3HX	TRANS-3-HEXENE
		T2HX	TRANS-2-HEXENE
		C2HX	CIS-2-HEXENE
		2M2P	2-METHYL-2-PENTENE
		3MT2P	3-METHYL-TRANS-2-PENTENE
		3MC2P	3-METHYL-CIS-2-PENTENE
		23DM2B	2,3-DIMETHYL-2-BUTENE
		233TM1B	2,3,3-TRIMETHYL-1-BUTENE
		34DM1P	3,4-DIMETHYL-1-PENTENE
		5M1HX	5-METHYL-1-HEXENE
		CHXE	CYCLOHEXENE
		5MT2HX	5-METHYL-TRANS-2-HEXENE
		34DMC2P	3,4-DIMETHYL-CIS-2-PENTENE
		5MC2HX	5-METHYL-CIS-2-HEXENE
		34DMT2P	3,4-DIMETHYL-TRANS-2-PENTENE
		1HP	1-HEPTENE
		T3HP	TRANS-3-HEPTENE
		C3HP	CIS-3-HEPTENE
		244TM1P	2,4,4-TRIMETHYL-1-PENTENE
		3E2P	3-ETHYL-2-PENTENE
		T2HP	TRANS-2-HEPTENE
		C2HP	CIS-2-HEPTENE
		244TM2P	2,4,4-TRIMETHYL-2-PENTENE
		4MCHXE	4-METHYLCYCLOHEXENE
		3MCHXE	3-METHYLCYCLOHEXENE
		1MCHXE	1-METHYLCYCLOHEXENE
		1OC	1-OCTENE
		2E1HX	2-ETHYL-1-HEXENE
		23DM2HX	2,3-DIMETHYL-2-HEXENE
		T2OC	TRANS-2-OCTENE
		26DM3HP	2,6-DIMETHYL-3-HEPTENE
		C2OC	CIS-2-OCTENE
AROMATICS			
BZ	BENZENE		
TOL	TOLUENE		
EBZ	ETHYLBENZENE		
PX	PARA-XYLENE		
MX	META-XYLENE		
OX	ORTHO-XYLENE		
1PRBZ	1-PROPYLBENZENE		
NPRBZ	N-PROPYLBENZENE		
1M3EBZ	1-METHYL-3-ETHYLBENZENE		
1M4EBZ	1-METHYL-4-ETHYLBENZENE		
135TM3Z	1,3,5-TRIMETHYLBENZENE		
1M2EBZ	1-METHYL-2-ETHYLBENZENE		
TBBZ	TERT-BUTYLBENZENE		
124TM3Z	1,2,4-TRIMETHYLBENZENE		
1BBZ	1-BUTYLBENZENE		
SBBZ	SEC-BUTYLBENZENE		
1M31PRBZ	1-METHYL-3-1-PROPYLBENZENE		
123TM3Z	1,2,3-TRIMETHYLBENZENE		
1M41PRBZ	1-METHYL-4-1-PROPYLBENZENE		
1M21PRBZ	1-METHYL-2-1-PROPYLBENZENE		

Table 1 - Typical Exhaust Hydrocarbon Analysis by Gas Chromatography and Calculation of Total Hydrocarbon Reactivity Index <sup>1</sup>

	A	B	C	D	E
PEAK	COMPONENT	CONCENTRATION PPMC	PPM	RELATIVE REACT.	REACT. INDEX
PARAFFINS					
1	METHANE	130.03	130.03	0.00	0.00
2	ETHANE	34.31	17.16	0.42	7.21
6	PROPANE	0.00	0.00	0.66	0.00
8	IB	3.91	0.98	1.05	1.03
10	NB	41.24	10.31	1.27	13.09
16	IP	91.20	18.24	1.66	30.28
19	NP	39.13	7.83	1.58	12.37
25	22DMB	6.62	1.10	1.34	1.48
28	CP	3.01	0.60	1.56	0.94
29	23DMB	27.39	4.57	1.86	8.49
30	2MP	27.99	4.67	1.59	7.42
31	3MP	17.46	2.91	1.64	4.77
33	NHX	23.78	3.96	1.58	6.26
37	MCP 22DMP	12.04	1.85	1.90	3.52
38	24DMP 223TMD	22.27	3.18	1.30	4.14
40	33DMP CHX	5.72	0.88	1.50	1.32
42	23DMP 2MHX	27.99	4.00	1.50	6.00
43	3MHX UNK 3	9.33	1.33	1.50	2.00
44	3EP 224TMP	160.56	21.07	1.30	27.39
45	NHP	13.24	1.89	1.51	2.86
47	MCHX 22DMHX	6.02	0.80	1.60	1.28
48	UNK 5	0.00	0.00	1.50	0.00
49	223TMP 25DMHX 24DMHX	47.86	5.98	1.50	8.97
50	33DMHX 234TMP 233TMP 23DMHX	133.64	16.71	1.60	26.73
51	UNK 6	21.67	2.71	1.50	4.06
52	UNK 7	9.73	1.24	1.50	1.86
53	3MNP	6.02	0.75	1.63	1.23
54	225TMHX T12DMCHX	16.25	1.91	1.60	3.06
55	NOC	6.62	0.83	1.46	1.21
56	UNK 11	0.30	0.03	1.50	0.05
57	UNK 12	2.71	0.30	1.50	0.45
59	C12DMCHX	0.00	0.00	1.70	0.00
60	UNK 13	0.90	0.10	1.50	0.15
61	UNK 15	0.70	0.10	1.50	0.15
62	UNK 17	1.50	0.17	1.50	0.25
63	UNK 19	0.00	0.00	1.50	0.00
64	UNK 20	0.00	0.00	1.50	0.00
65	UNK 21	1.50	0.17	1.50	0.25
66	UNK 23	1.81	0.20	1.50	0.30
67	UNK 24	2.71	0.30	1.50	0.45
68	NN	1.81	0.20	1.42	0.28
70	UNK 26	0.30	0.03	1.50	0.05
71	UNK 28	0.00	0.00	1.50	0.00
72	UNK 30	0.00	0.00	1.50	0.00
74	UNK 31	0.00	0.00	1.50	0.00
75	UNK 32	0.00	0.00	1.50	0.00
76	UNK 33	1.20	0.12	1.50	0.18
79	ND	0.00	0.00	1.40	0.00
84	OTHER PARAFFINS	0.00	0.00	1.40	0.00
SUB-TOTAL		968.92	269.22		191.53
ACETYLENES					
4	ACETYLENE	157.72	78.86	0.00	0.00
7	MA WITH PROPADIENE	0.00	0.00	3.90	0.00
SUB-TOTAL		157.72	78.86		0.00

(con't)

<sup>1</sup> Reprinted from M.W. Jackson, "Effects of Some Engine Variable and Control Systems On Composition and Reactivity of Exhaust Hydrocarbons", SAE transactions Vol. 75 (1967). SAE Publication # 660404.

Table 1 (con't)

PEAK	A COMPONENT	B CONCENTRATION PPMC	C PPM	D RELATIVE REACT.	E REACT. INDEX
AROMATICS					
39	BZ	89.33	16.55	0.56	9.27
50	TOL	633.30	90.47	2.20	199.64
63	EBZ	47.56	5.94	2.03	12.07
64	PX MX	90.30	11.29	4.92	55.53
66	OX	56.29	7.04	4.41	31.03
69	IPRBZ	2.71	0.30	1.64	0.49
72	NPRBZ	25.89	2.88	1.70	4.89
73	1M3EBZ 1M4EBZ	57.79	6.42	4.10	26.33
74	135TMBZ	20.47	2.27	8.64	19.65
75	1M2EBZ	28.29	3.14	3.60	11.32
77	TGBZ 124TMBZ	79.46	8.36	3.30	27.60
78	1BBZ SUBZ	5.12	0.51	1.00	0.51
79	1M3IPRBZ 123TMBZ	19.26	2.03	5.80	11.76
80	1M4IPRBZ	0.00	0.00	2.90	0.00
81	1M2IPRBZ	6.02	0.60	2.90	1.75
82	13DBZ 1M3NPRBZ	28.29	2.83	4.20	11.88
83	1M4NPRBZ NBBZ 12CEBZ 13DMSEBZ 14DEBZ	19.56	1.96	3.40	6.65
84	OTHER AROMATICS	130.63	11.88	5.00	59.38
SUB-TOTAL		1350.29	174.48		489.15
OLEFINS					
3	ETHYLENE	204.68	102.34	2.88	294.74
5	PROPYLENE	176.99	59.00	5.93	349.85
7	PROPADIENE	30.10	10.03	3.90	39.13
9	1B 1BE 13B	178.77	44.70	6.04	269.98
11	T2B	27.09	6.77	18.98	128.54
13	C2B	15.65	3.91	12.03	47.07
14	UNK 1	0.90	0.23	4.00	0.90
15	3M1B	6.02	1.20	4.58	5.51
17	1P	8.43	1.69	3.56	6.00
18	2M1B	24.08	4.82	5.76	27.74
20	2M13B	12.04	2.41	6.27	15.10
21	T2P	16.86	3.37	13.05	43.99
22	C2P	8.43	1.69	9.15	15.42
23	2M2B	30.53	7.71	32.20	248.12
24	T13P	0.00	0.00	6.80	0.00
25	33DM1B	3.01	0.50	3.56	1.79
26	C13P	0.00	0.00	6.80	0.00
27	CPE	3.01	0.60	38.98	23.47
28	4M1P	6.02	1.00	3.90	3.91
29	23DM1B	12.64	2.11	3.73	7.86
30	4MC2P 4MT2P	6.62	1.10	6.61	7.30
31	UNK 2	0.00	0.00	4.00	0.00
32	2M1P 1HX	6.02	1.00	3.39	3.40
33	2E1B	7.22	1.20	3.90	4.70
34	C3HX T3HX T2HX C2HX	7.22	1.20	8.40	10.11
35	2M2P	9.63	1.61	27.12	43.54
36	3MT2P	3.01	0.50	20.30	10.18
37	3MC2P	8.43	1.40	17.00	23.88
38	23DM2B 233TM1B	8.43	1.30	52.90	68.59
39	34DM1P	0.00	0.00	2.50	0.00
41	5M1HX	4.82	0.69	2.50	1.72
42	CHXE	10.23	1.71	5.93	10.11
43	5MT2HX 34DMC2P 5MC2HX 34DMT2P	21.67	3.10	11.00	34.06
44	1HP	45.75	6.54	2.54	16.60
45	T3HP C3HP	9.03	1.29	7.00	9.03
46	244TM1P 3E2P T2HP	6.02	0.82	9.40	7.72
47	C2HP UNK 4	4.21	0.60	5.90	3.55
49	244TM2P 4MCHXE 3MCHXE	13.24	1.81	13.00	23.49
51	1MCHXE	0.00	0.00	9.73	0.00
52	UNK 8	5.42	0.68	7.00	4.74
53	UNK 9	3.01	0.38	7.00	2.63
54	10C 2E1HX UNK 10	10.23	1.28	2.80	3.58
55	23DM2HX T20C	5.42	0.68	32.40	21.94
57	26DM3HP	0.60	0.07	6.80	0.45
58	C20C	0.30	0.04	4.20	0.16
60	UNK 14	0.00	0.00	6.00	0.00
61	UNK 16	0.60	0.07	6.00	0.40
62	UNK 18	1.20	0.13	6.00	0.80
65	UNK 22	1.50	0.17	6.00	1.00
67	UNK 25	0.00	0.00	6.00	0.00
70	UNK 27	0.60	0.06	6.00	0.36
71	UNK 29	0.00	0.00	6.00	0.00
84	OTHER OLEFINS	0.00	0.00	6.00	0.00
SUB-TOTAL		973.73	283.48		1843.19
TOTAL		3450.67	806.04		2523.07

## APPENDIX C

### An Analysis Of The Two-Cycle Combustion Process

The two-stroke cycle engine was developed by Sir Dugald Clark in 1878. As the name implies, the basic difference between the two and the four cycle engine is the number of piston strokes required to complete one cycle of events. Referring to the illustrations (Figures 1 & 2) below, the two-cycle engine requires two strokes of the piston and one revolution of the crankshaft to complete one cycle of operation comprising intake, compression, power and exhaust, while the four cycle requires four strokes and two revolutions.

A diagrammatic cross section of a three-port, two-stroke engine is shown in Figure 3. "A" represents the crankcase inlet port, which is fully uncovered when the piston is at the outer end of its stroke. "B" is the transfer port, which is uncovered by the piston as it approaches the inner end of the stroke. In the drawing the piston is shown in the position where it begins to uncover the transfer port. An expansion stroke has just taken place, and the burnt gases are shown escaping through the exhaust port, which is partly uncovered by the piston before the latter begins to uncover the transfer port. During the interval between the beginning of exhaust-port opening and the beginning of transfer-port opening --- the blowdown period --- enough of the burnt gases in the combustion chamber must escape through

the exhaust port to cause the pressure in the combustion chamber to drop to that in the crankcase. During the remainder of the in-stroke and the early part of the out-stroke, while both ports are open, the inflow of fresh charge under pressure through the transfer port blows some of the remaining burnt gases from the combustion chamber. This is known as the scavenging process. Naturally, there is some mixing of combustible mixture with burnt gases, and it is impossible in an engine of this type to completely scavenge the combustion chamber of burnt gases and to prevent loss of fresh charge through the exhaust port before the latter is closed. In order to prevent "short-circuiting" of the flow of gases through the engine as far as possible, the piston is provided with a deflector D opposite the transfer port, which is intended to deflect the incoming current of mixture upward on the side of the cylinder at which it enters, compelling it to pass down on the opposite side and sweep the burnt gases before it.

This type of scavenging is designated "loop" in order to distinguish it from the type of engine which does not have such a deflector and is called "cross-scavenged".

This short "circuiting" or loss of the fresh air-fuel mixture out of the the exhaust is the basic deficiency of the two-cycle engine, and the main reason why for a given displacement it does not develop twice as much power as a four-cycle engine. The other predominate reason is the poor scavenging of the burnt exhaust gases from the cylinder due to mixing with the fresh

incoming air-fuel mixture.

In order to overcome this basic engine characteristic many attempts have been made to improve the scavenging efficiency of two-cycle engines, and hence their specific power output. Perhaps the best known of these is a separate pump or blower which is found on all two-cycle diesel engines. Other approaches have used rotary exhaust valves, conventional automotive type poppet valves, sleeve valves, reverse loop scavenging, opposed pistons and U-cylinders. All these means add cost and complexity of course, which to a greater or lesser degree detract from the main two-cycle engine attributes of low cost and simplicity.

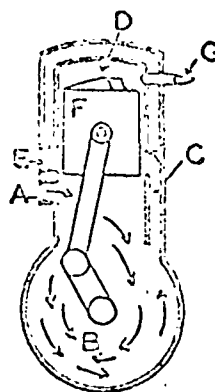
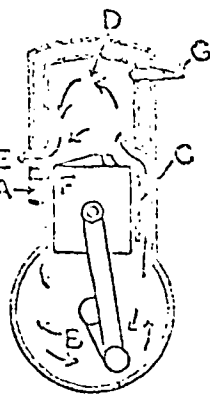
If the basic scavenging process for a two-cycle engine is examined from the standpoint of predicting exhaust emissions it is apparent that in all probability the emissions will be high for the same reason that the average BMEP (Brake Mean Effective Pressure) and consequent power output is low --- poor cylinder scavenging. In the ideal scavenging process the fresh incoming air-fuel mixture would push the residual gases before it without mixing or exchanging heat with them, and this process would continue until all the burned gases had been replaced with fresh mixture, at which point the flow would cease. In this idealized scavenging process not only is the cylinder filled with fresh mixture, but also no fresh mixture escapes from the exhaust ports. However, in actual engines of course, the fresh mixture actually does mix and exchange heat with the residual gases during the scavenging process and some portion of the fresh mixture is

lost through the exhaust ports. The amount of fresh mixture loss to the exhaust will vary primarily with the efficiency of the scavenging process, and hence for a given operating condition will be a function of specific engine design.

This loss of carburetted mixture through the exhaust port is believed to be prima facie evidence that the exhaust emissions in terms of concentration of hydrocarbons and partially-oxidized hydrocarbons for a two-cycle engine is of a significantly higher order than emissions from a four-cycle engine.

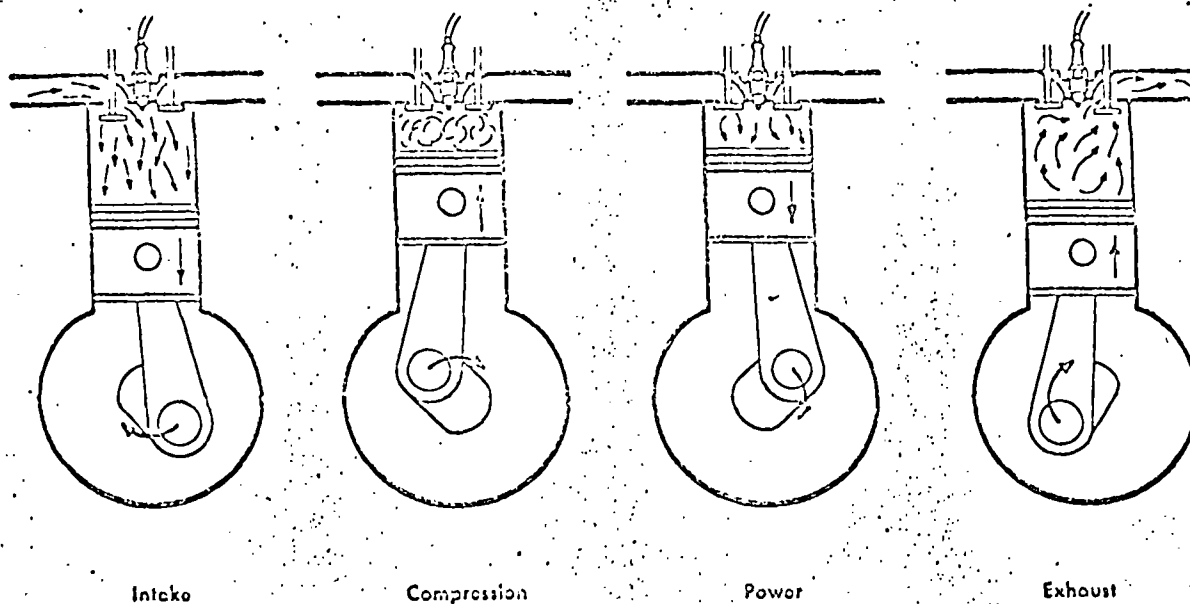


The resulting combustion pressure forces the piston downward (power stroke) furnishing power to turn the propeller. As piston descends it closes intake port "A" and compresses mixture charge in the crankcase. Towards the end of the stroke exhaust port "E" is opened; then bypass port "C" is opened which permits new mixture to flow into cylinder "D", displacing the burned gases through exhaust port "E".

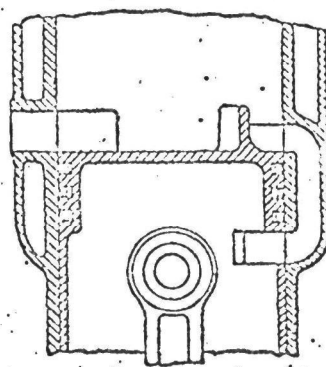
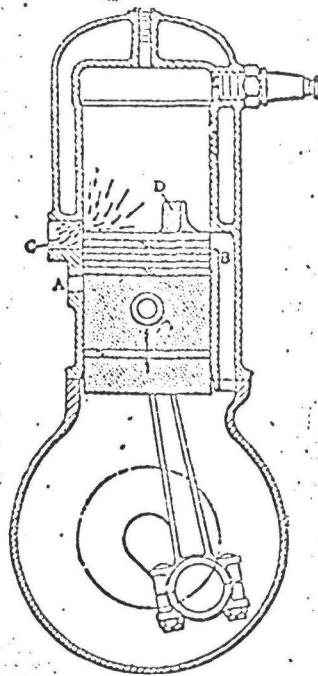


Upward (compression) stroke compresses mixture in cylinder "D" in preparation for ignition. Simultaneously, it creates a partial vacuum in the crankcase so that, as intake port "A" is uncovered fuel-oil-air mixture for a new charge flows in from the carburetor. At the end of the upward (compression) stroke, spark plug "G" ignites the compressed mixture.

### The Operating Principle Of The Two-Stroke Gasoline Engine



### The Operating Principle Of The Four-Stroke Gasoline Engine



Transfer Port  
Detail

Three-Port type of  
Two-stroke engine

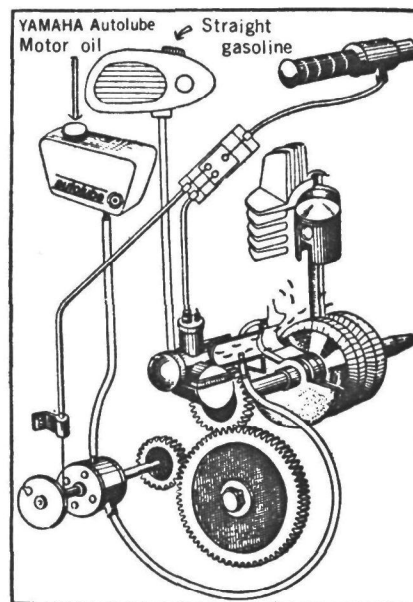
## CHAPTER II YAMAHA AUTOLUBE

### A. WHAT IS YAMAHA AUTOLUBE?

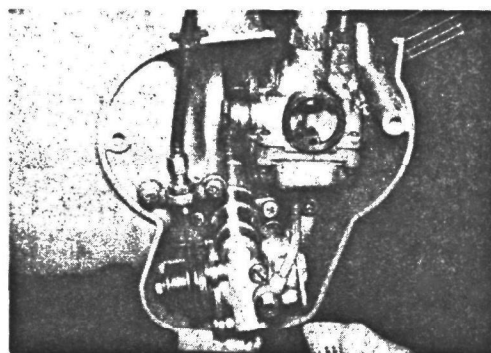
Yamaha Autolube is an automatic engine lubrication system based on a revolutionary "separate lubrication" principle, which outmodes the conventional 2-stroke pre-mixed system.

### B. FEATURES OF YAMAHA AUTOLUBE:

1. The oil pump is driven by the engine through a reduction gear, and is connected to the throttle valve of the carburetor which is controlled by the accelerator grip.
2. Lubricating oil is fed to the engine after being automatically metered in proportion to engine rpm and throttle opening. Thus the engine provides and regulates its own lubrication.
3. Yamaha Autolube eliminates lubrication problems peculiar to 2-stroke engines with the conventional "pre-mix" system, and improves many inherent advantages of 2-stroke design. (Fig. 2-1 & 2)
  - a. Autolube supplies only the flow of engine lubricant the engine needs for its specific operating condition, allowing:
    - 1) Savings in oil consumption.
    - 2) Decreased carbon accumulation.
    - 3) Decreased exhaust smoke, and
    - 4) More effective engine lubrication.



2-1



2-2

## APPENDIX E

### Calibration of Constant Mass Sampler (CMS):

Before the system can be used to measure exhaust, the Roots blower must be calibrated. This can be done by the following procedure.

1. Operate system until equilibrium temperatures are reached.
2. Introduce pure propane (99.5 +) by means of a wet test meter or other accurate flow measuring device into the inlet of the heat exchanger.

Note: If a wet test meter is used, the propane should be preconditioned by passing it through a water bubbler. Also in the final calibration a water vapor correction must be made.

3. Measure concentration of propane at inlet to large Roots blower, using NDIR analyzer or FID that has been accurately calibrated with propane calibration gases.
4. Repeat at different propane flow rates until several data are obtained.
5. Plot propane flow rate as concentration. A straight line which passes through the origin should be obtained.
6. Calculate flow rate using perfect gas laws  
(  $PV = nRT$  ) and the following formula.

APPENDIX E - Cont'd

Blower flow rate, CFM =

$$\frac{\text{Pure Propane flow rate, (CFM X } 10^6\text{)}}{\text{measured Propane concentration (PPM)}}$$

7. Example of Calculations:

a. Assume: 300 liters/hour  $C_3H_8$  introduced 650 PPM

$C_3H_8$  measured

$$\begin{aligned} \text{Then: } & \frac{\text{liters} \times \text{hours}}{\text{hour}} \times \frac{\text{ft}^3}{28.32 \text{ liters/ft}^3} = \text{ft}^3/\text{min.} \\ & \frac{\text{ft}^3}{\text{min.}} \times \frac{1}{60} \times \frac{10^6}{28.32} = \text{ft}^3/\text{min.} \\ & \text{min.} \quad \text{PPM} \end{aligned}$$

$$300 \times \frac{1}{60} \times \frac{1}{28.32} = 0.1765 \text{ ft}^3/\text{min.}$$

$$0.1765 \times \frac{1,000,000}{650} = 272.0 \text{ ft}^3/\text{min.}$$

b. Make correction for  $H_2O$  vapor present at ambient temperature e.g., Temp = 21.8° C, Vapor  $H_2O$  = 19.7 mm Hg. Barometer = 760 mm

$$\text{Then: } 760 - 19.7 = 740.3 \text{ mm Hg.}$$

$$\frac{740.3}{760} \times 272 \text{ ft}^3/\text{min.} = 264 \text{ ft}^3/\text{min. dry air.}$$

c. Determine density of air at ambient temperature and pressure.

APPENDIX E - Cont'd

d. Then:  $\text{Lbs/ft}^3 \times \text{ft}^3/\text{min.} = \text{Pounds/minute of air.}$

e. Knowing number of pump revolutions and time  
determine revolutions per minute (rev/min).

f. Then:  $\frac{\text{Lbs.}}{\text{min.}} \times \frac{\text{min.}}{\text{rev.}} = \frac{\text{Lbs.}}{\text{rev.}}$

g.  $\frac{\text{Lbs}}{\text{rev.}} \times \frac{\text{rev.}}{1} = \text{Pounds, etc.}$

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