Incorporation of a Test for Exhaust Sulfate Emissions into the Federal Emission Testing Procedure

by

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Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air and Waste Management
U.S. Environmental Protection Agency

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Abstract

There are many possible sequences in which a test procedure for gaseous exhaust emissions, evaporative emissions, and exhaust sulfate emissions could be conducted. This report identifies a few of these sequences which appear to be appropriate for the measurement of these emissions. These candidate test procedures are then compared on the basis of test result accuracy and consistency, and the laboratory requirements of test time and manpower.

Introduction

The EPA is developing test procedures for the measurement of exhaust sulfuric acid emission. At present, vehicles are certified for certain gaseous exhaust emissions and evaporative hydrocarbon emissions. Unfortunately, it is not appropriate to measure both the gaseous and sulfate emissions during the same type of vehicle operation. Therefore, a vehicle driving cycle has been developed for the measurement of exhaust sulfate levels.

It is desirable to perform the sulfate emission testing in such a way that it will not affect the measured values of either the gaseous exhaust or evaporative emissions. Since the levels of these emissions may be affected by the vehicle's history for some period of time prior to testing, it is desirable to minimize any changes to the current test procedure. Other considerations in the addition of a sulfate test to the established procedures are increases in test time and manpower requirements, and the test accuracy and repeatability. The purpose of this report is to identify the possible test sequences which would be most appropriate. The advantages and disadvantages of these procedures are then discussed.

A major change in the evaporative emission test procedure is currently being proposed. This report assumes that this newly proposed procedure (SHED technique) will be in effect prior to the publication of the sulfuric acid test procedure.

Discussion

In choosing candidate test procedures, it was desirable to identify sequences in which the sulfate test would have a minimum effect on the gaseous and evaporative tests. With this consideration, it was decided that certain sequences in the current procedure could not be changed. These were as follows:

1) The gaseous exhaust emission test (from initial key-on to the end of the hot transient test) could not be changed. That is, bag 3 could not be collected at some different time.

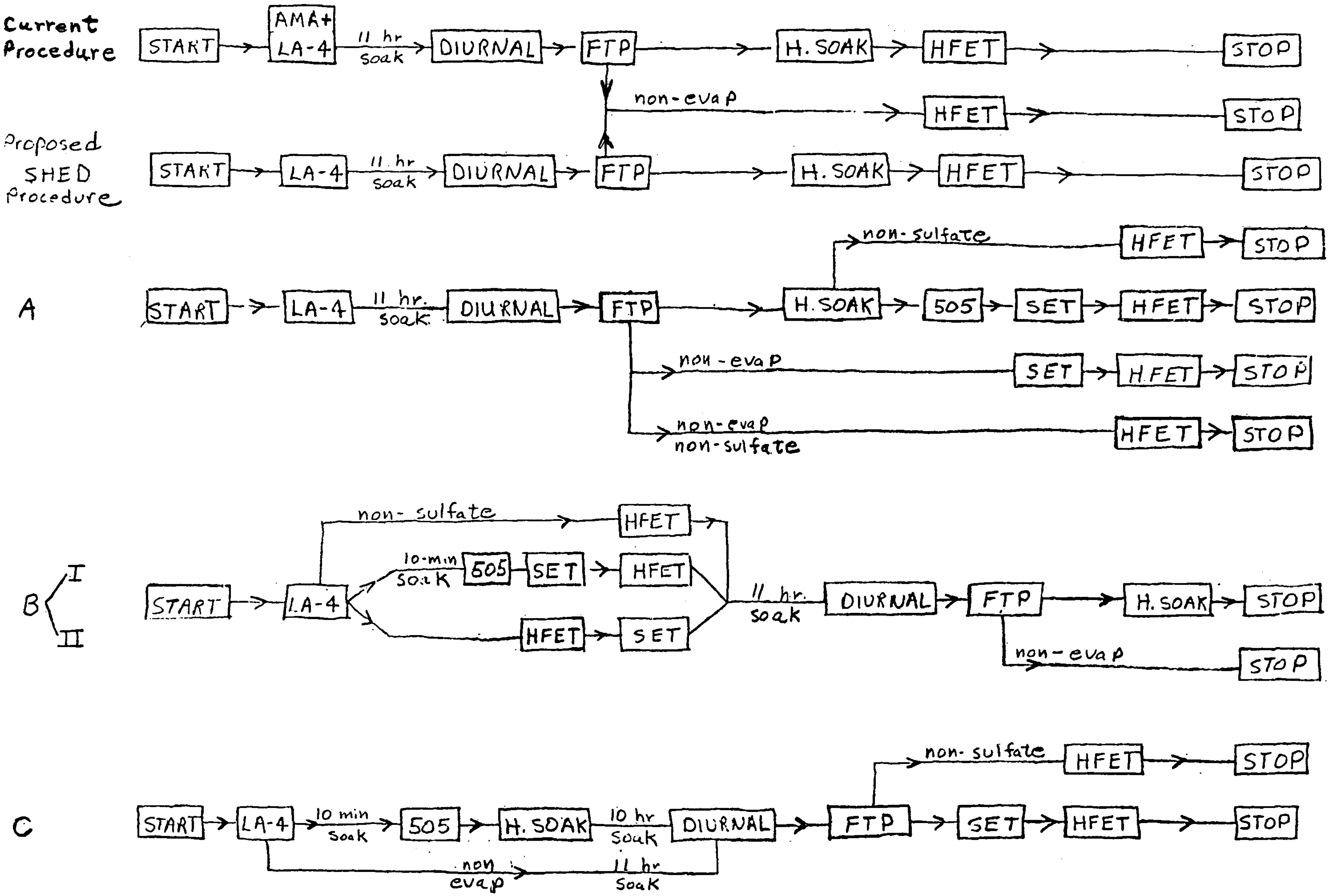
2) The gaseous exhaust emission test (hereafter referred to as the FTP) must be preceded by at least 12 hours of key-off condition.

3) The diurnal evaporative test must be preceded by at least 11 hours of key-off condition.

4) The hot-soak evaporative test must be preceded by an FTP driving cycle.

In addition, it was assumed that only one sulfate emission test (SET) cycle will be conducted, and that this SET can only follow an FTP, a hot start bag 3 portion of an FTP cycle, another SET or, possibly, a highway fuel economy test (HFET). The reasons for the latter restriction are that (1) sulfate baseline tests are being conducted using either an FTP, HFET, or another SET to precede the SET; (2) these three test cycles provide good representations of the different types of "immediate" preconditioning which should be considered; and (3) the addition of a different SET preconditioning cycle would significantly increase the time and manpower required to conduct the test.

Figure 1 - Test Sequences.



Considerable concern has been expressed regarding the influence of vehicle preconditioning on sulfate emissions. The sulfate emission baseline study now being conducted provides a comparison of FTP versus HFET preconditioning. Approximately one-half of the data from this program has now been received. The clearest message from this data is that measured sulfate values for individual vehicles have more variability than gaseous exhaust emissions. For some vehicles, the measured sulfate levels were higher after the FTP than after the HFET. Other vehicles showed the opposite trend. As a result, the data showed no statistically significant difference between FTP and HFET immediate preconditioning in regards to the level of sulfate emissions. Available baseline data also indicate that the type of preconditioning does not affect the repeatability of sulfate emission measurements. Consequently, no one of the candidate cycles appears preferable to the others on the basis of sulfate emission level or test repeatability.

Although sulfate baseline testing is not showing a difference in sulfate levels between immediate preconditioning with an FTP or HFET, other tests have shown that catalysts can store sulfates during some types of operation and release them during other types of operation.[1] Sulfate tests conducted under EPA contract at Southwest Research Institute on four vehicles have shown this quite clearly. Results of these tests are contained in Appendix A. As shown, three of the four vehicles stored sulfates during the 30 mph cruise mode and then released sulfates on the acceleration mode from 30 to 60 mph. Because of such occurrences, it is desirable to operate all vehicles in a similar manner for some period of time prior to testing for sulfate emissions. The type of operation the vehicles has undergone prior to their arrival at the Ann Arbor laboratory cannot be closely controlled. Because of this, there is an advantage in conducting the sulfate test near the end of the emission certification procedure, as done in sequence A.

Other concerns associated with a sulfate emission test are time and manpower needs. Table I is a comparison of test time and manpower requirements among the current test procedure and the various test procedures shown in Figure 1 (including evaporative testing and sulfate testing, where applicable). This analysis is based on OPM's "Technician Man-hours Required per Full 1975-type FTP", and "Technician Man-hours Required per HFET" as of April, 1975. These documents are attached as pages B-1 through B-3 of Appendix B of this report. The estimated time requirements of the proposed procedures are based

1. "Sulfate Control Technology, Appendix II", ECTD report.

TABLE I

COMPARISON OF TIME AND MAN-POWER REQUIREMENTS
FOR VARIOUS EMISSION TEST PROCEDURES

Test Procedure	Technician time, hr	Total time, hr	Working time, hr	2nd Day working time, hr	2nd Day Working + peripheral* time, hr
Current	11.2	20.7	9.7	6.5	7.8
SHED	9.4	18.9	7.9	6.0	7.2
A	10.3	19.4	8.4	6.5	7.8
BI	10.2	19.2	8.2	5.3	6.4
BII	9.6	18.9	7.9	5.3	6.4
C	10.2	18.2	8.2	4.6	5.5

*A prorated time for peripheral tasks as defined in Appendix B, page B-2 on modifications of the current test procedure. A detailed breakdown of the estimated time for each procedure is contained in Appendix B, Figures B-1 and B-2.

As shown in Table I, the current test procedure requires more time than the proposed SHED test. This is mainly because the SHED procedure does not include AMA preconditioning or fuel system pressure check. The candidate sulfate cycles require up to about one hour more technician time and one-half hour more working time than the proposed SHED procedure. In this analysis it was assumed that if the HFET follows the FTP or the SET driving cycle, then a preconditioning HFET cycle is not required. With this assumption, Table I shows the amount of working time required on the second day of the sulfate sequences is no longer than the working time required with the current procedure. It should be mentioned that the first four columns of Table I do not include time for peripheral tasks as defined in the time study in Appendix B. The fifth column does include this additional time requirement.

The major advantage of procedure A is that the sulfate test does not interfere with the exhaust and evaporative tests, and the estimated time requirement for procedure A is not much greater than that for the other procedures. However, this sequence requires the vehicle to be moved on and off the dynamometer twice on the second day instead of once as in the other candidate procedures. In the time estimate, it was assumed that the time required to move a vehicle on or off the dynamometer was always constant. Since there would be an additional vehicle move using procedure A, this might result in more congestion and a somewhat longer time per vehicle move (amounting to perhaps 0.1 or 0.2 additional hour per test).

Although procedures BI, BII, and C require less test time than procedure A, they do include changes in the present testing sequence. In procedure BI, the HFET precedes the diurnal test. A five-vehicle test conducted at the EPA Ann Arbor laboratory showed that there was a significant difference in diurnal losses between LA4 and HFET preconditioning cycles.[2] These tests were conducted by the SHED procedure, and the results are presented in Appendix C. As shown, the measured diurnal losses from each vehicle were lower when preconditioning was done with the HFET cycle. This was due to increased canister purging which resulted from the higher speed operation. The mean of all vehicles using LA4 preconditioning was 2.29 g/test,

2. "Vehicle Preconditioning: LA-4 vs. HFET", In-House Test Program, Report No. 2.

and the mean of all vehicles using HFET preconditioning was 1.73 g/test. The statistical analysis on page C-2 shows that this difference was significant at a 95% level of confidence.

In procedure BII, the SET cycle serves as preconditioning for the diurnal test. Tests have not been conducted to determine if preconditioning with this cycle will give different diurnal losses than preconditioning with the LA4 (FTP) cycle. The average speed is 15 mph higher on the SET than on the LA4. Therefore, it is expected that canister purging during the SET would be greater than during the LA4, but not as great as during the HFET (29 mph higher average speed than LA4).

In sequence C, it is also possible that evaporative emission levels will be different than as measured in the current sequence. During the hot-soak test, the temperature inside the SHED is significantly higher than in the current soak area. This difference is about 8°C (15°F). Therefore, more vapors are generated during a hot-soak SHED test than during a hot-soak in the soak area. Consequently, the canister is loaded more during the SHED test, and the vapors generated during the following diurnal test will probably be more difficult to control. Also, in sequence C, the hot-soak portion of the evaporative test is quite near the beginning of the test sequence. Because of this, it could be possible that the condition of the canister prior to the start of the test procedure may affect the result of the hot-soak test. A comparison of the advantages and disadvantages of the candidate test procedures is summarized in Table II.

Conclusions

1. All candidate test cycles which have been presented require less technician time, less working time, and less total time than the current testing procedure (with the evaporative test and HFET included).

2. Candidate test procedure A is the only one in which the current emission test procedure is not altered by the sulfate test.

3. Changes in the present emission test sequence (as required in procedures BI, BII, and C) could affect evaporative and/or exhaust emissions. Due to higher vehicle speed prior to parts of the evaporative test, it is estimated that any effect would be to decrease the severity of the evaporative test.

4. The shortest of the proposed sequences (procedure BII) is estimated to save 0.7 hour of technician time, and 0.5 hour of test time as compared to procedure A.

Recommendation

Proposed sequence A should be adopted as the official testing procedure when sulfate emission testing is conducted.

TABLE II

COMPARISON OF THE ADVANTAGES AND DISADVANTAGES
OF THE CANDIDATE EMISSION TEST PROCEDURES

Test Procedure	Advantages	Disadvantages	Comments
A	Sulfate testing does not affect current exhaust or evaporative procedure. All tests conducted on the same day so ambient and vehicle changes are minimal. Has the greatest amount of controlled preconditioning.	Takes most manpower and working time. Takes most time on 2nd day so more chance of running out of time.	Might require more than estimated time or need additional test coordination because vehicle must go on and off dynamometer twice during the 2nd day.
BI	Takes less time and substantially shorter 2nd day than sequence A.	Diurnal preceded by HFET which purges canister more than FTP. Hot-soak might be affected by HFET before the cold-soak.	HFET is incorporated into the testing procedure.
BII	Takes least time and substantially shorter 2nd day than sequence A.	Diurnal preceded by SET which probably purges canister more than FTP. Hot-soak might be affected by SET before cold-soak.	HFET is incorporated into the testing procedure.
C	Takes less time and substantially shorter 2nd day than sequence A.	Hot-soak might be affected by vehicle operation prior to start of testing sequence.	

APPENDIX A

Effect of Vehicle Operation on Sulfate Storage and Release

Test No.	Test Type
1	Cold LA-4
2	Hot LA-4
3	SET-7
4	SET-7
5	HWFET
6	HWFET
7	Accel to 30
8	30 mph
9	Accel to 60
10	60 mph

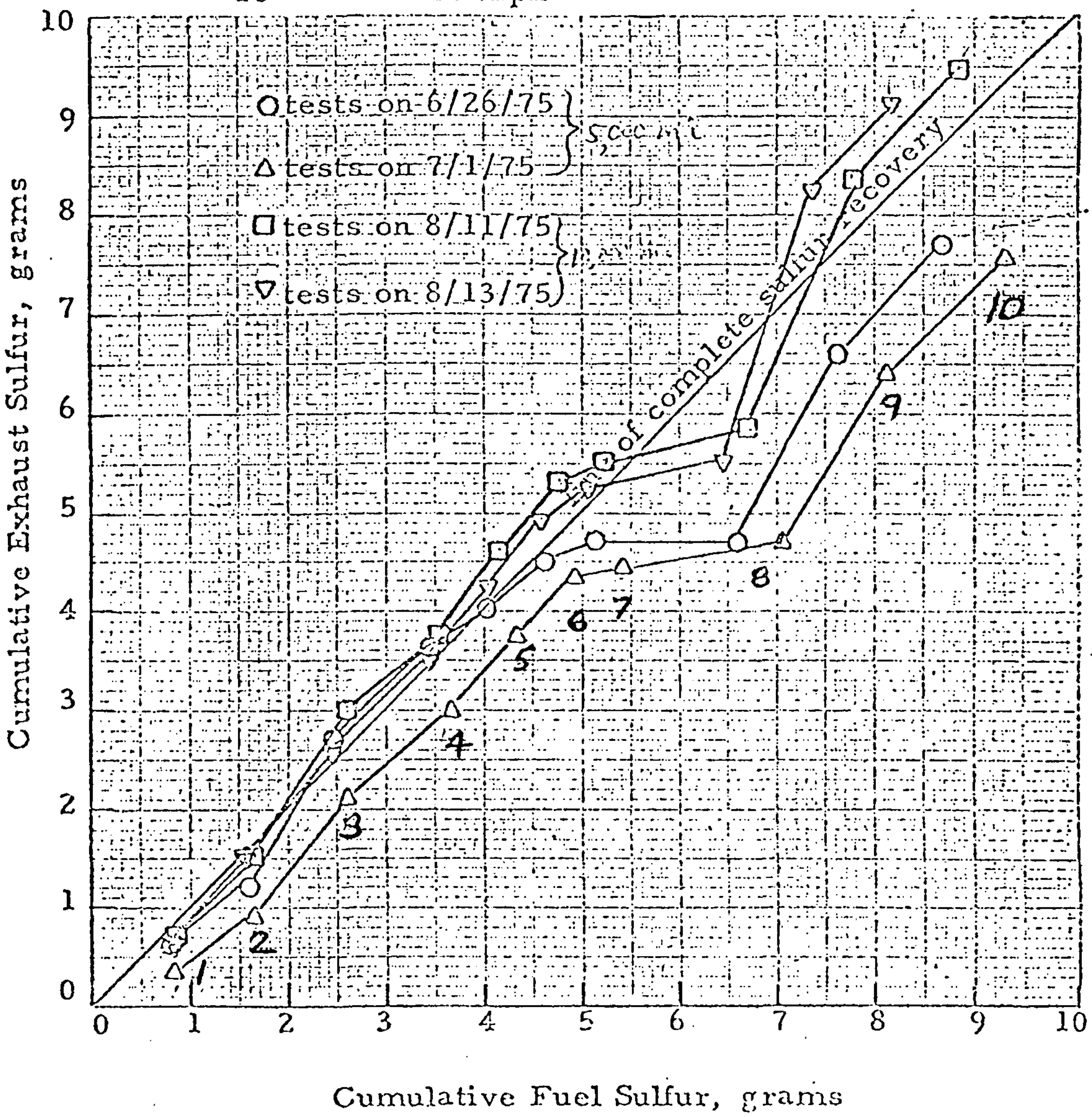


FIGURE 4. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED WITH FUEL FOR A 1975 49 STATE PLYMOUTH GRAN FURY (SwRI Car EM-1)

TEST NO.	TEST TYPE
1	Cold LA-4
2	Hot LA-4
3 and 4	SET-7
5 and 6	HWFET
7	Accel to 30 mph
8	30 mph Steady
9	Accel to 60 mph
10	60 mph Steady

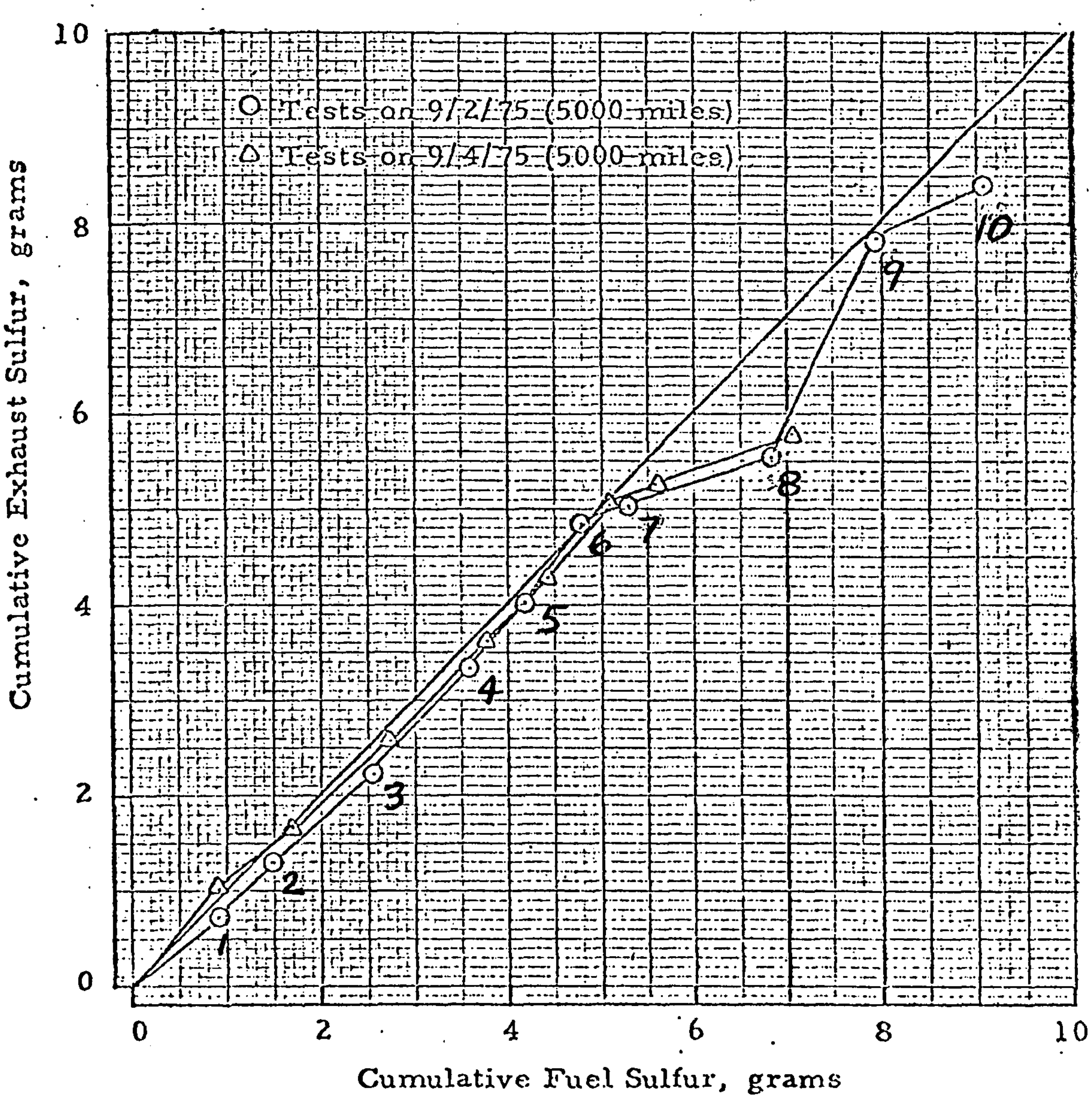


FIGURE 2. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED WITH FUEL IN A 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3) MONOLITH CATALYST WITH AIR INJECTION

TEST NO.	TEST TYPE
1	Cold LA-4
2	Hot LA-4
3 and 4	SET-7
5 and 6	HWFET
7	Accel to 30 mph
8	30 mph Steady
9	Accel to 60 mph
10	60 mph Steady

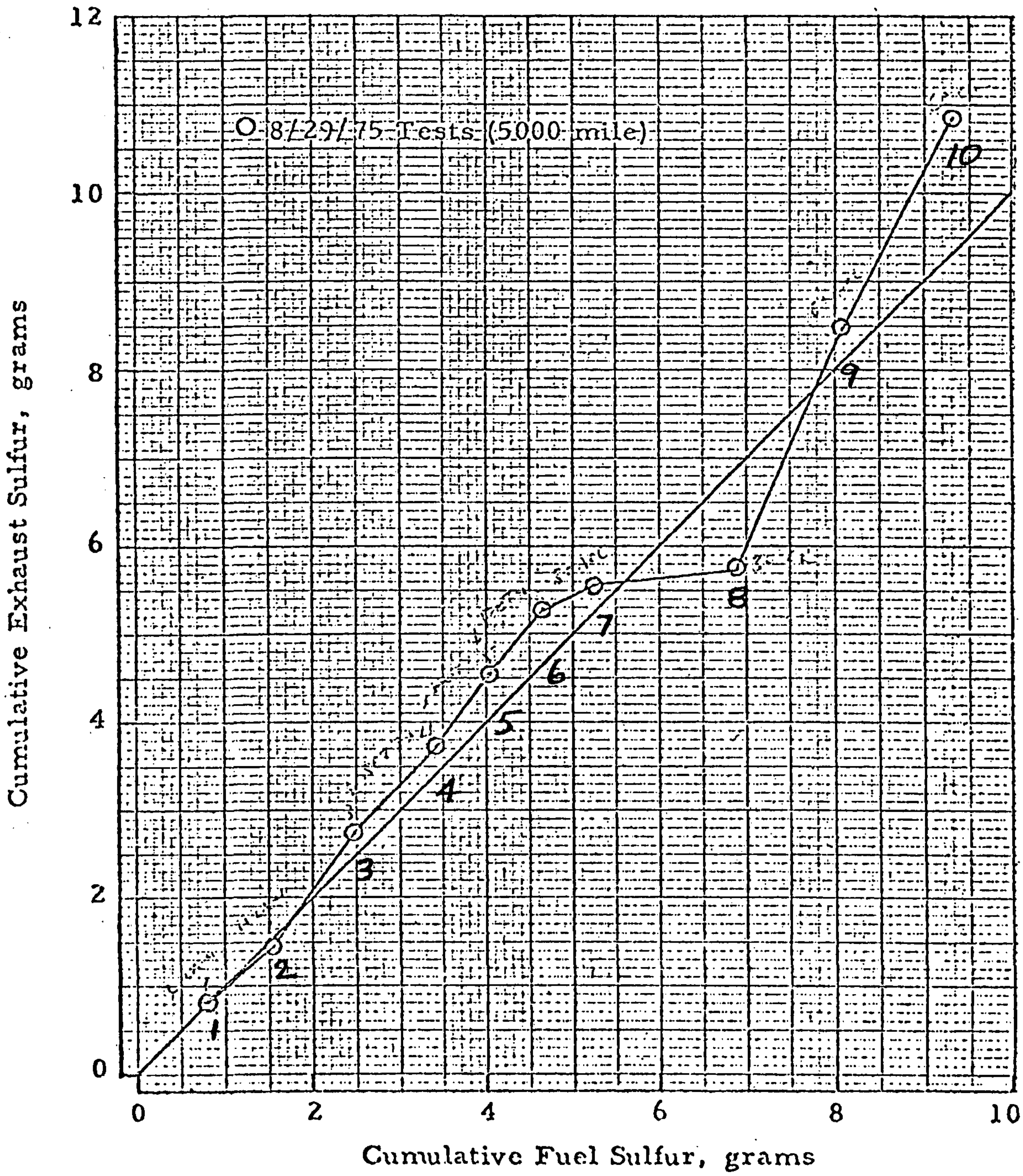


FIGURE 1. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED WITH FUEL IN A 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)

PELLETED CATALYST, NO AIR INJECTION

TEST NO.	TEST TYPE
1	Cold LA-4
2	Hot LA-4
3 and 4	SET-7
5 and 6	HWFET
7	Accel to 30 mph
8	30 mph Steady
9	Accel to 60 mph
10	60 mph Steady

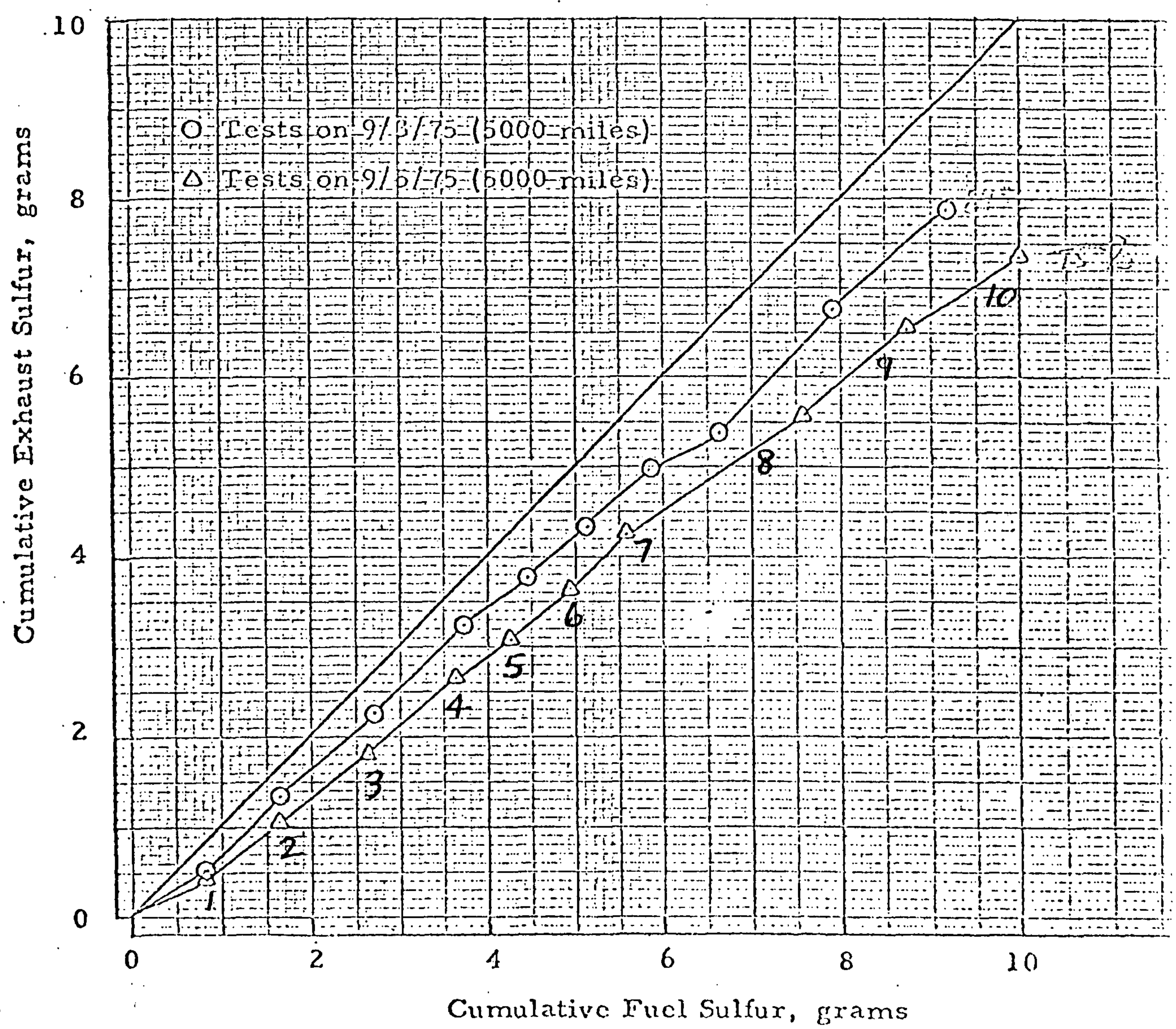


FIGURE 3. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED WITH FUEL IN A 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4) PELLETED CATALYST WITH AIR INJECTION

APPENDIX B

Technician Man-hour and Working Time Requirements for the Various Test Sequences

TECHNICIAN MAN-HOURS REQUIRED PER FULL 1975-TYPE FTP

Segment	Average Minutes of Technician Time
1. Vehicle Inspection and AMA	
a. Locate and inspect vehicle, paper work	12
b. Weigh vehicle	12
1/c. Add fuel	2
* d. Precondition vehicle (AMA)	60
e. Measure idle CO and speed, and timing	10
1/f. Measure axle ratio	20
Subtotal	116
2. Preconditioning	
a. Drain fuel	15
b. Pressure check	12
1/c. Add fuel	16
1/d. Install vehicle on dynamometer	12
e. Inertia and HP setting	5
f. LA-4	30
g. Remove vehicle from dynamometer	8
h. Soak	-
Subtotal	98
3. Diurnal and Evaporative Emission Measurement	
a. Drain fuel	12
* b. Canister preparation	7
* c. Installation of plumbing	18
* d. Installation of heat blanket, thermocouple, check recorder	10
* e. Weigh and install canisters	12
1/f. Add fuel (to 40% cap.)	20
* g. Heat build	80
* h. Seal and remove canisters, plumbing, blanket	8
Subtotal	167

4. Exhaust Emission Running Loss Measurement

	a. Set dynamometer HP and inertia	15
1/	b. Install vehicle on dynamometer	25
1/	c. Manufacturer Rep check	5
1/	d. Exhaust emission test	110
	e. Remove vehicle	6
	Subtotal	161

5. Evaporative Emission Test

*	a. Reinstall plumbing	6
*	b. Hot soak	-
*	c. Remove plumbing	12
*	d. Weigh canisters	6
	e. Complete and dispose of documentation	6
	f. Park vehicle and return keys	10
	Subtotal	40

Subtotal Total	582
Time prorated per test for peripheral tasks 2/	78
Total Minutes	660
Technician Man-Hours/Test	11.0

NOTES

* Deleted for non-evap test

1/ Includes more than 1 technician.

2/ Time prorated to FTP for peripheral tasks is to cover the following:

		Average Hours Per Day
1.	Trouble shooting	5.5
2.	Test coordination	5.5
3.	Making sample bags	.8
4.	Changing gas bottles	.25
5.	Locating manufacturer's special equipment	1.0
6.	Completing job orders, void reports, etc.	1.25
7.	Filling fuel carts	1.0
8.	Emptying dump fuel	.75
9.	Replacing paper and scale in recorders	.75
10.	Locating equipment for test	2.25
11.	Delay for idle set by manufacturer	1.0
	TOTAL	20.05

Prorated time/test (20.05 ÷ 15 average tests per day) 1.3 hrs (78 minutes)

TECHNICIAN MAN-HOURS REQUIRED PER HIGHWAY FUEL ECONOMY TEST

		Average Minutes of Technician Time
	After 24 Hours After FTP	
	1. Obtain keys and paper work	8
1/	2. Locate vehicle, check and add fuel	15
	3. Run AMA	60
1/	4. Re-enter building, install vehicle on dyno	16
	5. Set HP and inertia	10
	6. Run LA-4	23
1/	7. Warm-up and sample FET	50
	8. Remove vehicle	6
	9. Park vehicle and return keys	10
	10. Complete and dispose of documentation	6
		204 (3.4 hrs)
	3-24 Hours After FTP	
	Replace LA-4 + AMA with 5 min. warm-up	126 (2.1 hrs)
	Within 3 Hours After FTP	
	No 5 min. warm-up, no LA-4	121 (2 hrs)
	Immediately After Emission Test	
	Check paper, pen, dyno	5
	Wait for manufacturer, CSD Rep	5
	Warm up and sample FET	50
		60 (1 hr)

NOTE: 1/ Includes more than 1 technician.

Figure B-1 Man-Hour Requirements

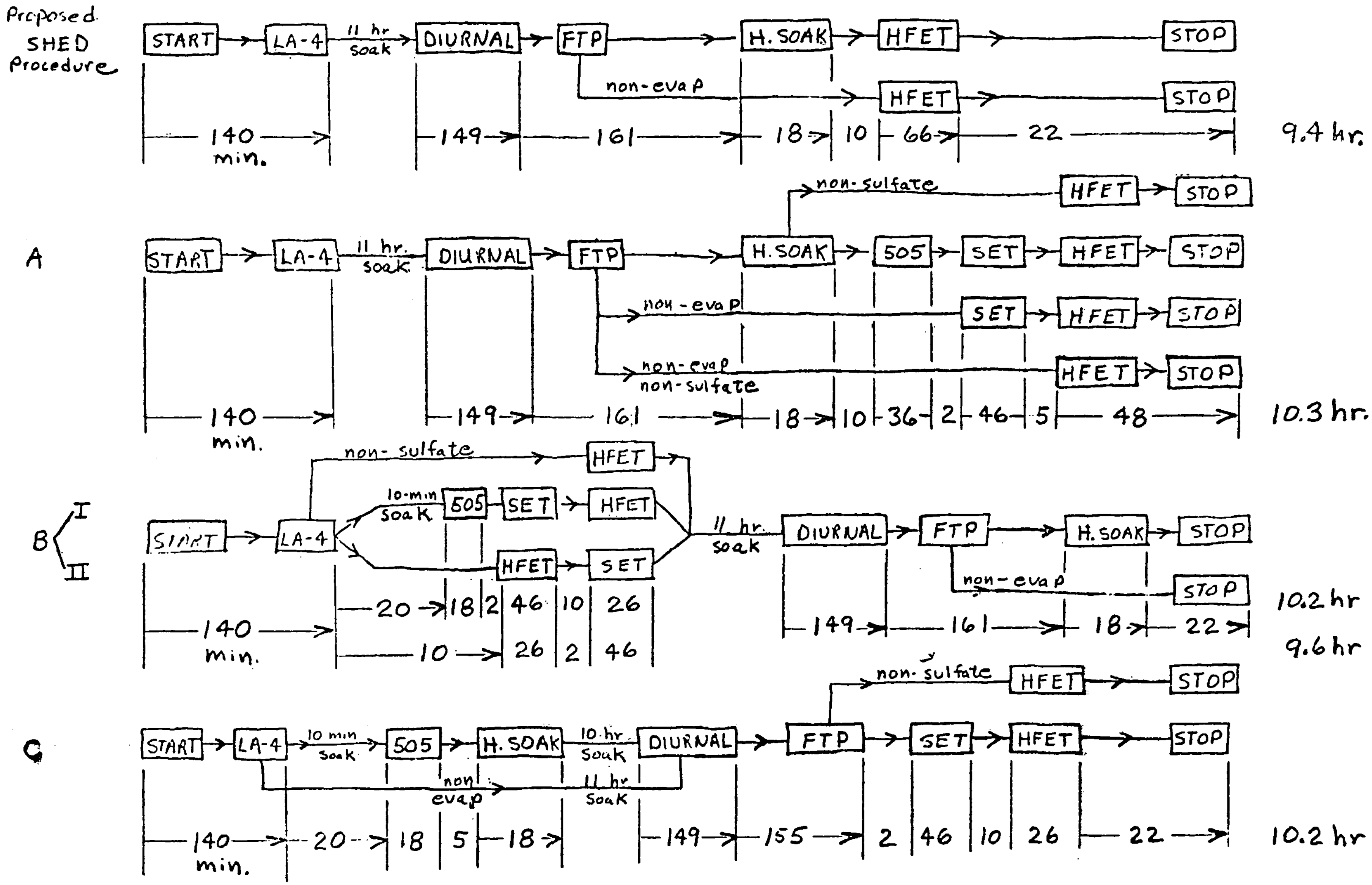
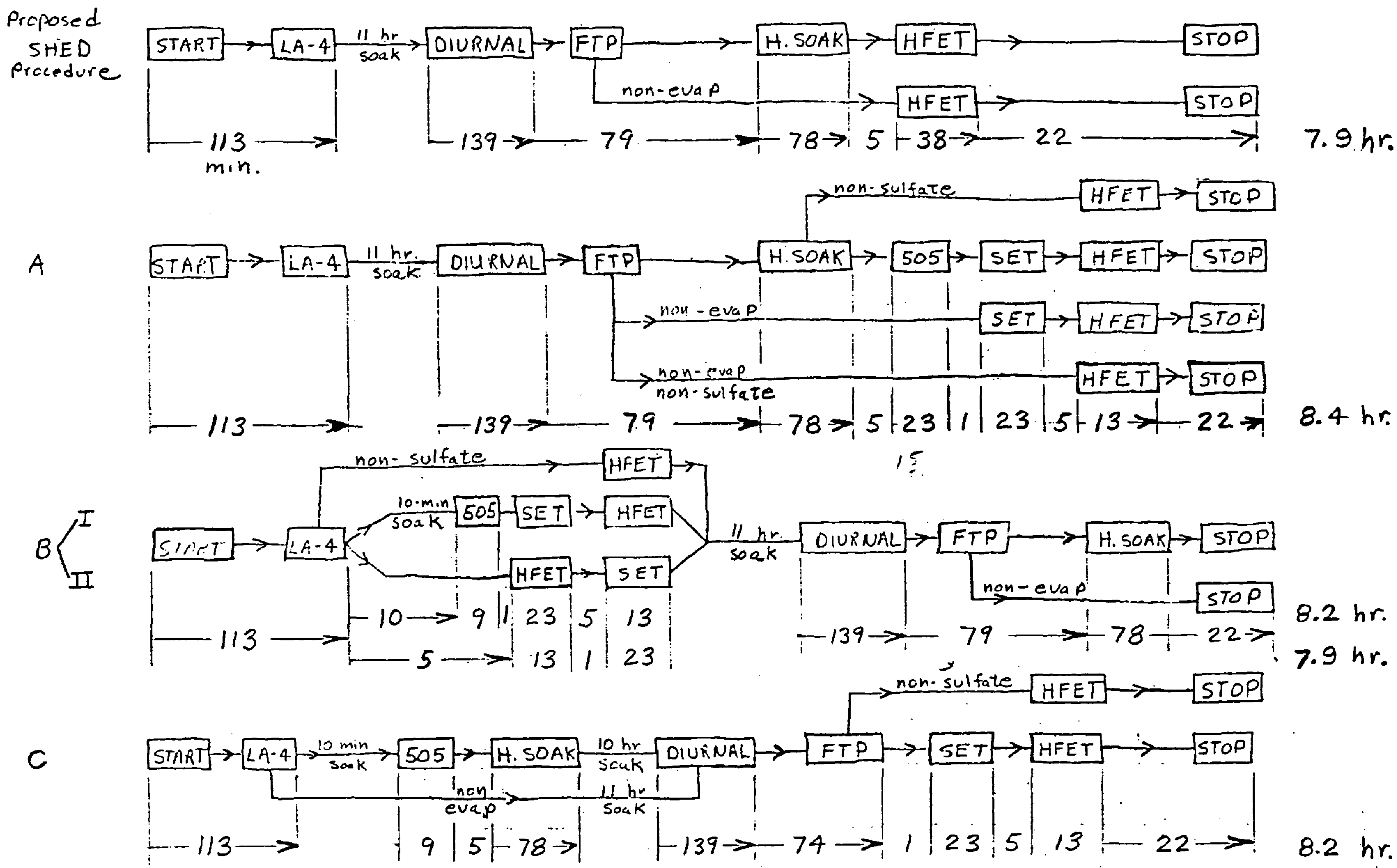


Figure B-2 Working Time Requirements



APPENDIX C

Effect of Pre-conditioning Cycles (LA4 and HFET) on Diurnal Evaporative Losses

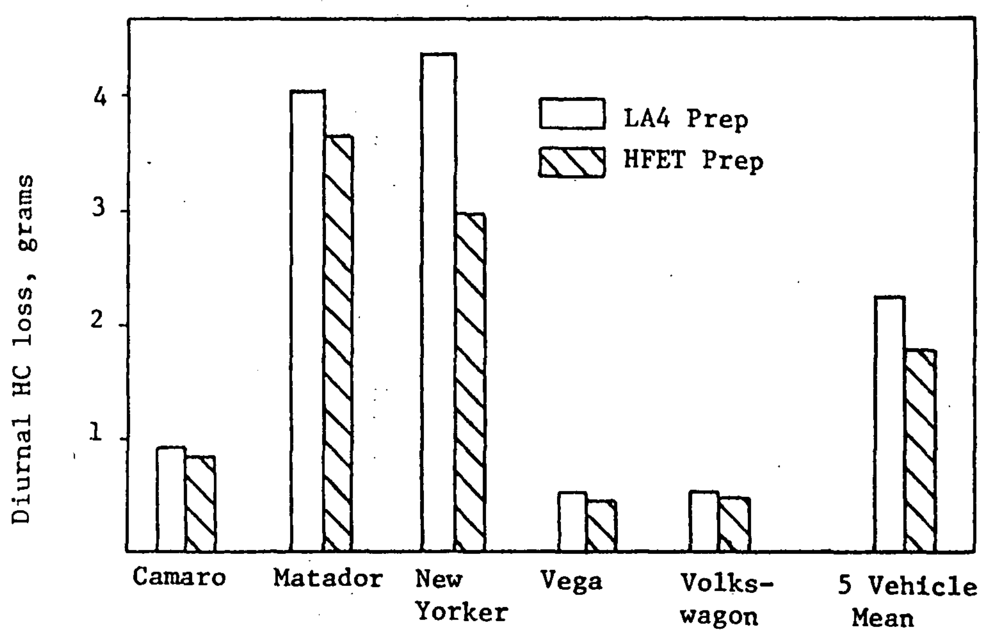


Figure C-1 Diurnal HC Losses for LA4 and HFET Preps

Analysis of Variance For Diurnal Loss Results

Vehicle / Test	Camaro	Matador	New Yorker	Vega	Volkswagen	T_r
LA-4 Prep	0.47 0.80 1.48	4.19 4.37 5.07	6.49 3.94 3.10	0.69 0.45 0.48	1.08 0.93 0.84	34.38
HFET Prep	0.61 1.01 0.54	2.91 4.05 3.99	2.51 3.68 2.68	0.52 0.52 0.45	0.78 0.82 0.91	25.98
T_c	4.91	24.58	22.40	3.11	5.36	T= 60.36

No. of columns, c = 5
No. of rows, r = 2

No. of replicates, n = 3
Total No. of tests, N = 30

T^2/N = 121.44

Σx^2 = 208.66

ΣTc^2 = 1168.45

ΣTr^2 = 1856.94

ΣTcr^2 = 598.91

$SS_c = \Sigma Tc^2/n \cdot r - T^2/N$ = 73.30

$SS_r = \Sigma Tr^2/n \cdot c - T^2/N$ = 2.35

$SS_{cr} = \Sigma T_{cr}^2/n - T^2/N - SS_c - SS_r$ = 2.54

$SS_t = \Sigma X^2 - T^2/N$ = 87.22

$SS_{res} = SS_t - SS_c - SS_r - SS_{cr}$ = 9.03

Source of Variation	SS	DF	M S, (SS/DF)	MSR, (MS/MS res)	< >	F (α = 0.05)
Vehicles	73.30	5-1 = 4	18.33	40.73	>	2.87
Test Type	2.35	2-1 = 1	2.35	5.22	>	4.35
Vehicle-Test Interaction	2.54	(4) (1) = 4	0.64	1.42	<	2.87
Residual	9.02	29 - 9 = 20	0.45			
Total	87.22	30 - 1 = 29				

Hoa: Rejected α 95% C.L.
Hob: Rejected α 95% C.L.
Hoc: Accepted