APPENDIX A. VEHICLE INFORMATION FOR TESTED BACKHOES, FRONT-END LOADERS, AND MOTOR GRADERS

LIST OF TABLES

During the data collection process, it was necessary to collect and record information about the vehicles that were being monitored. This information was recorded in the field on the Vehicle Information field sheet. This sheet includes information about how to identify the vehicle, the characteristics of its chassis and engine, and who was in charge of the use of and access to the vehicle. Information about the owner of the vehicle was also recorded on this sheet. The following tables provide the vehicle information for all backhoes, front-end loaders, and motor graders that were tested.

Table A1. Vehicle Information for Five Tested Backhoes

Backhoe						
Identification	**Project ID**	NCDOT BH1	NCDOT BH 2	NCDOT BH3	NCDOT BH4	NCDOT BH5
	Owner ID	FDP20882	803-0242	803-0241	808-0214	FDP22065
	VIN	CAT0420DEFDP20882	SLP215TCVE0464159	SLP215TCOE0464486	N/A	CAT0402DEF922065
Chassis	**Manufacturer**	CATERPILLIAR	JCB	JCB	CASE	CATERPILLAR
	Model	420D	215	2.15E-01	590SL	420D
	Year	2004	2001	2001	1999	2004
	GVW (lbs)	22,000	16,540	16,540	19,578	22,000
	Front Bucket (cy)	1.25	1.25	1.25	1.25	1.25
	Rear Bucket (cy)	0.237	0.237	0.237	0.237	0.237
Engine	**Manufacturer**	Caterpillar	Perkins	Perkins	CASE	Caterpillar
	Model	3054T	1000	1000	4T-390	3054T
	Year	2004	2001	2001	1999	2004
	Aspiration	Turbocharged	Turbocharged	Turbocharged	Turbocharged	Turbocharged
	Displacement	4	4.2	4.2	3.9	4
	Cylinders	4	4	4	4	4
	Horsepower	97	90	90	99	97
	RPM	2200	2200	2200	2500	2200
	Hours	78	11,528	2,792	3874	740
	Fuel	Diesel	Diesel	Diesel	Diesel	Diesel
User	**Company**	NCDOT- Wake	NCDOT - Wake	NCDOT - Nash	NCDOT - Nash	NCDOT- Wake
	Contact	Jason Holmes	Jason Holmes	Terry Ellis	Terry Ellis	Jason Holmes

Table A2. Vehicle Information for Four Tested Front-End Loaders

Front-End Loader					
Identification	**Project ID**	NCDOT FL01	NCDOT FL02	NCDOT FL03	NCDOT FL04
	Owner ID	010-0249	010-0301	010-5074	010-0388
	VIN	L702EJ10028	L70410264	JFF0060753	LF0210145
Chassis	**Manufacturer**	HYUNDAI	HYUNDAI	CASE	HYUNDAI
	Model	HL 740 TM-3	HL 740 TM-3	621B XT	HL740TM-7
	Year	2002	2002	2002	2005
	GVW (lbs)	29,000	29,000	28,000	29,000
	Bucket (cy)	2.5	2.5	2.5	2.5
Engine	**Manufacturer**	Cummins	Cummins	Cummins	Cummins
	Model	B 5.9C	B 5.9C	6T 590	QSB 5.9-C
	Year	2002	2002	2002	2005
	Aspiration	Turbocharged	Turbocharged	Turbocharged	Turbocharged
	Displacement	5.9	5.9	5.9	5.9
	Cylinders	6	6	6	6
	Horsepower	130	130	126	133
	RPM	2200	2200	2200	2200
	Hours	3,645	9,345	3,569	446
	Fuel	Diesel	Diesel	Diesel	Diesel
User	**Company**	Div 4-Nash Co.	Div 4-Nash Co.	Div 5-Wake Co.	NCDOT- Wake
	Contact	Terry Ellis	Terry Ellis	Jason Holmes	Jason Holmes

Table A3. Vehicle Information for Six Tested Motor Graders

Motor Grader							
Identification	**Project ID**	NCDOT MG 1	NCDOT MG 2	NCDOT MG 3	NCDOT MG 4	NCDOT MG 5	NCDOT MG 6
	Owner ID	955-0515	955-0606	955-0516	948-6647	955-0277	955-0633
	VIN	X033353X	X036740X	X033355X	G580001U1020178	720A187156823583	VCE06930P00040736
Chassis	**Manufacturer**	VOLVO	VOLVO	VOLVO	DRESSER	CHAMPION	VOLVO
	Model	G720VHP	G720B	G720VHP	850	G720	G930
	Year	2001	2004	2001	1990	1993	2007
	GVW (lbs)	37,000	37,000	37,000	37,000	37,000	37,000
	Blade Length (yd)	4	4	4	4	4	4
Engine	**Manufacturer**	Cummins	Volvo	Cummins	Dresser	Cummins	Volvo
	Model	6C8.3	D7DGBE2	6C8.3	D505T	6C8.3	D7
	Year	2001	2004	2001	1990	1993	2007
	Aspiration	Turbocharged	Turbocharged	Turbocharged	Turbocharged	Turbocharged	Turbocharged
	Displacement	8.27	7.1	8.27	8.27	8.27	7.2
	Cylinders	6	6	6	6	6	6
	Horsepower	195	195	195	167	160	198
	RPM	2,200	2,200	2,200	2,500	2,200	2,100
	Hours	4,367	841	3,044	440	4,554	3
	Fuel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
User	**Company**	Wake Co.	Nash Co.	Wake Co.	Wake Co.	Nash Co.	Wake Co.
	Contact	Jason Holmes	Terry Ellis	Jason Holmes	Jason Holmes	Terry Ellis	Bobby Robbins

APPENDIX B. SUMMARIES OF QUANTITY OF DATA AND SITE CONDITIONS FOR EACH TESTED VEHICLE

LIST OF TABLES

During the data collection process, it was necessary to record the amount of time that data were collected for each vehicle. This time is summarized in Table B1. This table provides quantities for the amount of raw data that was collected in the field for each task-oriented activity mode and the amount of raw data that has been processed through quality assurance. The amount of raw data and processed data for each activity mode is given for each vehicle that was tested. Table B1 also provides filenames for the electronically stored data.

Another necessary part of the data collection process was to assess and record the field conditions at the site where the construction vehicle was working and to record the nature of that work. This was done by completing the Construction Site and Activity Information field sheet. This sheet enabled information such as location, weather conditions, and terrain to be gathered. The sheet also contains information about the work activity being performed by the vehicle, as well as a brief description of the modes that were recorded during the work activity. The Construction Site and Activity Information Field Sheets are provided in Table B2 for all vehicles that were tested.

Table B1. Summary of Quantity of Raw and Processed Data by Task-Oriented Activity Modes for Each Tested Vehicle

Backhoe – Petroleum Diesel

General	**Project ID**	NCDOT BH 1	NCDOT BH 2	NCDOT BH 3	NCDOT BH 4	NCDOT BH 5	**Total**
	Date	5/24/2007	04/05/06	03/31/06	4/13/2007	5/23/2007	
	PEMS	NC 2	NC 2	NC 2	NC 2	NC 2	
Amount of Raw Data (seconds)	**Idling**	4,288	3,124	3,914	3,406	5,612	20,344
	Moving	1,246	2,722	4,810	1,477	919	11,174
	Bucket	2,587	2,733	5,708	2,688	1,557	15,273
	Scp/Dmp	1,105	2,988	3,805	1,076	1,017	9,991
Amount of Processed Data (seconds) [a]	**Idling**	4,104	2,884	3,251	3,214	5,593	19,046
	Moving	953	2,473	4,614	1,379	715	10,134
	Bucket	2,315	2,390	4,994	2,685	1,484	13,868
	Scp/Dmp	925	2,804	3,548	1,076	763	9,116
Data Filenames	**Field Folder**	BH070524	BH060405	BH060331	BH070413	BH070523	
	Field File	BH070524_raw.xls	BH060405_raw.xls	BH060331_raw.xls	BH070413_raw.xls	BH070523_raw.xls	
	Processed File	BH070524_sc.xls	BH060405_sc.xls	BH060331_sc.xls	BH070413_scr.xls	BH070523_sc.xls	
	Analyzed Folder	BH070524_an.xls	BH060405_an.xls	BH060331_an.xls	BH070413_an.xls	BH070523_an.xls	

Backhoe – B20 Biodiesel

General	**Project ID**	NCDOT BH 1	NCDOT BH 2	NCDOT BH 3	NCDOT BH 4	NCDOT BH 5	**Total**
	Date	4/26/2007	1/12/2006	5/7/2007	5/1/2007	4/25/2007	
	PEMS	NC2	NC 3	NC 2	NC2	NC2	
Amount of Raw Data (seconds)	**Idling**	2,389	11,053	8,108	4,489	3,598	29,637
	Moving	1,259	2,279	853	1,096	844	6,331
	Bucket	3,062	5,723	2,067	2,847	2,362	16,061
	Scp/Dmp	2,241	2,480	695	1,129	1,877	8,422
Amount of Processed Data (seconds) [a]	**Idling**	2,289	10,900	6,782	4,376	3,421	27,768
	Moving	1,079	2,200	846	796	787	5,708
	Bucket	2,992	5,662	2,055	2,277	2,161	15,147
	Scp/Dmp	1,743	2,424	693	465	1,303	6,628
Data Filenames	**Field Folder**	BH070426	BH060112	BH070507	BH070501	BH070425	
	Field File	BH070426_raw.xls	BH060112_raw.xls	BH070507_raw.xls	BH070501_raw.xls	BH070425_raw.xls	
	Processed File	BH070426_sc.xls	BH060112_sc.xls	BH070507_sc.xls	BH070501_sc.xls	BH070425_sc.xls	
	Analyzed Folder	BH070426_an.xls	BH060112_an.xls	BH070507_an.xls	BH070501_an.xls	BH070425_an.xls	

[a] Data remaining after applying quality assurance procedures (see Appendix D for details of these procedures)

(Continued on the next page)

Table B1. Continued

Front-End Loader – Petroleum Diesel						
General	**Project ID**	NCDOT FL01	NCDOT FL02	NCDOT FL03	NCDOT FL04	**Total**
	Date	3/8/2006	4/7/2006	5/18/2007	5/22/2007	
	PEMS	NC 2	NC 2	NC 2	NC 2	
Amount of Raw Data (seconds)	**Idling**	10,875	3,308	5,980	6,998	27,161
	Moving	2,785	4,926	2,854	2,154	12,719
	Scp/Dmp	6,557	4,740	2,116	1,622	15,035
Amount of Processed Data (seconds) [a]	**Idling**	9,988	3,283	5,940	6,901	26,112
	Moving	2,685	4,855	2,803	2,001	12,344
	Scp/Dmp	6,391	4,738	1,924	1,532	14,585
Data Filenames	**Field Folder**	FL060308	FL060407	FL070518	FL070522	
	Field File	FL060308_raw.xls	FL060407_raw.xls	FL070518_raw.xls	FL070522_raw.xls	
	Processed File	FL060308_sc.xls	FL060407_sc.xls	FL070518_sc.xls	FL070522_screened.xls	
	Analyzed Folder	FL060308_an.xls	FL060407_an.xls	FL070518_an.xls	FL070522_analyzed.xls	

Front-End Loader – B20 Biodiesel

General	**Project ID**	NCDOT FL01	NCDOT FL02	NCDOT FL03	NCDOT FL04	**Total**
	Date	5/8/2007	4/10/2007	7/21/2006	5/17/2007	
	PEMS	NC 2	NC 2	NC 2	NC 2	
Amount of Raw Data (seconds)	**Idling**	6,255	1,831	3,587	7,769	19,442
	Moving	1,346	2,640	2,139	1,986	8,111
	Scp/Dmp	1,222	4,700	3,072	3,312	12,306
Amount of Processed Data (seconds) [a]	**Idling**	6,228	1,774	3,297	7,528	18,827
	Moving	1,070	2,156	2,051	1,805	7,082
	Scp/Dmp	1,122	3,712	2,809	3,094	10,737
Data Filenames	**Field Folder**	FL070508	FL070410	FL060721	FL070517	
	Field File	FL070508_raw.xls	FL07410_raw.xls	FL060721_raw.xls	FL070517_raw.xls	
	Processed File	FL070508_sc.xls	FL07410_sc.xls	FL060721_sc.xls	FL070517_sc.xls	
	Analyzed Folder	FL070508_an.xls	FL070410_an.xls	FL060721_an.xls	FL070517_an.xls	

[a] Data remaining after applying quality assurance procedures (see Appendix D for details of these procedures)

(Continued on the next page)

Table B1. Continued

Motor Grader – Petroleum Diesel

General	**Project ID**	NCDOT MG 1	NCDOT MG 2	NCDOT MG 3	NCDOT MG 4	NCDOT MG 5	NCDOT MG 6	**Total**
	Date	2/1/2006	3/23/2006	5/25/2007	4/3/2007	1/17/2007	6/22/2007	
	PEMS	NC 2	NC 2	NC 2	NC 2	NC 2	NC 2	
Amount of Raw Data (seconds)	**Idling**	1,770	8,568	3,429	2,666	5,749	2,008	24,190
	Moving	7,005	2,133	1,689	4,871	1,565	4,001	21,264
	Blade	7,573	1,504	2,742	3,963	3,288	3,253	22,323
Amount of Processed Data (seconds) [a]	**Idling**	1,456	8,158	3,358	1,446	5,198	1,860	21,476
	Moving	6,774	2,060	1,599	4,643	1,422	3,684	20,182
	Blade	7,497	1,486	2,706	3,951	3,169	3,143	21,952
Data Filenames	**Field Folder**	MG060201	MG060323	MG070525	MG070403	MG070117	MG070622	
	Field File	MG060201_raw.xls	MG060323_raw.xls	MG070525_raw.xls	MG070403_raw.xls	MG070117_raw.xls	MG070622_raw.xls	
	Processed File	MG060201_sc.xls	MG060323_sc.xls	MG070525_sc.xls	MG070403_sc.xls	MG070117_sc.xls	MG070622_sc.xls	
	Analyzed Folder	MG060201_an.xls	MG060323_an.xls	MG070525_an.xls	MG070403_an.xls	MG070117_an.xls	MG0700622_anxls	

Motor Grader – B20 Biodiesel

General	**Project ID**	NCDOT MG 1	NCDOT MG 2	NCDOT MG 3	NCDOT MG 4	NCDOT MG 5	NCDOT MG 6	**Total**
	Date	2/14/2006	4/20/2007	8/4/2006	12/5/2006	2/21/2007	6/28/2007	
	PEMS	NC 2	NC 2	CATI	NC 2	NC2	NC2	
Amount of Raw Data (seconds)	**Idling**	5,653	12,058	5,352	8,477	5,267	4,028	40,835
	Moving	6,865	3,463	4,807	2,603	3,936	2,734	24,408
	Blade	7,014	2,192	3,256	3,224	5,403	2,738	23,827
Amount of Processed Data (seconds) [a]	**Idling**	5,466	11,035	4,744	7,702	4,864	3,926	37,737
	Moving	6,329	2,453	4,741	2,398	3,887	2,507	22,315
	Blade	6,652	1,511	3,248	3,038	5,397	2,659	22,505
Data Filenames	**Field Folder**	MG060214	MG070420	MG060804	MG061205	MG070221	MG062807	
	Field File	MG060214_raw.xls	MG070420_raw.xls	MG060804_raw.xls	MG061205_raw.xls	MG070221_raw.xls	MG070628_raw.xls	
	Processed File	MG060214_sc.xls	MG070420_sc.xls	MG060804_sc.xls	MG061205_sc.xls	MG070221_sc.xls	MG070628_sc.xls	
	Analyzed Folder	MG060214_an.xls	MG070420_an.xls	MG060804_an.xls	MG061205_an.xls	MG070221_an.xls	MG070628_an.xls	

[a] Data remaining after applying quality assurance procedures (see Appendix D for details of these procedures)

Table B2. Summary of Construction Site and Activity Information for Each Tested Vehicle

Backhoe 1			
General	**Project ID**	NCDOT BH1 PD	NCDOT BH1 B20
	Project	Pile Dirt	Pile Dirt
	Location	Maintenance yard, Nash County	Maintenance yard, Nash County
	Date	05/24/07	04/26/07
	Time	8:30AM-12:30PM	8:30AM-12:30PM
	Weather	68 F, 62% Humidity	75 F, 58% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Material Handling	Material Handling
	Unit [a]	Number of Scoops (Front Bucket)	Number of Scoops (Front Bucket)
	Quantity	57	64
	Procedure	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket
	Description	All four modes observed	All four modes observed

Backhoe 2			
General	**Project ID**	NCDOT BH2 PD	NCDOT BH2 B20
	Project	Road Maintenance	Road Maintenance
	Location	Old Stage Road, Garner, NC	Old Stage Road, Garner, NC
	Date	4/05/06	1/12/06
	Time	9:00 am - 2:30 pm	9:00 am - 4:30 pm
	Weather	58 F, 37% Humidity	59 F, 79% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Loading Dump Truck	Loading Dump Truck
	Unit [a]	Number of Scoops (Front Bucket)	Number of Scoops (Front Bucket)
	Quantity [b]	104	40
	Procedure	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket
	Description	All four modes observed	All four modes observed.

[a] Work using the rear bucket was observed but data were not recorded regarding the number of scoops with the rear bucket.

[b] On January 12, 2006, the operator used the front bucket for 1.5 hours. Thus, only 40 of scoops were observed.

(Continued on the next page)

Table B2. Continued

Backhoe 3			
General	**Project ID**	NCDOT BH3 PD	NCDOT BH3 B20
	Project	Load Truck	Pile Dirt
	Location	Bethlehem Road, Nash County	Maintenance yard, Nash County
	Date	03/31/06	05/07/07
	Time	7:30AM-2:00PM	8:30AM-12:30PM
	Weather	62 F, 56% Humidity	56 F, 53% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Load trucks	Material Handling
	Unit [a]	Number of Scoops (Front Bucket)	Number of Scoops (Front Bucket)
	Quantity	59	60
	Procedure	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket
	Description	All four modes observed	All four modes observed

Backhoe 4			
General	**Project ID**	NCDOT BH4 PD	NCDOT BH4 B20
	Project	Pile Dirt	Pile Dirt
	Location	Maintenance yard, Nash County	Pleasant Grove Church, Nash County
	Date	04/13/07	05/01/07
	Time	8:30AM-12:30PM	8:30AM-12:30PM
	Weather	57 F, 49% Humidity	76 F, 46% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Material Handling	Material Handling
	Unit [a]	Number of Scoops (Front Bucket)	Number of Scoops (Front Bucket)
	Quantity	55	62
	Procedure	1. Moves 2. Moves & carries load using front bucket 3. Dumps 4. Repeat	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket
	Description	All four modes observed	All four modes observed

[a] Work using the rear bucket was observed but data were not recorded regarding the number of scoops with the rear bucket.

[b] On January 12, 2006, the operator used the front bucket for 1.5 hours. Thus, only 40 of scoops were observed.

(Continued on the next page)

Table B2. Continued

Backhoe 5			
General	**Project ID**	NCDOT BH5 PD	NCDOT BH5 B20
	Project	Pile Dirt	Pile Dirt
	Location	Maintenance yard, Nash County	Maintenance yard, Nash County
	Date	05/23/07	04/25/07
	Time	8:30AM-12:30PM	8:30AM-12:30PM
	Weather	69 F, 60% Humidity	74 F, 58% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Material Handling	Material Handling
	Unit [a]	Number of Scoops (Front Bucket)	Number of Scoops (Front Bucket)
	Quantity	59	55
	Procedure	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat	1. Moves 2. Moves and carries load using front bucket 3. Dumps 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket	1. Idling 2. Moving 3. Scoop/Dump 4. Bucket
	Description	All four modes observed	All four modes observed

(Continued on the next page)

Table B2. Continued

Front-End Loader 1			
General	**Project ID**	NCDOT FL1 PD	NCDOT FL1 B20
	Project	Roadway Shoulder Construction	Dirt and Gravel Pile Dumping and Loading
	Location	Watson Seed Farm Road, Nash County	Pleasant Grove Church, Nash County
	Date	3/08/06	5/08/07
	Time	7:30AM-2:30PM	7:30AM-2:30PM
	Weather	57 F, 59% Humidity	60 F, 67% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Moving loose volume of soil	Moving loose volume of soil
	Unit	Number of Scoops	Number of Scoops
	Quantity [c]	184	125
	Procedure	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump	1. Idling 2. Moving 3. Scoop/Dump
	Description	All three modes observed	All three modes observed

Front-End Loader 2			
General	**Project ID**	NCDOT FL2 PD	NCDOT FL2 B20
	Project	Pile Dirt	Pile Dirt
	Location	Rocky Mount	Corinth Road, Nash County
	Date	4/07/06	4/10/07
	Time	8:30AM-1:30PM	8:30AM-1:30PM
	Weather	70 F, 42% Humidity	48 F, 48% Humidity
	Terrain	level	level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Moving loose volume of soil	Moving loose volume of soil
	Unit	Number of Scoops	Number of Scoops
	Quantity [d]	184	63
	Procedure	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump	1. Idling 2. Moving 3. Scoop/Dump
	Description	All three modes observed	All three modes observed

[c] On March 8 2006, the work duty was intensive in order to finish the project. Thus, the number of scoops was higher than the other project.

(Continued on the next page)

Table B2. Continued

Front-End Loader 3			
General	**Project ID**	NCDOT FL3 PD	NCDOT FL3 B20
	Project	Pile Dirt	Dirt and Gravel Pile Dumping and Loading
	Location	Maintenance Yard, Wake County	Deer Brook St., Fuquay-Varina
	Date	5/18/07	7/21/06
	Time	8:30AM-1:30PM	7:30AM-2:30PM
	Weather	60 F, 67% Humidity	82 F, 70% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Moving loose volume of soil	Moving loose volume of soil
	Unit	Number of Scoops	Number of Scoops
	Quantity [d]	55	153
	Procedure	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump	1. Idling 2. Moving 3. Scoop/Dump
	Description	All three modes observed	All three modes observed

Front-End Loader 4			
General	**Project ID**	NCDOT FL4 PD	NCDOT FL4 B20
	Project	Pile Dirt	Pile Dirt
	Location	Maintenance Yard, Wake County	Maintenance Yard, Wake County
	Date	5/22/07	5/17/07
	Time	8:30AM-1:30PM	8:30AM-1:30PM
	Weather	72 F, 59% Humidity	63 F, 77% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Moving loose volume of soil	Moving loose volume of soil
	Unit	Number of Scoops	Number of Scoops
	Quantity	63	68
	Procedure	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat	1. Moves forward scooping soil 2. Moves to dump truck 3. Dumps soil in truck 4. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Scoop/Dump	1. Idling 2. Moving 3. Scoop/Dump
	Description	All three modes observed	All three modes observed

[d] On April 10 2007 and May 18, 2007, the work duty was not intensive. Most of the data were idling. Thus, the number of scoops was less than on other dates.

(Continued on the next page)

Table B2. Continued

Motor Grader 1			
General	**Project ID**	NCDOT MG1 PD	NCDOT MG1 B20
	Project	Dirt Road Maintenance	Dirt Road Maintenance
	Location	Garner and Fuquay-Varina	Garner and Fuquay-Varina
	Date	2/01/06	2/14/06
	Time	9:00 AM - 3:30 PM	9:00 AM - 3:30 PM
	Weather	48 F, 43% Humidity	48 F, 38% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Scraping Dirt Road	Scraping Dirt Road
	Unit	Miles of road scraped	Miles of road scraped
	Quantity[a]	13.2	15.8
	Procedure	1. Lowers blade 2. Moves forward, scraping top surface of road 3. Continues until entire road is scraped	1. Lowers blade 2. Moves forward, scraping top surface of road 3. Continues until entire road is scraped
Modal Description	**Modes**	1. Idling 2. Moving 3. Blade	1. Idling 2. Moving 3. Blade
	Description	All three modes observed	All three modes observed

Motor Grader 2			
General	**Project ID**	NCDOT MG2 PD	NCDOT MG2 B20
	Project	Roadway Shoulder Construction	Roadway Shoulder Construction
	Location	Taylor Store Road, Nash County	Nashville
	Date	3/23/06	4/20/07
	Time	8:00AM - 2:00PM	8:00AM - 2:00PM
	Weather	47 F, 42% Humidity	64 F, 44% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Dirt Scraping	Dirt Scraping
	Unit	Miles of Shoulder scraped	Miles of Shoulder scraped
	Quantity	0.55	1.33
	Procedure	1. Use blade to push dirt from Point A to Point B 2. Return to Point A 3. Repeat	1. Use blade to push dirt from Point A to Point B 2. Return to Point A 3. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Blade	1. Idling 2. Moving 3. Blade
	Description	All three modes observed	All three modes observed

[a] On February 1 and February 14, 2006, Motor Grader 1 worked alone in the field. It scraped long distances of dirt road without any disturbances.

(Continued on the next page)

Table B2. Continued

Motor Grader 3			
General	**Project ID**	NCDOT MG3 PD	NCDOT MG3 B20
	Project	Roadway Shoulder Construction	Roadway Shoulder Construction
	Location	Apex, Wake County	Glory Road, Zebulon
	Date	5/25/07	8/04/06
	Time	9:00 AM - 12:30 PM	7:00 AM - 12:00 PM
	Weather	74 F, 54% Humidity	87 F, 63% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Dirt Scraping	Dirt Scraping
	Unit	Miles of Shoulder scraped	Miles of Shoulder scraped
	Quantity	2.2	2.5
	Procedure	1. Use blade to push dirt from Point A to Point B 2. Return to Point A 3. Repeat	1. Use blade to push dirt from Point A to Point B 2. Return to Point A 3. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Blade	1. Idling 2. Moving 3. Blade
	Description	All three modes observed	All three modes observed

Motor Grader 4			
General	**Project ID**	NCDOT MG4 PD	NCDOT MG4 B20
	Project	Dirt Road Maintenance	Roadway Shoulder Construction
	Location	Gralyn Road, Raleigh, NC	Pagan Road, NC
	Date	4/03/07	12/05/06
	Time	8:40 AM - 12:00 PM	8:30 AM - 1:30 PM
	Weather	73 F, 44% Humidity	45 F, 37% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	**Activity**	Scraping Dirt Road	Dirt Scraping
	Unit	Miles of road scraped	Miles of Shoulder scraped
	Quantity	3.5	2.0
	Procedure	1. Lowers blade 2. Moves forward, scraping top surface of road 3. Continues until entire road is scraped	1. Use blade to push dirt from Point A to Point B 2. Return to Point A 3. Repeat
Modal Description	**Modes**	1. Idling 2. Moving 3. Blade	1. Idling 2. Moving 3. Blade
	Description	All three modes observed	All three modes observed

(Continued on the next page)

Table B2. Continued

Motor Grader 5			
General	Project ID	NCDOT MG5 PD	NCDOT MG5 B20
	Project	Roadway Shoulder Construction	Roadway Shoulder Construction
	Location	Nashville	Nashville
	Date	1/17/07	2/21/07
	Time	9:00AM - 12:30PM	9:00AM - 12:30PM
	Weather	35 F, 39% Humidity	60 F, 72% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	Activity	Dirt Scraping	Dirt Scraping
	Unit	Miles of Shoulder scraped	Miles of Shoulder scraped
	Quantity	2.2	3.5
	Procedure	1. Use blade to push dirt from Point A to Point B 2. Return to Point A 3. Repeat	1. Use blade to push dirt from Point A to Point B 2. Return to Point A 3. Repeat
Modal Description	Modes	1. Idling 2. Moving 3. Blade	1. Idling 2. Moving 3. Blade
	Description	All three modes observed	All three modes observed

Motor Grader 6			
General	Project ID	NCDOT MG6 PD	NCDOT MG6 B20
	Project	Dirt Road Maintenance	Dirt Road Maintenance
	Location	Pilot, NC	Pilot, NC
	Date	6/22/07	6/28/07
	Time	9:00 AM - 12:30 PM	9:00 AM - 12:30 PM
	Weather	83 F, 42% Humidity	86 F, 56% Humidity
	Terrain	Level	Level
	Soils	Sandy Topsoil	Sandy Topsoil
Work Activity	Activity	Scraping Dirt Road	Scraping Dirt Road
	Unit	Miles of road scraped	Miles of road scraped
	Quantity	3.2	2.3
	Procedure	1. Lowers blade 2. Moves forward, scraping top surface of road 3. Continues until entire road is scraped	1. Lowers blade 2. Moves forward, scraping top surface of road 3. Continues until entire road is scraped
Modal Description	Modes	1. Idling 2. Moving 3. Blade	1. Idling 2. Moving 3. Blade
	Description	All three modes observed	All three modes observed

APPENDIX C: DATA COLLECTION PROCEDURES

Table of Contents

C.1 Introduction

The objective of this section is to explain the general procedures for portable on-board emissions data collection when collecting data on nonroad construction vehicles, such as front-end loaders, backhoes, and motor graders. These procedures are for nonroad construction vehicles and equipment. These procedures include pre-installation, installation, field data collection, decommissioning, and cleanup. For each of these major steps of data collection, a checklist and explanation of procedures is given.

C.2 Pre-Installation

Construction workers usually start working early in the morning. In order to have sufficient time to install the Montana system and not to interfere with their work, the data collection crew installed some of the major components the day before a test. This is referred to as "pre-installation."

Pre-installation involves installing the sensors, sampling hoses, the safety cage, the cables, and the connections, except for the final installation of the main unit. The main unit is installed on the morning of data collection. It would typically take two people two-to-three hours to finish the pre-installation procedure. Pre-installation differed from installation because pre-installation was done the day before a test, typically in the afternoon.

C.2.1 Checklist

Pre-installation includes the installation of the major test system components on the test vehicle, except for the instrument itself. The following sections explain these major components and installation procedures. Table C-1 shows the checklist for pre-installation. Two people were needed to finish pre-installation. Even with two people working together, pre-installation would take a minimum of two hours and forty minutes.

Figure C-1 shows the timeline for pre-installation when performed by two people. Due to different engine models and ambient conditions, the time period for pre-installation varied from two hours and forty minutes to three hours and forty minutes. Each type of vehicle has a different engine model and engine compartment shape. In some cases, pre-installation of engine sensors was very difficult due to the small engine compartment. If the data collection crew could not locate the port for the manifold absolute pressure sensor, the vehicle could not be tested.

When a new construction vehicle was to be tested (of a type not previously tested by the data collection crew), the data collection crew needed additional time to find the appropriate connections to install engine sensors. When the same model of construction vehicle was to be tested again, two hours and forty minutes was usually enough time for pre-installation. Table C-2 presents a typical pre-installation time period and pre-installation time range for a backhoe, motor grader, and front-end loader.

The height of the vehicle also presented another difficulty for completing pre-installation. It was difficult to work on the roof of the vehicle at a height of 9 – 11 feet above the ground. This area was slippery and possibly unsafe; extra care had to be taken to ensure safety. Therefore, additional time was sometimes required to complete pre-installation.

When pre-installation was complete, the main unit of the Montana system was brought to the laboratory and calibrated. There was a gap in time between pre-installation and calibration due to travel time from the construction site to the laboratory.

Table C-1. Pre-installation Checklist Form

Pre-Installation Procedure Checklist	
Safety Cage – Installation on hood or roof of test vehicle	☐
Exhaust Gases Sampling Hoses – Fasten to tailpipe and secure hoses from tailpipe to safety cage	☐
Sensor Unit – Secure sensor unit on the test vehicle – Secure cables from sensor unit to safety cage	☐
Manifold Absolute Pressure Sensor – Find the port on the engine after turbocharger which is used for regular testing of engine pressure – Install manifold absolute pressure sensor and attached the sensor to the engine – Connect the cable from manifold absolute pressure sensor to sensor unit	☐
Engine Speed Sensor – Attach the engine speed sensor to test vehicle – Install optical tape on the pulley – Connect the cable from engine speed sensor to sensor unit	☐

(Continued on next page)

Table C-1. Continued

Intake Air Temperature Sensor – Install intake air temperature sensor – Fix the intake air temperature sensor near the intake air flow using duct tape or plastic wire – Connect the cable from intake air temperature sensor to sensor unit	☐
External Power Source – Install external power source – Secure power cable to safety cage	☐
Measurement Instrument Pre-test – Install main unit of Montana system – Connect sensor unit to main unit – Read engine data to decide if it is necessary to re-install engine sensors	☐
Re-installation (if engine sensor is not installed properly) – Re-install sensors	☐
Re-test (after re-install sensors) – Read engine data to decide if it is necessary to re-install engine sensors again	☐
Wrap-up – Pick up tools and put into the toolbox	☐
Calibration of Montana System – Warm up the main unit for forty-five minutes – Perform calibration procedures according to "Operation Manual of OEM-2100 Montana System"	☐

(End of Table C-1)

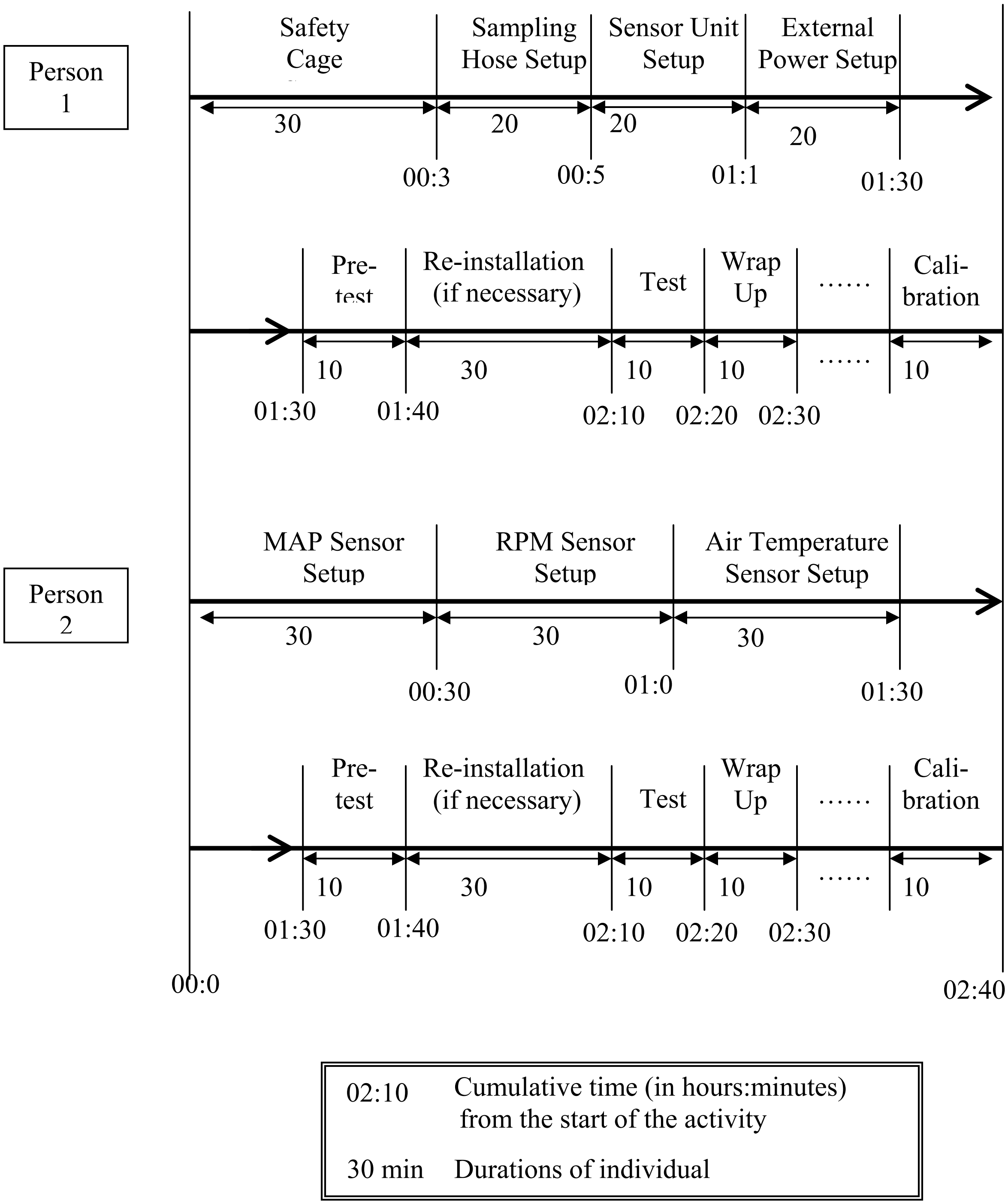


Figure C-1. Timeline for Pre-installation Procedures Performed by Two People

Table C-2. Typical Time Period and Range for Pre-Installation

Vehicle Type	Pre-Installation Time Period	
	Typical	Range
Backhoe	2 hr 40 min	2 hr 40 min to 3 hr 40 min
Motor Grader	2 hr 40 min	2 hr 40 min to 3 hr 40 min
Front-End Loader	2 hr 40 min	2 hr 40 min to 3 hr 40 min

C.2.2 Safety Cage

To protect the Montana system from damage and to help control transmission of vibration from the vehicle to the Montana system, a sturdy metal safety cage was developed. The cage was large enough to enclose the main unit of the Montana system. The cage was intended to protect the main unit from being impacted by tree branches or other potential obstacles that might be encountered at a construction site.

Vibration of the construction vehicle may cause a short circuit and disconnection of cables within the Montana unit. To dampen vibrations, a flexible rubber pad was installed between the safety cage and the main unit. The cage was secured to the hood or roof of the test vehicle using straps. The safety cage was covered to protect it from dust at the construction site. Figure C-2 depicts the safety cage.

The Montana was located on the vehicle so that it did not block the driver's or operator's view of the task being performed, nor interfere with the task-oriented functions of the vehicle. For a backhoe and front-end loader, the typical location for the safety cage was on the roof of the vehicle. For a motor grader, the typical location for the safety cage was on the engine hood of the vehicle. Figures C-3 and C-4 show the typical locations for a backhoe and a motor grader, respectively.

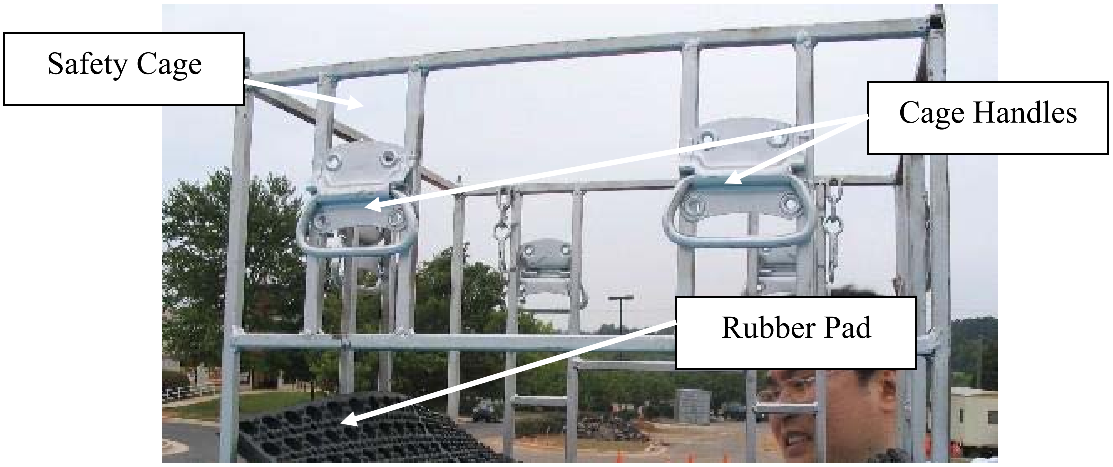


Figure C-2. Safety Cage for Montana Installation

Figure C-3. Safety Cage on a Backhoe

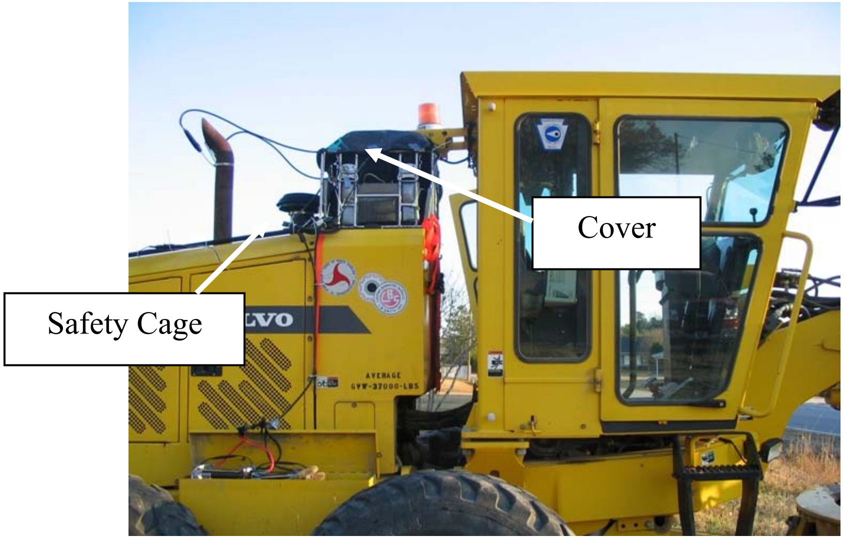


Figure C-4. Safety Cage on a Motor Grader

C.2.3 Exhaust Gases Sampling Hoses

Two sampling hoses were used to take exhaust gas samples from the tailpipe. An exhaust gas sample for particulate matter was obtained from one sampling hose and the other sampling hose obtained samples for NO, HC, CO, CO_2, O_2. The sampling hoses included a probe that was inserted into the exhaust pipe. The probe assembly was secured to the tailpipe using an adjustable metal hose clamp shown in Figure C-5.

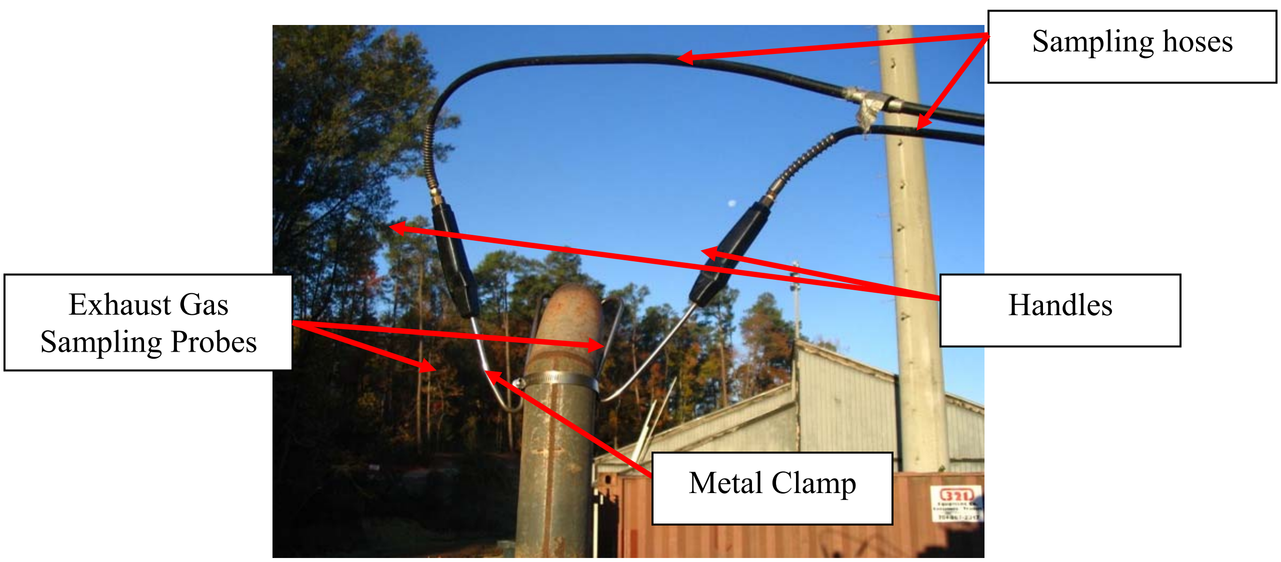


Figure C-5. Attachment of Exhaust Gas Sampling Probes to the Tailpipe

The probe handles and the hoses were located so that they were not in the path of hot gases and so that they were not likely to get caught on any obstacles. The sampling hoses were secured to the equipment and there was minimal slack in the line between the tailpipe and the main unit. Each sampling hose was attached to the main unit through a sample bowl. Figure C-6 shows how a sampling hose was connected to the main unit.

Figure C-6. Attachment of the Sampling Hose to the Main Unit

The exhaust sampling probes were inserted directly into the tailpipe in order to obtain accurate tailpipe emissions. However, some construction vehicles have a gap between the muffler and tailpipe as shown in Figure C-7. Fresh ambient air may enter the tailpipe from this gap and dilute the pollutant concentration. In order to get accurate emissions data, it was preferred not to have excess air enter the tailpipe and dilute the exhaust gas. A method that was used with success in the field was to use several layers of aluminum foil with two clamps for sealing the gap as shown in Figure C-8. The area where aluminum foil was used for sealing the gap was hot and care was taken when working with it.

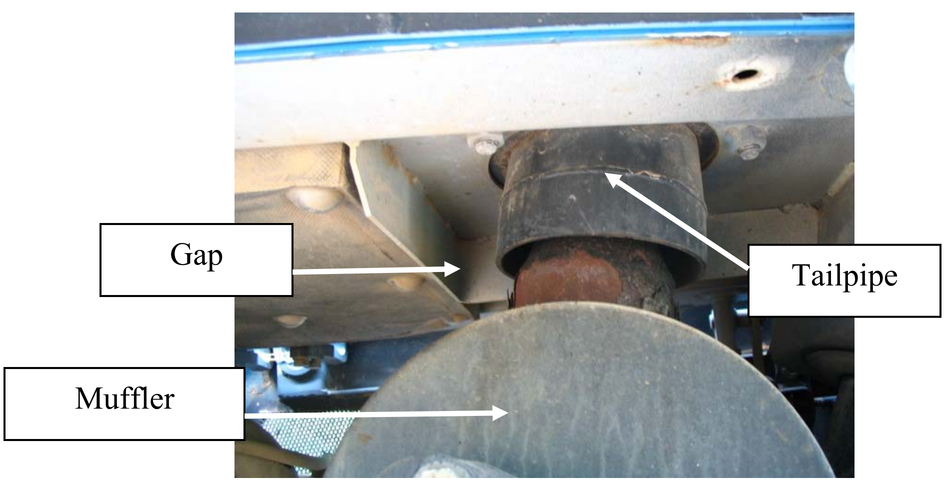


Figure C-7. Illustration of a Typical Gap between Muffler and Tailpipe

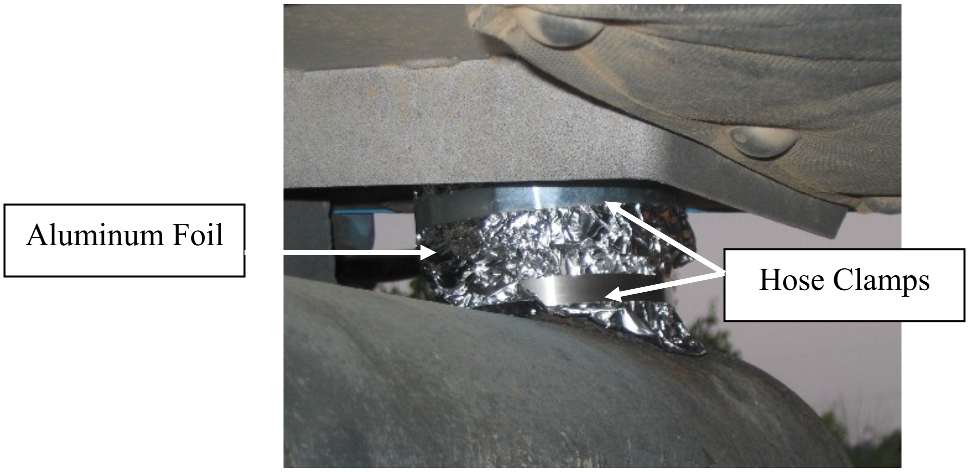


Figure C-8. Sealing a Gap Using Aluminum Foil and Hose Clamps

C.2.4 Sensor Array

A sensor array unit was connected to the main unit to provide engine data. The sensor array was composed of a manifold air boost pressure (MAP) sensor, engine speed sensor, intake air temperature sensor, and sensor unit.

C.2.4.1 *Manifold Air Boost Pressure Sensor*

In order to measure MAP, a pressure sensor was installed on the engine. There was a port on the engine after the turbocharger as shown in Figure C-9. In a regular engine performance check, this port was used for performance testing of the turbocharger. The MAP sensor installation involved replacing Bolt "A", shown in Figure C-9, with a barb fitting, shown in Figure C-10. The data collection crew installed a barb fitting and connected it to the MAP sensor. Plastic ties were used to route and secure the MAP sensor cable between the engine and the main unit. Figure C-11 shows the MAP sensor attached to a construction vehicle engine. The MAP sensor provided manifold air pressure data for the computer of the main unit through a cable that connected the sensor to the MAP port located in the back of the main unit. The MAP sensor was secured to adjacent engine parts using plastic ties as shown in Figure C-11.

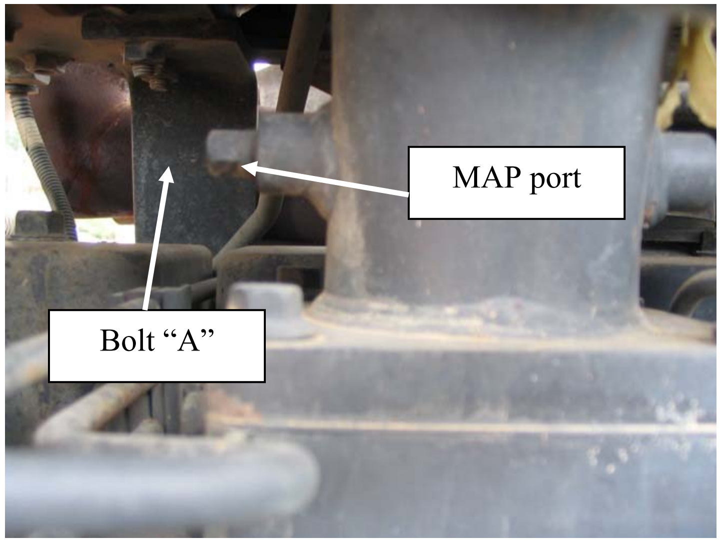


Figure C-9. Illustration of MAP Port

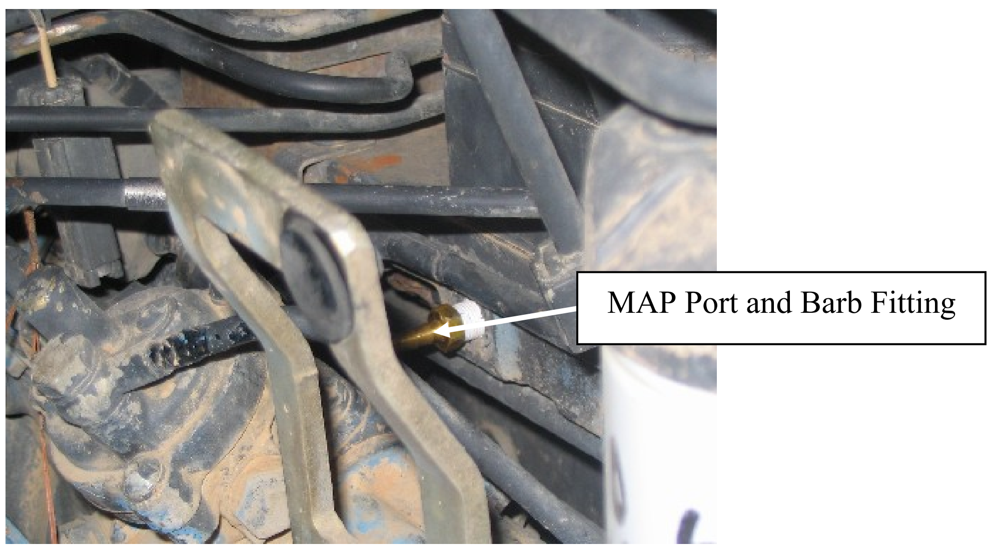


Figure C-10. Engine MAP Port with Barb Fitting Attached to Port

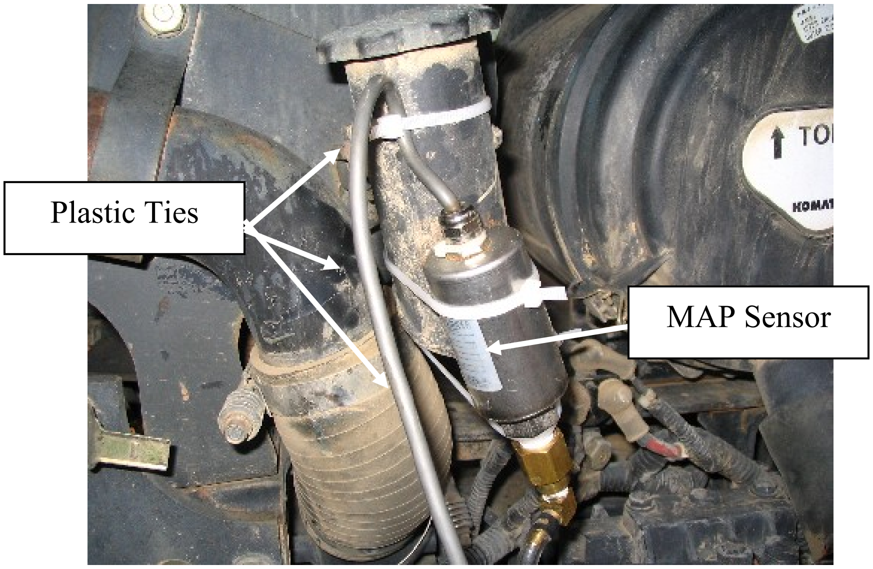


Figure C-11. MAP Sensor after Installation

C.2.4.2 *Engine Speed Sensor*

The engine speed sensor was installed at an adequate location in order to provide accurate data. The engine speed sensor had a strong magnet that enabled it to be attached easily to metal objects as shown in Figure C-12. Optical tape was installed on the pulley which is connected to the crankshaft. Thus, the location of the engine speed sensor depended on the location of the optical tape. The optical tape reflects light from the engine speed sensor. Based on this reflection, the engine speed sensor estimated engine revolutions per minute. Thus, the correct placement of the optical tape was essential to collecting engine speed data.

Figure C-13 shows the location of the optical tape on a pulley. Here are some suggestions for the placement of the engine speed sensor:

1. Place in a position with no fans or other engine related obstacles
2. Place in a position with enough space to attach the sensor tightly
3. Place in a position within reachable length of the engine speed sensor cable

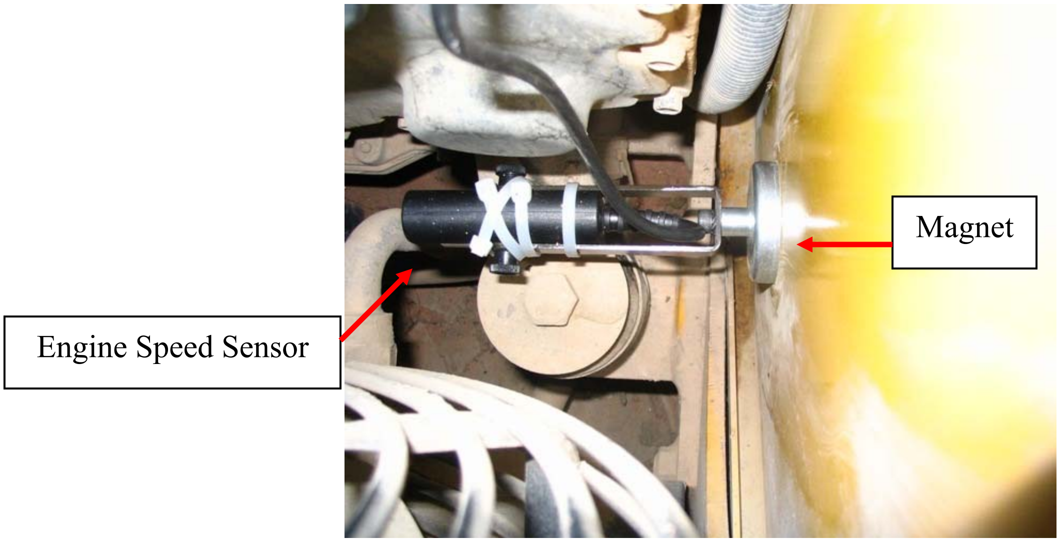


Figure C-12. Engine Speed Sensor Attached with Magnet

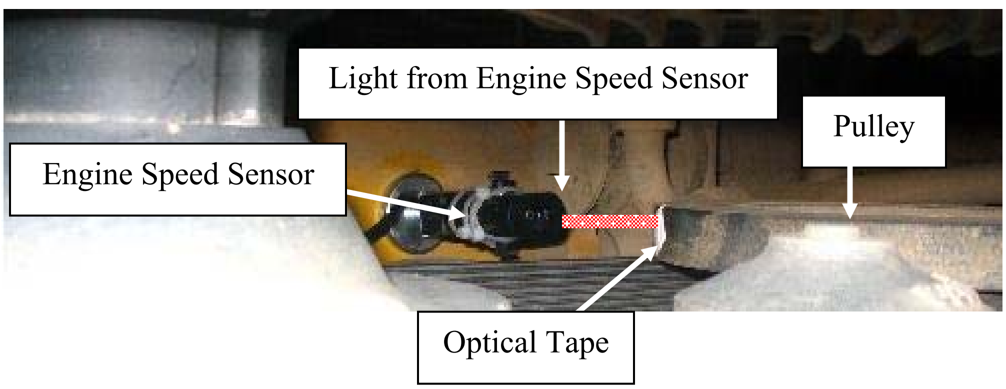


Figure C-13. Engine Speed Sensor and Optical Tape

C.2.4.3 *Intake Air Temperature Sensor*

The engine intake air sensor needed to be installed in the intake air flow path. The sensor is able to detect temperature. Installation of the intake air temperature sensor was easier to install than the engine speed and MAP sensors. Using duct tape or a plastic tie, the intake air temperature sensor was placed near the intake air flow where the MAP port is located. Figure C-14 illustrates the location of the intake air temperature sensor installed on the engine. The temperature sensor and MAP port are close to each other, as shown in Figure C-14.

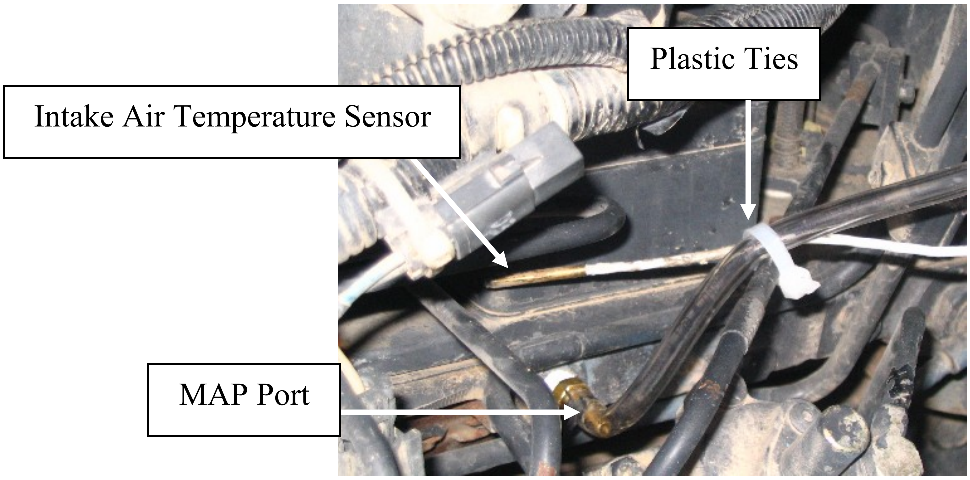


Figure C-14. Installation of Intake Air Temperature Sensor

C.2.4.4 *Sensor Unit*

The sensor unit is the device which connected the intake air temperature and engine speed sensors to the main unit. The sensor unit was protected by the box shown in Figure C-15. Plastic ties were used to secure the sensor unit to the construction vehicle. If the sensor unit could not be attached to the vehicle using plastic ties, duct tape was used to secure the sensor unit.

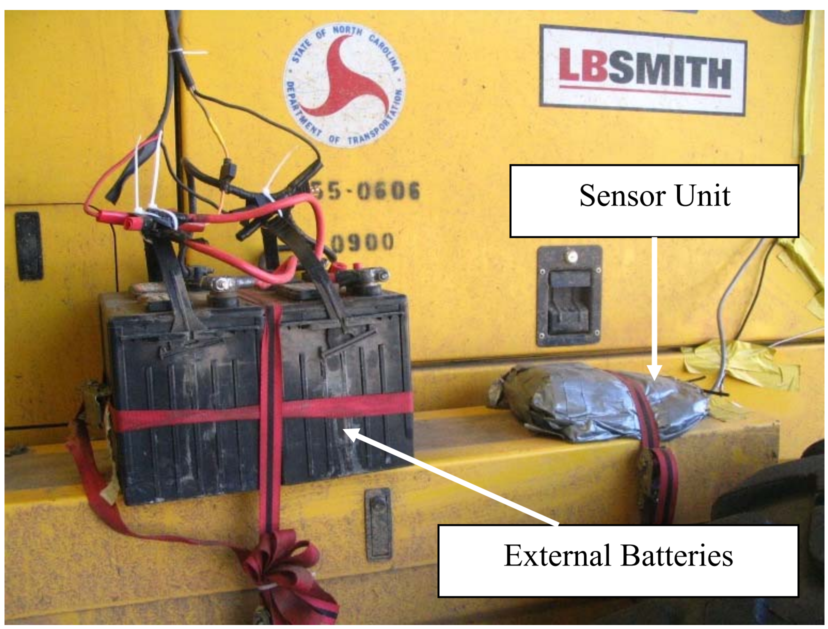


Figure C-15. Sensor Unit and External Power Source on a Motor Grader

C.2.5 External Power Source

The main unit of the Montana needs at least 12 volts and four-to-six amps of direct current electricity. Although it was possible to obtain such power from the vehicle, the use of external batteries as a power source avoided putting additional load on the engine. Each battery can operate the Montana system for four-to-five hours. Also, using external batteries avoided an unintended shutdown of the Montana system if the vehicle operator inadvertently turned off the engine.

When moving these batteries from the laboratory to the job site, it was important to tape all of the connectors using duct tape to avoid a short circuit. Also, the batteries were placed into an appropriate container to protect them from being damaged. When installed on the vehicle, the batteries were secured to the body of the vehicle using a strap as shown in Figure C-15.

C.2.6 Measurement Instrument Pre-test

After the setup of the safety cage, exhaust gas sampling hoses, sensors, and batteries, the next step was to make sure that the main unit of the Montana system obtained valid data from the engine sensors. Generally, there was no problem with the MAP and intake air temperature sensors. However, the engine speed sensor often needed to be tested several times in order to find the best way to set up the sensor and the optical tape. If the Montana could not obtain engine speed data or if the engine speed values fluctuated rapidly, it was necessary to re-install the engine speed sensor. If the Montana read engine RPM data properly after the re-installation of the engine speed sensor, the pre-installation procedure is done. Otherwise, the pre-installation testing was repeated until the Montana could read RPM data properly.

C.3 Installation

One difference between pre-installation and installation is that the installation procedure was done before the vehicle operator started working on the test day, whereas pre-installation is done the day before the test. The data collection crew arrived at the job site approximately two hours before the construction crew would begin work. When the installation was done, the Montana was ready to collect data from the construction vehicle.

C.3.1 Checklist

Some of the major components of the Montana system were pre-installed on the construction vehicle as described previously in Section C.2. On the test day, the installation procedures focused on the set-up of the main unit of the Montana system, the Geographical Positioning System (GPS), the video capture instrument (camcorder), and the laptop computer. Table C-3 shows the checklist for installation.

The Montana main unit must warm-up for 45 minutes before collecting data. The data collection crew installed other instruments while the main unit was warming up. Two people were needed to operate the camcorder and the laptop computer separately during data collection. Figure C-16 shows the timeline for installation procedures performed by two people. The installation procedures took one hour to finish. As with pre-installation, the time period for installation varied due to the ambient conditions and the height of the construction vehicle. Table C-4 shows the typical installation time period and range for a backhoe, motor grader, and front-end loader.

Table C-3. Installation Checklist Form

Installation Procedure Checklist	
Main Unit – Locate the main unit in the safety cage – Connect the engine sensors to the main unit – Warm up for forty-five minutes	☐
Geographical Positioning System – Affix the GPS receiver on the top of the construction vehicle – Connect the cable from GPS to the main unit – Secure the cable to the safety cage	☐
Camcorder – Connect the camcorder with the tripod – Slide the POWER switch to turn on the camcorder	☐
Laptop Computer – Turn on the laptop computer – Open Microsoft Excel – Run the Visual Basic Macro	☐
Synchronize – Synchronize the time of the main unit, camcorder, and laptop computer	☐

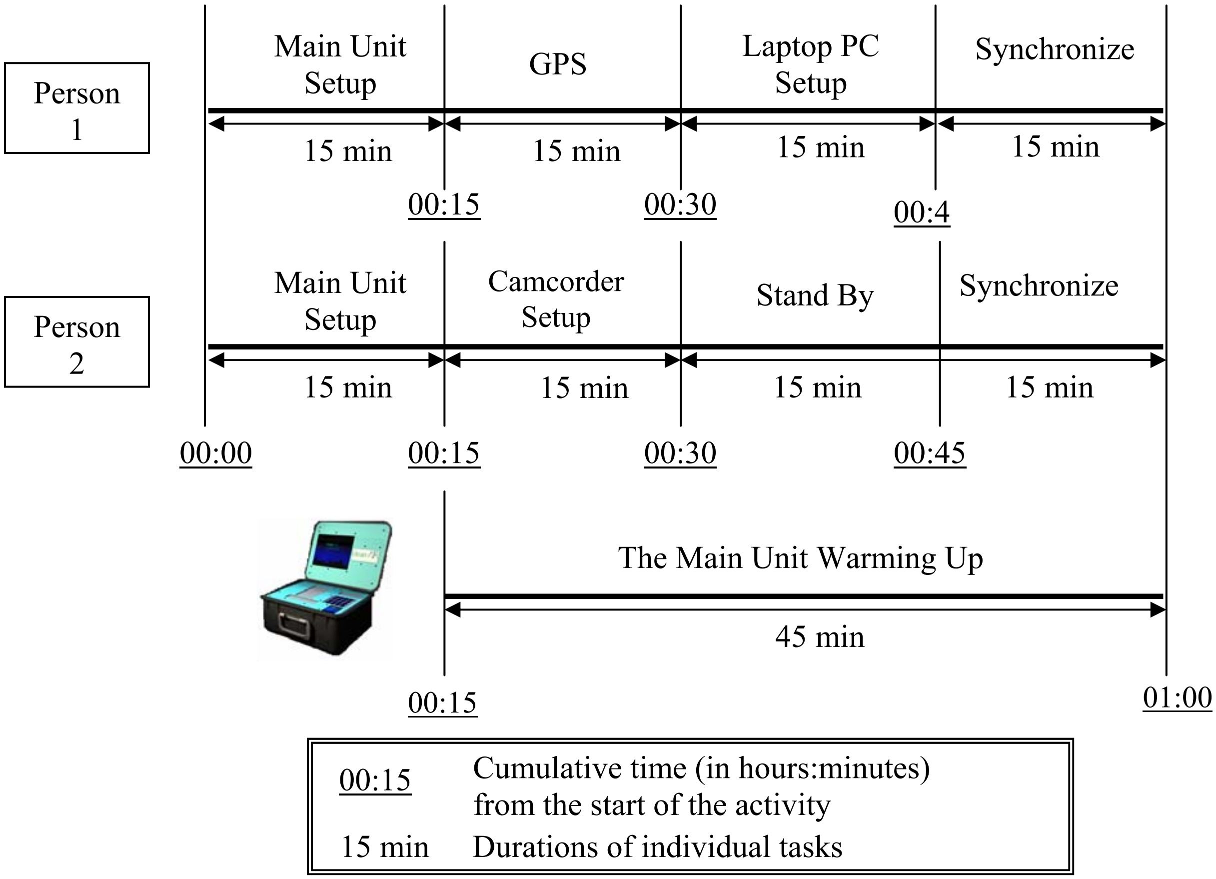


Figure C-16. Timeline for Installation Procedures Performed by Two People

Table C-4. Typical Time Period and Range for Installation

Vehicle Type	Installation Time Period	
	Typical	Range
Backhoe	1 hr 00 min	1 hr 00 min to 1 hr 50 min
Motor Grader	1 hr 00 min	1 hr 00 min to 1 hr 50 min
Front-End Loader	1 hr 00 min	1 hr 00 min to 1 hr 50 min

C.3.2 Main Unit

When the data collection crew arrived at the construction site on the day of the test, the first step was to install the main unit of the Montana system. Flexible rubber pads and foam rubber were placed underneath the main unit of the Montana system in order to reduce vibration from the construction vehicle as shown in Figure C-2. The main unit was secured within the safety cage using plastic ties. After the installation was done, the main unit would be warmed-up for 45 minutes. During this period, the data collection crew set up the GPS, the camcorder, and the laptop computer.

C.3.3 Geographical Positioning System

The Geographical Positioning System (GPS) is a device used to determine the construction vehicle's position by triangulating distances from satellites. This device has strong magnetic tape under the receiver to hold it in place. Thus, the receiver can be affixed to a steel surface on the vehicle. The recommended location of the GPS receiver is on the roof of the vehicle so that it has the best signal from satellites. Figure C-17 shows a picture of the GPS receiver of the Montana system.

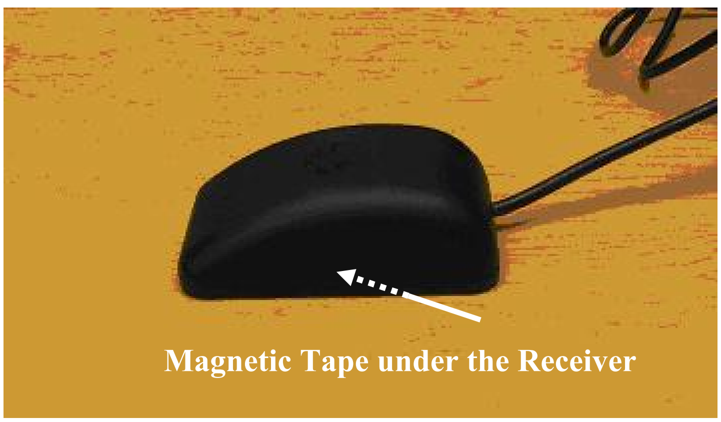


Figure C-17. Trimble GPS Receiver

C.3.4 Camcorder

A camcorder with a tripod was used to record the activity pattern of the construction vehicle. The camcorder was installed in a safe place that was not too close to the work zone. A member of the data collection crew operates the camcorder and made a video recording of the work activities. For example, as a motor grader moved around a large area, the data collection crew followed the motor grader and recorded the work activities. For other construction vehicles, such as backhoes and front-end loaders, the data collection crew could often stay in one place and record the video without moving the camcorder setup.

C.3.5 Laptop Computer

A laptop computer with Microsoft Excel was used to record data regarding the modal activity of the vehicle. A Visual Basic program was prepared for recording modal activity. The program runs during data collection. A member of the data collection crew records modal activity using the keyboard. The laptop computer can be used for three hours. Its use was limited by battery capacity. It was recommended that the laptop computer be charged every two hours. The data collection crew used the cigarette lighter in a passenger vehicle to provide the power for the laptop computer. Thus, data collection was not interrupted when the laptop computer is recharging.

C.3.6 Synchronizing the Main Unit, Camcorder, and Laptop Computer

The data collection crew synchronized the time of the camcorder and the laptop computer based on the main unit of the Montana system. Data analysis was based on second-by-second data. Therefore, if the time shown on the main unit, laptop computer, and camcorder were different, it would be a problem for data analysis. Thus, it was important to synchronize these instruments before data collection began.

C.4 Data Collection

On the day that data was to be collected, the researchers typically arrived at the construction site approximately two hours before data collection was to begin in order to prepare the instruments. When installation was completed and the Montana had warmed-up for 45 minutes, the Montana could be used to collect data from the construction vehicle. During data collection, the camcorder would make a video recording of the construction vehicle and the laptop computer was used to record the modal activity. This section describes the field procedures during data collection.

C.4.1 Checklist

After the main unit was warmed-up for 45 minutes, it was ready for collecting data. One person used the camcorder to record the work pattern of the construction vehicle. A second person recorded modal activities using the laptop computer. The checklist for data collection is shown in Table C-5. Figure C-18 shows the timeline of the data collection procedures.

Table C-5. Data Collection Checklist Form

Data Collection Checklist	
Montana System Measurement – Start a new file for data collection	☐
Camcorder – Make a video recording of the construction vehicle	☐
Laptop Computer – Record modal activities of the construction vehicle	☐
Periodic Checking of Montana System – Check the screen of the main unit – Perform corrective action as needed	☐

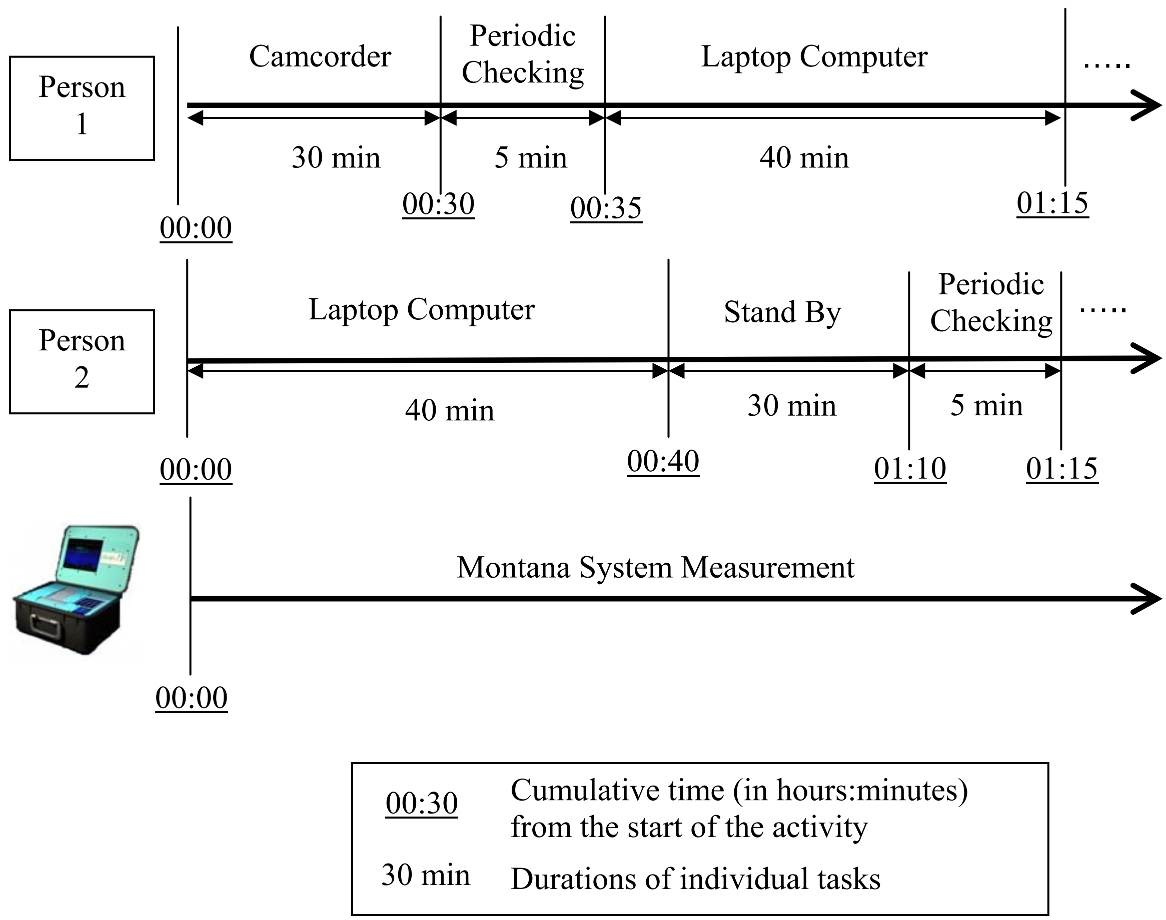


Figure C-18. Timeline for Data Collection Procedures

C.4.2 Main Unit

During the data collection process, the main unit of the Montana was checked frequently to ensure that it was functioning properly. These checks were performed at approximately 30 minute intervals and took approximately 10 minutes to complete. If a problem was detected with the Montana, it was corrected immediately. The following items were typically checked:

1. Engine RPM - The engine RPM should be consistent and uniformly level while the construction vehicle is idling. If the engine RPM fluctuates rapidly, then the RPM sensor may not be working properly.
2. Oxygen Level - The oxygen level of the exhaust gas should be approximately 17% - 18.5%. If the oxygen level is higher than 18.5%, then there may be air leakage within the Montana system.
3. Difference Between Two Benches - The concentrations of NO_x, HC, CO, CO_2, and PM should have small differences. If the difference is large, there may be a problem.
4. Time - At unpredictable times, the Montana system may malfunction and stop recording data. When this happens, the timer shown on the screen will not change. Therefore, the timer must be regularly checked to ensure that data is still being collected.

When the data collection process had been completed, the research team removed the Montana system from the construction vehicle. This decommissioning process typically would take approximately 30 minutes to complete. All equipment was returned to the laboratory to be cleaned. The decommissioning process is described in detail in Section C.5 of this appendix.

C.4.3 Video Camera

A video camera (camcorder) was used to record the activity pattern of the construction vehicle at the construction site. The video camera was set up in a location that enabled it to observe all activities of the construction vehicle, but without interfering with the work of the construction vehicle. The video records the following:

- The typical activity mode of operation
- The type of work being done at the site
- The project site characteristics, including terrain and weather

The video can be used to some extent to verify activity modes seen in the data. Figure C-19 shows a member of the research team using the video camera to record the work activities of a construction vehicle.

Figure C-19. Recording Work Activities Using the Camcorder

Enough video data was obtained to document the typical work activities and activity modes of the construction vehicle. This could usually be done with approximately 15 to 30 minutes of video. It was not necessary to record everything that the construction vehicle did, but only those activities that represented the typical activity modes for which data was collected. In addition, a general panoramic view of the job site was recorded to show the working conditions of the construction vehicle. Essentially, the video enabled the data collection team to gather another form of data (visual) regarding the site, the vehicle, and the work done by the vehicle. It is anticipated that this might be a useful future resource.

After the video had been recorded, the video camera was turned off and stored in a safe location on the job site until the data collection team returned to the laboratory. The video data was archived on both a digital video disc (DVD) and another computer for future use.

C.4.4 Laptop Computer

The data obtained from the Montana system was linked to a Visual Basic program in Microsoft Excel through the use of a laptop computer. After the Montana had been installed, the laptop computer was prepared for use. The laptop computer was set up in a location from which it was possible to view the activities of the construction vehicle being monitored. The laptop computer ran a Visual Basic program in preparation of receiving the data from the Montana system. When finished, the laptop computer was ready to record modal activity of the construction vehicle.

The purpose of observing activity modes is to determine if there are varying level of emissions based on what the vehicle is doing. The activity modes are based on the timeline of work activity for the vehicle rather than the overall functionality of the equipment. The time setting of the laptop computer was synchronized with the time setting of the Montana system to provide a second-by-second analysis of the emissions by activity mode of operation.

After the laptop computer had been set up, it was ready to record modal activity of the construction vehicle. This was accomplished by using a numeric keypad connected to the laptop computer. Each activity mode of the construction vehicle had a keypad number. For example, the activity modes and their corresponding number for a front-end loader were as follows:

1. Idling
2. Moving
3. Scoop/Dump

Each time the front-end loader began one of these activity modes, the corresponding number was pressed on the numeric keypad. When the front-end loader began to idle, the 1 key was pressed on the keypad; when the front-end loader began to move, the 2 key was pressed on the keypad. Since the time was recorded for each keystroke, this provided the duration of each recorded activity mode. Both the Montana emission data collector and the laptop modal data collector were synchronized to the current time and recorded data on a second-by-second basis. Furthermore, the data from the Montana system was linked and synchronized with the Microsoft Excel spreadsheet to provide a detailed timeline of emissions activity for the construction vehicle emissions data collection. In order to resolve unpredictable problems that occurred during data collection, the data collection crew checked the PEMS periodically, as shown in Figure C-20.

When a data collection session had ended, the data was saved and the laptop computer was turned off. The data was backed up on a compact disc (CD), as well as another computer. Both the emissions data and modal data was later reviewed and screened for quality assurance by the researchers. If there were no errors found in the emissions data, then the emissions data was acceptable for use in emissions analysis. If there were significant errors found within the emissions data, then the emissions data was unusable and must be collected again. A detailed discussion of data quality was presented in Section 2.4 of the report.

Figure C-20. Periodic Checking of Montana System

C.5 Decommissioning

When data collection activity was finished, each instrument and sensor was removed or disconnected from the construction vehicle. It typically took 30 minutes to finish the decommissioning. All instrumentation was brought to the laboratory for cleanup after decommissioning.

C.5.1 Checklist

The decommissioning procedures coul be completed by either one or two persons. Table C-8 shows the checklist of decommissioning procedures. The timeline for decommissioning by one person is shown in Figure C-21. Figure C-22 depicts the timeline for two persons. Overall, it took one person about one hour and ten minutes to complete decommissioning and it takes 2 people about 35 minutes.

Table C-4. Decommissioning Checklist Form

Decommissioning Checklist	
Main Unit – Disconnect the sampling hoses in the back of the main unit – Disconnect the sampling bowl – Disconnect the cables – Disconnect the GPS – Disconnect the keyboard – Bring the main unit to the laboratory	☐
Safety Cage – Dismantle the safety cage – Bring the safety cage to the laboratory	☐
Exhaust Gases Sampling Hoses – Disconnect the exhaust gases sampling hoses from the tailpipe – Put the exhaust gases sampling hoses into a plastic bag – Bring the sampling hoses to the laboratory	☐
Sensor Unit – Disconnect the cable from sensor unit to the engine sensors – Put the sensor unit into the box – Bring the sensor unit to the laboratory	☐
MAP Sensor – Disconnect the MAP sensor – Put the MAP sensor into the box – Bring the MAP sensor to the laboratory	☐

(Continued on the next page)

Table C-4. Continued

Engine Speed Sensor – Disconnect the engine speed sensor – Put the engine speed sensor into the box – Bring the engine speed sensor to the laboratory	☐
Intake Air Temperature Sensor – Disconnect the intake air temperature sensor – Put the intake air temperature sensor into the box – Bring the intake air temperature sensor to the laboratory	☐
External Power Sources – Disconnect external power sources – Tape all the connector using duct tape – Place the battery into a container – Bring the battery to the laboratory	☐
Geographical Positioning System – Disconnect geographical positioning system – Bring the GPS to the laboratory	☐
Video – Turn off the camcorder – Put the camcorder into the bag – Bring the camcorder to the laboratory	☐
Laptop Computer – Save the Excel file – Turn off the laptop computer – Put the laptop computer into the bag – Bring the laptop computer to the laboratory	☐
Wrap Up – Pick up tools and put into the toolbox	☐

(End of Table C-4)

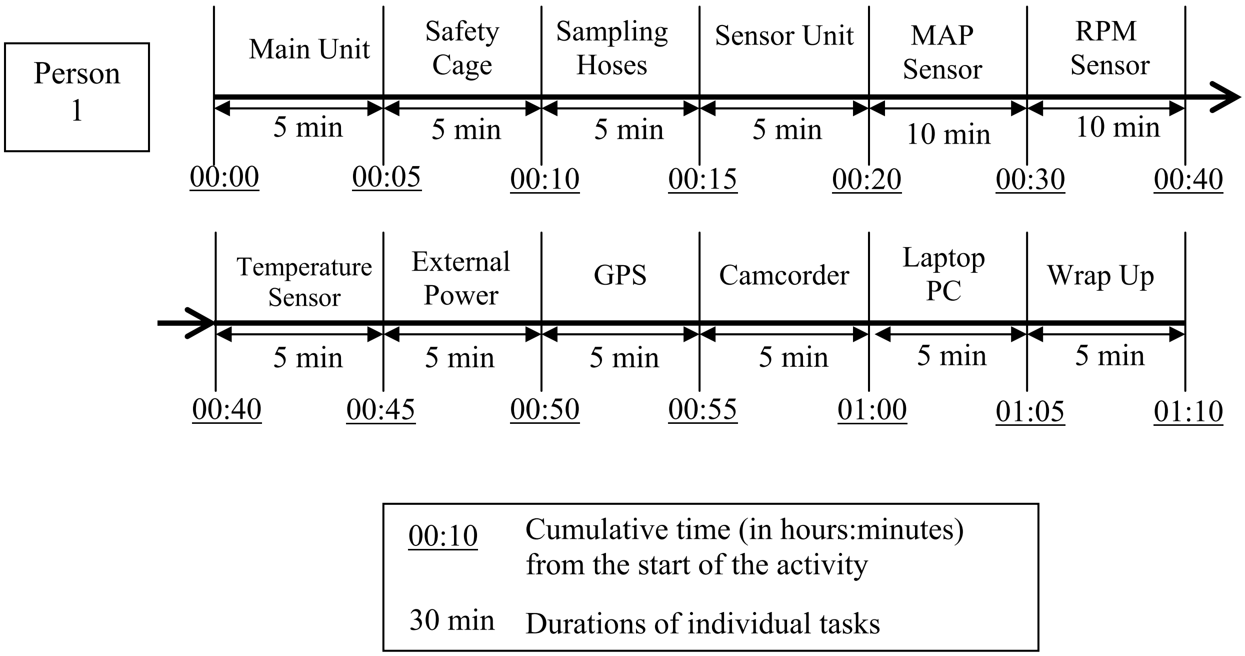


Figure C-21. Timeline for Decommissioning Performed by One Person

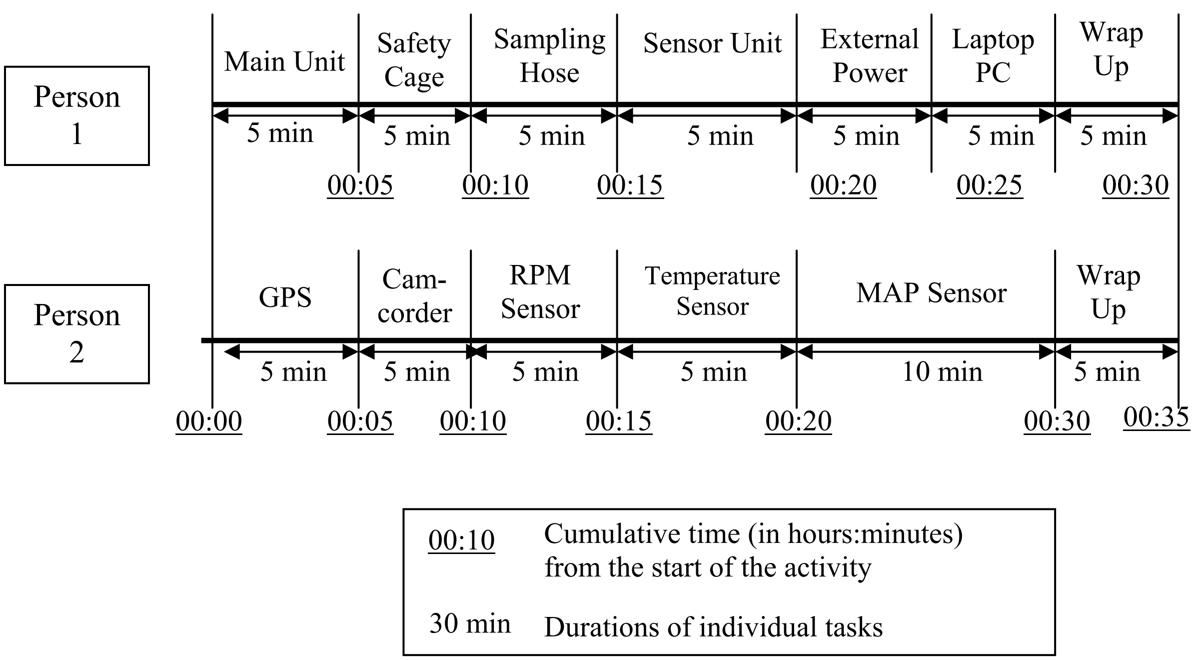


Figure C-22. Timeline for Decommissioning Performed by Two Persons

C.5.2 Main Unit

The decommissioning of the main unit included removing the safety cage and the main unit of the Montana system from the construction vehicle. First, the cables and the sampling hoses were disconnected from the main unit. The main unit was usually installed on the roof of cab. The unit was taken out of the safety cage and lowered to the ground. This was done by one person climbing to the roof and transferring the main unit to the other person.

C.5.3 Exhaust Gases Sampling Hoses

The decommissioning of sampling hoses was not difficult and took approximately five minutes to finish. The plastic ties were removed first. The sampling probes were disconnected from the tailpipe. The sampling probes were very dirty after a full day of testing. Thus, the sampling hoses were stored in a plastic bag for their return to the laboratory.

C.5.4 Engine Sensors

The decommissioning of engine sensors included disconnection of the sensor unit, the MAP sensor, the intake air temperature sensor, and the engine speed sensor. Even after the engine of a construction vehicle had been shut off, the engine temperature can still be very high. For safety purposes, the data collection crew usually started decommissioning the sensors no sooner than ten minutes after the engine stops. Even then extreme care must be taken to prevent injuries.

C.5.5 External Power Source, Geographical Positioning System, Camcorder, and Laptop Computer

The decommissioning of the batteries, the GPS, the camcorder, and the laptop computer was the last step. The connectors of the batteries were covered with duct tape. Then the battery was placed into an appropriate container to protect the battery from being damaged. After the GPS was disconnected from the main unit, it was put into the storage box. The camcorder was turned off before decommissioning. The camcorder and tripod were returned to the laboratory. Prior to decommissioning the laptop computer, the Excel file of modal activities was saved. The laptop computer was turned off and returned to the laboratory. It was important to make sure that all instruments were returned to the laboratory.

C.6 Cleanup after Data Collection

Each part of the main unit was cleaned: outside the box, the gas analyzer, and the computer. Cleanup procedures for other instruments are also identified in this section. The checklist for cleanup procedure is shown in Table C-9.

Table C-5. Cleanup Checklist Form

Cleanup Checklist	
Main Unit – Clean up outside the box – Clean up the gas analyzers – Clean up the computer	☐
Safety Cage – Remove dust from the safety cage – Clean up the rubber pads	☐
Exhaust Gases Sampling Hoses – Remove dust from the hoses – Clean up the sampling probe – Clean up the sampling gas and PM bowl – Replace the filter for the gas sampling bowl as needed	☐
Engine Sensors – Remove dust from the MAP sensor – Remove dust from the engine speed sensor – Remove dust from the intake air temperature sensor – Remove dust from the sensor unit	☐
External Power Source – Remove dust from the batteries – Recharge the batteries	☐
Geographical Positioning System – Remove dust from the GPS	☐

(Continued on next page)

Table C-5. Continued

Camcorder – Remove dust from the camcorder – Remove dust from the tripod – Download the video file	☐
Laptop Computer – Remove dust from the laptop computer – Remove dust from the keyboard – Download the Excel file of modal activities	☐

(End of Table C-5)

C.6.1 Main Unit

The section explains the sequential steps that were necessary and critical for cleaning the Montana after data collection. These procedures were initiated after every field data collection operation was completed. Figure C-23 shows the Montana system and identifies the different sections addressed in this cleaning procedure.

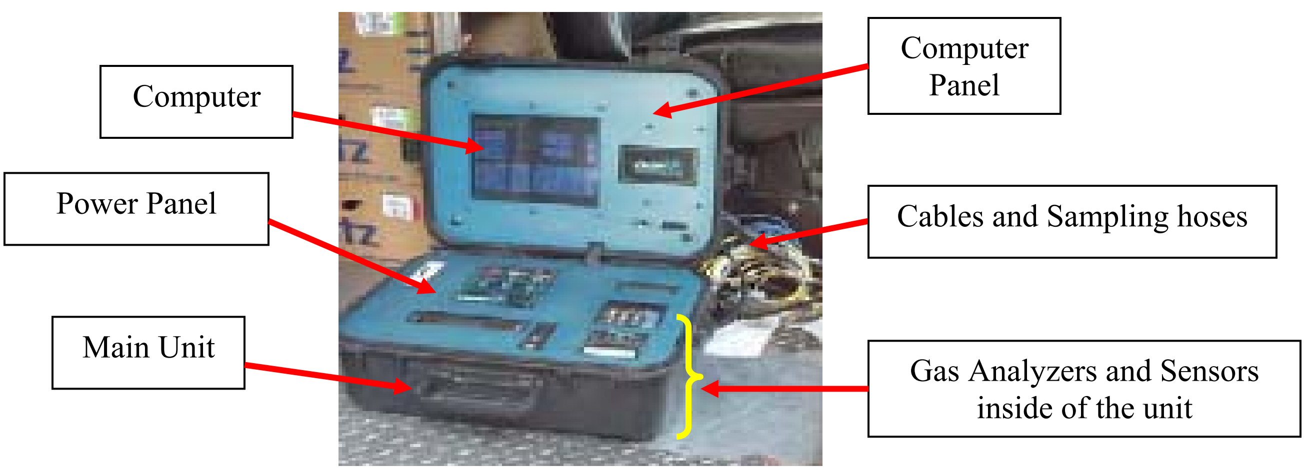


Figure C-23. Parts of the Montana Addressed in the Cleaning Procedure

C.6.2 Outside the Box

The procedures for cleaning the box are listed below:

1. Close the top panel of the main unit.
2. Ensure that all ports located on the back panel of the main unit are unplugged and that all caps are closed.
3. Use a dust remover to clean the outside of case.

4. Leave the main unit open for three-to-five minutes to allow air circulation to dry any accumulated moisture.
5. Open the top panel of the main unit.
6. Clean the power panel and computer panel using a dust remover.
7. Leave the main unit open for three-to-five minutes to allow air circulation to dry any accumulated moisture.

C.6.1.1 *Gas Analyzers*

The procedures for cleaning the gas analyzers are listed below:

1. Open the power panel to check the inside of the main unit.
2. Find the location of the gas analyzers and sensors and check their status.
3. Tilt the main unit about 30 to 45 degrees to the opposite side of where the electronic boards are located.
4. Use a compressed clean air spray to remove dust.
5. Check the gas sampling hoses to see if dust has collected inside of them and to determine if they need to be replaced.
6. Check the PM and gas filters to see if they need to be replaced (changing color from yellow to black is a good indicator of time for the replacement).
7. Check for loose screws and connections before move to the next cleaning stage.
8. Close the power panel after finishing steps 1 through 7.

C.6.1.2 *Computer*

The procedures for cleaning the computer are listed below:

1. Put a soft cover on the power panel to avoid damage of computer monitor.
2. Clean dust on the computer panel using dust remover.
3. Open the computer panel slowly not to damage the electronic connections.
4. Use the compressed clean air spray to remove dust from board.
5. Check for loose screws and connections before moving to the next cleaning stage.
6. Close the computer panel after finishing steps 1 through 5.

C.6.3 Safety Cage

The procedures for cleaning the safety cage are listed below:

1. Remove dust from the safety cage.
2. Clean the rubber pads.

C.6.4 Exhaust Gases Sampling Hoses

The procedures for cleaning the sampling hoses are listed below:

1. Remove dust from the cables and sampling hoses.
2. Clean the sampling gas and PM bowl.
3. Replace the filter for the gas sampling bowl if necessary.

C.6.5 Engine Sensors

The procedures for cleaning the engine sensors are listed below:

1. Remove dust from the intake air temperature, the manifold air pressure, and engine speed sensors.
2. Keep the sensor connectors away from the chemical cleaner due to potential damage.

C.6.6 External Power Source

The procedures for cleaning the engine sensors are listed below:

1. Remove dust from the batteries.
2. Store the batteries safely and well-organized.
3. Recharge the batteries after cleanup.

C.6.7 Geographical Positioning System

The procedures for cleaning the GPS are listed below:

1. Remove dust from the GPS.
2. Store the geographical positioning system in the box.

C.6.8 Camcorder

The procedures for cleaning the camcorder are listed below:

1. Remove dust from camcorder.
2. Remove dust from the tripod.
3. Download the video file.

C.6.9 Laptop Computer

The procedures for cleaning the laptop computer are listed below:

1. Remove dust from the laptop computer.
2. Remove dust from the keyboard.
3. Download the file of modal activity from laptop computer.

C.7 References

North Carolina State University (2005). “Data Quality Assurance of Nonroad Construction Vehicle”; Department of Civil, Construction, and Environmental Engineering; pp. 19-24

APPENDIX D: DATA SCREENING AND QUALITY ASSURANCE

Table of Contents

D.1 Introduction

Data screening and quality assurance are procedures for reviewing data collected in the field, determining whether any errors or problems exist in the data, correcting such errors or problems where possible, and removing invalid data if errors or problems cannot be corrected. The goal of data screening and quality assurance is to produce a database that contains valid data. In this report, NO is reported as equivalent NO_2.

From previous work, a number of possible errors and problems have been identified (Frey *et al.*, 2001; 2005). In the previous work, engine data were collected via the electronic data link of the vehicle, such as the on-board diagnostic link of light duty gasoline vehicles and the engine control module link of heavy duty vehicles. However, in the current study, engine data are obtained using a sensor array. Thus, the data screening and quality assurance procedures required modification for this work to account for problems and errors that can occur in conjunction with the sensor array. One possible concern is the synchronization of the data streams from the sensor array and the gas analyzers. The others are the communication between sensor array and computer.

In addition to development of data screening and quality assurance procedures, a technique for evaluation of the data obtained from diesel engines was developed that involves comparison of the observed air-to-fuel ratio from the data with general expectations for the variability in air-to-fuel ratio for diesel engine as reported by others. This comparison can provide insight regarding whether air leakage might be a problem in the sampling line or gas analyzer of the Montana system. In the following sections, problems and errors associated with the synchronization, the sensor array, and the gas analyzer are identified and procedures for dealing with them are detailed. Another topic deals with comparison of the observed versus expected air-to-fuel ratios. Figure D1 shows the overview of the data quality assurance programs.

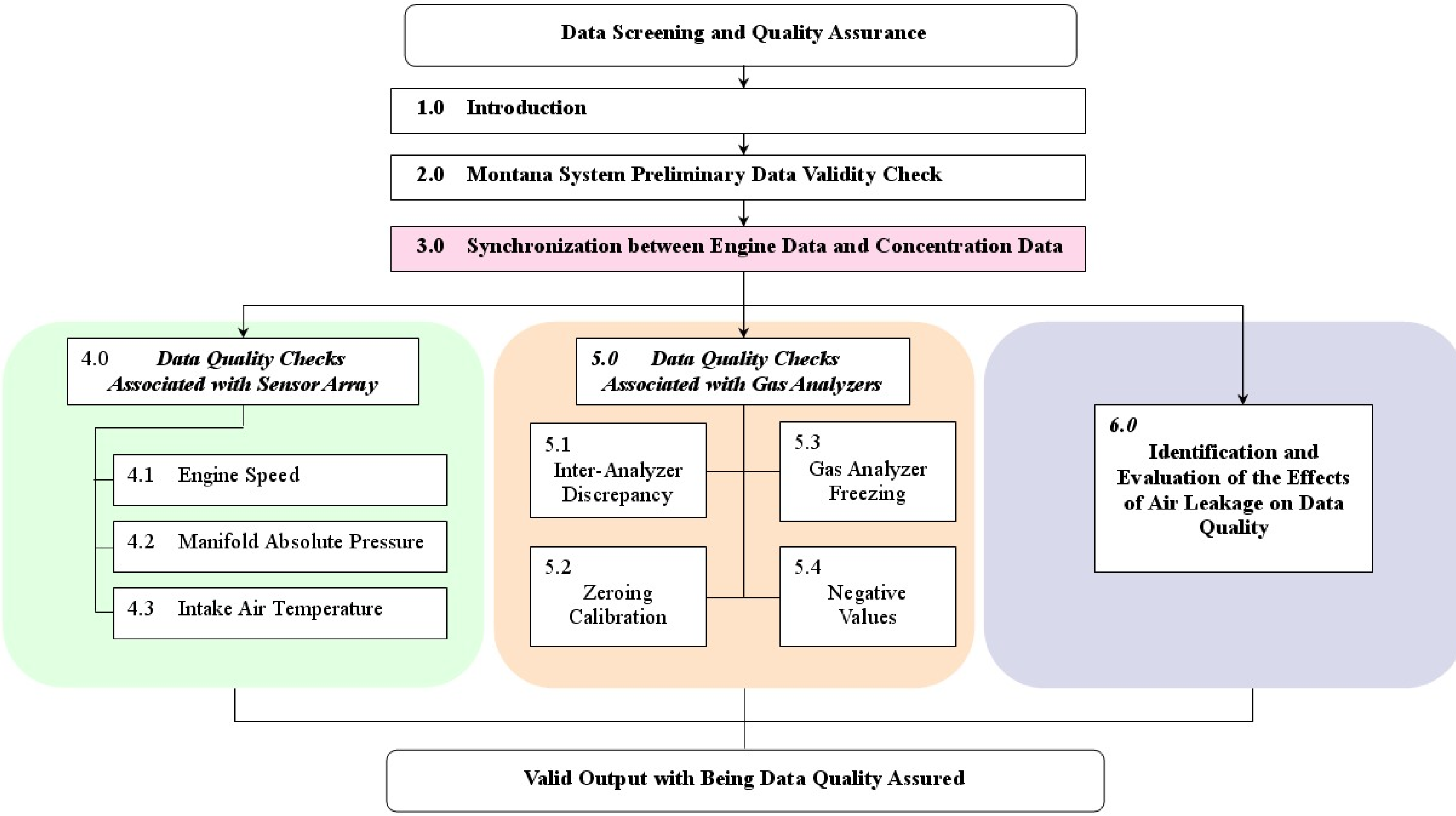


Figure D1. Overview Flow Diagram of Data Quality Assurance Procedures

D.2 Montana System, Preliminary Data Validity Check

The Montana system performs a preliminary data validity check and reports indications of data quality problems in some situations. The purpose of this section is to describe how to deal with data that are flagged as invalid by the Montana system.

The Montana system detects exhaust concentration in units of parts per million (ppm) or volume percent (vol-%). In order to convert exhaust concentrations to mass emission rates (g/sec), engine data (engine speed, intake air temperature, and manifold absolute pressure) are needed. A reported value of "YES" means that the emission rate can be converted to a gram-per-second basis. On the other hand, a reported value of "NO" means that the emission rate can not be converted to a gram-per-second basis.

The reasons for not being able to make the conversion are numerous. The engine may not be running or the engine sensors may not be connected to the Montana system. In this case, the engine data are zero and there is no emission data that can be detected by the Montana system. If the communication between the sensor array and the main unit of the Montana system is lost, the Montana system will flag the MAP data indicator as "-34." During the first few seconds of testing when the Montana system is initially turned on, both gas analyzers are zeroing. Thus, there is no exhaust emission that is detected by the Montana system. All of the indicators used by the Montana system are shown in Table D1.

Table D1. Indicators Flagged by the Montana System

<table>
<tr><th colspan="2">Category of Data</th><th>Indicator</th><th>Description</th></tr>
<tr><td rowspan="2">Engine Data</td><td>Engine Speed, IAT[a],MAP[b]</td><td>Zero</td><td>The engine is off or engine sensors are not connected to the Montana system.</td></tr>
<tr><td>MAP[b]</td><td>-34</td><td>Manifold absolute pressure is missing.</td></tr>
<tr><td colspan="2">Gas Analyzer Data</td><td>Zero</td><td>Both gas analyzers are zeroing. There is no pollutant concentration detected by the Montana system.</td></tr>
<tr><td colspan="2" rowspan="2">Emission Data</td><td>YES</td><td>The reported emission rate is potentially valid.</td></tr>
<tr><td>NO</td><td>The emission rate is not reported because of one or more data validity problems.</td></tr>
</table>

[a] IAT = intake air temperature
[b] MAP = manifold absolute pressure

In order to show all of the possible data validity problems, Table D2 presents four examples where the Montana system flagged data as valid or invalid. For Case 1, both the engine and emissions data are detected by the Montana system, thus emission rates can be converted to a gram-per-second basis. Thus, Case 1 is valid and the data are flagged as "YES."

For Case 2, the engine data are detected by the Montana system, but emission data are zero. This can happen during the first few seconds of testing when the Montana system is initially turned on. At this time, both gas analyzers are zeroing and there are no exhaust emissions that are detected by the Montana system. Therefore, the emission rates cannot be converted to a gram-per-second basis. Case 2 is invalid and is flagged as "NO." The seconds of data for this case will be excluded.

For Case 3, the exhaust emissions are detected by the Montana system, but the engine data are unavailable. This can happen when the engine is turned off or when the engine sensors are not connected to the Montana system. As a result, the emission rates cannot be correctly converted to a gram-per-second basis. Thus, Case 3 is also invalid and is flagged as "NO." The data for this case will be excluded.

For Case 4, the exhaust emissions, engine speed, and intake air temperature are detected and recorded by the Montana system. However, manifold absolute pressure is missing due to various reasons such as vibration. The reported value of "-34" is an indicator that MAP data is missing. In some cases, the missing MAP data can be estimated based on Section D.4.2. For these cases, after estimating the missing MAP, the emission rate can be converted to a gram-per-second basis. Thus, in some cases, an emission rate can be estimated even if MAP data are partially missing. If this is done, the data for this case will be kept in the screening dataset.

Table D2. Examples of Data Flagged as Valid and Invalid

Category of Data	Case			
	1	2	3	4
Valid Data	YES[c]	NO[d]	NO[d]	NO[d]
Engine Speed (RPM)	799	798	**0**	797
IAT[a] (°C)	30	25	**0**	25
MAP[b] (kPa)	100	100	**0**	**-34**
NO_x (ppm)	383	**0**	385	384
HC (ppm)	27	**0**	31	31
CO (vol-%)	0.016	**0**	0.016	0.016
CO_2 (vol-%)	1.93	**0**	1.95	1.95
O_2 (vol-%)	18	**0**	18	18

[a] IAT = intake air temperature
[b] MAP = manifold absolute pressure
[c] YES = emission rate can be converted to a gram-per-second basis
[d] NO = emission rate can NOT be converted to a gram-per-second basis
[e] "-34" = indication that MAP is missing

In summary, when one dataset is running the data validity check, Case 2 and Case 3 are two situations in which the data will be excluded from the dataset. Case 1 is the situation that the data will be retained in the dataset. If the missing MAP can be estimated in Case 4, the seconds of data can be still retained in the dataset. Otherwise, the seconds of data will be excluded from the dataset.

D.3 Synchronization of Engine and Emissions Data

A possible concern with on-board emission measurements from construction vehicles is the synchronization of the data streams from the engine sensor array and the gas analyzers. The objective of this section is to present a procedure for identifying and correcting synchronization problems.

It takes time to sample and analyze exhaust gas concentrations. The typical time for exhaust gas samples to be drawn from the exhaust system and analyzed by the analyzers is estimated to be 12 seconds based on the default value assumed by CATI, Inc. for the Montana system. The delay time is the sum of three time periods. The first applies to the exhaust gas travel time from the engine to the end of the tailpipe where samples are drawn from the exhaust system. The second applies to the travel time from the inlet of the sampling hose to the analyzers, inside the main unit of the Montana system. The third part of delay time applies to the time taken by the analyzers to analyze exhaust gas samples. The total delay time is:

$$T_{DL} = T_{EX} + T_{SH} + T_{SR} \tag{1}$$

where,

- T_{DL} = The Montana system's default total delay time value which is 12 seconds.
- T_{EX} = Travel time in the exhaust system which is typically 1-2 seconds as estimated in Section D.3.2.
- T_{SH} = Travel time in the sampling hoses which is typically 2 seconds. The procedure of estimating T_{SH} is given below.
- T_{SR} = Pollutants measurement time by the sensors which is typically 8 seconds and is estimated from subtraction of T_{SH} and T_{EX} from T_{DL}.

The T_{SH} is estimated 2 seconds based on the length, cross area, and volumetric flow rate of exhaust gas sample in the sampling hose as follows:

$$T_{SH} = \frac{L_{SH} \times A_{SH}}{Q_{SH}} \tag{2}$$

where,

- L_{SH} = the length of sample hose, which is 6.1 m, as given in the Montana system's manual.
- A_{SH} = the cross sectional area of the sample hoes, which is 4.6×10^{-5} m^2 measured by NCSU.
- Q_{SH} = volumetric flow rate of the exhaust gas flow in the sampling hose which corresponds to the sampling flow of the pumps of 1.4×10^{-4} m^3/sec, given in the Montana system's manual.

For any emission test using the Montana system, T_{SH} and T_{SR} are constant because there is no change in sampling hose length and samples are drawn from the exhaust system at a constant rate and analyzed in the same amount of time. However, T_{EX} may vary depending on the exhaust flow rate and size of the tailpipe, including its length and diameter. Since onroad vehicles and nonroad construction equipment have different exhaust flow and the tailpipe length and diameters, there is a possibility that T_{EX} and, therefore, synchronization of engine and concentration data, might be different for nonroad equipment compared to onroad vehicles.

D.3.1 Variability of T_{EX} for Nonroad and Onroad Vehicles

The objective of this section is to estimate T_{EX} for onroad and nonroad vehicles to show whether modification of T_{DL}, shown in Equation 1, is necessary when testing nonroad vehicles. Using the ideal gas law, the relationship between the exhaust flow parameters is described as:

$$P_e V_e = n_e R T_e \tag{3}$$

where,

P_e = Pressure in exhaust flow (atm)
V_e = Volume of exhaust flow (m^3)
n_e = Number of moles of exhaust flow (mole)
R = Universal gas constant (0.082058×10^{-3} m^3-atm/mol-K)
T_e = Exhaust temperature (K)

To calculate the gas volume and the number of moles per unit time (i.e. volumetric and molar flow rate), both sides of Equation 3 are divided by T_{EX}:

$$P_e \left(\frac{V_e}{T_{EX}} \right) = \left(\frac{n_e}{T_{EX}} \right) R T_e \tag{4}$$

Assuming a cylindrical shape for the tailpipe of nonroad construction equipment with a length of “L” and a diameter of “D,” the volume of the tailpipe is calculated:

$$V_e = \frac{\pi D^2 L}{4} \tag{5}$$

The molar flow rate of exhaust gas is:

$$M_e = \frac{n_e}{T_{EX}} \tag{6}$$

The analytical procedure for calculating M_e is given in Section D.6.1. From Equations 4, 5, and 6 we have:

$$T_{EX} = \frac{\pi D^2 L P_e}{4 R T_e M_e} \tag{7}$$

P_e is assumed to be 1 atm. For the purpose of estimating variability of T_{EX} for nonroad equipment, a Monte Carlo simulation approach was applied to Equation 7 assuming distributions for the equation inputs as shown in Table D3. Monte Carlo simulation is a method of generating random values from a known distribution for the purposes of numerical experimentation. This is accomplished by generating pseudo random numbers for the input variables of Equation 7 and estimating possible outcomes of T_{EX}. A computer program written in MATLAB was used for this purpose.

Table D3. Distribution of Variables in Equation 7 for Nonroad Equipment

Variable	Mean	Standard Deviation	Assumed Distribution	Source of Data
D [m]	0.11	0.03	Normal	Analytical Engineering, Inc.
L [m]	0.90	0.45	Normal	Caterpillar Performance Handbook[1]
T_e [K]	520	68	Normal	Data supplied by EPA as "SPOT" data[2]
M_e [mol/s]	2.73	1.75	Normal	Emission tests done by NCSU[3]

1. The length of tailpipe was obtained for backhoes, dozers, excavators, and front end loaders.
2. The data is for five different dozers, two haulers, an excavator, a front end loader supplied by the EPA.
3. The data is for a Caterpillar Excavator tested by NCSU on November 2, 2005.

The mean and standard deviation of D were estimated using the dimensions reported by Analytical Engineering, Inc. (AEI, 2002) for different types of construction equipment. The mean and standard deviation of L were estimated using the dimensions given for different models of backhoes, dozers, excavators, and front end loaders in the Caterpillar Performance Handbook (Caterpillar, 2004). The mean and standard deviation of T_e was estimated using exhaust temperature data from five different types of dozers, two haulers, an excavator, a front end loader tested by the EPA (AEI, 2002). The mean and standard deviation of M_e was estimated using data from three different sizes of excavators, a front end loader, a backhoe, and a dozer tested by NCSU.

Summary information for the tested equipment is shown in Table D4. Results of the Monte Carlo simulation of T_{EX} for nonroad equipment are shown in Figure D2. The 2.5 percentile, average, and 97.5 percentile of T_{EX} are estimated to be 9, 25, and 456 milliseconds, respectively. The variation of T_{EX} estimated for nonroad equipment is less than the temporal measurement resolution of the Montana system of one second. Thus, variation in all input variables of Equation 7 will not significantly affect T_{EX} and proportionally T_{DL} values for a given vehicle.

Table D4. Characteristics, Test Date, and Estimated Synchronization Time for Six Different Vehicles

Equipment	Make	Model	Model Year	Engine size (L)	Engine Horsepower (hp)	Date Tested	T_{synch} (sec)	T_{synch} (+,-)[1]
Front-End Loader	CAT	930G	2004	6	149	1/27/2006	1	+
Backhoe	CAT	420D	2004	4	85	12/20/2005	2	+
Excavator	Komatsu	PC300	2001	8.27	245	8/24/2005	1-2	+
Dozer	CAT	D5G	2003	6	90	11/17/2005	1	+
Excavator	CAT	320C	2002	6.37	138	11/02/2005	1-2	+
Excavator	Kobelco	SK130	1998	3.9	93	1/16/2006	1	+

[1] Positive T_{synch} is positive when the emissions data respond before the engine data and is negative (-) otherwise.

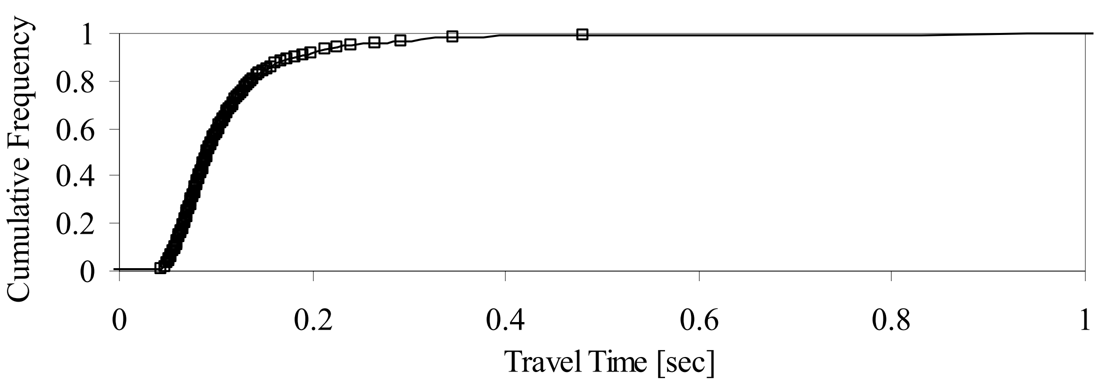


Figure D2. Variation of T_{EX} Travel Time for Nonroad Equipment

To estimate variability of T_{EX} for onroad vehicles, distributions were assumed for the input variables of Equation 7 as shown in Table D5. The mean and standard deviation of D were estimated using the product specifications given on the websites of different onroad vehicle tailpipe suppliers. The tailpipe diameter ranges between 4.4 cm and 7.6 cm depending on the size of the engine. To estimate the mean and standard deviation of L, it was assumed that the length of the exhaust system is equal to the length of the vehicle. Although the straight line distance between the engine and rear of the vehicle is shorter than the length of the vehicle, the tailpipe is not a straight line. Based on this assumption, the mean and standard deviation of L were estimated using lengths of different vehicles reported by the manufacturers in their websites. The mean and standard deviation of T_e was estimated from tailpipe temperature data measure by Lee *et al.* (2002) on a 1.8 liter spark ignition engine. The mean and standard deviation of M_e was estimated from a combination of measurements performed by NCSU for a 2005 Chevrolet Cavalier with a 2.2 liter engine and a 2005 Chevrolet Tahoe with a 5.3 liter engine.

Table D5. Distribution of Variables in Equation 7 for On-Road Vehicles

Variables	Mean	Standard Deviation	Assumed Distribution	Source of Data
D [m]	0.05	0.02	Normal	Websites of tailpipe suppliers[1]
L [m]	4.8	0.35	Normal	Given in Appendix A
T_e [K]	350	70.3	Normal	Data reported by Lee *et al.*(2002)
Me [mol/s]	2.47	0.91	Normal	North Carolina State University[2]

1 Data obtained from the websites of "Advanced Exhaust Tech I" and "Aliabad Exhaust."

2 The emissions test performed by NCSU from a 2005 Chevrolet Cavalier with a 2.2 liter engine tested on October 4-22, 2004, and a 2005 Chevrolet Tahoe with a 5.3 liter engine tested on November 8-26, 2004.

The result of Monte Carlo simulation for onroad vehicles is compared to nonroad equipment as shown in Figure D3. The 2.5 percentile, average, and 97.5 percentile values of T_{EX} are estimated to be 0.13, 1.76, and 5.1 seconds, respectively. The difference between the average T_{EX} for onroad and nonroad vehicles, $T\Delta_{EX}$, is:

$$T\Delta_{EX} = T_{EX,\ onroad} - T_{EX,\ nonroad} = 1.76 \text{ sec} - 0.25 \text{ sec} = 1.51 \text{ sec} \qquad (8)$$

where,

$T_{EX,\ onroad}$ = T_{EX} for onroad vehicles, 1.76 sec

$T_{EX,\ onroad}$ = T_{EX} for nonroad vehicles, 0.25 sec

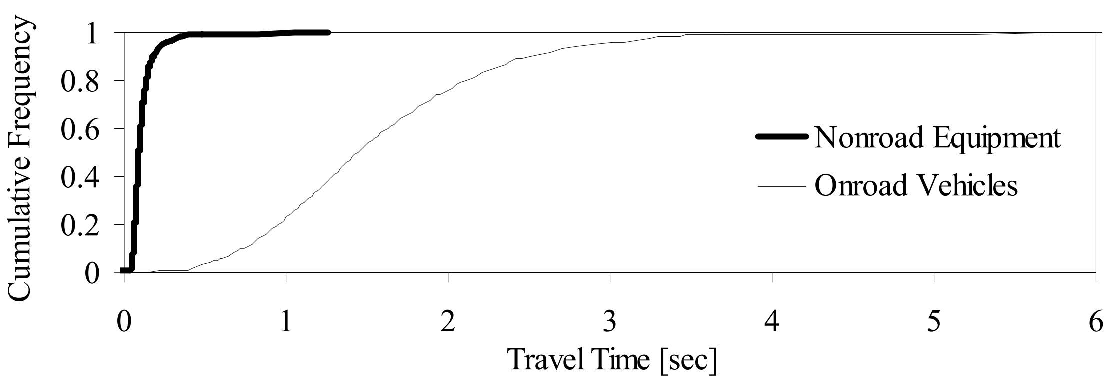


Figure D3. Comparison of Variation T_{EX} Travel Time for Nonroad and Onroad Vehicles

The value of $T\Delta_{EX}$ is larger than the temporal resolution of the Montana system. Thus, the hypothesis that there might be a significant difference between T_{EX} for onroad and nonroad vehicles is verified because the difference is higher than the temporal resolution of the system. Furthermore, the T_{DL} for nonroad and onroad vehicles will be significantly different compared to the temporal resolution of the Montana system.

D.3.2. Criteria for Detecting Synchronization Effects

The objective of this section is to verify synchronization problems in data measured by the Montana system from different types of construction vehicles and to develop a procedure for correcting these effects.

In order to identify the synchronization effects, a detailed review of engine and exhaust data was performed for six different types of construction vehicles, given the equipment summary information in Table D5. Examples of small time series of data were selected and analyzed in order to assure synchronization. These data were selected taking into account the following considerations:

- Need for short time series of consecutive seconds of data with no gaps
- No errors such as freezing, discrepancy, or zeroing effects were observed in the data
- Engine data had a substantial change such as a change in engine speed of greater than 200 RPM in one second and for a total of 500 RPM or more over one or more seconds
- Emission concentrations including NO (ppm), HC (ppm), CO (vol%), CO_2 (vol%), were used for the synchronization analysis instead of mass emission rates because concentrations are directly measured at the tailpipe. Oxygen concentrations were not included in the analysis

For the selected data, the following comparison and inference were made:

- Temporal trends of NO, HC, CO, and CO_2 concentrations were compared to the temporal trends of engine speed and MAP data in order to identify which gas concentration is the best indicator of variation in engine data for the selected seconds of the data.
- Two pollutants were selected as primary and secondary indicators of synchronization to engine data in order to confirm or better detect substantial changes in engine data.
- The time difference between the initial rise (or initial decrease) for a peak in engine versus exhaust data is referred to as "synchronization time," T_{synch}.
- Engine data are shifted in time to properly align with the emissions concentration data after estimating T_{synch}. Emission rates must be recalculated by applying the analytical procedure represented in Section D.6.1.

For each reviewed data file, only two or three segments of data that met the requirements given above were found for the analysis. For example, among the data obtained from a dozer tested on December 22, 2005, only two segments of data were found to be useful for synchronization checks. For illustration purposes, the two data segments are shown in Figure D4 and D-5, respectively.

In Figure D4, engine speed increases by 784 RPM from elapsed seconds 3 to 5 and again by 376 RPM from elapsed seconds 13 to 14. Although MAP also increases at these times, the relative change in MAP is much smaller than the relative change in engine speed. However, the concentration data begin to rise approximately one second before the engine data. For example, the concentrations of NO, CO, and CO_2 begin to rise between elapsed seconds 2 and 3, approximately one second before the corresponding increase in engine speed and MAP.

Similarly, the concentrations of CO and CO_2 begin to rise between elapsed seconds 12 and 13, approximately one second before the corresponding change in engine data. Figure D5 illustrates a situation in which engine speed increases by 1331 RPM from elapsed seconds 4 to 8. The relative change in MAP is very similar to relative change in engine speed at these times. Similar to Figure D4, the concentration data begin to rise approximately one second before the engine data. For example, the concentrations of NO, CO, and CO_2 begin to rise between elapsed seconds 3 and 4.

Since the Montana system is comprised of two identical analyzers, another possible concern is synchronization of emissions concentrations from the two analyzers, which is referred to as inter-analyzer synchronization. The possibility of inter-analyzer differences in synchronization was investigated for all data files obtained from the equipment shown in Table D5. There was no inter-analyzer synchronization problem observed in any of the datasets. Figure D6 illustrates inter-analyzer synchronization for the data shown in Figure D5. The graphs for the pollutants of NO, HC, CO, and CO_2 include data obtained from Analyzers A and B of the Montana system. The concentrations of NO, CO, and CO_2 for both analyzers begin to rise in elapsed seconds 3 and 4.

In another effort, synchronization of pollutants measured by non-dispersive infrared (NDIR) such as CO and CO_2, were checked in comparison to NO, which is measured by an electrochemical sensor. There was no synchronization problem observed between pollutants measured by the NDIR or electrochemical sensor in any of the datasets. As an example of this verification, Figure D5 illustrates that in elapsed second 2 the concentrations of NO, CO, and CO_2 begin to rise at the same time. Similarly, the concentrations of NO, CO and CO_2 begin to rise in elapse time second 3 in Figure D6 and D-7.

For illustrative purposes, Figure D6 conceptually represents T_{synch} for the dozer tested on December 22, 2005. Figure D7 is based on data given in Figure D5. The concentration of CO_2 begins to rise one second before engine speed. The difference in time for these observations is a synchronization discrepancy and is referred to as T_{synch}. A similar discrepancy is seen in the difference in times of the peak values that occur in elapsed second 7 for CO_2 and elapsed second 8 for engine speed. A decision was made to consider T_{synch} positive when the emissions data responds before the engine data and negative otherwise.

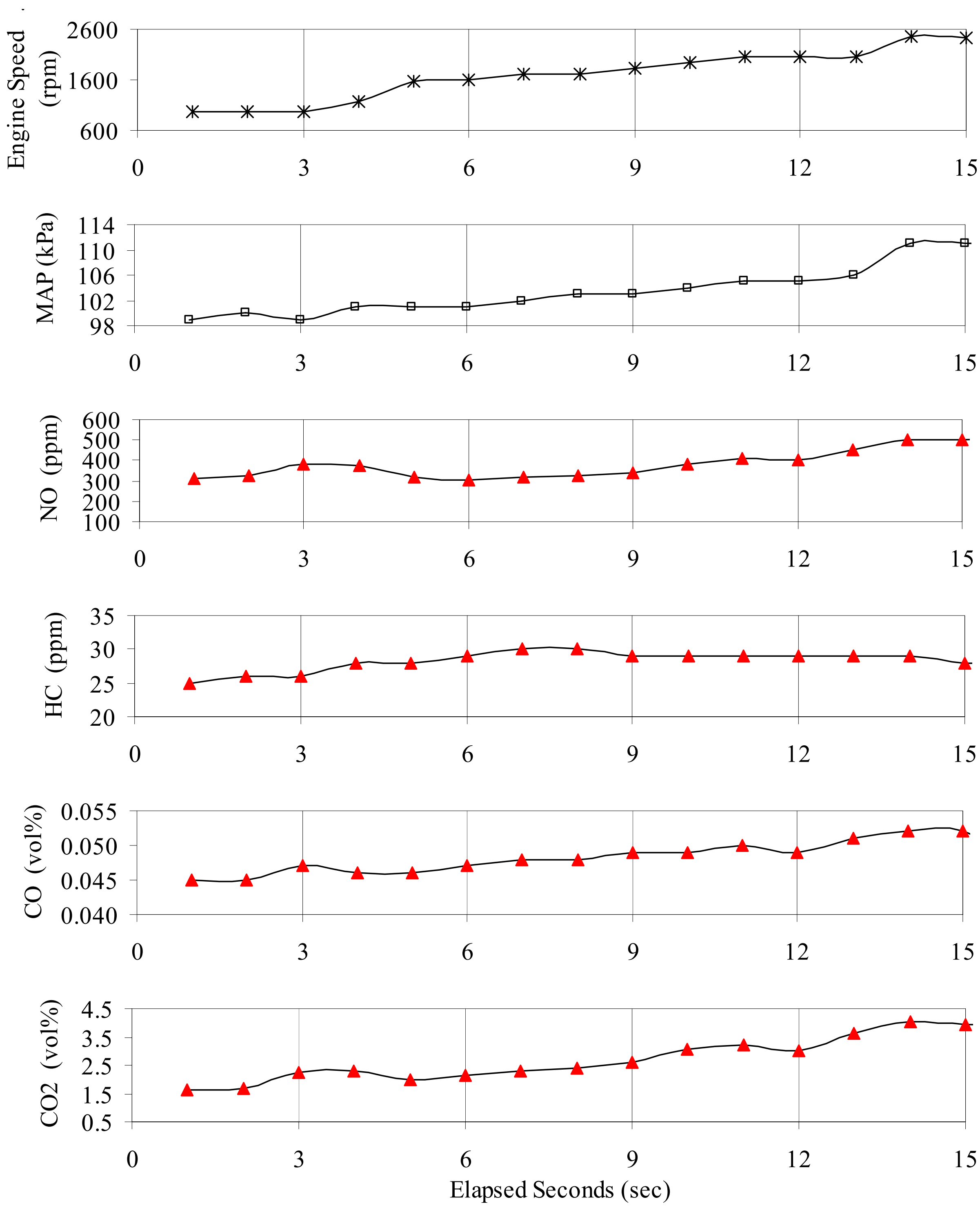


Figure D4. Comparison of Engine Data and Exhaust Concentration for a Dozer tested on December 22, 2005: Data Segment (1)

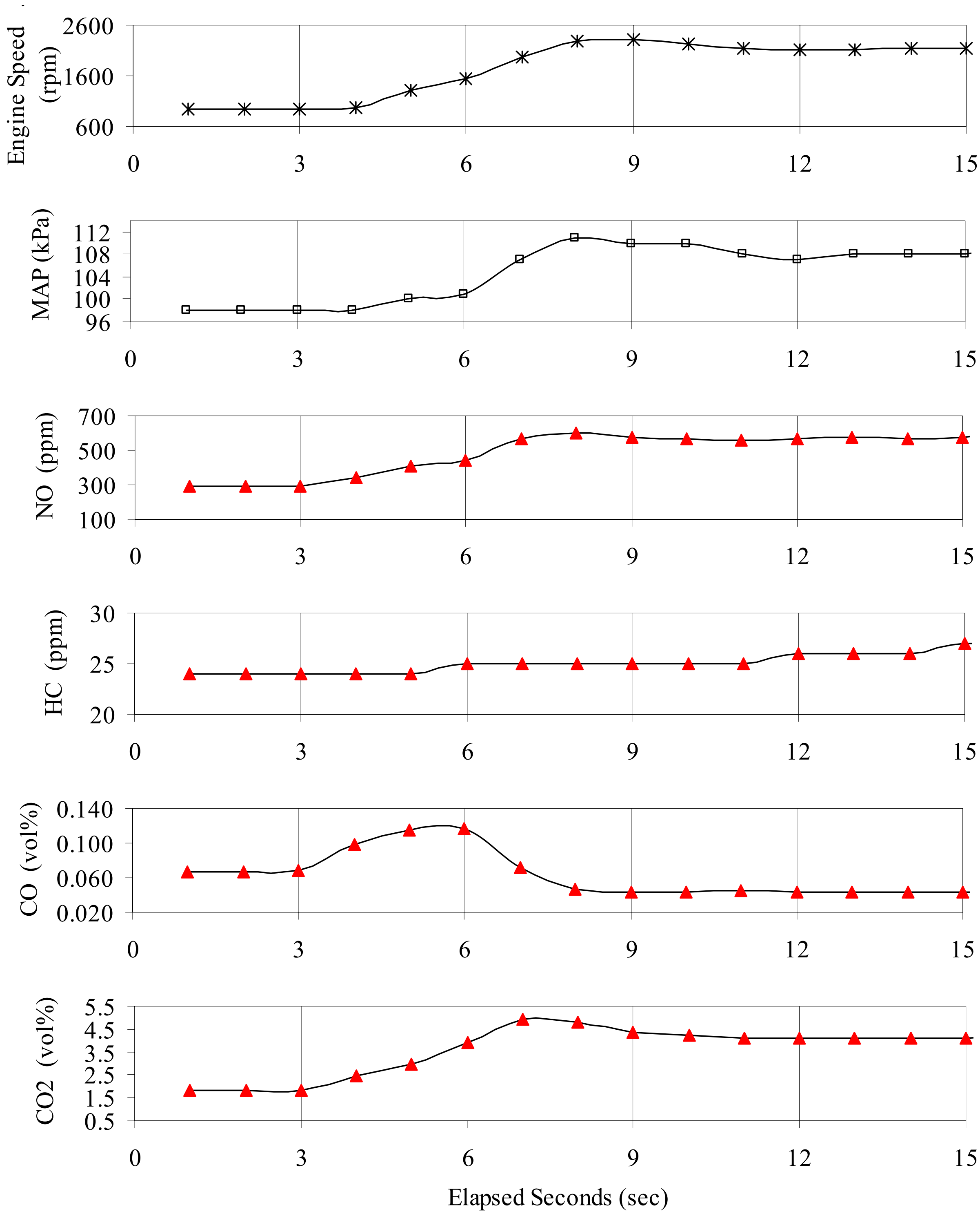


Figure D5. Comparison of Engine Data and Exhaust Concentration for a Dozer tested on December 22, 2005: Data Segment (2)

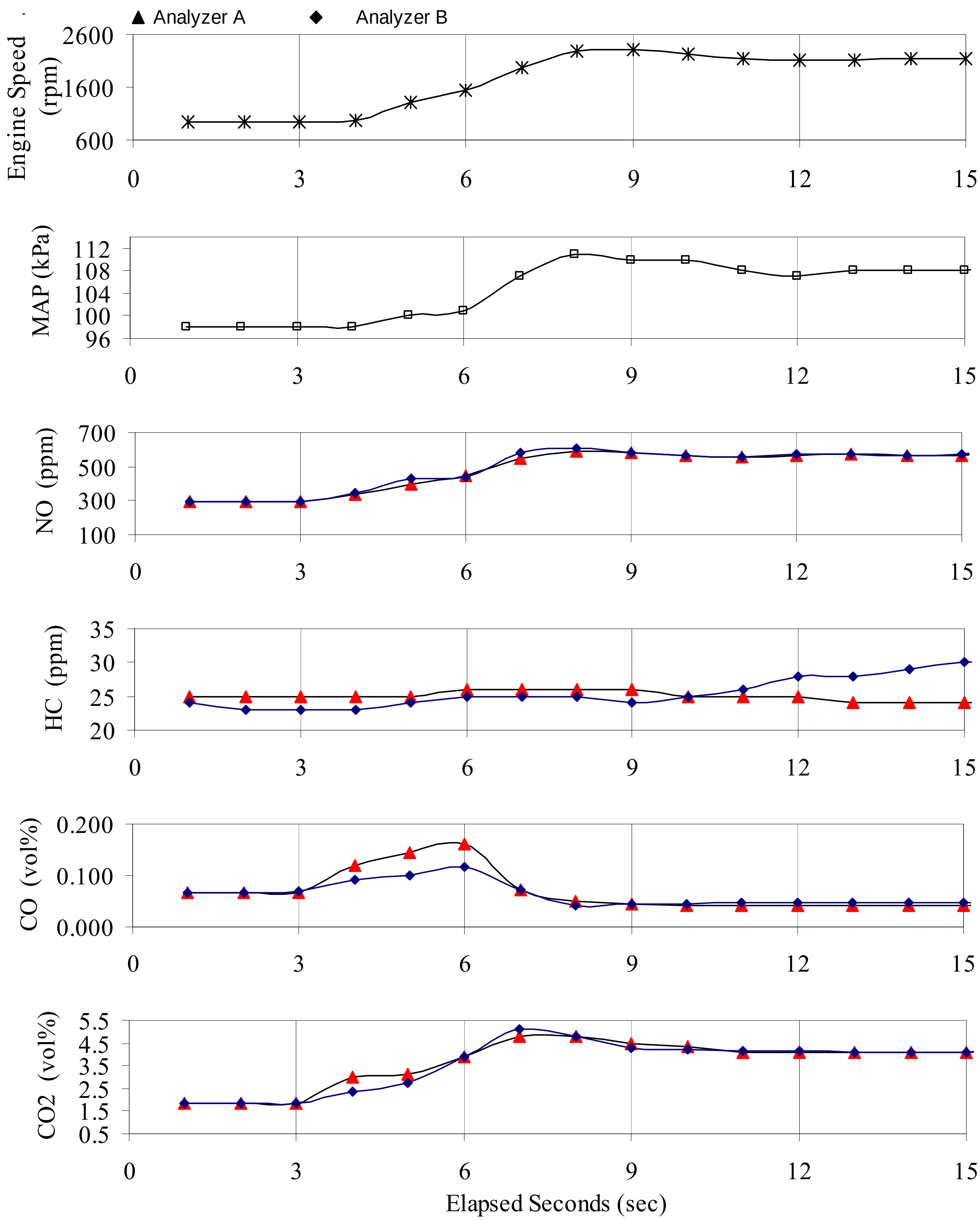


Figure D6. Interanalyzer Synchronization Check Performed for a Dozer Tested on December 22, 2005

The results of synchronization analysis performed for an additional five construction vehicles tested by NCSU are represented in Table D3. The synchronization time for all of the vehicles varies between 1 and 2 seconds. Therefore, all of the T_{synch} values are positive which means the emissions data respond before the engine data.

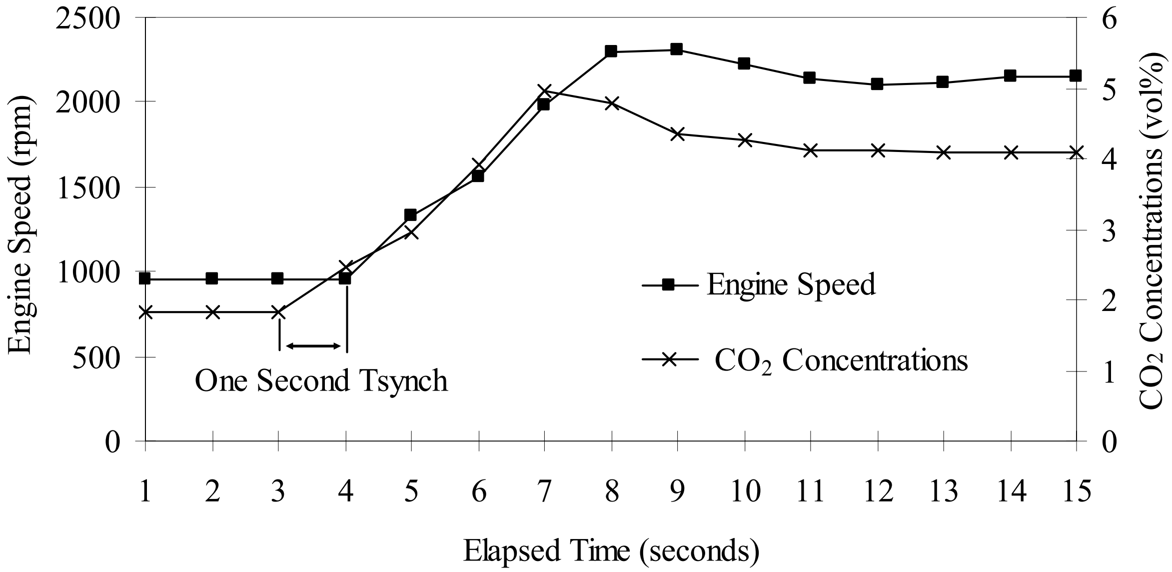


Figure D7. Synchronization Time, T_{synch}, Estimated for a Dozer Tested on December 22, 2005

D.3.3 Criteria for Correcting Synchronization Effects

Based upon a detailed review of results for all six tested vehicles, a judgment was made to use the following procedure for synchronization check of engine and exhaust data:

- Engine speed is used as an indicator of synchronization among engine data because substantial absolute changes are observed in engine speed more so than for MAP and/or intake air temperature data.
- Among the gas concentration measurements, CO_2 concentrations offer the advantage of typically being the most responsive to variation of engine speed compared to the other gas concentrations. The reason is because a change in engine speed is directly associated with a change in fuel consumption and CO_2.
- CO concentrations are selected as a secondary indicator because they are more responsive than NO and HC to variation in engine speed.

Table D4 illustrates synchronization time observed for six tested vehicles. For all of these, a rise in CO_2 and/or CO concentrations was observed earlier than engine speed. As shown in Table D4, the T_{synch} time for these vehicles varies from one to two seconds. In order to properly synchronize the engine and exhaust data, the engine data should be paired with exhaust data that are reported in the previous one or two seconds, and the emission rates must be recalculated. It is assumed that "synchronization time" observed in real data is related to the difference between T_{EX} for onroad and nonroad vehicles. The Montana system has a default value for T_{DL} of 12 seconds which may be appropriate for onroad vehicles. For nonroad vehicles, a more appropriate typical value of T_{DL} is expected to be 10 or 11 seconds. In order to minimize or eliminate synchronization effects in real world data from nonroad equipment, two actions need to be taken before and after data collection. These are estimating a new delay time, $T_{DL, new}$, before data collection and verifying and, if necessary, correcting synchronization effects after data collection. They are explained in the flowing sections.

D.3.3.1 *Minimizing Synchronization Effects before Data Collection*

Before doing data collection, it is necessary to estimate the new delay time, $T_{DL, new}$, for a vehicle test using the Montana system's default delay time, the estimated $T\Delta_{EX}$ given in Equation 8, and an estimate of T_{EX} with the diameter and length of tailpipe for the test equipment. The new delay time is estimated as:

$$T_{DL, new} = T_{DL, default} - T\Delta_{EX} + T_{EX, new} \quad (9)$$

where,

$T_{DL, new}$ = New delay time (sec)
$T_{DL, default}$= Default delay time (sec); the Montana system's default value - 12 sec
$T_{EX, new}$ = New estimated exhaust gas travel time for test equipment (sec)

As noted early, $T_{DL, default}$ is 12 seconds and $T\Delta_{EX}$ is estimated 1.51 seconds. The new exhaust gas travel time, $T_{EX, new}$, is estimated from Equation 7 applying the new exhaust diameter (D) and length (L) values measured from test equipment. Exhaust pressure is assumed to be 1 atm. The average exhaust temperature of 520 K from Table D3 is used as a default value. M_e is estimated based on engine displacement. Thus, M_e is expected to be highly correlated with engine displacement. This correlation is reflected in a coefficient of determination (R^2) of 0.84 as shown in Figure D8.

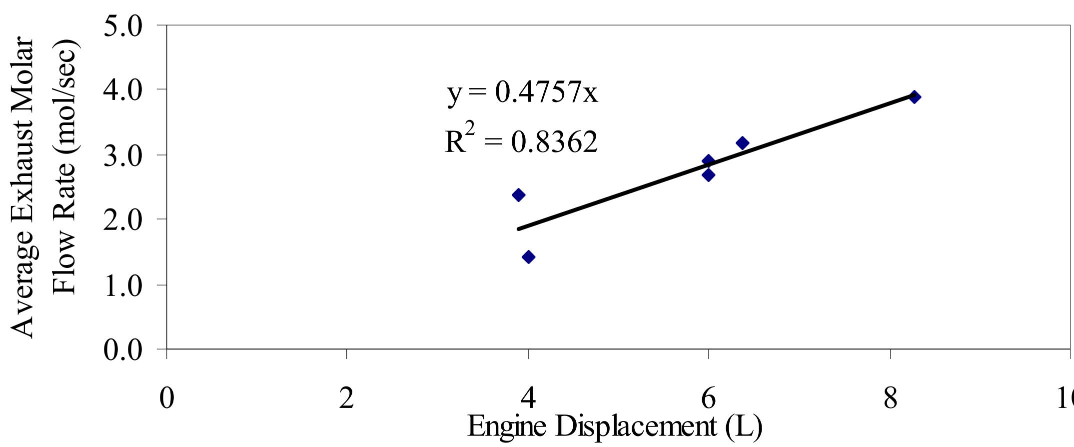


Figure D8. Ordinary Least Square Regression of Exhaust Molar Flow Rate vs. Engine Displacement

The average molar flow rates were estimated from the second-by-second engine and emissions data. Thus, M_e is estimated as:

$$M_e = 0.4757 \times ED \tag{10}$$

where,

$ED =$ Engine displacement (L)

Thus, the average $T_{EX,\,new}$ is estimated applying estimated values for D, L, T_e, and M_e to Equation 7. The $T_{DL,\,new}$ must be rounded to the nearest integer. After defining $T_{DL,\,new}$, it needs to be entered into the Montana system as a new delay value. Changing the delay default value must be done during the procedure of entering vehicle engine information to the Montana system. As a part of this procedure, the Montana system asks the operator of the system to enter new delay time or accept the default value. The procedure of correcting delay time before data collection is shown in Figure D9 as a flow diagram.

D.3.3.2 *Minimizing Synchronization Effects after Data Collection*

After data collection, it is necessary to verify, and if necessary correct, the synchronization of engine and exhaust data. The procedure explained in Section D.3 to identify segments of consecutive data for synchronization check is applied to check data after data collection. If there is a synchronization problem involved with the data, then T_{synch} must be estimated and the exhaust gas data must be shifted to properly synchronize with the engine data, as previously explained. Furthermore, if a correction is needed then the emission rates must be recalculated.

D.4 Data Quality Checks Associated With Sensor Array

The sensor array includes sensors for engine speed, manifold absolute pressure, and intake air temperature. This section identifies the possible problems and errors that can occur associated with these sensors, as well as detailed procedures for avoiding or dealing with such problems and errors.

D.4.1 Engine Speed

Engine speed is the number of revolutions per minute (rpm) at which the engine crankshaft turns whether the vehicle is stationary or in motion. The engine speed for a diesel engine typically varies from at least 500 rpm to not more than 4,000 rpm (Caterpillar, 2003). If the measured engine speed exceeds this range, then an error is suspected. This type of error is rare and has not been observed to date.

The criterion for detecting an unusual engine speed in a dataset is:

$$ES_t \leq 500 \text{ rpm or } ES_t \geq 4{,}000 \text{ rpm} \tag{11}$$

where,

ES_t = Engine Speed at time t; rpm

Measure diameter (D) and length (L) of the tailpipe for the test equipment

↓

Estimate the average new exhaust gas travel time, $T_{EX, new}$ from:

$$M_e = 0.4757 \times ED$$

$$T_{EX,new} = \frac{\pi D^2 L P_e}{4 R T_e M_e}$$

Assuming exhaust parameters values of:

P_e = 1 atm
T_e = 520 K
M_e = Exhaust molar flow rate mol/s (calculated above)
ED = Engine Displacement (L) for the specific vehicle
R = 0.082058×10^{-3} m^3-atm/mol-K

↓

Estimate new delay time, $T_{DL, new}$, from:

$$T_{\Delta EX} = 1.41 \text{ sec}$$

$$T_{DL, new} = T_{DL, default} - T_{\Delta EX} + T_{EX, new}$$

$T_{DL, new}$ = New delay time (sec)
$T_{DL, default}$ = Default delay time 12 sec

↓

Round $T_{DL, new}$ to the nearest integer

↓

Enter $T_{DL,new}$ to the Montana system as a new default value while entering the test equipment information

Figure D9. The Procedure for Estimating Delay Time for Entry into the Montana System before Testing Nonroad Equipment

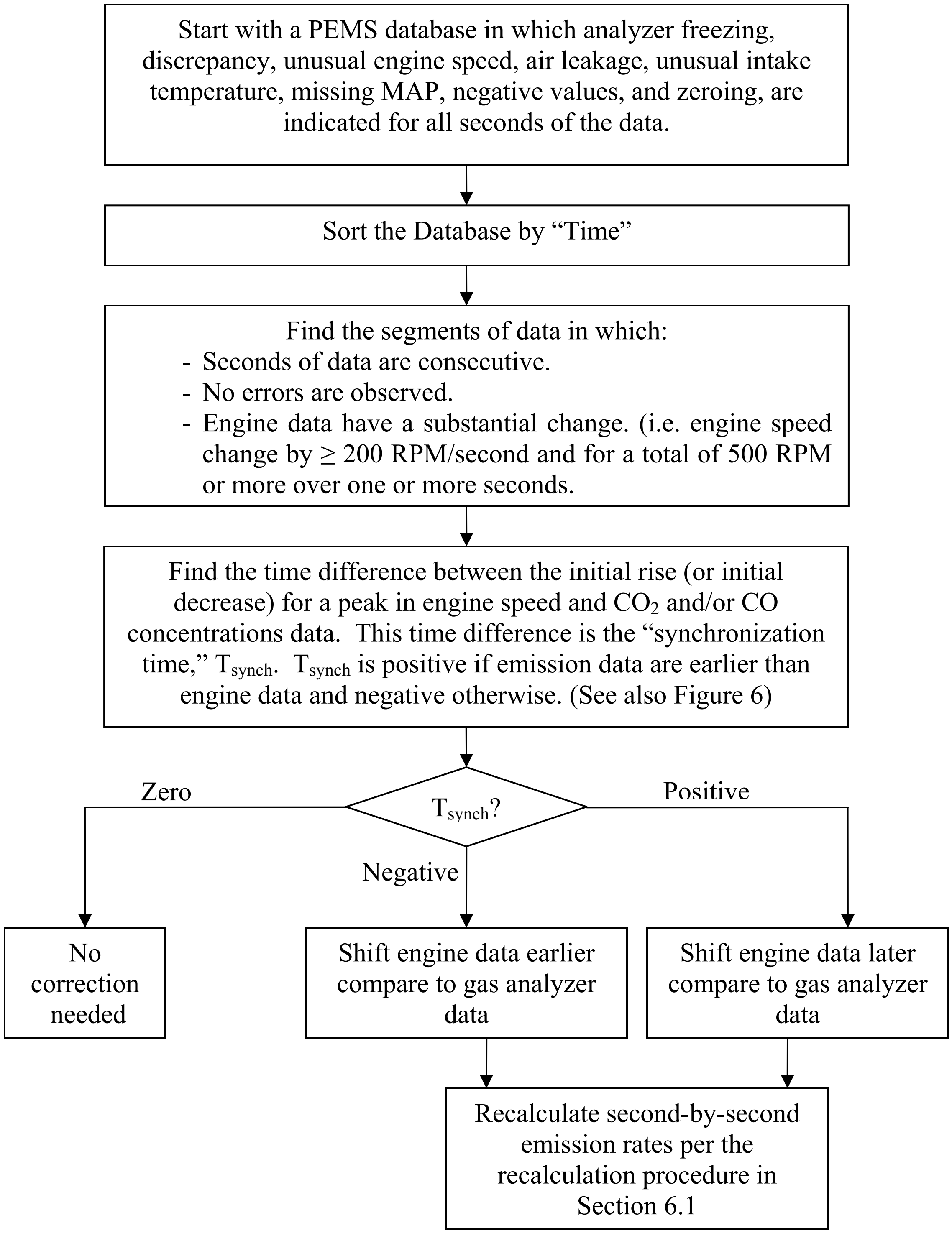


Figure D10. Procedure for Checking and Correcting Synchronization between Engine and Exhaust Data after Data Collection

If the observed engine speed exceeds the acceptable range, then all emission rate data for that specific second needs to be removed from the data set. This is because engine speed is used to estimate the exhaust flow rate, which in turn is used to convert the pollutant concentration data into a mass emission rate.

D.4.2 Manifold Absolute Pressure

Manifold absolute pressure (MAP) is used to estimate the intake air and exhaust flow rate for the engine, the latter of which is used to estimate mass emission rates. On occasion, communication between the sensor array and the Montana system might be lost, leading to loss of MAP data. For example, MAP errors were observed in 927 out of 23,893 seconds, or 3.88%, of data for an excavator that was tested on August 25, 2005. Typically, missing values occurred for 3 or fewer consecutive seconds of data. The problem of missing MAP data was observed in two days of data collection and the reason for missing MAP data was the vibration of connection cable of MAP sensor due to operation of construction equipment. The problem was solved for the further experiments.

D.4.2.1 *Criteria for Detecting Missing Manifold Absolute Pressure*

Missing values are represented in the Montana system by a data missing code of "-34" for each second in which a missing value occurs. Therefore, the criterion for identifying missing MAP data is:

$$MAP_t = -34 \tag{12}$$

where,

MAP_t = Manifold Absolute Pressure at time t; kPa

Typically, other measured data including engine and emissions data are valid at the time when a missing MAP value occurs. Therefore, it is desirable to replace missing values with an estimate of MAP in situations where such estimates can be done with confidence. In turn, emissions rates can be estimated based on the valid values of the other measured variables and the estimate of MAP.

D.4.2.2. *Criteria for Evaluating Manifold Absolute Pressure*

The procedure for evaluating missing MAP data involves several steps. The first step is to calculate the absolute relative difference (ARD) between MAP values that occur before and after missing values. In the second step, the magnitude of ARD is evaluated to determine whether corrective action is possible. If the ARD is less than or equal to a threshold value, then the missing values are replaced with estimates. If the ARD is too large, then the estimation process is deemed to be unreliable and no emission estimates should be made or used during the seconds for which the missing MAP data occur.

The ARD is calculated based on the two seconds of observed MAP data that occur before the missing value(s), and the two seconds of MAP data that occur immediately following the missing value(s). This procedure is applied when missing values occur for 1, 2, or 3 consecutive seconds:

$$\text{ARD} = \left| \frac{(MAP_{t+i} + MAP_{t+i+1}) - (MAP_{t-1} + MAP_{t-2})}{(MAP_{t-1} + MAP_{t-2})} \right| \times 100 \qquad (13)$$

where,

ARD	=	Absolute value of Relative Difference
t	=	time at which the first missing MAP is observed
i	=	number of MAP errors that occur consecutively, i =1, 2, 3
MAP_{t+I}	=	MAP value at time $t+i$ immediately after missing value(s); kPa
MAP_{t+i+1}	=	MAP value at time $t+i+1$ after missing value(s); kPa
MAP_{t-1}	=	MAP value at time $t-1$ immediately before missing value(s); kPa
MAP_{t-2}	=	MAP value at time $t-2$ before missing value(s); kPa

The emission rates estimated by the Montana system are approximately a linear function of MAP. For example, if the MAP estimate varies by plus or minus 5%, while all other measured variables are held constant, then the emission estimate (g/sec) will vary by -5% to +5%. In order to prevent the error associated with estimation of missing MAP values to exceed this range of variation for the emission estimates, the following criteria were established:

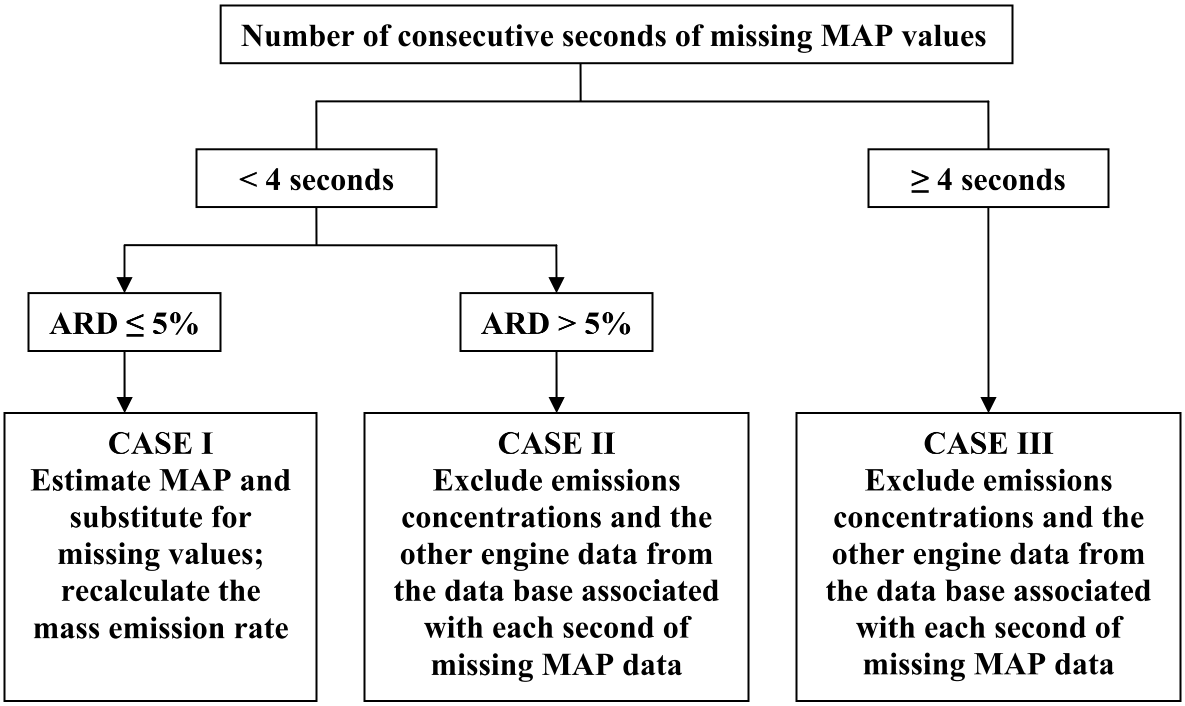
Case I: If ARD $\leq$ 5%, then the missing MAP values are replaced with the following estimate(s) for each second in which missing values occur:

$$\frac{MAP_{t+i} + MAP_{t+i+1} + MAP_{t-1} + MAP_{t-2}}{4}$$

Case II: If ARD > 5%, then the missing MAP values are not replaced. Instead, MAP and all mass emission rate (g/sec) estimates that are based on MAP are deleted from the database for each second in which the missing values occur.

Case III: Four or more seconds of missing data occur, in which case the estimation procedure is deemed to be unreliable. In this case, MAP and all emission concentrations and the other engine data MAP are deleted from the database for each second in which the four or more missing values occur.

If the observed MAP is the same in the two seconds immediately before and after the missing values, then Case I simplifies to replacement of the missing values with these observed values. Figure D11 summarizes the procedure for identifying and estimating missing MAP values.



ARD: Absolute relative difference (ARD) between MAP values that occur before and after missing values

Figure D11. Criteria for Detection of Missing Manifold Absolute Pressure (MAP) Data and for Estimation of Missing Values

D.4.2.3 *Application of Estimating Manifold Absolute Pressure Values to Real Data*

The objective of this section is to illustrate the application of the criteria for identifying and estimating MAP values in a data file obtained from an excavator tested on August 25, 2005. A visual basic program was written to check data files in order to identify missing MAP data and to estimate MAP when the criteria for the number of consecutive seconds of missing data, and the ARD, were satisfied. After estimation of missing MAP data, the visual basic program estimates mass emission rates per time using engine speed, intake air temperature, MAP, and emissions concentrations.

To illustrate the application of the procedure for identifying and estimating missing MAP values, examples are shown in Table D6. The first example illustrates a case in which the MAP values before and after missing data are constant, for which ARD is 0%. Therefore, the estimates of the missing value(s) are identical to the observed values immediately before and after the occurrence of missing data. In the second example, the ARD is less than 5%. In this example, the missing values are estimated. In the third example, the ARD is greater than 5%, in which case the mass emission rates for each second in which MAP is missing cannot be calculated reliably and thus must be deleted from the database.

Table D6. Examples of the Application of Criteria for Identifying and Estimating Missing MAP Values Based on Field Data for an Excavator Tested on August 25th, 2005

Case	Time (sec)	Observed MAP (kPa)	Absolute Value of Relative Difference (ARD) Between MAP Data Before and After Missing Values (%)	Estimated MAP (kPa)
I	30,182	99		99
	30,183	99		99
	30,184	***-34***	$\left\lvert \frac{(99+99)-(99+99)}{(99+99)} \right\rvert \times 100 = 0\%$	***99***
	30,185	***-34***		***99***
	30,186	99		99
	30,187	99		99
	42,154	161		161
	42,155	159		159
	42,156	***-34***	$\left\lvert \frac{(157+157)-(159+161)}{(159+161)} \right\rvert \times 100 = 1.9\%$	***158.5***
	42,157	***-34***		***158.5***
	42,158	157		157
	42,159	157		157
II	28,504	159		159
	28,505	202		202
	28,506	***-34***	$\left\lvert \frac{(160+160)-(202+159}{(202+159)} \right\rvert \times 100 = 11.4\%$	-*
	28,507	***-34***		-*
	28,508	160		160
	28,509	160		160
III	This case was not observed in the datasets			

* Emission concentrations and the other engine data are removed from the data set.

D.4.3 Intake Air Temperature

Intake air temperature (IAT) is measured after the turbocharger at the intake manifold of the engine. During initial startup of the engine, the IAT might be similar to the ambient air temperature. When the turbocharger is operating, heat will be transferred from other components of the engine. It results in an increase of IAT. Generally, IAT changes gradually over time. If the IAT value changes rapidly, there may be problems with the IAT sensor. Therefore, the purpose of this section is to describe the criteria for detecting IAT errors.

D.4.3.1 *Criteria for Detecting Intake Air Temperature Errors*

Intake air temperature should change gradually over time. Based on previous field data collection, the differences of IAT between two consecutive seconds are in the range of -1 to 1 ^{o}C. Figure D12 presents the cumulative frequency of IAT difference between two consecutive seconds of backhoe tested on December 30, 2005. More than 95% of the data does not change over two consecutive seconds.

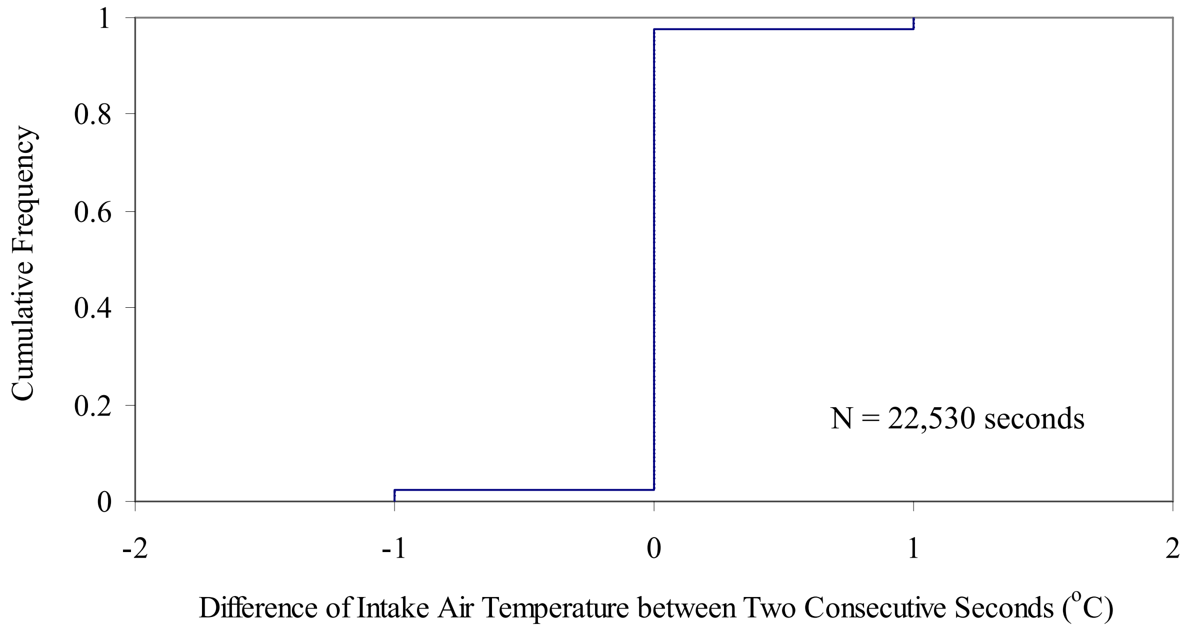


Figure D12. Cumulative Frequency of the Difference of Intake Air Temperature between Consecutive Seconds Based on a Backhoe Tested on December 30, 2005.

Based on the previous field data, the differences of IAT between two consecutive seconds never exceed 1 °C. Therefore, ±1 °C can be the lower and upper limit for the differences of IAT between two consecutive seconds. The following criterion was established at any given time *t*.

$$-1\ ^{o}C \leq IAT_{t+1} - IAT_{t} \leq 1\ ^{o}C \qquad (14)$$

where,

IAT_t	= Intake air temperature for time *t* (°C)
1 °C	= Upper limit of IAT difference between two consecutive seconds (°C)
-1 °C	= Lower limit of IAT difference between two consecutive seconds (°C)

The verification procedures for IAT include:

1. Calculate the difference between two consecutive seconds
2. Check the difference if it is in the range of -1 to 1 °C
3. If yes, proceed to check the next data
4. If no, the second of data will be excluded from the dataset

D.4.3.2 *Application of Intake Air Temperature Values to Real Data*

To validate the criteria shown in Equation 14, an analysis was made using the field data of a skid-steer loader tested on January 20, 2006. Figure D13 shows the cumulative frequency of IAT differences between two consecutive seconds. If there is an error which the IAT difference between two consecutive seconds is not in the range of -1 to 1 °C, the data will be excluded. Fortunately, all of the IAT differences between two consecutive seconds are in the range of -1 to 1 °C. Therefore, there is no IAT error in this dataset.

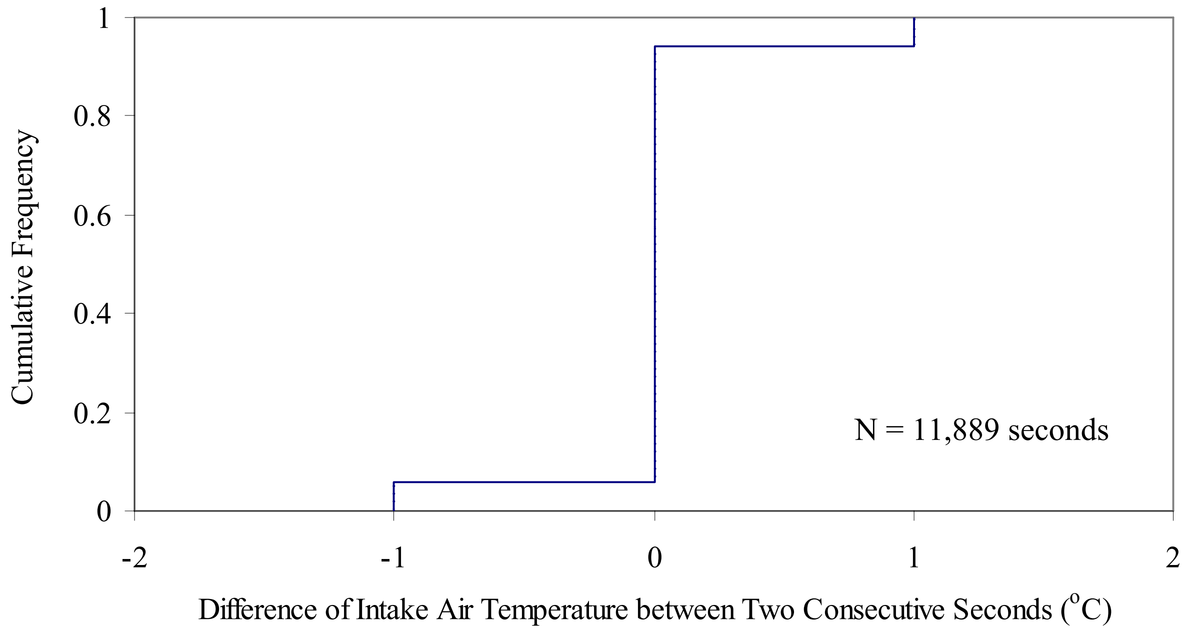


Figure D13. Cumulative Frequency of the Difference of Intake Air Temperature between Consecutive Seconds Based on a Skid Steer Loader Tested on January 20, 2006.

D.5 Data Quality Checks Associated With Gas Analyzer

The objective of this section is to explain how the errors associated with the gas analyzer are considered for data quality assurance. The most common errors indicated in this study and previous works in NCSU regarding gas analyzer are: discrepancy between readings of analyzer, zeroing procedure of analyzer, gas analyzer freezing, and negative emissions values. Criteria for screening, detecting, and correcting theses errors and procedures will be described in the following sections.

D.5.1 Inter-Analyzer Discrepancy

In this section, the methods for examining differences between simultaneous readings of the two analyzers are discussed. The Montana system is composed of two identical gas analyzers to measure NO, HC, CO, and CO_2 pollutants from exhaust flow. Each gas analyzer receives a continuous sample of exhaust gas simultaneously. However, these analyzers may not produce identical measurements due to the influence of environmental factors, drift in data, or the effect of zeroing calibration process. The EPA and the University of California at Riverside have identified the following environmental factors influencing portable emission measurements from diesel engines (EPA, 2005; Norbeck *et al.,* 2001):

- Barometric ambient pressure
- Ambient temperature
- Vibration
- Ambient hydrocarbons

D.5.1.1 *Objective*

This section characterizes the differences in measurements between the two analyzers quantitatively. These differences are referred to as inter-analyzer discrepancies (IAD). The criteria for detecting discrepancies address the following questions:

- What difference in measurement of a given pollutant is observed between the two analyzers?
- Are there explainable reasons for these differences?
- If the differences are experienced, what should be done to ensure data quality?

D.5.1.2 *Criteria for Detecting Inter-Analyzer Discrepancy*

Inter-analyzer discrepancy (IAD) is the absolute value of the difference in measured pollutant concentration for a given pollutant between Analyzer A and Analyzer B. The IAD is compared to the maximum acceptable difference (MAD) between the readings of both analyzers to determine if further examinations of the data are needed.

The MAD for each pollutant is determined by the level of precision of each sensor. Table D7 provides the levels of precision for each pollutant, as reported by the sensor manufacturer (Andros, 2005). For example, the precision of the NO sensor is reported as ± 25 ppm for the NO measurement in the concentration range 0 to 4,000 ppm. This implies that the concentration of NO in one second of data collection can be reported 25 ppm higher than the true concentration from one analyzer, while the other analyzer provides 25 ppm less than the true concentration. Thus, the typical maximum allowable difference between the two analyzers' readings for NO will be 50 ppm. Therefore, a MAD value of 50 ppm is assured for NO. If the IAD for NO is less than the MAD of 50 ppm, then an average of NO_x analyzer concentrations is used to estimate emission rates. However, if the difference between the analyzers is greater than the MAD, further investigation is needed to determine if an error has occurred. The MAD values for HC, CO, and CO_2 emissions are shown in Table D7.

Table D7. Measurement Precision and Maximum Acceptable Difference Estimates for Inter-Analyzer Discrepancies (IAD)

Gases	Analyzer Specifications Provided by Andros Inc.			Detection Limit Estimated by NCSU[b]	Maximum Acceptable Difference (MAD)
	Precision	Concentration Range	Detection Limit[a]		
NO as Equivalent NO_2	± 25 ppm	0 ~ 4,000 ppm	1 ppm	1 ppm	50 ppm
HC	± 4 ppm[c]	0 ~ 2,000 ppm	1 ppm	11 pm	28 ppm[d]
CO	± 0.020 *vol*-%	0.000 ~ 10.0 *vol*-%	0.001 *vol*-%	0.003 *vol*-%	0.040 *vol*-%
CO_2	± 0.30 *vol*-%	0.00 ~ 16 *vol*-%	0.01 *vol*-%	0.02 *vol*-%	0.60 *vol*-%

[a] Detection limits of each pollutants provided from manufacturer (Andros, 2005)

[b] Estimated detection for the Montana system based on measurements of ambient air in the laboratory on September 9th, 2005. After 45 minutes warming up the Montana system, detection limits were tested 4 times. Each test lasted 2 minutes. Among 4 test results, the worst case was selected as the estimated detection limit.

[c] ± 4 ppm is the precision of NDIR calibrated with *n*-Hexane to detect HC concentrations in the range of 0 to 2,000 ppm. However, according to Andros Inc., this NDIR can detect HC concentration in the range of 0 to 30,000 ppm (Andros, 2003).

[d] The MAD for HC emission is specified as 28 ppm.

D.5.1.2.1 The Maximum Acceptable Difference (MAD) for Hydrocarbon

Regarding HC readings, the reported level of precision (see Table D7) is not applicable in practice as a basis for estimating the MAD value. Non-dispersive infrared sensors (NDIRs) are designed to measure *n*-hexane, one of the major constituents of total hydrocarbons in exhaust fumes. In order to measure *n*-hexane, the NDIR analyzer should be calibrated using *n*-hexane as a span calibration gas. However, *n*-hexane is not practical for use in the field because it is relatively expensive, unstable, and condenses into a liquid. Historically, propane has been preferred as a calibration gas for NDIR analyzers. Propane absorbs infrared energy at approximately the same wavelength used for *n*-hexane measurement (Andros, 2003). The precision for measurement of HC (as reported by Andros in Table D7) is for circumstances in which the NDIR analyzer is calibrated using *n*-hexane. However, in this study, propane is used as a span calibration gas. By using propane instead of *n*-hexane as a calibration gas, lower precision is expected for measuring HC; thus, the acceptable level of precision will be higher than ± 4 ppm for each analyzer.

In the field, vibrations can affect the precision of HC measurements. Hydrocarbons are measured at a lower wavelength of NDIR compared to CO and CO_2 emissions. The measured concentration values can change with respect to vibration, particularly for the lower wavelengths of HC detection (Norbeck *et al.*, 2001; Andros, 2003). For this reason, the reported HC precision cannot be used to estimate the MAD level for HC. However, if the precision level is assumed to be ±14 ppm, then MAD will be 28 ppm. In assured value of MAD, 99% of HC readings from both analyzers are below the MAD. Based on these considerations, a MAD level of 28 ppm is chosen. An additional consideration is that diesel vehicles tend to have low HC emission. Thus, the sensitivity of HC measurements to environmental factors, combined with low values of HC, may lead to a high frequency of large discrepancies between analyzers, compared to the MAD.

D.5.1.2.2 Application of Determined MAD Values to Real-World Data

In this section, real-world data obtained from measurements of a 1999 excavator with an 8.0-liter engine tested on August 25, 2005 were used to help evaluate the use of MAD values. Table D8 shows the discrepancies between two analyzers. The IADs are less than the MAD values for 93% to 100% of the data for all pollutants, except for HC. As explained in the previous section, HC measurements are sensitive to environmental conditions; therefore, a higher frequency of discrepancies is expected. If the IAD is higher than the MAD, the data should be further evaluated for possible problems such as malfunctioning of sensors, NDIR damage by dust, or pump blockage by condensation.

Table D8. Inter-Analyzer Discrepancies (IAD)

	Estimated MAD[a]	**95 Percent Range of IAD[b]**		**IAD > MAD Percentage**
		2.5 %	**97.5 %**	
NO as Equivalent NO_2	50 ppm	7 ppm	71 ppm	7.0
HC	28 ppm	0 ppm	32 ppm	1.0
CO	0.040 *vol*-%	0.00 *vol*-%	0.01 *vol*-%	0.0
CO_2	0.60 *vol*-%	0.00 *vol*-%	0.70 *vol*-%	4.0

[a] MAD (Maximum Acceptable Difference) from Table D7

[b] 95% ranges of IAD are from second by second data for an excavator with an 8.0-liter engine, tested on August 25, 2005.

D.5.1.3 *Characterizing Cases of Inter-Analyzer Differences (IAD)*

The IADs mentioned above can be classified into several cases. With two parallel gas analyzers, four cases are possible, as explained below:

- Case I IAD < MAD. There is no need for further evaluation;
- Case II IAD > MAD, and the concentration values from both analyzers are greater than the detection limits;
- Case III IAD > MAD, and the concentration value from one analyzer for one or more pollutants is lower than the detection limit; or
- Case IV IAD > MAD, and the concentration values from both analyzers are lower than the detection limits.

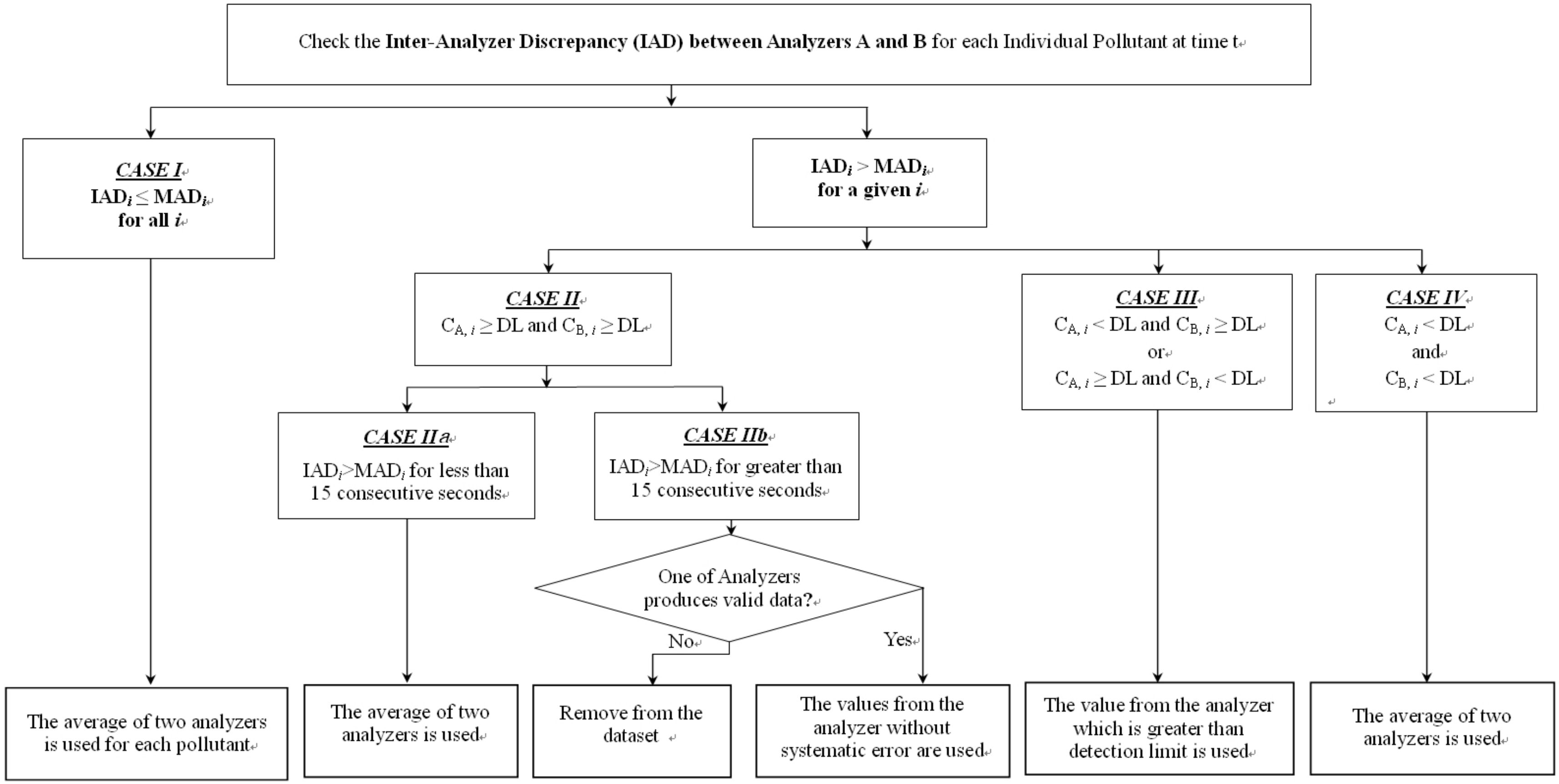
When IAD>MAD for a particular pollutant, the data need to be checked. Figure D14 shows the procedures for detecting IADs, and solutions for all four cases. As illustrated in Figure D14, Case II has typical situations:

- Case IIa For situations in which $IAD_i > MAD_i$ occurs for a few consecutive seconds ($t \leq 15$), it is typically the case that IAD_i is only slight larger than MAD_i (e.g. by a few ppm or hundredths *vol*-%, depending on the pollutant). These situations are further explained below.
- Case IIb When $IAD_i>MAD_i$ for all four pollutants and for an extended period of time (t > 15 consecutive seconds), systematic errors in at least one gas analyzer typically exist, as explained below.

D.5.1.3.1 Case IIa

Case IIa is a typical situation for $IAD_i>MAD_i$. Approximately 90% of instances where $IAD_i>MAD_i$ are associated with Case IIa. As explained above, this case implies that IAD exceeds the MAD by few ppm (or fraction of a *vol*-%) of concentration over the cases of just a few seconds.

In general, if IAD is greater than the MAD, a preference between two analyzers should be determined if possible. However, when IAD is slightly greater than MAD and when data from both analyzers follow similar trends, it may not be possible to establish a preference between them. To justify analyzer preference, the engine speed is used as a reference line. However, it must be determined whether engine speed data can be used to establish a preference between the two analyzers when IAD slightly exceeds MAD for brief periods. Because the electro-chemical NO detector and NDIR sensor for CO, CO_2, and HC might respond differently, they are considered separately.



DL$_i$ = Detection Limit for pollutant i; the detection limits for each pollutant are shown in Table 7

IAD$_i$ = Inter-Analyzer Discrepancy for pollutant i at a given time

MAD$_i$ = Maximum Acceptable Difference for pollutant i; the MADs for each pollutant are shown in Table 7

$C_{A,i}$ = Concentration of pollutant i as measured by Analyzer A

$C_{B,i}$ = Concentration of pollutant i as measured by Analyzer B

Figure D14. Flow Diagram of the Procedures for Evaluations of Inter-Analyzer Discrepancies (IAD) between Two Analyzers and Their Solutions

Figure D15 illustrates a typical example of Case IIa based on data collected on February 1, 2006 for a 2001 Volvo motor grader with an 8.27-liter Cummins engine. The figure shows 10 consecutive seconds that include periods which IAD is slightly greater than MAD for two pollutants (NO and CO_2). IAD>MAD periods are indicated using a downward arrow in the figure. For this period, IAD>MAD only for NO and CO_2, but not for HC or CO. Furthermore, both gas analyzers have the same relative trend compared to each other for a given pollutant. For example for NO, both analyzers indicate a slight drop in NO concentration during the first four seconds, followed by a slight increase in the last two seconds. Engine speed is changing moderately during this period, but neither analyzer indicates that the change in engine speed in this situation is governing the change in emissions. Therefore, there is no basis here to prefer one analyzer over the other. The emissions are calculated in this type of situation based on the average of the concentrations reported by each analyzer in each second.

To further illustrate the scenario of Case IIa, anther sample of data is shown in Figure D16. These data represent 10 consecutive seconds of measurements of CO and CO_2 for a 2002 front-end loader with a 5.9-liter Cummins engine that was tested on March 8, 2006. In this example, IAD_{NO} >MAD_{NO} for two consecutive seconds and IAD_{CO2} is greater than MAD_{CO2} in one second. However, IAD for HC and CO is less than the applicable MAD. For all four pollutants, both gas analyzers indicate a slight downward trend in concentrations, which is consistent with a modest decrease in engine speed. There is no clear basis for preferring one analyzer over the other. Hence, an average of both is used.

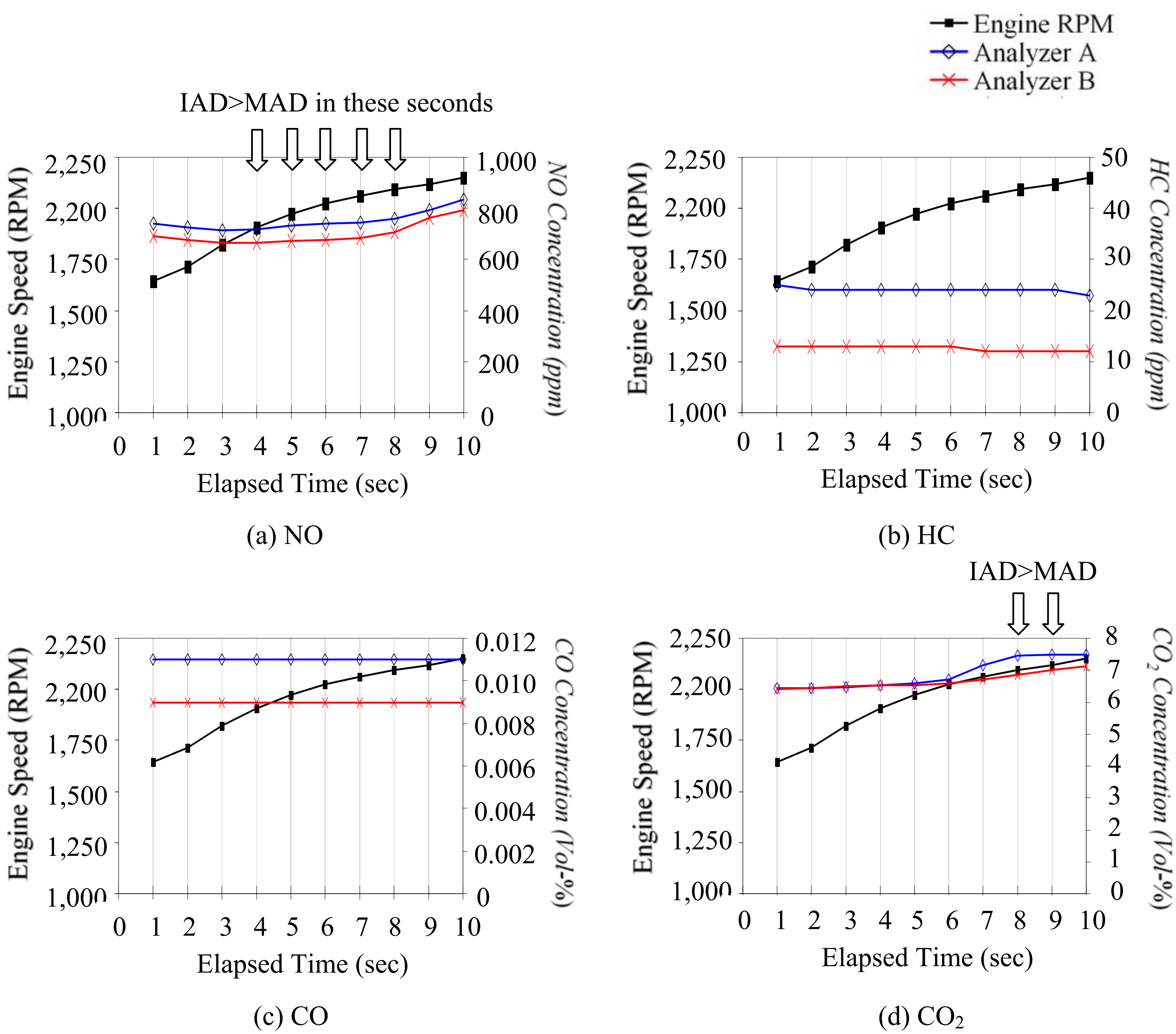


Figure D15. Example of IAD >MAD for NO and CO_2 based on 10 Consecutive Seconds Data for a 2001 Volvo Motor Grader Powered by an 8.27-Liter Cummins Engine Tested on February 1, 2006

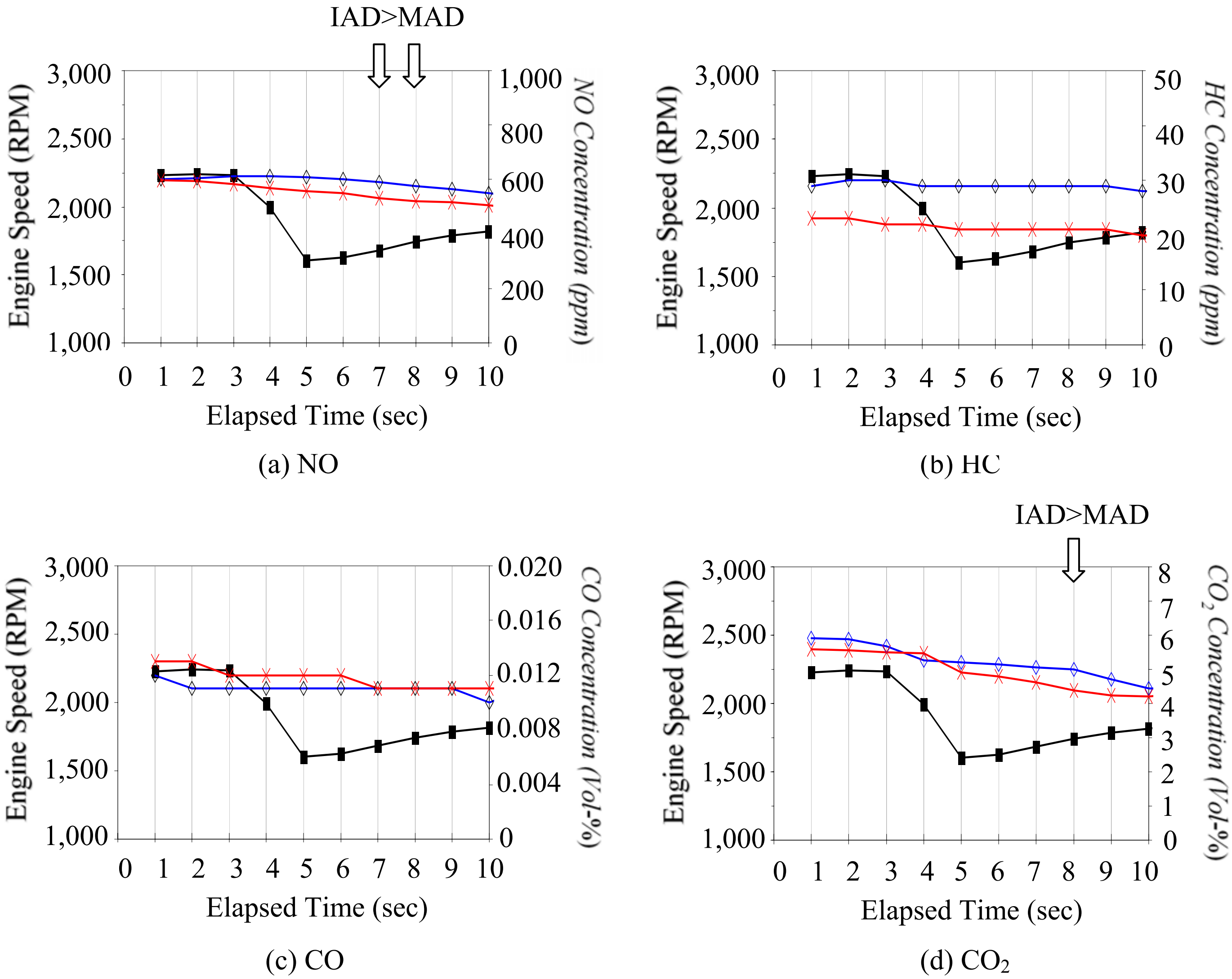


Figure D16. Example of IAD >MAD for NO and CO_2 based on 10 Consecutive Seconds Data for a 2002 Front-End Loader Powered by a 5.9-Liter Cummins Engine Tested on March 8, 2006

In order to provide additional empirical support regarding the identification and implications of Case IIa additional case studies were identified based on a random sampling procedure.

Table D9 shows the results of 30 randomly selected samples of situations in which IAD>MAD of these 30 cases, there are 18 for the NO sensor and 9 for the NDIR sensor that support the appropriateness of using the average values of two analyzers in IAD>MAD for Case IIa. In Table D9, each event was compared separately for the NO and the NDIR sensor after randomly selecting 30 events in which IAD>MAD for one or more pollutants from data collected on February 1, 2006. Even though $IAD_{NO}>MAD_{NO}$ in most of these cases, it was difficult to determine a preference for one specific analyzer in 18 of 20 of these events. For 2 events (Events 19 and 25), a preference could be determined for one of the analyzers. In the remaining 10 events, $IAD_{NO}<MAD_{NO}$ and hence an average of both analyzers were use. The NDIR sensor in which IAD>MAD for either HC or CO_2 had a similar trend to the NO sensor, but fewer cases of IAD>MAD. In 9 of 11 events, it was difficult to determine a preference between the two analyzers. In two of these events (Events 23 and 29), one of the analyzers was preferred. In 19 events, IAD<MAD for all pollutants and averages between the two analyzers were used. Of these 30 randomly selected events, Event 15 was graphed in Figure D15.

The types of results obtained in Table D9 for a motor grader were also obtained for other tests and types of test vehicles, as exemplified by Table D10. Table D10 shows the result of a test conducted on March 8, 2006 for a front-end loader. Figure D16 represents Event 7 in Table D10. In Table D10, 19 of 20 cases where $IAD_{NO}>MAD_{NO}$ were Case IIa, while for the NDIR sensor, 11 out of 15 cases were IAD>MAD for one or more pollutants were Case IIa. Thus, Case IIa is a common one. Detailed review of each Case IIa event in Table D9 and D-10 confirms that when IAD>MAD by only small amounts for a short period of time, it is not possible to determine a preference between the two analyzers.

D.1.3.2 Case IIb

Case IIb is a situation where IAD>MAD and in which there are also systematic errors for one of the gas analyzers. Such systematic errors are assumed to be a temporary malfunction of a gas analyzer. Thus, the data for the errant analyzer needs to be excluded.

As an example of Case IIb, Figure D17 presents a result from a 1998 Kobelco excavator with a 3.9-liter engine tested on January 16, 2006. This example reveals large differences between the two analyzers over 160 consecutive seconds for all four measured pollutants. In Figure D17(a), the NO concentration measured by Analyzer B increases monotonically, which is not inconsistent with the nearly cyclic variation in engine speed. However, Analyzer A follows a trend similar to that of the engine speed. Thus, there is confidence that Analyzer A is responding appropriately, whereas it is clear that Analyzer B is providing incorrect data.

Table D9. Randomly Selected Samples of IAD>MAD for Data from a 2001 Volvo Motor Grader with 8.27 Liter Cummins Engine [a]

Event	Actual Time	IAD – MAD when IAD > MAD [b]				Duration (seconds)		Preferred Analyzer [c]		Case[d]	
		NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (*vol*-%)	CO_2 (*vol*-%)	NO Sensor	NDIR	NO Sensor	NDIR	NO Sensor	NDIR
1	11:00:26	1				2	0	Diff	Avg	IIa	I
2	11:05:14				0.05	0	1	Avg	Diff	I	IIa
3	11:22:20		1			0	6	Avg	Diff	I	IIa
4	11:28:55	1				2	0	Diff	Avg	IIa	I
5	11:31:00	2~15				4	0	Diff	Avg	IIa	I
6	11:32:00	1				2	0	Diff	Avg	IIa	I
7	11:37:23	4~14				3	0	Diff	Avg	IIa	I
8	11:59:51	1~5				2	0	Diff	Avg	IIa	I
9	12:09:30		1			0	3	Avg	Diff	I	IIa
10	12:10:05		1			0	1	Avg	Diff	I	IIa
11	12:16:20		1			0	1	Avg	Diff	I	IIa
12	12:37:46	3~8				3	0	Diff	Avg	IIa	I
13	12:56:44	1				1	0	Diff	Avg	IIa	I
14	1:06:31	1				1	0	Diff	Avg	IIa	I
15	1:26:21	2~13			0.05	5	2	Diff	Diff	IIa	IIa
16	1:38:04	9				1	0	Diff	Avg	IIa	I
17	1:40:39				0.08	0	1	Avg	Diff	I	IIa
18	1:43:52				0.05	0	1	Avg	Diff	I	IIa
19	1:48:19	2~11				5	0	B	Avg		I
20	2:16:28	5~14				5	0	Diff	Avg	IIa	I
21	2:20:43	7~8				2	0	Diff	Avg	IIa	I
22	2:28:51	2~18				4	0	Diff	Avg	IIa	I
23	2:33:45				0.04	0	1	Avg	A	I	
24	2:45:31				0.02	0	1	Avg	Diff	I	IIa
25	2:59:48	1~8				6	0	B	Avg		I
26	3:05:14	8~11				3	0	Diff	Avg	IIa	I
27	3:08:10	3				1	0	Diff	Avg	IIa	I
28	3:10:33	4~11				2	0	Diff	Avg	IIa	I
29	3:18:38				0.02	0	1	Avg	A	I	
30	3:21:14	2~3				3	0	Diff	Avg	IIa	I

[a] This test was performed on February 1, 2006 for 4.36 hours.

[b] At each event, IAD exceeded the MAD for the shown values of each pollutant in the column; If it is blank, IAD does not exceed the MAD

[c] Preferred analyzer means the analyzer which produced the values following the trend of engine speed; Engine speed is used as the reference line to determine "Preferred Analyzer."

Diff = Difficult to determine a preference between analyzers; an average of Analyzers A and B is used.

Avg = The average between two analyzers is used because it is not associated with cases where IAD>MAD

A = Analyzer A, B = Analyzer B

[d] This column represents the specific case for each event; I= Case I, IIa= Case IIa, blank= possibly determine a preference of one bench, but not obvious situation

Table D10. Randomly Selected Samples of IAD>MAD for Data from a 2002 Front-End Loader with 5.90 liter Cummins Engine [a]

Event	Actual Time	IAD – MAD when IAD > MAD [b]				Duration (seconds)		Preferred Analyzer [c]		Case[d]	
		NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (*vol*-%)	CO_2 (*vol*-%)	NO Sensor	NDIR	NO Sensor	NDIR	NO Sensor	NDIR
1	10:02:49	1~3				2	0	Diff	Avg	IIa	I
2	10:03:06	4~14			0.03	4	1	A	Diff		IIa
3	10:03:43				0.03	0	1	Avg	B	I	
4	10:05:26	4~9			0.01	5	1	Diff	Diff	IIa	IIa
5	10:09:56	3~5			0.01	3	1	Diff	Diff	IIa	IIa
6	10:14:28				0.03~0.06	0	2	Avg	Diff	I	IIa
7	10:23:40	7			0.02	2	1	Diff	Diff	IIa	IIa
8	10:44:03	1				1	0	Diff	Avg	IIa	I
9	11:02:24	12				1	0	Diff	Avg	IIa	I
10	11:10:40	3~13				5	0	Diff	Avg	IIa	I
11	12:50:43		1~3			0	9	Avg	Diff	I	IIa
12	1:11:22				0.09	0	1	Avg	B	I	
13	1:29:39	7				1	0	Diff	Avg	IIa	I
14	1:35:03				0.07	0	1	Avg	Diff	I	IIa
15	1:42:33	8~10				2	0	Diff	Avg	IIa	I
16	1:49:08	5~8				2	0	Diff	Avg	IIa	I
17	1:49:45				0.01~0.09	0	3	Avg	A	I	
18	1:56:11	1~7				4	0	Diff	Avg	IIa	I
19	1:58:34	1				2	0	Diff	Avg	IIa	I
20	2:00:42				0.08	0	1	Avg	Diff	I	IIa
21	2:06:05	5				1	0	Diff	Avg	IIa	I
22	2:10:07	4				1	0	Diff	Avg	IIa	I
23	2:22:57	6				2	0	Diff	Avg	IIa	I
24	2:28:25	1				2	0	Diff	Avg	IIa	I
25	2:32:48				0.05	0	1	Avg	B	I	
26	2:42:46				0.01	0	1	Avg	Diff	I	IIa
27	2:53:08				0.09	0	1	Avg	Diff	I	IIa
28	2:59:50	3~11				4	0	Diff	Avg	IIa	I
29	3:08:54	9			0.02	1	1	Diff	Diff	IIa	IIa
30	3:14:43	8~9				2	0	Diff	Avg	IIa	I

[a] Test was performed on March 8, 2006 for 4.85 hours.

[b] At each event, IAD exceeded the MAD for the shown values of each pollutant in the column; If it is blank, IAD does not exceed the MAD

[c] Preferred analyzer means the analyzer which produced the values following the trend of engine speed; Engine speed is used as the reference line to determine "Preferred Analyzer."

Diff = Difficult to determine a preference between analyzers; an average of Analyzers A and B is used.

Avg = The average between two analyzers is used because it is not associated with cases where IAD>MAD

A = Analyzer A, B = Analyzer B

[d] This column represents the specific case for each event; I= Case I, IIa= Case IIa, blank= possibly determine a preference of one bench, but not obvious situation

In Figure D17(b) and D-17(c), representing HC and CO concentration values respectively, Analyzer B produces extreme values, compared to Analyzer A, that range from -100 ppm to 400 ppm for HC and from -0.02 *vol*-% to 0.07 *vol*-% for CO. In contrast, Analyzer A reports nearly constant and low concentrations, where the engine speeds are fluctuating only slightly relative to a typical value of approximately 2,000 RPM. The incompatibility of the trend between Analyzer B and the engine speed data suggests that data from this analyzer are invalid during this period of time.

In Case IIb, systematic errors are suspected if IAD is greater than MAD for all four pollutants with a large magnitude of difference over a substantial number of consecutive seconds. In this case, data from the non-preferred analyzers should be removed, and values from the analyzer that is deemed to be free of systematic error, should be used to calculate emission rates. The CO2 concentration measured by the Analyzer A follows a similar trend as the engine speed data, which is expected because fuel flow and CO_2 emissions are a function of engine speed. However, Analyzer B is providing much lower CO_2 values that are not sensitive to the fluctuations in engine speed. Therefore, Analyzer A is preferred in this case. Overall for all for pollutants in this example, Analyzer A is preferred.

D.5.2 Zeroing Procedures of PEMS Instrument

The Montana system includes two identical but separate analyzers referred as Analyzer "A" and "B". Each of the analyzers perform periodic zero calibration with ambient air every 10 minutes. The mechanism of starting and ending periodic zeroing is potentially a source of error in measurement.

The Montana system takes an average of readings from both analyzers in order to estimate emissions and fuel use rates except when one of the analyzers is performing periodic zero calibration. In this case, the Montana system takes readings from the analyzer for which the zeroing procedure is not in progress. When zeroing begins, a solenoid valve switches from intake of exhaust gas to intake of ambient air. An example of such a valve is shown in Figure D18. When the zeroing procedure ends, the solenoid valve switches again and the analyzer takes in emissions from the tailpipe. There is a period of transition while this switching occurs. The sensors of oxygen, NO, HC, CO, and CO_2 need several seconds to respond to the switching of gases. To allow adequate time for a complete discharge of the previous gas from the analyzer, a time delay of 10 seconds is assumed. Thus, for 10 seconds before starting the periodic zero calibration procedure and 10 seconds after ending the procedure, emissions rates are estimated using the data from the analyzer at which the zeroing procedure is not in progress.

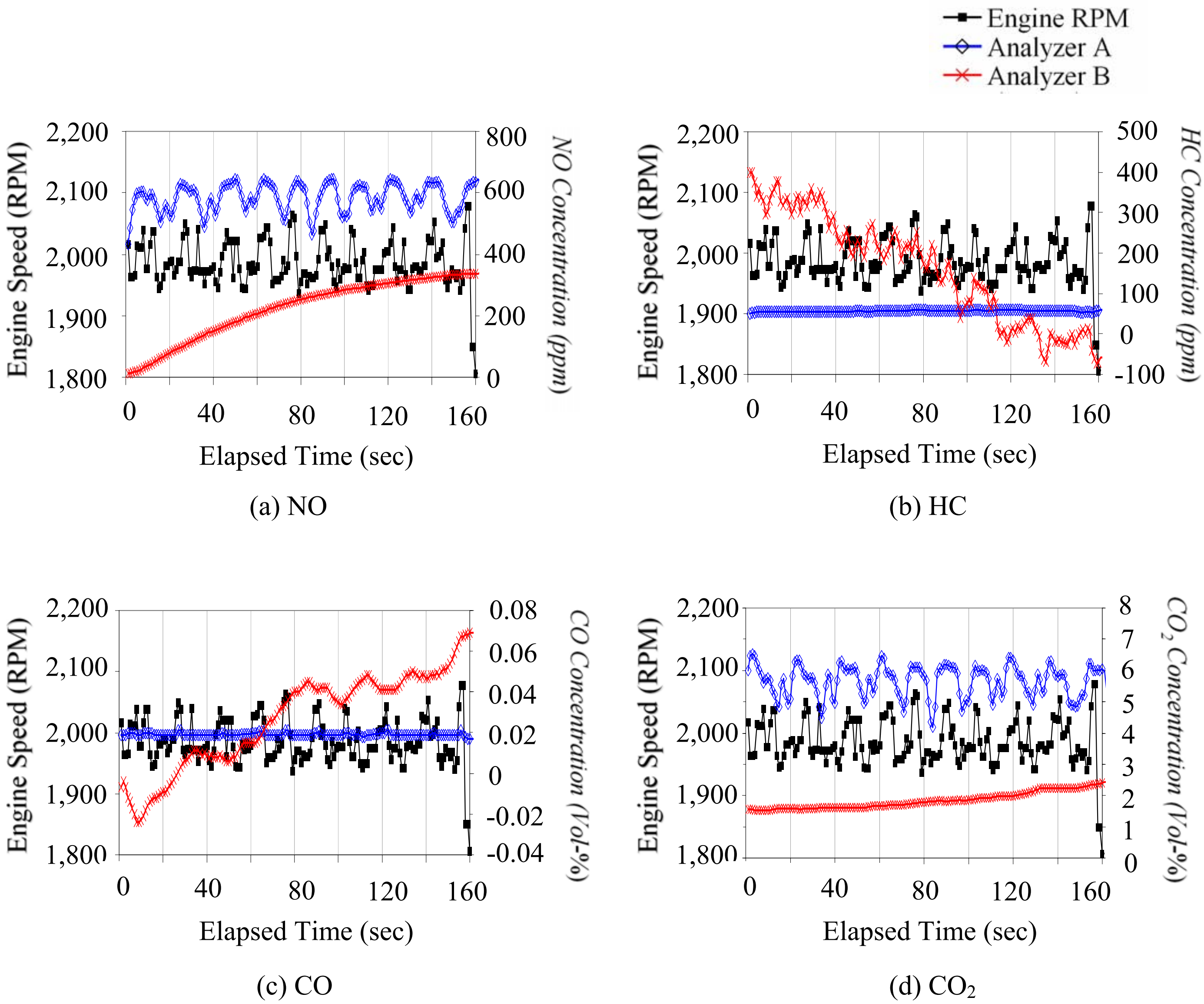


Figure D17. An Example of IAD >MAD for Four Pollutants in 160 Consecutive Seconds Data for a 1998 Kobelco Excavator Powered by a 3.9-Liter Engine Tested on January 16, 2006 for Concentrations of: (a) NO as Equivalent NO_2, (b) HC, (c) CO, and (d) CO_2

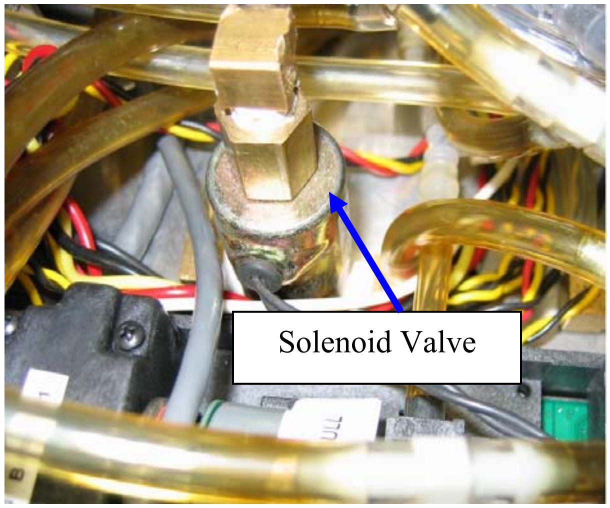


Figure D18. The Solenoid Valve Inside the Montana System

D.5.2.1 *Criteria for Detecting and Correcting Zeroing Effects*

The criteria of detecting and correcting zeroing effects in a database are composed of two steps. In the first step, the periods in which zeroing may affect emissions data are indicated in a given database. A visual basic program was written with this purpose by NCSU team.

Computer of the Montana system separately records operating status of each of the analyzers in a second-by-second basis. In an output emission data file given by the Montana system, the code of "3,000,000" represents that an analyzer is properly measuring exhaust gases and the code of "19,000,000" shows periodic zero calibration. These codes are used to detect periods associated with zeroing effects. Both analyzers have been programmed to have no zero calibration at the same time. The visual basic program screens a given database and indicates emissions records in the 10 seconds before and after each zeroing period.

In the second step, mass emission and fuel consumption rates are recalculated using NO, HC, CO, CO_2, and O_2 concentrations from the analyzer that is not performing zero calibration.

D.5.2.2 *Examples of Dealing with Data Affected by Zeroing*

Table D11 shows an actual example indicating start and end point of zeroing procedure for Analyzer A. In Table 16, zeroing in Analyzer A starts at time of 39,635 seconds and ends at 39,669. Codes of "3,000,000" or "19,000,000" indicate that analyzer is measuring emissions properly or zeroing, respectively.

Table D11. Criteria for Indicating Start and End of Zeroing Procedure

Time (sec)	Analyzer Status Code		
	Analyzer A	Analyzer B	
39,623	3,000,000	3,000,000	Measuring Emissions from the exhaust
39,624	3,000,000	3,000,000	
39,625	3,000,000	3,000,000	*Assuming zeroing period in Analyzer A*
.	.	.	
.	.	.	
39,633	3,000,000	3,000,000	
39,634	3,000,000	3,000,000	
39,635 *	***19,000,000***	***3,000,000***	*Actual Zeroing in Analyzer A*
39,636	19,000,000	3,000,000	
.	.	.	
.	.	.	
39,668	19,000,000	3,000,000	
39,669 *	***19,000,000***	***3,000,000***	
39,670	3,000,000	3,000,000	*Assuming zeroing period in Analyzer A*
39,671	3,000,000	3,000,000	
.	.	.	
.	.	.	
39,679	3,000,000	3,000,000	
39,680	3,000,000	3,000,000	Measuring Emissions from the exhaust
39,681	3,000,000	3,000,000	

D.5.3 Gas Analyzer Freezing

From the previous on-board diagnostics study at NCSU, it is known that emissions readings on the computer screen do not update for several consecutive seconds. While the engine data keep changing, emissions data from the analyzers stay the same for a period of several seconds (Frey *et al.*, 2001; 2005). This error is called "Gas Analyzer Freezing" (GAF). The criteria of detecting and correcting GAF errors involve several steps. In next section, the criteria for detecting and correcting these errors are explained.

D.5.3.1 *Criteria for Detecting Gas Analyzer Freezing Errors*

The criteria of detecting GAF errors deal with the comparison of corresponding engine data and emissions concentrations of benches A and B in two consecutive seconds. If corresponding emission values of Bench A or Bench B are the same, the GAF error is suspected while engine data varies for two consecutive seconds. In order to detect GAF errors, all seconds of data in the database need to be screened consecutively. In other words, if corresponding emissions and engine data are compared at time "*t*" and "*t+1*", then the next step is the comparison of data at time "*t+1*" to "*t+2*".

There is an exceptional situation that a lack of change in measured emissions concentrations might occur when emission readings are lower than the Montana's detection limit, given in Table D8. This situation is not considered as the GAF error in a database, and no correction applies to this case. However, it might be a systematic error if "freezing" occurs in concentrations higher than estimated detection limits. In this situation, the procedure explained in Section D.5.3.3 must be followed in order to correct corresponding error seconds. The criteria of detecting GAF error is defined as:

$$GAF_{t,\,t+1} = \begin{cases} 1 & C_{i,t} = C_{i,t+1} > DL_i,\ ED_{k,t} \neq ED_{k,t+1} \\ 0 & \text{otherwise} \end{cases} \tag{15}$$

where,

- $GAF_{t,\,t+1}$ = Gas analyzer freezing error at time t and $t+1$
- $C_{i,\,t}$ = Concentration of emission i at time t; i=NO (ppm), HC (ppm), CO (*vol*-%), CO_2(*vol*-%), O_2 (*vol*-%)
- $C_{i,\,t+1}$ = Concentration of emission i at time $t+1$; i= NO (ppm), HC (ppm), CO (*vol*-%), CO_2 (*vol*-%), O_2 (*vol*-%)
- $ED_{k,\,t}$ = Engine data k at time t; k = engine speed(rpm), MAP(kPa), IAT($^{\circ}$C)
- $ED_{k,\,t+1}$ = Engine data k at time $t+1$; k = engine speed (rpm), MAP(kPa), IAT($^{\circ}$C)
- DL_i = Detection limit of the Montana system to measure emission i, given in Table 7; i= NO(ppm), HC(ppm), CO(*vol*-%), CO_2(*vol*-%), O_2(*vol*-%)

D.5.3.2 *Criteria of Correcting Gas Analyzer Freezing Errors*

The objective of this section is to explain corrections applied to GAF errors. In each two consecutive seconds of data, the following eight cases might be observed considering GAF errors:

- Case I — Bench A is experiencing GAF errors and Bench B is measuring without any errors
- Case II — Bench A is experiencing GAF errors and Bench B is zeroing
- Case III — Bench A is measuring without any error errors and Bench B is zeroing
- Case IV — Bench B is experiencing GAF errors and Bench A is measuring without any errors
- Case V — Bench B is experiencing GAF errors and Bench A is zeroing
- Case VI — Bench B is measuring without any error errors and Bench A is zeroing
- Case VII — Both benches are experiencing GAF errors
- Case VIII — None of benches are experiencing GAF errors

Cases I and IV are similar. In both cases, one bench is experiencing GAF errors while the other bench is measuring emissions without any error. In these cases, mass emissions and fuel consumption rates must be recalculated based upon the concentration values measured by the bench which is free of any errors.

Cases II and V refer to the situation in which one bench includes error seconds while the other bench is performing periodic zero calibration. In these two cases, mass emission rates cannot be recalculated based on the invalid reading of the other bench. Mass emission estimates are deleted from the database.

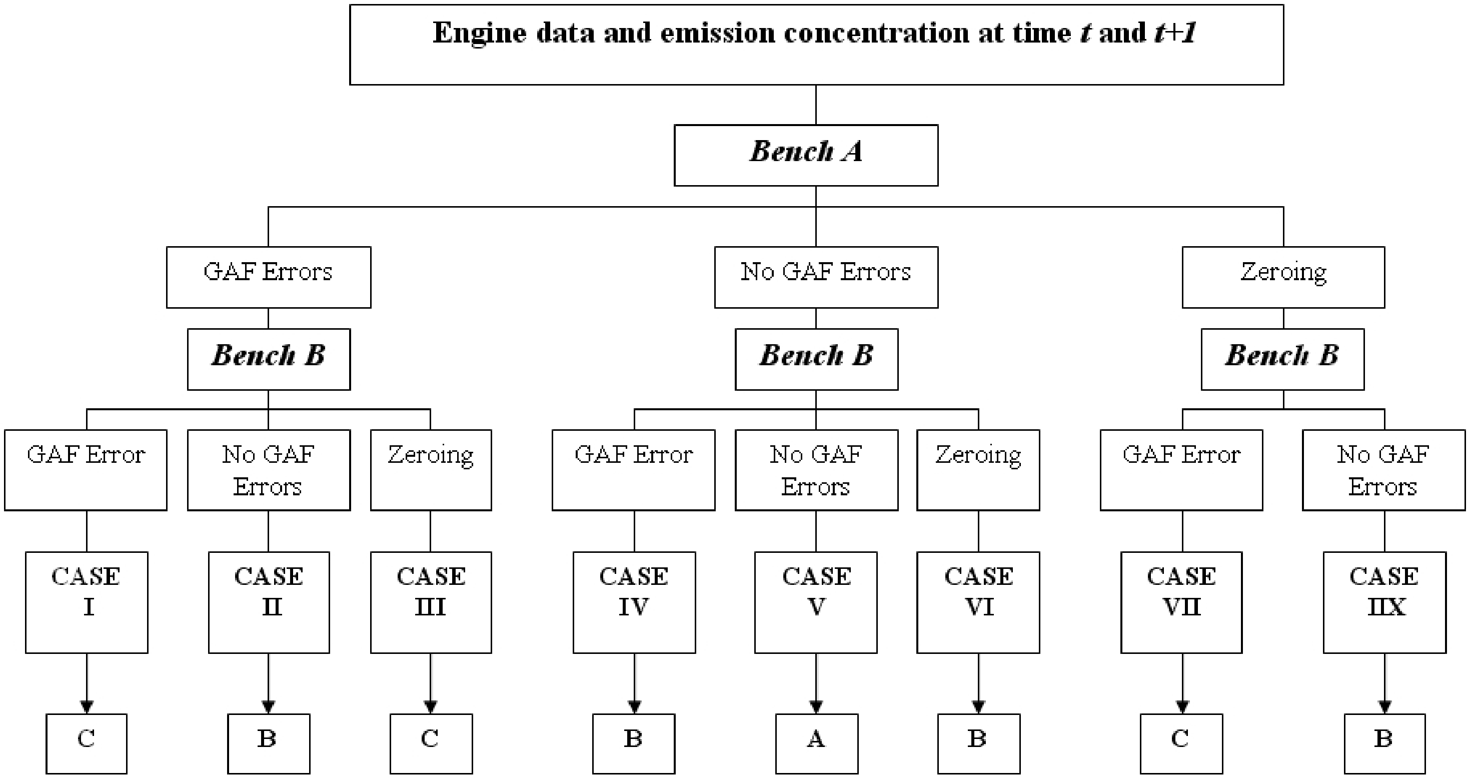
Cases III and VI refer to the normal operation of the analyzers of Montana in which one of the benches is zeroing while the other bench is measuring emissions. In these cases, no correction applies to the data.

Case VII refers to the situation in which GAF errors are observed in both benches. In this case, no analytical procedure of recalculation applies to the emission concentrations values and all mass emission estimates are deleted from the database. Case IIX refers to the normal operation of the Montana system in which both benches are measuring emission concentrations without any errors. Figure D19 summarizes the procedure of detecting and correcting GAF errors in a database.

D.5.3.3 *Application of Freezing Error Checking*

A visual basic program was written to indicate this type of error in the dataset. Results of running the program on the data collected from an excavator on August 25, 2005 showed that analyzer freezing error occurred in 387 out of 23,893 seconds, or 1.62%. The GAF errors observed from five consecutive seconds to no more than eight consecutive seconds. Maximum and minimum concentrations observed in error seconds are shown in Table D12. The results of observing different cases in the database were:

- Case I 39 seconds of errors were observed both benches
- Case II 166 seconds of errors were observed in Bench A, but not in Bench B
- Case IV 143 seconds of errors were observed in Bench B, but not in Bench A
- Case V 23,506 seconds of normal operation of analyzer
- Case III, VI, VII, and IIX: These cases were not observed in the database.



A = In this case, no mass emission estimation is needed.
B = Mass emissions must be recalculated using emission values of the bench which includes no GAF errors.
C = All mass emissions estimations must be removed from the database.

Figure D19. Flow Diagram of the Criteria of Detecting and Correcting Freezing Errors in a Database

Table D12. Pollutants Ranges in Observed GAF Error Seconds

Pollutants	Variations of Concentrations	
	Minimum	**Maximum**
NO as Equivalent NO_2	271	388
HC (ppm)	3	27
CO (*vol*-%)	0.006	0.014
CO_2 (*vol*-%)	1.82	2.43

D.5.4 <u>Negative Emissions Values</u>

Negative pollutant concentrations are sometimes reported by the gas analyzers. Because of random measurement errors, some of the measured concentrations might have negative values that are not statistically different from zero (Frey *et al.*, 2002). In this case, negative values are not associated with any errors. Thus, some negative values of emission readings may be due to the random variation of the instruments. However, in some cases, negative values may indicate a data quality problem.

D.5.4.1 *Criteria for Detecting and Correcting Negative Values*

The criteria for detecting negative values are identified based on the level of precision of the Montana system. Negative values typically occur when the emissions are in low concentrations that are not significantly different from zero. Using the levels of precision presented in Table D7, the criteria for acceptable negative values (ANV) for each pollutant are defined (see Table D13).

Table D13. Acceptable Negative Values (ANV) for Each Pollutant

Pollutant	ANV Value
NO as Equivalent NO_2	-25 ppm
HC	-14 ppm
CO	-0.02 *vol*-%
CO_2	-0.3 *vol*-%

For example, NO has a ± 25 ppm level of precision. Thus, the NO concentration is expected to measure as low as -25 ppm when the true value of NO is a low concentration (such as 0 ppm). Therefore, ANV_{NO} = -25 ppm. For HC concentrations, ± 14 ppm level of precision was chosen. Therefore, ANV_{HC} = -14 ppm. If negative values are larger in magnitude than ANV, this means systematic errors are possibly occurring. For example, if the observed concentration of NO is reported as -30 ppm, this is beyond the range of acceptable negative values. Considering the ANV for each pollutant in comparison to measured values, several cases are defined for identifying and correcting negative concentration errors as shown in Figure D20.

Description for Each Case in Figure D20

Case I refers to situations in which readings from both Analyzers A and B are between ANV and zero. In these situations, concentrations are assigned to zero and emission rates are recalculated based on the new values.

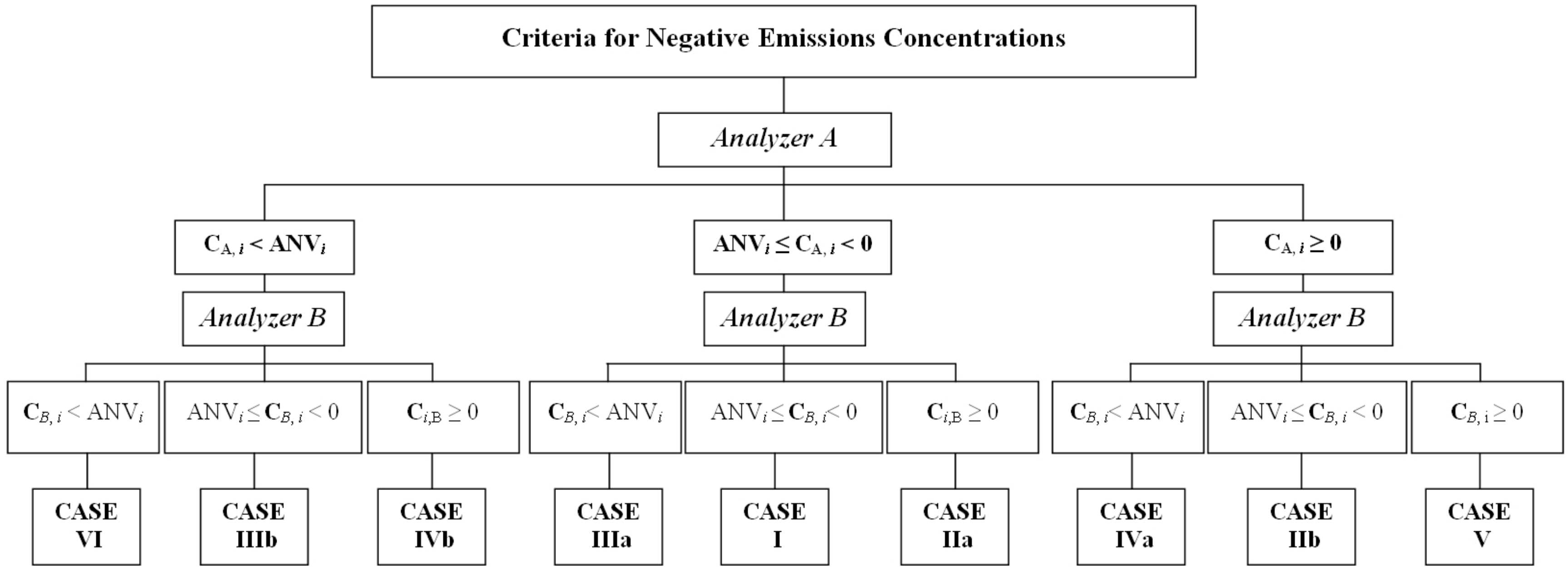
In Cases IIa and IIb, readings from one analyzer are between ANV and zero, while the others are greater than, or equal to, zero. The values between ANV and zero are assigned to zero, and the average between two analyzers is used to recalculate emission rates. For example, if the HC in Analyzer A is -2 ppm and Analyzer B measures 10 ppm, then the average emission concentration is 5 ppm. Emission rates are recalculated based on the new readings.

In Cases IIIa and IIIb, readings from one analyzer are between ANV and zero, while the others are below ANV. In this case, the values between ANV and zero are assigned to zero, and emission rates are recalculated based on the new assigned values.

In Cases IVa and IVb, readings in one analyzer are less than ANV but are greater than, or equal to, zero in the other. In these cases, emission rates are recalculated based on the positive values. For example, if the HC in Analyzer A is -70 ppm but 32 ppm in Analyzer B, the emission rate is recalculated based on the HC reading from Analyzer D.

Case V refers to normal operation of the Montana system in which both readings are greater than, or equal to, zero. Then the averages of the two analyzers are used for estimating emission rates.

Case VI illustrates both analyzers having less than ANV; in this case, emissions concentrations should be excluded from the database.



ANV_i = Acceptable Negative Values for pollutant *i*; the ANVs for each pollutant are shown in Table 7

$C_{A,i}$ = Concentration of pollutant *i* as measured by Analyzer A

$C_{B,i}$ = Concentration of pollutant *i* as measured by Analyzer B

Figure D20. Diagram for the Criteria of Acceptable Negative Values (ANV) for Each Pollutant, and Correction Methods

Solutions for Each Case in Figure D20

- Case I — Assign emission concentration of pollutant *i* to zero, and recalculate emission rates: *i* = NO (ppm), HC (ppm), CO (*vol*-%), CO_2 (*vol*-%)
- Case IIa — Assign emission concentration $C_{i,A}$ to zero, and average concentrations $C_{i,A}$ and $C_{i,B}$ to recalculate emission rates
- Case IIb — Assign emission concentration $C_{i,B}$ to zero, and average concentrations $C_{i,A}$ and $C_{i,B}$ to recalculate emission rates
- Case IIIa — Assign emission concentration $C_{i,A}$ to zero, and recalculate emission rates based on the new assigned value of $C_{i,A}$
- Case IIIb — Assign emission concentration $C_{i,B}$ to zero, and recalculate emission rates based on the new assigned value of $C_{i,B}$
- Case IVa — Recalculated emissions rates using the concentration of pollutant *i* from Analyzer A
- Case IVb — Recalculated emissions rates using the concentration of pollutant *i* from Analyzer B
- Case V — Normal operation of Montana system; no additional recalculation required
- Case VI — Exclude emissions concentrations from the database

D.5.4.2 *Application of ANV to Real-World Data*

A visual basic program was written to detect ANV errors in the dataset. This program was applied to data collection for an excavator tested on August 25, 2005. ANV errors were not detected for NO, CO, or CO_2. However, 0.33% (79 of 23,829 seconds) of HC concentrations was below ANV; this data was collected early when the engine was idling. Typically, idling is one of the operating modes that can produce the lowest emissions (Frey and Kim, 2005). Table D14 shows the results before and after removing rows associated with ANV errors. Total and average emissions were recalculated after 79 rows associated with ANV errors were removed. Based on Table D14, NO, CO, and CO_2 total emissions did not change. HC total emissions and average emission rates changed by 0.10%.

Table D14. Total Emissions and Average Emission Rates[a] Before and After Removing Rows Associated with Acceptable Negative Value (ANV) Errors

Pollutants	Total Emissions		Average Emission Rates	
	Before (g)	After (g)	Before (g/sec)	After (g/sec)
NO as Equivalent NO_2	2,662	2,662	0.1117	0.1117
HC	146.0	146.1	0.00614	0.00615
CO	270.0	270.0	0.0113	0.0113
CO_2	221,900	221,900	9.311	9.311

[a] Data were used from a 1999 excavator with 8.0 liter engine, tested for 23,829 seconds on August 25, 2005

D.6 Identification and Evaluation of the Effects of Air Leakage on Data Quality

The purpose of this section is to develop a quality assurance procedure in order to determine whether an air leakage problem exists in the Montana system and how the leakage affects the mass emission rate (g/sec). Leakage might be observed either in the sampling hoses or inside the main unit of the Montana system. When leakage occurs, air enters the sampling system upstream of the gas analyzers and, therefore, more excess air appears in the exhaust flow. To indicate the possibility of a leakage occurrence, the air-to-fuel ratio (AFR) is used as an indicator.

D.6.1 Air-to-Fuel Ratio

The mass-basis ratio of intake air to fuel consumption is known as the "Air-to-Fuel Ratio (*AFR*)". In order to estimate *AFR* for a diesel engine, the mass balance of diesel combustion should be considered. Generally, a diesel engine operates with a fuel lean mixture of fuel and air in which there is excess air. For general combustion, the chemical mass balance is:

$$CH_xO_z + u_t(0.21O_2 + 0.79N_2) \rightarrow b_tCO_2 + c_tCO + d_tC_6H_{14} + e_tNO + f_tH_2O + g_tO_2 + h_tN_2 \qquad (16)$$

where,

CH_xO_z = equivalent molecular formula of fuel
$u_t, b_t, c_t, d_t, e_t, f_t, g_t, h_t$ = stoichiometric coefficient of combustion for time t

The air-to-fuel ratio (*AFR*) is the ratio of mass of air to mass of fuel input into the engine:

$$AFR = \frac{M_{a,t}\left(\frac{mole}{s}\right) \times y_{O2,t,in} \times 32\left(\frac{g}{moleO_2}\right) + M_{a,t} \times y_{N2,t,in} \times 28\left(\frac{g}{moleN_2}\right)}{M_{f,t}\left(\frac{mole}{s}\right) \times (12 + x + 16z)\left(\frac{g}{moleCH_xO_z}\right)} \qquad (17)$$

where

AFR = air-to-fuel ratio (gram Air/gram fuel)
$M_{a,t}$ = intake air molar flow rate (mole/sec) for time t assumed to be a mixture of 21 vol-% O_2 and 79 vol-% N_2
$M_{f,t}$ = fuel molar flow rate (mole/sec) for time t
$y_{O2,t,in}$ = mole fraction of O_2 (0.21) in the ambient air on a dry basis for time t
$y_{N2,t,in}$ = mole fraction of N_2 (0.79) in the ambient air on a dry basis for time t

The intake air molar flow rate (M_a) is estimated based on the engine data, including engine speed, intake air temperature, intake manifold air pressure, engine displacement, compression ratio, and engine volumetric efficiency. Thus, the intake air molar flow rate is calculated as:

$$M_a = \frac{\left(P_M - \frac{P_B}{ER}\right) \times EV \times \left(\frac{ES}{120}\right)}{R \times (T_{\text{int}} + 273.15)} \times \eta_{ev} \tag{18}$$

where,

ER = engine compression ratio
ES = engine speed (RPM)
EV = engine volume (liters)
M_a = intake air molar flow rate (mole/sec) assumed to be a mixture of 21 vol-% O_2 and 79 vol-% N_2
P_M = manifold absolute pressure (kPa)
P_B = barometric pressure (typically 101kPa)
R = ideal gas constant (8.314 kPa-l/mol-k)
T_{int} = intake air temperature (^oC)
η_{ev} = engine volumetric efficiency (typically 0.95)

In order to estimate fuel flow rate (M_f), dry exhaust flow rate (M_e), Equations 19, 20 and 21 present the mass balance of element C, H and O based on intake air flow rate (M_a), fuel flow rate (M_f), dry exhaust flow rate (M_e), and exhaust water flow rate (M_w):

For C: $$1 \times M_{f,t} = y_{CO2,t,dry} \times M_{e,t} + y_{CO,t,dry} \times M_{e,t} + 6 \times y_{C6H14,t,dry} \times M_{e,t} \tag{19}$$

For H: $$x \times M_{f,t} = 14 \times y_{C6H14,t,dry} \times M_{e,t} + 2 \times M_{w,t} \tag{20}$$

For O: $$z \times M_{f,t} + 2 \times 0.21 \times M_{a,t} = 2 \times y_{CO2,t,dry} \times M_{e,t} + y_{CO,t,dry} \times M_{e,t} + M_{w,t} + 2 \times y_{O2,t,dry} \times M_{e,t} + y_{NO,t,dry} \times M_{e,t} \tag{21}$$

where

$M_{e,t}$ = dry exhaust molar flow rate (mole/sec) for time t
$M_{f,t}$ = molar flow rate of the fuel (mole/sec) for time t
$M_{w,t}$ = molar flow rate of water (mole/sec) for time t
$y_{i,t,dry}$ = mole fraction of species *i* on dry basis (gmol/gmol dry exhaust gases) for time t
x, z = elemental composition of fuel CH_xO_z

The fuel molar flow rate (M_f) can be estimated based on the dry exhaust flow rate (M_e) from Equation 19:

$$M_{f,t} = \left(y_{CO2,t,dry} + y_{CO,t,dry} + 6 \times y_{C6H14,t,dry}\right) \times M_{e,t} \tag{22}$$

The exhaust molar flow rate on a dry basis (M_e) is estimated based on the intake air molar flow rate (M_a). The relation between M_e and M_a can be derived from Equations 19, 20 and 21 as follow:

$$M_{e,t} = \frac{2 \times 0.21 \times M_{a,t}}{\left(2 + \frac{x}{2} - z\right) y_{CO2,t,dry} + \left(1 + \frac{x}{2} - z\right) y_{CO,t,dry} + 2 y_{O2,t,dry} + y_{NO,t,dry} + \left(\frac{x}{2} - 7 - 6z\right) y_{C6H14,t,dry}} \tag{23}$$

Therefore, air-to-fuel ratio (AFR) in Equation 17 can be rewritten based on M_e and M_a:

$$AFR_t = \frac{M_{a,t}\left(\frac{mole}{s}\right) \times y_{O2,t,in} \times 32\left(\frac{g}{moleO_2}\right) + M_{a,t} \times y_{N2,t,in} \times 28\left(\frac{g}{moleN_2}\right)}{\left(y_{CO2,t,dry} + y_{CO,t,dry} + 6 \times y_{C6H14,t,dry}\right) M_{e,t}\left(\frac{mole}{s}\right) \times \left(12 + x + 16z\right)\left(\frac{g}{moleCH_xO_z}\right)} \tag{24}$$

McCormick *et al.* (2001) reported the elemental composition of diesel fuel is 86.6 wt-% of carbon and 13.4 wt-% of hydrogen. This corresponds to an equivalent molecular formula of $CH_{1.857}$. The default value of diesel fuel property in the Montana system is 86.4 wt-% of carbon and 13.6 wt-% of hydrogen which differs from McCormick *et al.* (2001) by 0.2%. Because there is no reference for the default value of the Montana system, $CH_{1.857}$ based on data reported by McCormick *et al.* (2001) was used to do the mass balance of diesel combustion.

For biodiesel B20, NREL (2001) reported the elemental composition of B20 is 84.6 wt-% of carbon, 13.4 wt-% of hydrogen, and 2.0 wt-% of oxygen. This corresponds to an equivalent molecular formula of $CH_{1.901}O_{0.284}$.

For biodiesel B100, the elemental composition of B100 is obtained from the average of three studies (Graboski et al., 2003, McDonnald et al., 1995, and Schmaucher, 1993). The average elemental composition of B100 is 76.9 wt-% of carbon, 12.1 wt-% of hydrogen, and 11.0 wt-% of oxygen. This corresponds to an equivalent molecular formula of $CH_{1.888}O_{1.717}$. Table D15 shows the equivalent molecular formula for petroleum diesel, biodiesel B20, and biodiesel B100.

Table D15. Equivalent Molecular Formulas for Diesel, Biodiesel B20, and Biodiesel B100

Fuel	CH_xO_z	
	x	z
Diesel	1.857	0
B20	1.901	0.284
B100	1.888	1.717

D.6.2 Leakage Effect on Mass Emission Rate

The purpose of this section is to evaluate the effects of air leakage on the estimated emission rates. When there is leakage, mole fractions of CO_2, CO, HC and NO ($y_{CO2,t,dry}$, $y_{CO,t,dry}$, $y_{C6H14,t,dry}$, $y_{NO,t,dry}$) in the dry exhaust are decreased. However, mole fractions of O_2 and N_2 ($y_{O2,t,dry}$, $y_{N2,t,dry}$) will increase due to additional air into the system. When there is a leakage in the measurement system, the coefficient "u_t" in Equation 16 will increase. Table D16 shows measured data from a generator tested on November 11, 2005 including the ppm or volume percent of exhaust gases and the calculated molar ratios per mole of carbon consumed. Table D17 shows the NO, HC, CO, CO_2 and O_2 concentrations of real data and the corresponding concentrations that would be observed for other values of the coefficient "u_t."

Table D16. An Example of One Second of Emission Data from a Generator Tested on November 11, 2005

	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
Concentration on a dry basis	295	14	0.025	2.42	17.4
	$y_{NO,t,dry}$	$y_{C6H14,t,dry}$	$y_{CO,t,dry}$	$y_{CO2,t,dry}$	$y_{O2,t,dry}$
Mole fraction in the dry exhaust	2.95E-04	1.4E-05	2.5E-04	2.42E-02	0.174

Table D17. Example Case Study of the Predicted Effect of Air Leakage on Observed Concentrations of Pollutants from a Generator Tested on November 11, 2005

Ratio of Oxygen to Fuel (gmol Air/gmol C)[a,b]	AFR [c] (g air/g fuel)	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
u_t = 16.2	84	295	14.0	0.025	2.42	17.4
u_t = 19.0	98	255	12.1	0.025	2.45	17.6
u_t = 29.0	150	169	8.04	0.022	2.09	18.1
u_t = 37.9	196	127	6.02	0.014	1.39	19.1
u_t = 56.9	295	84	4.01	0.011	1.04	19.6
u_t = 75.9	393	63	3.00	0.007	0.69	20.1
u_t = 94.8	491	51	2.40	0.005	0.52	20.3

[a] First row is based on an observed measurement. Subsequent rows are based on other scenarios for air leakage

[b] u_t refers to coefficient of Equation 16 for time t

[c] AFR = Air-to-Fuel ratio (g air/g fuel)

For each second, the Montana system estimates mass emissions rates (g/sec) based upon the mole fraction on a dry basis, dry exhaust molar flow rate and molar weight of exhaust gas:

$$E_{i,t} = y_{i,t,dry} \times M_{e,t} \times MW_i \tag{25}$$

where,

$y_{i,t,dry}$ = mole fraction of species *i* (gmol/gmol dry exhaust gases) on a dry basis for time t

$E_{i,t}$ = mass emission rate of pollutant *i* (g/sec), i = NO, HC, CO, CO_2, for time t

$M_{e,t}$ = exhaust molar flow rate (mole/sec) on a dry basis for time t

MW_i = molecular weight of species i (g/mol)

When there is leakage, the mole fractions of NO, HC, CO and CO_2 decrease as shown in Table D17. However, the corresponding dry exhaust molar flow rate (M_e) increases due to the excess air. The mass emission rates (g/sec) of each pollutant are calculated based on Equation 25 and an example based on data from a generator is shown in Table D18. Whether there is leakage, the mass emission rates are exactly the same. Therefore, even when there is leakage in the measurement system, the mass emission rate may still be valid.

Table D18. Mass Emission Rate of Each Pollutant at Different Ratio of Oxygen to Fuel from a Generator Tested on November 11, 2005

Ratio of Oxygen to Fuel (gmol Air/gmol C)[a,b]	AFR [c]	M_e (mole/sec)	NO as Equivalent NO_2 (g/sec)	HC (g/sec)	CO (g/sec)	CO_2 (g/sec)
u_t = 16.2	84	2.48	0.0341	0.0030	0.0176	2.673
u_t = 19.0	98	2.90	0.0341	0.0030	0.0176	2.673
u_t = 29.0	150	4.45	0.0341	0.0030	0.0176	2.673
u_t = 37.9	196	5.83	0.0341	0.0030	0.0176	2.673
u_t = 56.9	295	8.77	0.0341	0.0030	0.0176	2.673
u_t = 75.9	393	11.70	0.0341	0.0030	0.0176	2.673
u_t = 94.8	491	14.63	0.0341	0.0030	0.0176	2.673

[a] First row is based on an observed measurement. Subsequent rows are based on other scenarios for air leakage

[b] u_t refers to coefficient of Equation 16 for time t

[c] AFR = Air-to-Fuel ratio (g air/g fuel)

D.6.3 Criteria for Air-to-Fuel Ratio

The purpose of this section is to develop evaluation procedures based on air-to-fuel ratio (*AFR*) for data quality in the dataset. Taylor (1985) and Thiessen *et al.* (1996) reported that the normal range of air-to-fuel ratio for diesel engine is from 25 to over 100. Figure D21 shows the cumulative frequency of air-to-fuel ratio based on field measurement data for six examples of construction equipment. More than 99.9% of the second-by-second AFRs are within the range of 25 to 150. Based on this information, a judgment was made that AFR values between 25 and 150 are representative of normal operations. Conversely, values outside of this range are not expected and require additional evaluation. The typical expected ranges that correspond to the acceptable AFR range are 9.1 to 19.2 vol-% for O_2 and 1.4 to 8.7 vol-% for CO_2. The expected range may vary due to the different concentration of CO and HC in the dry exhaust.

As previously described, the mass emission rates are unchanged whether there is leakage. However, when the AFR is high, the mole fraction of each pollutant is low. In such a situation, random measurement error in the mole fraction may cause significant uncertainty in the mass emission rate (g/sec). Thus, there is a need to evaluate the data quality of the mass emission rate. Two examples are shown to represent two different scenarios. The first example is for a case in which all NO, CO, HC, and CO_2 concentrations are within the precision of the Montana system as shown in Table D19.

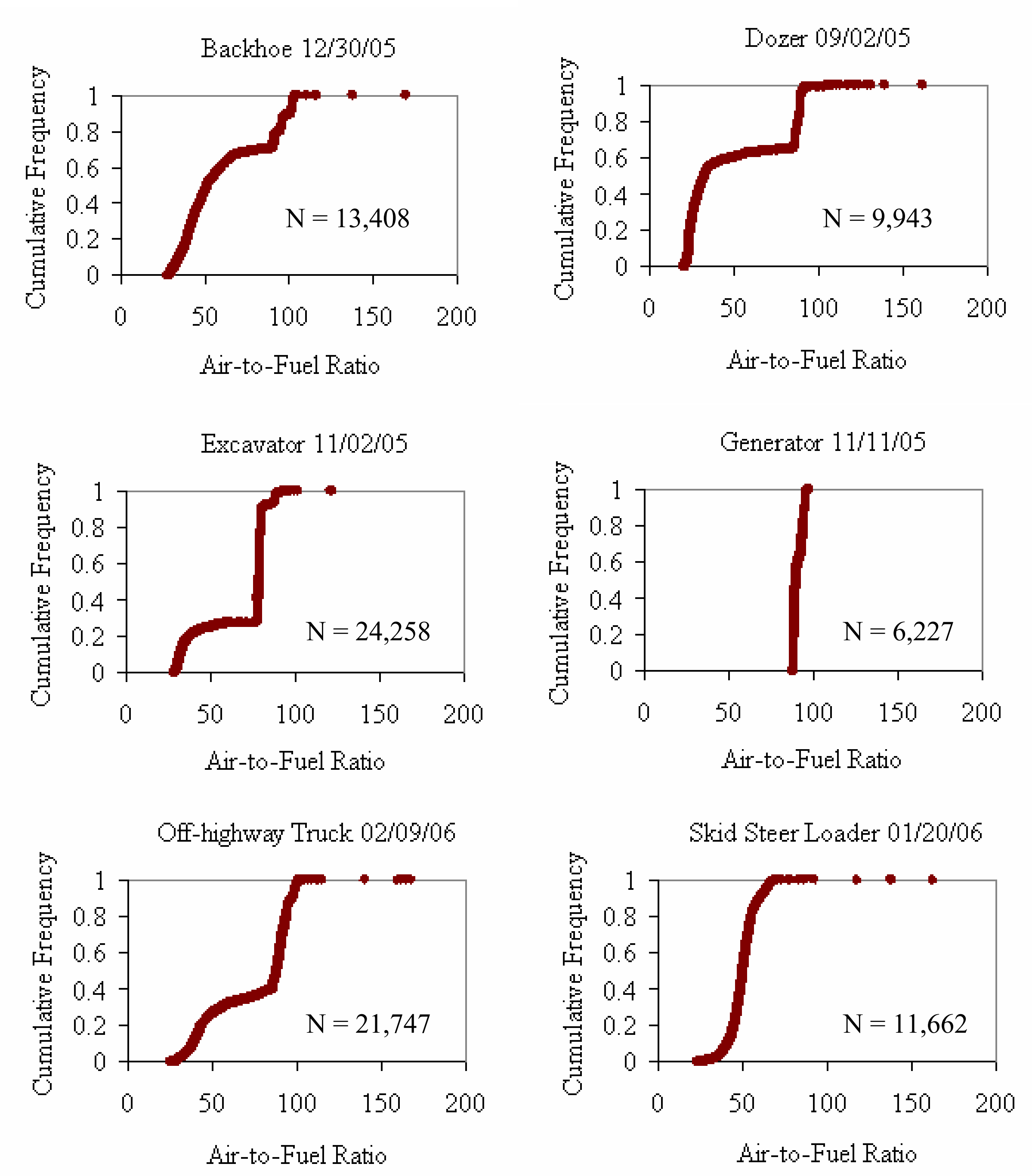


Figure D21. Cumulative Frequency of Air-to-Fuel Ratio for Different Construction Equipment, with Type of Equipment and Data of Field Measurement Indicated

Table D19. Case Study of One Second of Emission Data below the Precision of the Montana System

	Emission Data			
	NO as Equivalent NO_2 (ppm)	CO (vol-%)	HC (ppm)	CO_2 (vol-%)
Concentration on a dry basis	20	0.007	3	0.20
Precision of the Montana System	±25	±0.02	±4	±0.30

The second example shows typical tailpipe emissions from an off-highway truck tested on February 09, 2006. The emission data are given in Table D20. All of the NO, CO, HC, and CO_2 concentrations are above the precision of the Montana system. In order to understand the leakage effect on the mass emission rate, the molar ratio of intake air to C (u_t) is varied from 2.23 to 41, which corresponds to AFR ranging from 25 to 459.

Theoretically, when the pollutant concentration is below the precision of the Montana system, the random measurement error may result in larger uncertainty in the mass emission rate. An uncertainty analysis is conducted for both scenarios to investigate the uncertainty range of mass emission rates due to the precision of the Montana system.

Table D20. Case Study of the Observed and Predicted Emission Data on a Dry Basis from an Off-Highway Truck Tested on February 09, 2006

Ratio of Oxygen to Fuel (gmol Air/gmol C)[a,b]	AFR [c] (g air/g fuel)	NO_{dry} as Equivalent NO_{2dry} (ppm)	HC_{dry} (ppm)	CO_{dry} (%)	$CO_{2,dry}$ (%)
$u_t = 2.23$	25	647	28	0.610	7.33
$u_t = 8.20$	92	172	7.6	0.163	1.95
$u_t = 13.4$	150	105	4.6	0.099	1.19
$u_t = 16.4$	184	86	3.8	0.081	0.97
$u_t = 24.6$	275	57	2.5	0.054	0.65
$u_t = 32.8$	367	43	1.9	0.041	0.48
$u_t = 41.0$	459	34	1.5	0.032	0.39

[a] First row is based on an observed measurement. Subsequent rows are predicted based on other scenarios for air leakage
[b] u_t refers to coefficient of Equation 16 for time t
[c] AFR = Air-to-Fuel ratio (g air/g fuel)

The mass emission rates are calculated based on the engine data and pollutant concentrations. Details of mass emission rates are discussed in Section D.6.1. Pollutant concentrations are the inputs and mass emission rates are the outputs for the uncertainty analysis. The first step of uncertainty analysis is to define the probability distribution of all the inputs. Pollutant concentrations are assumed to be normal distributions with the indicated mean and standard deviation. The mean value of pollutant concentrations are shown in Tables D-14 and D-15. The standard deviation of each pollutant concentration is one-half of the precision. Table D21 shows input assumptions for uncertainty analysis based on one second of data from Table D19 and one second of data from Table D20.

Table D21. Input Assumptions for Uncertainty Analysis

Pollutant	Case Study					
	Emissions below the Precision			Off-Highway Truck		
	Point Estimate[a]	Distribution	Parameter[b]	Point Estimate[a]	Distribution	Parameter[b]
NO as Equivalent NO2 (ppm)	20	Normal	Mean=20 SD=12.5	600 ppm	Normal	Mean=600 SD=12.5
HC (ppm)	3.0	Normal	Mean=3 SD=2	27 ppm	Normal	Mean=27 SD=2
CO (vol-%)	0.007	Normal	Mean=0.007 SD=0.01	0.57 %	Normal	Mean=0.57 SD=0.01
CO_2 (vol-%)	0.20 vol-%	Normal	Mean=0.20 SD=0.15	6.81 %	Normal	Mean=6.81 SD=0.15

[a] Point estimate is based on one second of the data shown in Tables 19 and 20
[b] SD = standard deviation

Monte Carlo simulation with 10,000 trials was used to quantify the uncertainty range in the mass emission rates. The simulation was done using the Crystal Ball™ for Microsoft Excel™. Table D22 and D-23 show the uncertainty range of each pollutant emission rate based on one second of data from Table D21.

Table D22 shows the 95% probability range of the mass emission rate when there apparently was air leakage in the Montana system. Air leakage is suspected here because AFR is 867, in excess of expected values. Because the mole fractions of NO, HC, CO, and CO_2 concentrations are below the precision of the Montana system, the uncertainty in the emission rate is in a large range. With such a large range of uncertainty for concentrations and large air leakage, the estimated emission rates here are unreliable.

Table D22. 95% Probability Range of Mass Emission Rates of One Second of Data below the Precision of the Montana System

Ratio of Oxygen to Fuel (gmol Air/gmol C)[a]	AFR[b]	NO as Equivalent NO_2 (mg/sec)	HC (mg/sec)	CO (mg/sec)	CO_2 (g/sec)
		95% Range	95% Range	95% Range	95% Range
u_t = 174	867	2.22 ± 2.75	0.63 ± 0.81	4.78 ± 13.4	0.25 ± 0.32

[a] u_t refers to coefficient of Equation 16 for time t
[b] AFR = Air-to-Fuel ratio (g air/g fuel)

Table D23. 95% Probability Range of Mass Emission Rates of One Second of Data from an Off-Highway Truck Tested on February 09, 2006

Ratio of Air to Fuel (gmol Air/gmol C)[a,b]	AFR[c]	NO as Equivalent NO_2 (mg/sec)	HC (mg/sec)	CO (mg/sec)	CO_2 (g/sec)
		95% Range	95% Range	95% Range	95% Range
u_t = 2.23	25	66.9 ± 2.6	5.5 ± 0.8	387 ± 12	7.26 ± 0.29
u_t = 8.20	92	66.9 ± 9.7	5.5 ± 2.9	387 ± 48	7.26 ± 1.10
u_t = 13.4	150	66.9 ± 14.4	5.5 ± 4.3	387 ± 69	7.26 ± 1.60
u_t = 16.4	184	66.9 ± 19.4	5.5 ± 5.8	387 ± 93	7.26 ± 2.15
u_t = 24.6	275	66.9 ± 29.0	5.5 ± 8.7	387 ± 140	7.26 ± 3.35
u_t = 32.8	367	66.9 ± 40.0	5.5 ± 11.5	387 ± 188	7.26 ± 4.48
u_t = 41.0	459	66.9 ± 49.5	5.5 ± 14.5	387 ± 241	7.26 ± 5.48

[a] First row is based on an observed measurement. Subsequent rows are predicted based on other scenarios for air leakage
[b] u_t refers to coefficient of Equation 16 for time t
[c] AFR = Air-to-Fuel ratio (g air/g fuel)

The case study of an off-highway truck is shown in Table D23. When the AFR is greater than 150, the uncertainty range becomes larger. In this situation, the measurement error of the Montana system may cause larger uncertainty in the emission rates as described in the previous example. Thus, when the AFR is greater than 150, the spreadsheet cell containing the affected emission data will be automatically flagged as a different color by a Visual Basic Macro in Excel. If the pollutant concentration is below the precision of the Montana system, and if AFR exceeds 150, that second of data will be excluded from the dataset.

The following criteria and procedures were established to identify whether unusual values of AFR exist and regarding what actions, if any, to take if an unusual value occurs. The first step is to calculate the AFR_t based upon Equation 24. A choice regarding whether to retain or exclude data associated with large AFR values is made. The steps of the verification procedure are listed below. Figure D22 shows the flow diagram of the verification procedures for the mass emission rate.

The evaluation procedures of air-to-fuel ratio (AFR) include:

1. Calculate second-by-second AFR_t
2. If the AFR_t is less than 150, the data will be kept in the dataset
3. If the AFR_t is greater than 150, the row in Excel that contains the data in question will be flagged with an indicator:
    - If all of the pollutant concentrations are above the precision of the Montana system (0.02 vol-% for CO, 4ppm for HC, 25ppm for NO and 0.3 vol-% for CO_2), the second of data will be kept in the dataset; and
    - If one or more pollutant concentration is less than the precision of the Montana system, the data will be excluded from the dataset.

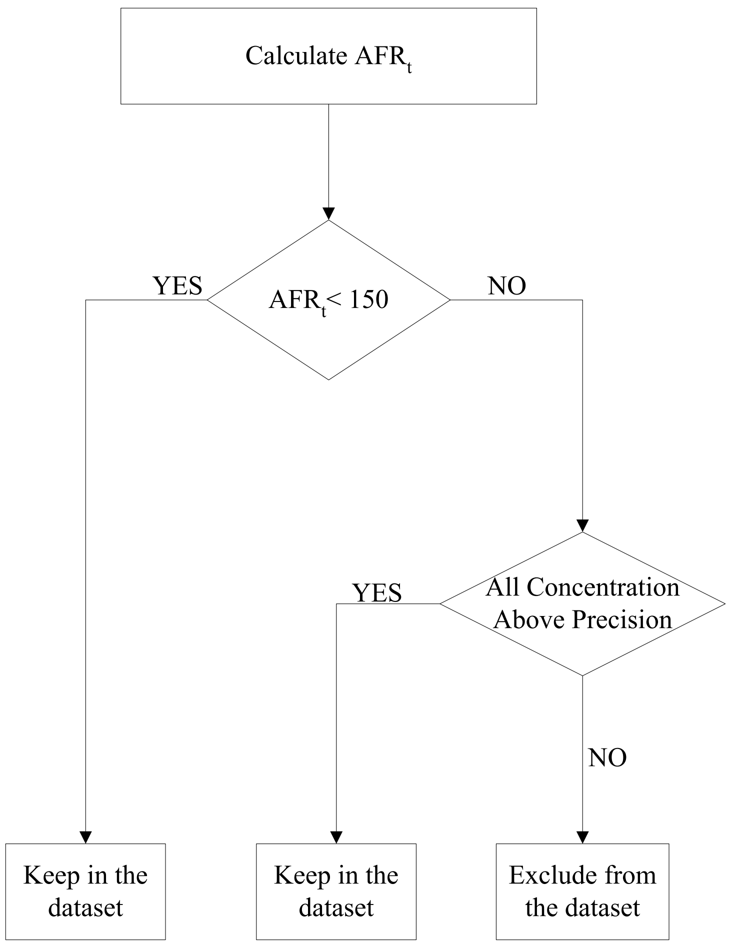


Figure D22. Flow Diagram of the Evaluation Procedures for Air-to-Fuel Ratio

Problems with unusual values of AFR appear to be rare. For example, 97,406 seconds of data from six construction vehicles were evaluated with respect to second-by-second AFR values. As shown in Table D24, only 1090 seconds of these data, or 1.12% of the total amount of data, had AFR>150. Of these unusual values, only 999 seconds had measured concentrations below the precision of the measurements for one or more pollutants. These 999 seconds of data were excluded. Thus, only 1.02 % of data from these six construction vehicles were lost due to unusual AFR values.

Table D24. Application of Criteria for Air-to-Fuel Ratio to Six Pieces of Construction Equipment

Equipment [a]	Field Time (No. of seconds)	AFR>150 (No. of seconds)	AFR>150 and One or More Pollutant Concentrations below the Instrument Precision (No. of seconds)
Backhoe	19,753	94	94
Dozer	10,113	22	20
Excavator	25,932	39	39
Generator	6,569	0	0
Off-Highway Truck	23,138	935	846
Skid Steer Loader	11,901	0	0
Total	97406	1090	999

[a] Based on a Backhoe Tested on December 30, 2005, a Dozer Tested on September 02, 2005, an Excavator Tested on August 26, 2005, a Generator Tested on November 11, 2005, an Off-Highway Truck Tested on February 09, 2006, and a Skid Steer Loader Tested on January 20, 2006

D.7 References

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APPENDIX E: DESCRIPTION OF MACROS DEVELOPED FOR DATA SCREENING AND QUALITY ASSURANCE OF ON-BOARD DATA COLLECTED FROM NONROAD CONSTRUCTION EQUIPMENT

Table of Contents

E.1 Introduction

The objective of this section is to explain the algorithms and computer programs developed for quality checks and preliminary analyses of data. This document provides the user with an interface to communicate with inputs and outputs of the programs. All programs were written in Visual Basic. The programs can be used as the macros incorporated with Microsoft Excel. In this report, NO is reported as equivalent NO_2.

As shown in Figure E1, for raw data collected from nonroad construction equipment, a quality assured database is developed in 19 steps. Sixteen of these steps are performed running macros and three steps are performed manually. Each of the steps in Figure E1 will be explained in the following sections.

E.2 Description of Raw Database

A raw database downloaded from the Montana system is used as input for developing a quality assured database. Table E1 provides descriptions for the variables available in the raw database for data screening and quality assurance purposes. Since the Montana system is used for collecting data from both onroad and nonroad vehicles, there are several fields of data for which no data is collected when measuring emissions from nonroad construction vehicles. These variables are shown in Table E1. For example, no data is collected for vehicle speed or acceleration for nonroad vehicles. Thus, in the database, a zero value is observed for all seconds of the data.

E.3 Getting Start

A Microsoft Excel file named "Data Quality Check and Analysis File (DQCAF)" is used for data quality assurance purposes. All macros have been incorporated in this file as 22 Visual Basic programs. From a raw database, all data needs to be copied and pasted in DQCAF. The list of the macros can be accessed clicking on "Tools" and then "Macros". Figure E2 presents an example of what is seen on the screen before running each of the macros.

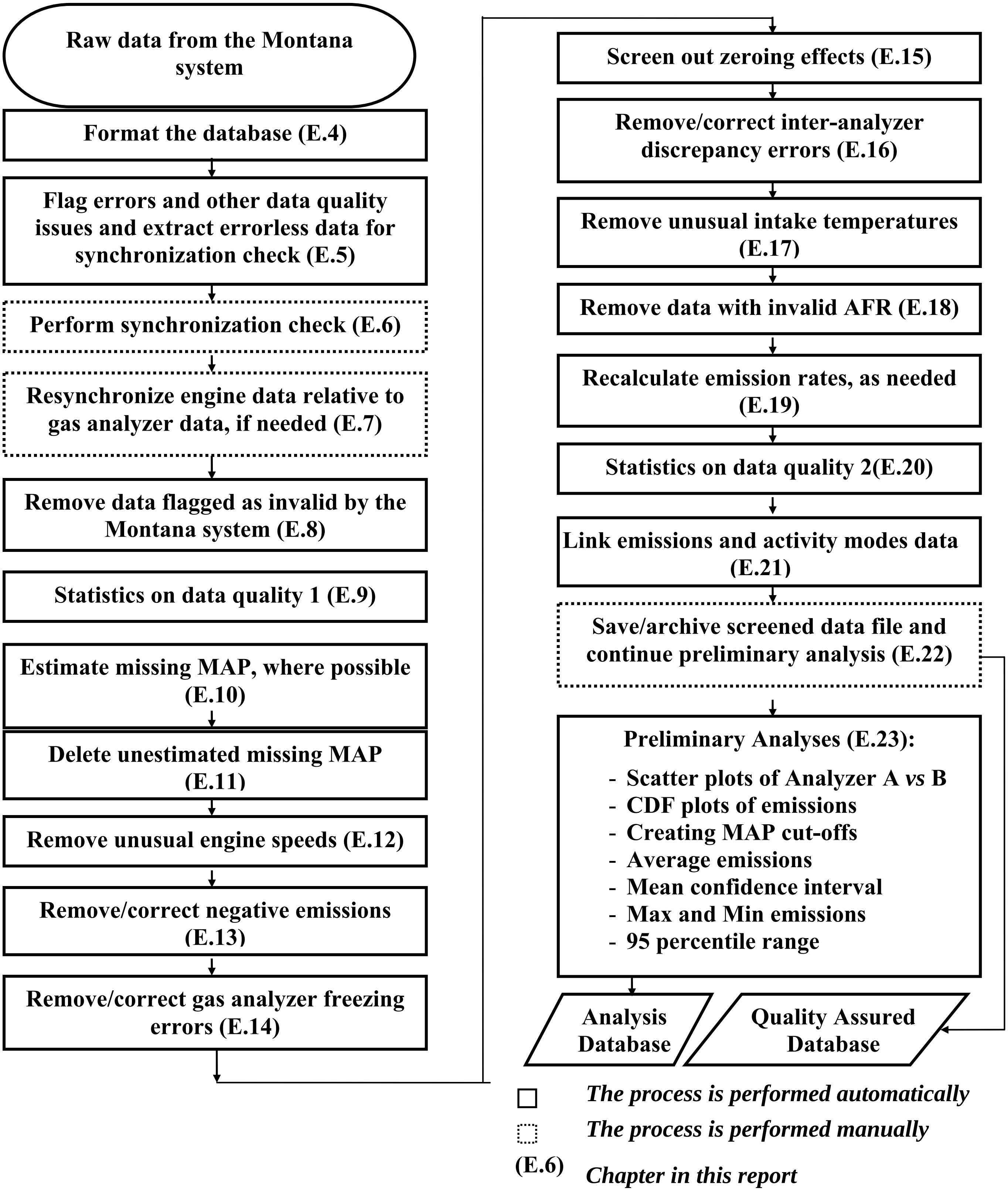


Figure E1. Flow Diagram of Data Quality Assurance and Preliminary Analysis Macros

Table E1. Description of Variables Available for Data Screening and Quality Assurance Checks in a Raw Database

No.	Variable	Variables Available for Screening	No.	Variable	Variables Available for Screening
1	time [s]	Recording time in second	30	HC[g/gal]	Estimated average HC rate
2	valid_g/gal	Validity of data	31	CO[g/gal]	Estimated average CO rate
3	Bag_No	Separating data into bags	32	CO_2[g/gal]	Estimated average CO_2 rate
4	Bag_distance[mi]	Not Available (NA)	33	PM[mg/gal]	Estimated average PM rate
5	Bag_time[s]	Duration of each bag	34	A_Valid	Validity of data of analyzer A
6	mph	NA	35	A_Stats	Operation status of analyzer A
7	accel[mph/gal]	NA	36	A_NOx[ppm]	NO from analyzer A
8	SENSED_RPM	Engine speed	37	A_HC[ppm]	HC from analyzer A
9	SENSED_TEMP[C]	Intake air temperature	38	A_CO[%]	CO from analyzer A
10	SENSED_MAP[kPa]	Manifold absolute pressure	39	A_CO_2[%]	CO_2 from analyzer A
11	eng_rpm	The same as item 8	40	A_O_2[%]	O_2 from analyzer A
12	coolant[C]	NA	41	B_Valid	Validity of data of analyzer B
13	throttle[%]	NA	42	B_Stats	Operation status of analyzer B
14	MAP[kPa]	The same as item 10	43	B_NOx[ppm]	NO from analyzer B
15	IAT[C]	The same as item 9	44	B_HC[ppm]	HC from analyzer B
16	torque[lbf]	NA	45	B_CO[%]	CO from analyzer B
17	intake_air[g/gal]	Mass flow of intake air	46	B_CO_2[%]	CO_2 from analyzer B
18	dry_exh[g/gal]	Mass flow of dry exhaust gas	47	B_O_2[%]	O_2 from analyzer B
19	total_exh_flow[scf]	Total mass flow of exhaust	49		NA – blank column
20	fuel[g/gal]	Estimated fuel flow rate	50	GPS_Fix	GPS Status
21	fuel[mpg]	NA	51	GPS_Satellites	Number of satellites
22	NOx[ppm]	Average NO	52	GPS_time[seconds]	Recording time for GPS
23	HC[ppm]	Average HC	53	GPS_time[hh:mm:ss]	Recording time for GPS
24	CO[%]	Average CO	54	GPS_speed[mph]	NA
25	CO_2[%]	Average CO_2	55	grade[%]	Road grade
26	O2[%]	Average O_2	56	Lon	Longitude
27	PM[%FS]	Particulate Matters in %FS	57	Lat	Latitude
28	PM[mg/m^3]	Particulate Matters in mg/m^3	58	alt[ft]	Altitude
29	NOx[g/gal]	Estimated average NO rate	59	bearing	NA

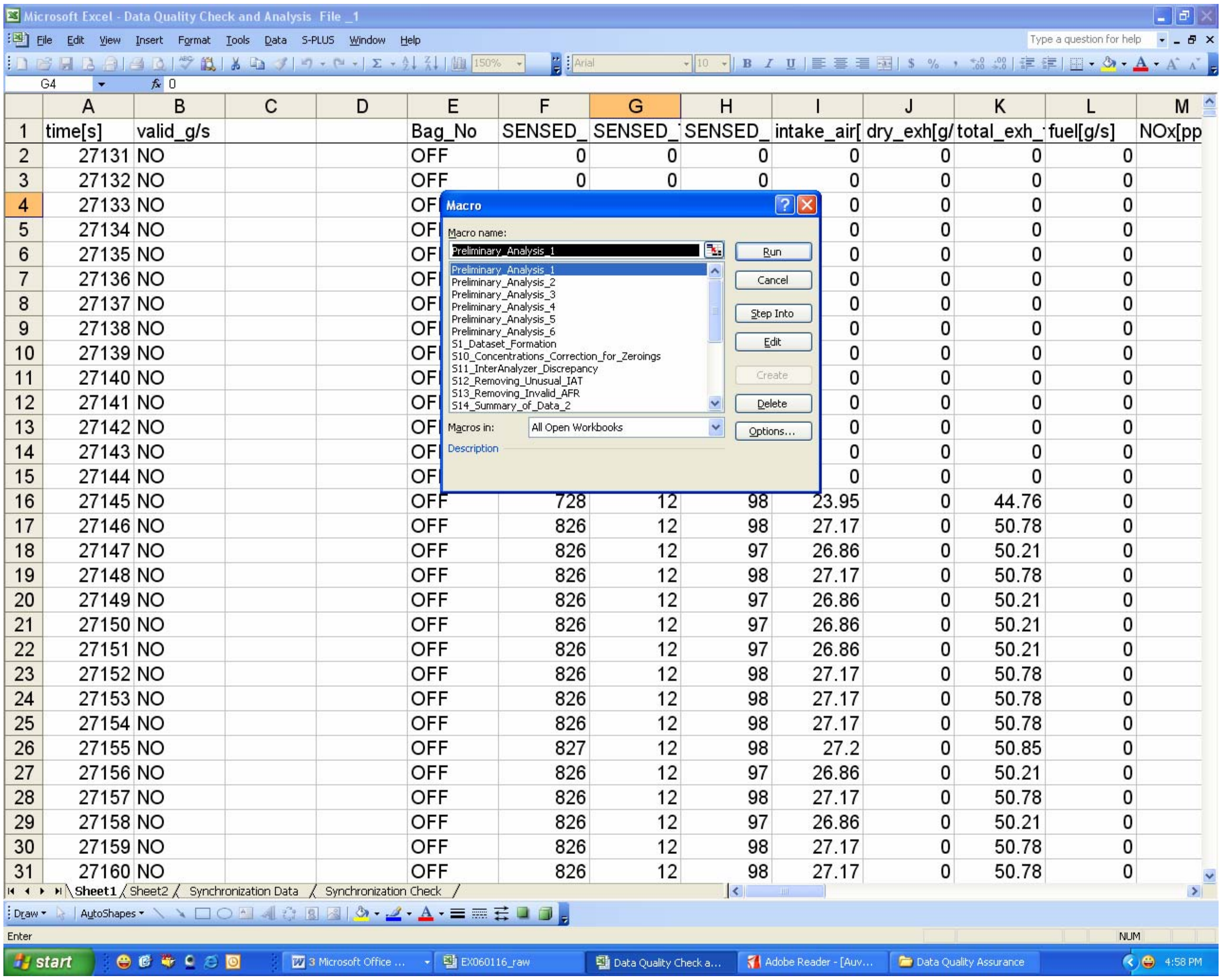


Figure E2. List of the Macros on the Screen before each Run

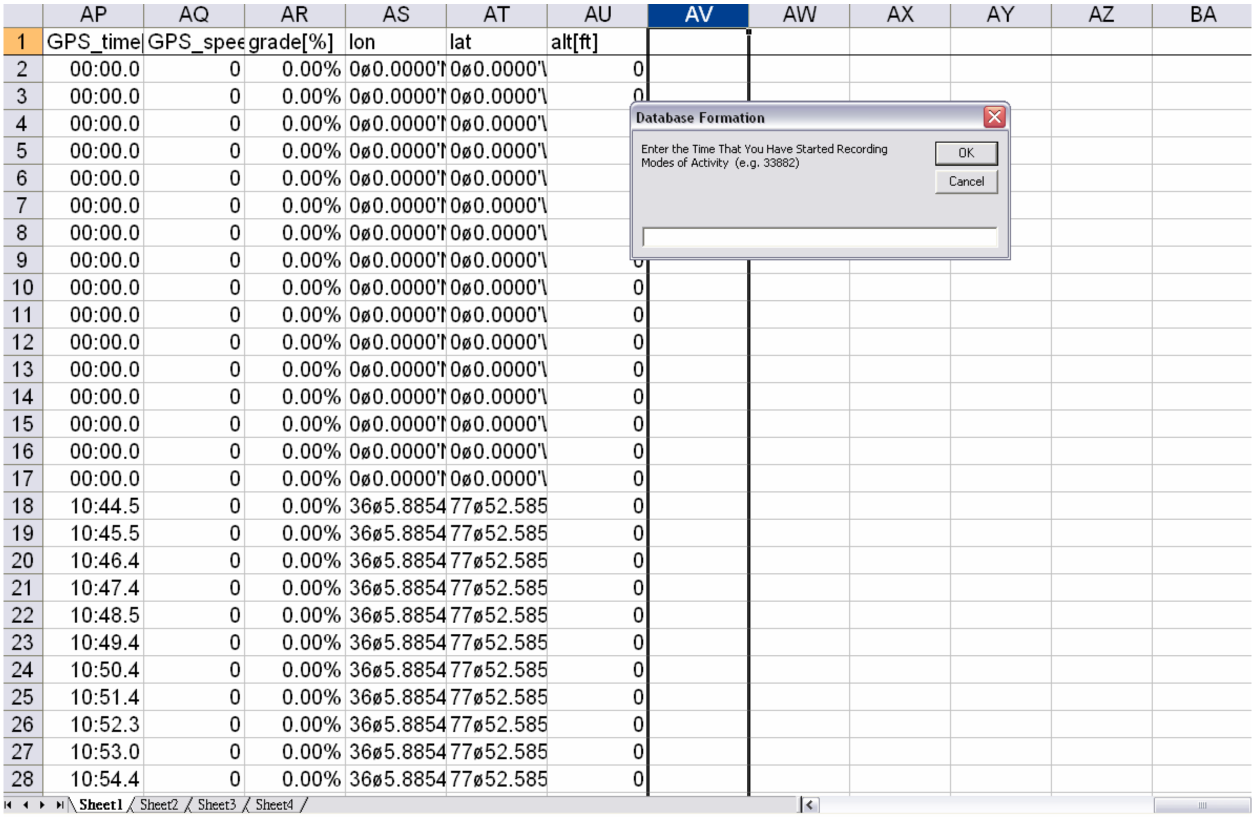
E.4 List of Macros and Manual Steps

This section lists 19 macros and manual steps which were developed for data screening and quality assurance of on-board emission data.

E.4.1 Formatting The Database

Formatting a raw database is performed by the first macro referred to as "S1_Database_Formation." This program creates two columns after the column of "Bag_No". The new columns will be used for modes of activity and time in an "hh:mm:ss" format. Furthermore, the program deletes columns of data for which no data was collected or estimated by the Montana system. These columns are shown as item numbers 4, 6, 7, 12, 13, 16, 21, 49, 54, 55, and 59 in Table E1. The variables in the formatted database are shown in Table E2.

In addition, the macro excludes the Montana system's warm up time from the database. In order to do so, the program will ask the user to enter the time at which recording modes of activity had been started. The user should have this time from another Excel file that contains recorded modes of activity data. Detailed information about this file is provided in Section E.21. The user will be asked to enter the start time through a pop-up window on the screen. Figure E3 presents a picture of what the user will see on the screen.



	AP	AQ	AR	AS	AT	AU
1	GPS_time	GPS_spee	grade[%]	lon	lat	alt[ft]
2	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
3	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
4	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	
5	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	
6	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	
7	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	
8	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	
9	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	
10	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
11	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
12	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
13	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
14	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
15	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
16	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
17	00:00.0	0	0.00%	0ø0.0000'	0ø0.0000'	0
18	10:44.5	0	0.00%	36ø5.8854	77ø52.585	0
19	10:45.5	0	0.00%	36ø5.8854	77ø52.585	0
20	10:46.4	0	0.00%	36ø5.8854	77ø52.585	0
21	10:47.4	0	0.00%	36ø5.8854	77ø52.585	0
22	10:48.5	0	0.00%	36ø5.8854	77ø52.585	0
23	10:49.4	0	0.00%	36ø5.8854	77ø52.585	0
24	10:50.4	0	0.00%	36ø5.8854	77ø52.585	0
25	10:51.4	0	0.00%	36ø5.8854	77ø52.585	0
26	10:52.3	0	0.00%	36ø5.8854	77ø52.585	0
27	10:53.0	0	0.00%	36ø5.8854	77ø52.585	0
28	10:54.4	0	0.00%	36ø5.8854	77ø52.585	0

Figure E3. The User Is Asked to Enter Starting Time of Modes of Activity Recording

E.4.2 Flagging Errors and Other Data Quality Issues

The objective of applying the second macro to the database is to flag errors and other data quality issues and extract errorless data for a synchronization check. This macro is called "S2_Errors_Indication." Each second of data is screened and flagged, if needed, for the following errors:

- Missing manifold absolute pressure
- Unusual engine speed
- Unusual intake air temperature
- Negative emissions values
- Gas analyzer freezing
- Zeroing effects
- Inter-analyzer discrepancy
- Effects of air leakage

Table E2. Description of Variables Available for Data Screening after Formatting the Database

No.	Variable	Variables Available for Screening	No.	Variable	Variables Available for Screening
1	time[s]	Recording time in second	30	A_CO_2[%]	CO_2 from analyzer A
2	valid_g/gal	Validity of data	31	A_O_2[%]	O_2 from analyzer A
3		Blank for time (hh:mm:ss)	32	B_Valid	Validity of data of analyzer B
4		Blank for modes of activity	33	B_Stats	Operation status of analyzer B
5	Bag_No	Separating data into bags	34	B_NOx[ppm]	NO from analyzer B
6	SENSED_RPM	Engine speed	35	B_HC[ppm]	HC from analyzer B
7	SENSED_TEMP[C]	Intake air temperature	36	B_CO[%]	CO from analyzer B
8	SENSED_MAP[kPa]	Manifold absolute pressure	37	B_CO_2[%]	CO_2 from analyzer B
9	intake_air[g/gal]	Mass flow of intake air	38	B_O_2[%]	O_2 from analyzer B
10	Dry_exh[g/gal]	Mass flow of dry exhaust gas	39	GPS_Fix	NA – blank column
11	total_exh_flow[scf]	Total mass flow of exhaust	40	GPS_Satellites	GPS Status
12	fuel[g/gal]	Estimated fuel flow rate	41	GPS_time[seconds]	Number of satellites
13	NO_x[ppm]	Average NO	42	GPS_time[hh:mm:ss]	Recording time for GPS
14	HC[ppm]	Average HC	43	GPS_speed[mph]	Recording time for GPS
15	CO[%]	Average CO	44	grade[%]	Road grade
16	CO_2[%]	Average CO_2	45	lon	Longitude
17	O_2[%]	Average O_2	46	lat	Latitude
18	PM[%FS]	Particulate Matters in %FS	47	alt[ft]	Altitude
19	PM[mg/m^3]	Particulate Matters in mg/m^3			
20	NOx[g/gal]	Estimated average NO rate			
21	HC[g/gal]	Estimated average HC rate			
22	CO[g/gal]	Estimated average CO rate			
23	CO_2[g/gal]	Estimated average CO_2 rate			
24	PM[mg/gal]	Estimated average PM rate			
25	A_Valid	Validity of data of analyzer A			
26	A_Stats	Operation status of analyzer A			
27	A_NOx[ppm]	NO from analyzer A			
28	A_HC[ppm]	HC from analyzer A			
29	A_CO[%]	CO from analyzer A			

Definitions and criteria of detection of each of the errors have been explained in the "Data Quality Assurance Report." The following columns are created for flagging the errors in the database:

- Column 48 labeled as "Invalid" for flagging invalid data
- Column 49 labeled as "Missing MAP" for flagging missing MAP
- Column 50 labeled as "Un_RPM" for unusual engine speed
- Column 51 labeled as "Un_IAT" for unusual intake air temperature
- Column 52 labeled as "NVI" for negative emission values
- Column 53 labeled as "GAF_B" for gas analyzer freezing of Analyzer B
- Column 54 labeled as "GAF_A" for gas analyzer freezing of Analyzer A
- Column 55 labeled as "GAF_AB" for gas analyzer freezing of both analyzers
- Column 56 labeled as "ZE_A_be " for zeroing effects of Analyzer A (before zeroing)
- Column 57 labeled as "ZE_A_af " for zeroing effects of Analyzer A (after zeroing)
- Column 58 labeled as "ZE_B_be " for zeroing effects of Analyzer B (before zeroing)
- Column 59 labeled as "ZE_B_be " for zeroing effects of Analyzer B (after zeroing)
- Column 60 labeled as "Discpy" for inter-analyzer discrepancy
- Column 61 labeled as "AFR" for air leakage effects

The above errors are flagged by assigning a value of "1" to each column in the corresponding row of data when an error is detected. After flagging the errors, the program will copy and paste the errorless seconds of data onto "Sheet3." This data is then used for a synchronization check which will be explained in the following sections. Sheet 3 is renamed as "Synchronization Data" by this macro.

E.4.3 Performing Synchronization Check

As shown in Figure E1, the synchronization check is preformed manually. The instructions for performing this check are given on the "Synchronization Check" sheet in DQCAF. According to the instructions, the user should screen the data on the "Synchronization Data" sheet and copy and paste 15 consecutive seconds of data in which engine speed has had a substantial change (such as a change greater than 200 RPM) in one second and for a total of 500 RPM or more over one or more seconds. Then, the user should check the synchronization according to the criteria given in the "Data Quality Assurance" report and define a synchronization time of T_{synch}.

E.4.4 Re-Synchronizing Engine Data Relative To Gas Analyzer

After defining T_{synch}, synchronization of engine and emission data need to be corrected, if needed. The engine data needs to be shifted earlier or later compared to emissions data as explained in the "Data Quality Assurance" report. The synchronization correction applies to data on Sheet 1 which contains all collected data. No emission rate recalculation applies to the data in this section.

E.4.5 Removing Data Flagged As Invalid By The Montana System

A macro named "S3_Removing_Invalid_Data" is used to remove rows of data in which Column 48 (i.e. labeled as "Invalid") includes the value of 1. This column has been created by the "S2_Errors_Indication" macro when indicating errors in the raw database. The data excluded in this section is referred to as situations in which either the sensor array or the sampling hoses have not been connected to the Montana system. Thus, engine data and/or pollutant concentrations are not detected in this situation.

E.4.6 Statistics On Data Quality (1)

In this step, a macro called "S4_Summary_of_Data_1" provides a set of summary statistics of data for the user in Sheet 2 before excluding any data from the database. Figure E4 illustrates what the user observes on the screen with respect to the summary statistics after running the macro. The summary statistics are based on the following parameters:

- Time
- Engine data
- Emissions concentrations
- Mass emissions rates
- Operation of Analyzer A
- Operation of Analyzer B

Time: the following items are reported with respect to time:

- Data collection start time (hh:mm:ss)
- Data collection end time (hh:mm:ss)
- Total data before screening (seconds)
- Data deleted because of invalid data (seconds)
- Data deleted because of missing MAP (seconds)
- Data deleted because of unusual engine speed (seconds)
- Data deleted because of unusual intake air temperature (seconds)
- Data deleted because of analyzer freezing (seconds)
- Data deleted because of inter-analyzer discrepancy freezing (seconds)
- Data deleted because of air leakage (seconds)
- Data deleted because of negative emission concentrations (seconds)
- Total data collection after screening (seconds)

Engine Data: the following items are reported with respect to engine data:

- For Engine speed: maximum, minimum, zero engine speed, and a number of unusual engine speeds
- For IAT data: maximum, minimum, zero IAT, and unusual IAT data values
- For MAP data: maximum, minimum, zero MAP, and some estimated MAP values

Emissions Concentrations: maximum and minimum are reported for the concentrations of NO, HC, CO, CO_2, PM, and O_2. Therefore, the number of seconds in which concentrations are below the precision of the Montana system (i.e. NO<-25 ppm, HC<-14 ppm, CO<-0.02 vol%, CO_2<-0.30 vol%) are reported as well.

Mass Emission Rates: maximum, minimum, and average mass emission rates for NO, HC, CO, CO_2, and PM are reported.

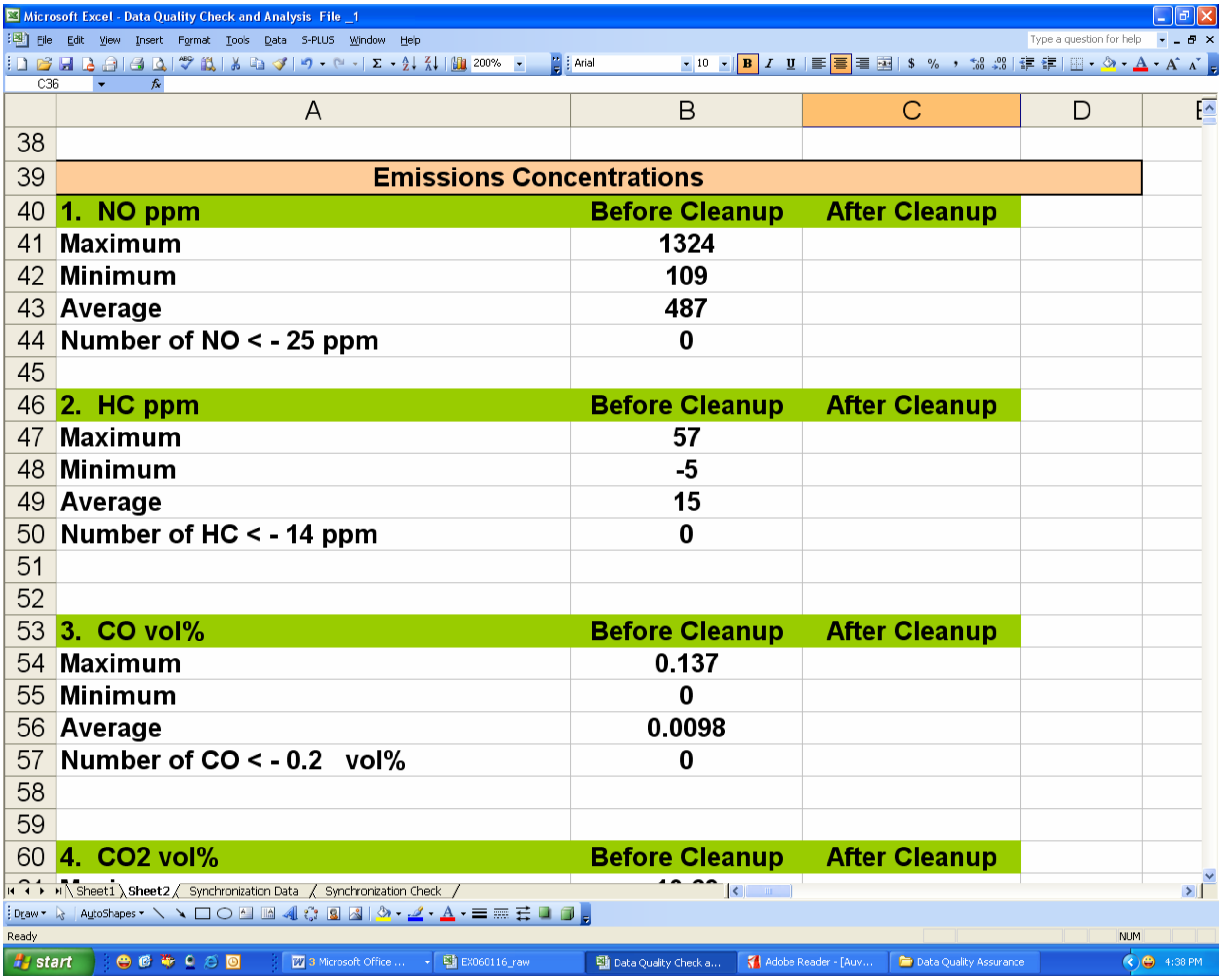
Operation of Analyzers A and B: for each of the analyzers A and B, the number of seconds in which the analyzer has been operated normally or performed zero calibration are reported separately.

E.4.7 Estimating Missing Manifold Absolute Pressure (MAP)

Missing MAP data will be estimated, where possible, by the developed criteria in the "Data Quality Assurance" report. This step is performed by a macro called "S5_MAP_Estimations." There is no recalculation of emission rates performed in this section.

E.4.8 Removing Un-Estimated Missing Manifold Absolute Pressure

Missing MAP data that have not been estimated are removed from the database by running the macro "S6_Delete_Remaining_MAP." There is no recalculation of emission rates performed in this section. A row of data is excluded from the database in this step if MAP is equal to "-34". There should not be any observed missing MAP after running this macro because part of the missing values were estimated in a previous section and the remaining un-estimated values were deleted in this section. The reason that estimating and removing MAP data are preformed in two steps is to give the user the opportunity of screening out data and determining how MAP data were estimated and many missing data are remaining.



	A	B	C	D
38				
39	**Emissions Concentrations**			
40	**1. NO ppm**	**Before Cleanup**	**After Cleanup**	
41	**Maximum**	**1324**		
42	**Minimum**	**109**		
43	**Average**	**487**		
44	**Number of NO < - 25 ppm**	**0**		
45				
46	**2. HC ppm**	**Before Cleanup**	**After Cleanup**	
47	**Maximum**	**57**		
48	**Minimum**	**-5**		
49	**Average**	**15**		
50	**Number of HC < - 14 ppm**	**0**		
51				
52				
53	**3. CO vol%**	**Before Cleanup**	**After Cleanup**	
54	**Maximum**	**0.137**		
55	**Minimum**	**0**		
56	**Average**	**0.0098**		
57	**Number of CO < - 0.2 vol%**	**0**		
58				
59				
60	**4. CO2 vol%**	**Before Cleanup**	**After Cleanup**	

Figure E4. Summary Statistics of Data Shown on the Screen after Running the Macro

E.4.9 Removing Unusual Engine Speed

The macro "S7_Removing_Unusual_RPM" deletes unusual engine speeds from the database. The program screens Column 50 labeled as "Un_RPM" and exclude the row of data from the database if the value "1" appears in this column.

E.4.10 Removing/Correcting Negative Emissions

Negative pollutant emissions refer to some of the measured concentrations that are not statistically different from zero. If this error is found, a "1" is flagged in column 52. The macro "S8_Negative_Concentrations" uses the "1" flagged indication to correct or remove negative concentration errors.

E.4.11 Removing/Correcting Gas Analyzer Freezing Errors

Analyzer freezing error refers to a miscommunication between the computer and the analyzer in the main unit of the Montana system. This happens because of vibration from the testing vehicles. While the engine data keeps changing, emissions data from the analyzers remains the same for a period of several seconds. This error is called "Gas Analyzer Freezing" (GAF). The criteria for detecting and correcting GAF errors are described in the data quality assurance report.

The macro, "S9_Analyzer_Freezing_Error" was made to remove or correct gas analyzer freezing errors. Based on the data quality assurance report, the macro flag "1" is indicated in column 53, 54, or 55. As mentioned in Section A.5, such an indication in column 53 refers to the GAF errors in Analyzer A. Such an indication in columns 54 and 55 represent GAF errors in analyzer B and GAF errors in both analyzers respectively. Based on the criteria described in the data quality assurance report, concentration data will be replaced by analyzer B data when GAF is found in analyzer A. In the same way, analyzer B data will be replaced by analyzer A data when GAF is found in analyzer B. If GAF is detected in both analyzers, that period of error seconds will be removed.

E.4.12 Screening Out Zeroing Effects

The macro "S10_Concentrations_Correction_for_Zeroing" is used to correct the effects of a zero calibration process on the fuel consumption and average emission rates. The macro was conceptually developed based on what was explained in the "Data Quality Assurance" report for correcting zero calibration effects. There is no recalculation performed when running the macro in this step. The macro indicates a 10 second before and after zeroing procedure for each of the analyzers from the flagged columns 56, 57, 58, and 59 which are labeled by "ZE_A_be," "ZE_A_af," "ZE_B_be," and "ZE_B_af." When Columns 56 or 57 contain the value "1", the macro copies and pastes the concentrations in Columns 34 through 38 to Columns 13 through 17, as shown in Table E2. Therefore, when Columns 58 or 59 are "1," then Columns 27 through 31 will be copied and pasted to Columns 13 through 17. Concentrations in Columns 13 through 17 will be used along with engine data in Columns 6 through 8 for recalculating fuel consumption and emission rates.

E.4.13 Removing/Correcting Inter-Analyzer Discrepancy Errors

The macro "S11_InterAnalyzer_Discrepancy" is used to correct inter-analyzer discrepancy errors. Inter-analyzer discrepancy (IAD) is the absolute value of the difference in measured pollutant concentration for a given pollutant between Analyzer A and Analyzer B. The IAD is compared to the maximum acceptable difference (MAD) between the readings of both analyzers to determine if further examinations of the data are needed. The MAD for each pollutant is determined by the level of precision of each sensor, shown in Section B.5.1 of the data quality assurance report.

In Section E.5, inter-analyzer discrepancy is indicated in column 60 using a "1" indication symbol. The macro "S11_Interanlyzer_Discrepancy" will change the row color of the inter-analyzer discrepancy error periods to yellow, green, or pink. The indications of these three colors help in additional manual data checks in the future when needed. Each color refers to:

- Yellow means that the averages between the two analyzers are used in the inter-analyzer discrepancy
- Pink means that the pollutant concentrations from analyzer A are used in inter-analyzer discrepancy
- Green means that the pollutant concentrations from analyzer B are used to solve inter-analyzer discrepancy

If problems are detected in both analyzers, that error period will be removed. The number of removed error seconds will be described in another spreadsheet called "Summary of Data."

As shown in Figure E1, the inter-analyzer discrepancy check performs additional manual data checks when needed. If the S11 macro is operated, a user will be asked the question, "Do you have systematic errors in today's data collection?" This question asks if any problems were detected during periodic system checks in data collection. For example, pump blockage or any other analyzer related problems can be observed without indication of error messages on the computer monitor. This means that there will be additional manual data checks that are necessary after finishing the S11 macro using the criteria described in the data quality assurance report. Also, the long-term consecutive periods of IAD will be detected in this step.

E.4.14 Removing Unusual Intake Air Temperature

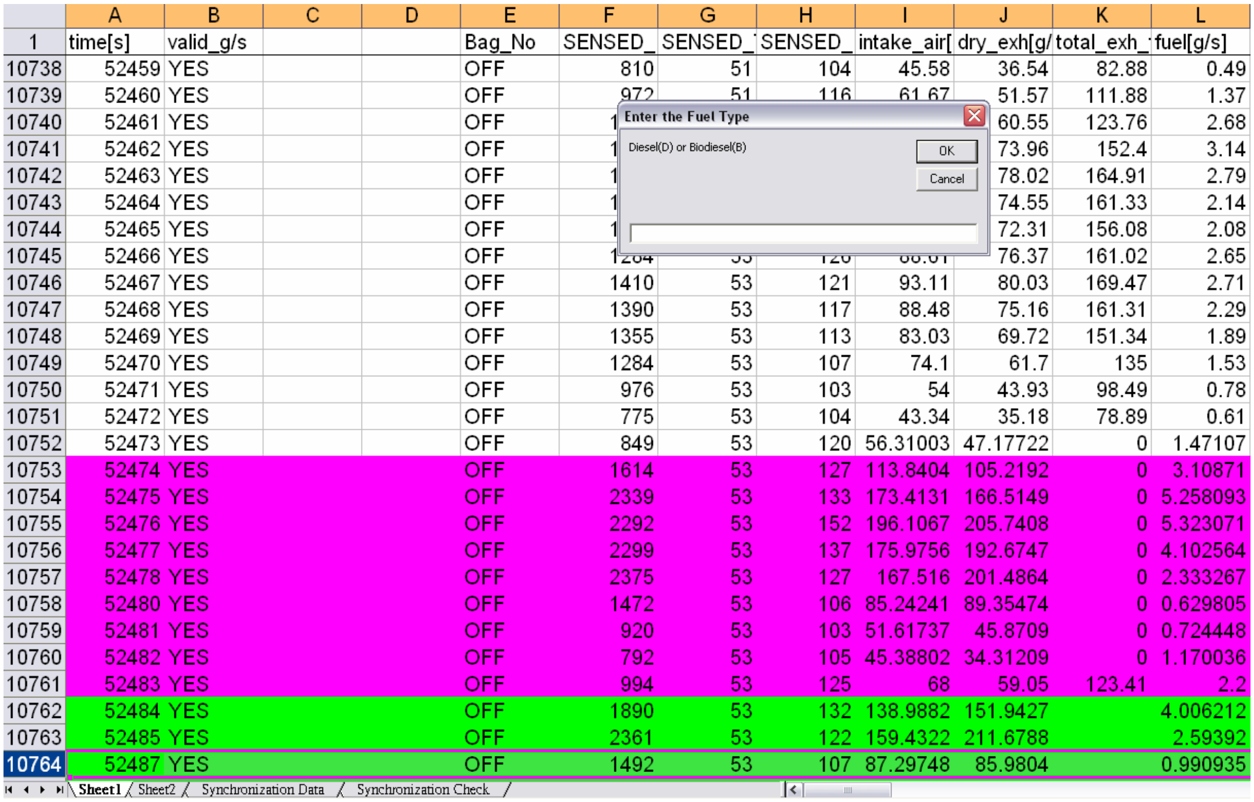
The macro "S12_Removing_Unusual_IAT" is used to exclude unusual intake air temperature (IAT). Generally, IAT typically changes only gradually over time. If the IAT value changes rapidly there may be a problem with the IAT sensor. Based on the previous field data, the differences of IAT between two consecutive seconds never exceed 1 ^{o}C. Therefore, ±1 ^{o}C can be the lower and upper limit for the differences of IAT between two consecutive seconds. If the difference of IAT between two consecutive seconds is greater than 1, the macro will indicate the error using a "1" indication symbol in Column 51 "Un_IAT" and exclude the row of data from the database if a value of "1" does appear in this column.

E.4.15 Removing Data With Invalid Air-To-Fuel Ratio

The macro "S13_Removing_Invalid_AFR" is used to avoid the effects of air leakage on data quality. The macro was conceptually developed based on what was explained in the "Data Quality Assurance" report for air leakage. The air-to-fuel ratio (AFR) is used as an indicator to indicate the possibility of a leakage occurrence. If the AFR is greater than 150 and one or more pollutant concentrations is less than the precision of the Montana system, the macro will indicate the error using a "1" indication symbol in Column 61 and exclude the row of data from the database if a value of "1" does appear in this column.

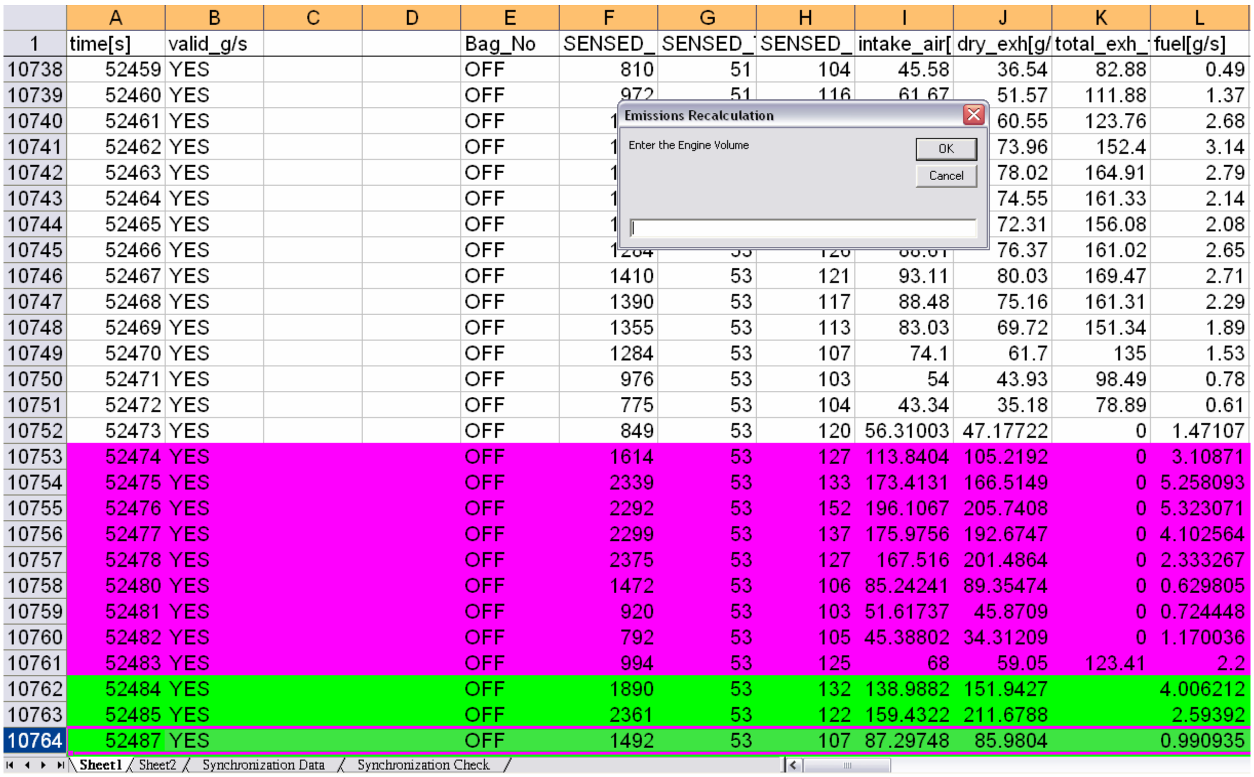
E.4.16 Recalculating Emission Rates

As mentioned previously, none of the above macros is involved with the recalculation of mass fuel use and emission rates. The macro "S14_Recalculations" was created to perform all fuel use and emission recalculations. At the beginning of the macro, a window appears and asks the user about the type of fuel. There are two options for the answer which are D (i.e. diesel) and B (i.e. biodiesel) for fuel type, as shown in Figure E5. The next input variable that is asked to be entered through another pop-up window is the engine displacement, as shown in Figure E6.



	A	B	C	D	E	F	G	H	I	J	K	L
1	time[s]	valid_g/s			Bag_No	SENSED_	SENSED_	SENSED_	intake_air[	dry_exh[g/	total_exh_	fuel[g/s]
10738	52459	YES			OFF	810	51	104	45.58	36.54	82.88	0.49
10739	52460	YES			OFF	972	51	116	61.67	51.57	111.88	1.37
10740	52461	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	60.55	123.76	2.68
10741	52462	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	73.96	152.4	3.14
10742	52463	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	78.02	164.91	2.79
10743	52464	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	74.55	161.33	2.14
10744	52465	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	72.31	156.08	2.08
10745	52466	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	76.37	161.02	2.65
10746	52467	YES			OFF	1410	53	121	93.11	80.03	169.47	2.71
10747	52468	YES			OFF	1390	53	117	88.48	75.16	161.31	2.29
10748	52469	YES			OFF	1355	53	113	83.03	69.72	151.34	1.89
10749	52470	YES			OFF	1284	53	107	74.1	61.7	135	1.53
10750	52471	YES			OFF	976	53	103	54	43.93	98.49	0.78
10751	52472	YES			OFF	775	53	104	43.34	35.18	78.89	0.61
10752	52473	YES			OFF	849	53	120	56.31003	47.17722	0	1.47107
10753	52474	YES			OFF	1614	53	127	113.8404	105.2192	0	3.10871
10754	52475	YES			OFF	2339	53	133	173.4131	166.5149	0	5.258093
10755	52476	YES			OFF	2292	53	152	196.1067	205.7408	0	5.323071
10756	52477	YES			OFF	2299	53	137	175.9756	192.6747	0	4.102564
10757	52478	YES			OFF	2375	53	127	167.516	201.4864	0	2.333267
10758	52480	YES			OFF	1472	53	106	85.24241	89.35474	0	0.629805
10759	52481	YES			OFF	920	53	103	51.61737	45.8709	0	0.724448
10760	52482	YES			OFF	792	53	105	45.38802	34.31209	0	1.170036
10761	52483	YES			OFF	994	53	125	68	59.05	123.41	2.2
10762	52484	YES			OFF	1890	53	132	138.9882	151.9427		4.006212
10763	52485	YES			OFF	2361	53	122	159.4322	211.6788		2.59392
10764	52487	YES			OFF	1492	53	107	87.29748	85.9804		0.990935

Figure E5. Defining the Fuel Type for the Macro



	A	B	C	D	E	F	G	H	I	J	K	L
1	time[s]	valid_g/s			Bag_No	SENSED_	SENSED_	SENSED_	intake_air[	dry_exh[g/	total_exh_	fuel[g/s]
10738	52459	YES			OFF	810	51	104	45.58	36.54	82.88	0.49
10739	52460	YES			OFF	972	51	116	61.67	51.57	111.88	1.37
10740	52461	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	60.55	123.76	2.68
10741	52462	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	73.96	152.4	3.14
10742	52463	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	78.02	164.91	2.79
10743	52464	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	74.55	161.33	2.14
10744	52465	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	72.31	156.08	2.08
10745	52466	YES			OFF	[illegible]	[illegible]	[illegible]	[illegible]	76.37	161.02	2.65
10746	52467	YES			OFF	1410	53	121	93.11	80.03	169.47	2.71
10747	52468	YES			OFF	1390	53	117	88.48	75.16	161.31	2.29
10748	52469	YES			OFF	1355	53	113	83.03	69.72	151.34	1.89
10749	52470	YES			OFF	1284	53	107	74.1	61.7	135	1.53
10750	52471	YES			OFF	976	53	103	54	43.93	98.49	0.78
10751	52472	YES			OFF	775	53	104	43.34	35.18	78.89	0.61
10752	52473	YES			OFF	849	53	120	56.31003	47.17722	0	1.47107
10753	52474	YES			OFF	1614	53	127	113.8404	105.2192	0	3.10871
10754	52475	YES			OFF	2339	53	133	173.4131	166.5149	0	5.258093
10755	52476	YES			OFF	2292	53	152	196.1067	205.7408	0	5.323071
10756	52477	YES			OFF	2299	53	137	175.9756	192.6747	0	4.102564
10757	52478	YES			OFF	2375	53	127	167.516	201.4864	0	2.333267
10758	52480	YES			OFF	1472	53	106	85.24241	89.35474	0	0.629805
10759	52481	YES			OFF	920	53	103	51.61737	45.8709	0	0.724448
10760	52482	YES			OFF	792	53	105	45.38802	34.31209	0	1.170036
10761	52483	YES			OFF	994	53	125	68	59.05	123.41	2.2
10762	52484	YES			OFF	1890	53	132	138.9882	151.9427		4.006212
10763	52485	YES			OFF	2361	53	122	159.4322	211.6788		2.59392
10764	52487	YES			OFF	1492	53	107	87.29748	85.9804		0.990935

Figure E6. Entering the Engine Displacement to the Macro

E.4.17 <u>Statistics On Data Quality (2)</u>

In this step, a macro called "S15_Summary_of_Data_2" provides summary statistics of data for the user on Sheet 2 after screening data and performing quality assurance steps. The same procedure and information as explained in Section E.9 is provided by the macro in this step.

E.4.18 <u>Linking Emissions And Modes Of Activity Data</u>

The macro called "S16_Time_Mode_Synchronization" links emissions data to modes of activity data. The following procedure needs to be followed in order to complete the process of linking emissions data to activity data:

1. Open the file in which modes of activity data have been collected. Mode of activity files are normally labeled as "Time_mode". For example, for a backhoe it should be "Time_mode_Backhoe."
2. Run a macro in a "Time_mode" file named "Detail_Time_Mode". This macro will provide the user with time and modes of activity on a second-by-second basis.
3. Copy Columns 5 and 6 which are labeled "Time (sec)" and "Mode of Activity." Paste the copied columns in Columns 62 and 63 of DQCAF. In order to make sure data for linking emissions and activity data is available, a message window pops up to remind the user to complete the process of copying.
4. Make sure the value of cell (2, 62) is the same as cell (2, 1). If not, then delete pairs of time and mode in Columns 62 and 63 and shift the data when cell (2,62) is equal to cell (2,1).
5. Run the macro "S16_Time_Mode_Synchronization."

As a result of following the above procedure, Columns 3 and 4 in DQCAF will be filled with both time (in a “hh:mm:ss” format) and modes of activity data, respectively. Sheet 1 will be renamed to “Data” and Sheet 2 to “Data Summary.”

E.4.19 Saving/Archiving Data File And Continue Preliminary Analysis

The above steps results in a file that is referred to as a quality assured database (QAD). This file is ready for any further analysis. However, before running the preliminary analysis macros, it is necessary to save the QAE. The user is reminded through a message window at the end of the “S16_Time_Mode_Synchronization” macro to save the QAE. The QAD should be saved as “Screened” and “Analysis” files. The “Screened” file will be archived for future use and the “Analysis” file will be used for preliminary analysis. This step is performed manually as shown in Figure E1.

E.5 Preliminary Analysis

The objective of performing a preliminary analysis is to analyze data as quickly as possible to provide the user with an overview of the quality of collected data. It was desirable to have one macro for preliminary analysis but it was not possible to do so because the program became larger and longer than is allowed by Excel to be as a macro. Thus, to avoid this problem, six macros were developed instead of one. Breaking one macro into six provides the opportunity of checking the results partially between the multiple macros. It is recommended that the user close and open the “Analysis” file one time before running the preliminary analysis macros. The user should run the macros sequentially. The macros are:

- Preliminary_Analysis_1
- Preliminary_Analysis_2
- Preliminary_Analysis_3
- Preliminary_Analysis_4
- Preliminary_Analysis_5
- Preliminary_Analysis_6

The following sheets are created running “Preliminary_Analysis_1”:

- Summary (MAP) for saving the results of Engine-Based modes analysis
- MAP1 to MAP10 for 10 different MAP cutoffs which have been defined based on 10% of total NO in each cutoff
- A_B Analyzers for comparing the data measured by Analyzers A and B

Products of running the preliminary analysis macros appeared on “Summary(MAP)” and “A_B Analyzers” sheets. These products are categorized in two groups: (1) preliminary Engine-Based modes analysis and (2) comparison of data measured by each of the analyzers.

According to the Engine-Based modes analysis, data is sorted based on MAP values and binned with respect to MAP. This macro considers a total 10 of bins for each vehicle and each bin accounts for approximately 10% of the total NO emission. For each of the 10 MAP bins, the following are estimated and appear on the Summary (MAP) sheet:

1. Minimum and maximum MAP (kPa)
2. Number of data records (seconds)
3. Average fuel consumption rate (g/s)
4. Average emission rates of NO (g/s), HC (g/s), CO(g/s), CO_2(g/s), PM (g/s)
5. 95th percentile ranges for NO (g/s), HC (mg/s), CO(mg/s), CO_2(g/s), PM (mg/s)
6. Minimum and maximum NO (g/s), HC (mg/s), CO(mg/s), CO_2(g/s), PM (mg/s)
7. Average emission rates of NO (g/gal),HC (g/gal),CO(g/gal),CO_2(g/gal),PM (g/gal)
8. 95th percentile range for NO (g/gal), HC (g/gal), CO(g/gal), CO_2(g/gal), PM (g/gal)
9. Minimum and maximum NO (g/gal), HC (g/gal), CO(g/gal), CO_2(g/gal), PM (g/gal)
10. Distribution of time, fuel use, NO, HC, CO, CO_2, and PM among the bins

Therefore, the user is provided with the following graphs for data visualization purposes:

1. Bar charts of the average emissions and fuel use in each bin on a mass per time basis
2. Bar charts of the average emissions in each bin on a mass per gallon of fuel use basis
3. Distribution of time, fuel use, NO, HC, CO, CO_2, and PM among the bins

Figure E7 presents an example of the graphs that a user will observe on the screen for the “Summary(MAP)” sheet.

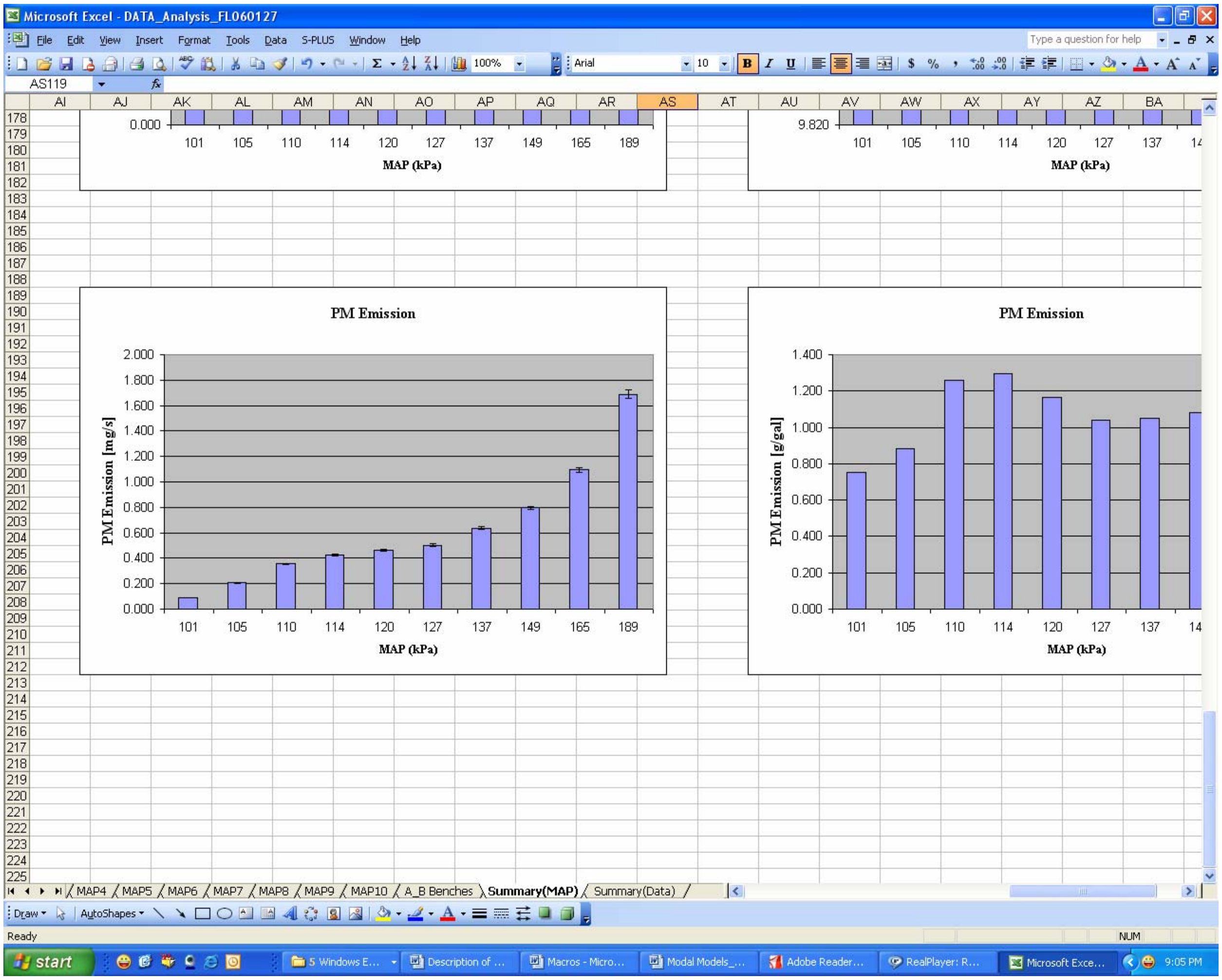


Figure E7. Example of Bar Chart Graphs Developed by the Macro Regarding Average Emission Rates in each Bin

To provide the user with an overview of the general status of the analyzers during data collection, the following graphs were developed for the "A_B Analyzers" sheet:

1. NO concentrations of Analyzer A versus Analyzer B (ppm)
2. HC concentrations of Analyzer A versus Analyzer B (ppm)
3. CO concentrations of Analyzer A versus Analyzer B (vol%)
4. CO_2 concentrations of Analyzer A versus Analyzer B (vol%)
5. Cumulative frequency of average NO concentrations (ppm)
6. Cumulative frequency of average HC concentrations (ppm)
7. Cumulative frequency of average CO concentrations (vol%)
8. Cumulative frequency of average CO_2 concentrations (vol%)

An example graphs developed for the "A_B Analyzers" sheet is shown below in Figure E8.

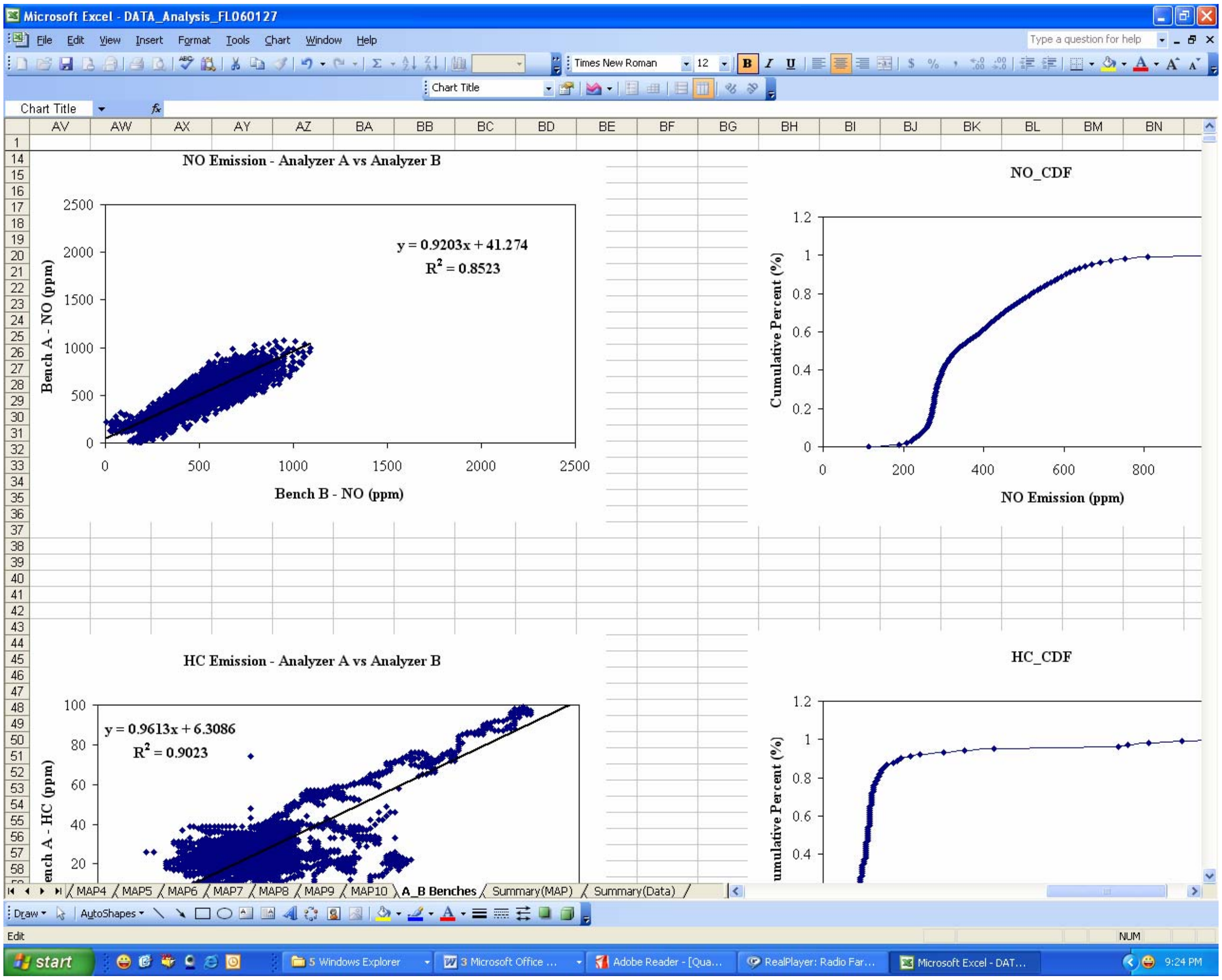


Figure E8. An Example of Graphs Developed "A_B Analyzers" Sheet

APPENDIX F. MEASURED TIME-BASED MODAL FUEL USE AND EMISSION RATES AND FUEL-BASED EMISSION RATES FOR ENGINE AND TASK ORIENTED MODES FOR ALL TESTED VEHICLES

LIST OF FIGURES

Appendix F provides supplementary Figures and Tables for Section 3.6. Results for five backhoes, four front-end loaders, and six motor graders are summarized in this appendix. Table F1 summarizes the test ID, vehicle ID, engine type of tested vehicles, and test date for each fuel.

For each tested vehicle, there are four different types of figures:

- Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes
- Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes
- Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes
- Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes

Based on engine-based MAP bins, modal emission rates for fuel use, CO_2, HC, CO, and opacity are presented on a time basis for both petroleum diesel and B20 biodiesel using two different fuels in the first figure. The second figure provides a comparison of engine-based average modal emission rates for the two fuels on a per unit of fuel consumed basis.

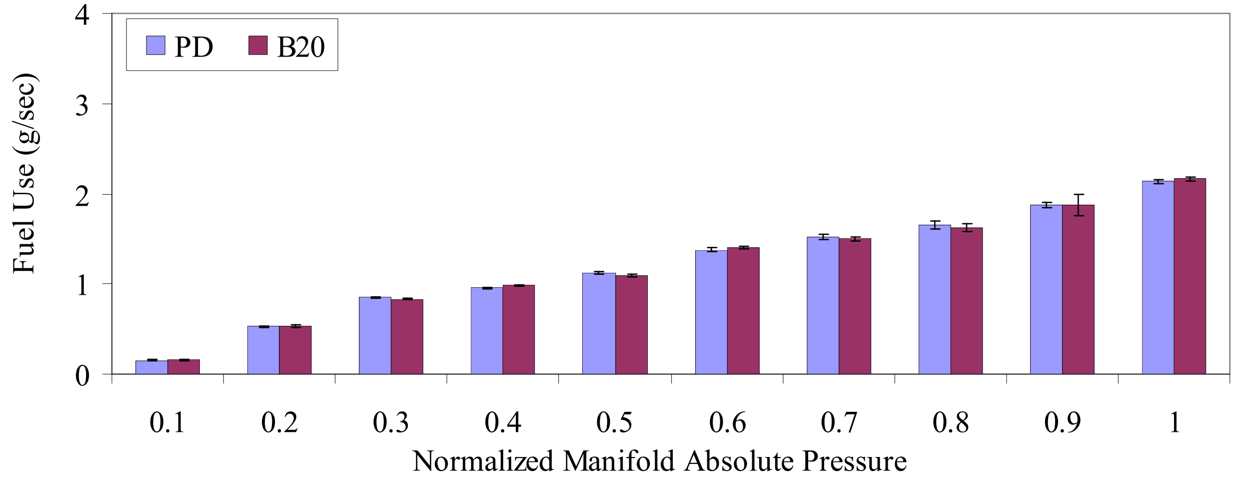
A comparison of the two fuels with respect to fuel use and emission rates for the task-oriented modes is given in the third (for time basis) and fourth figures (for fuel consumed basis). The task-oriented modes do not explain as much of the variability in fuel use and emission rates as the engine-based data, but they provide some indication of how fuel use and emission rates change for task-oriented modes of operation. For the explanation of task-oriented modes, see Section 3.6.

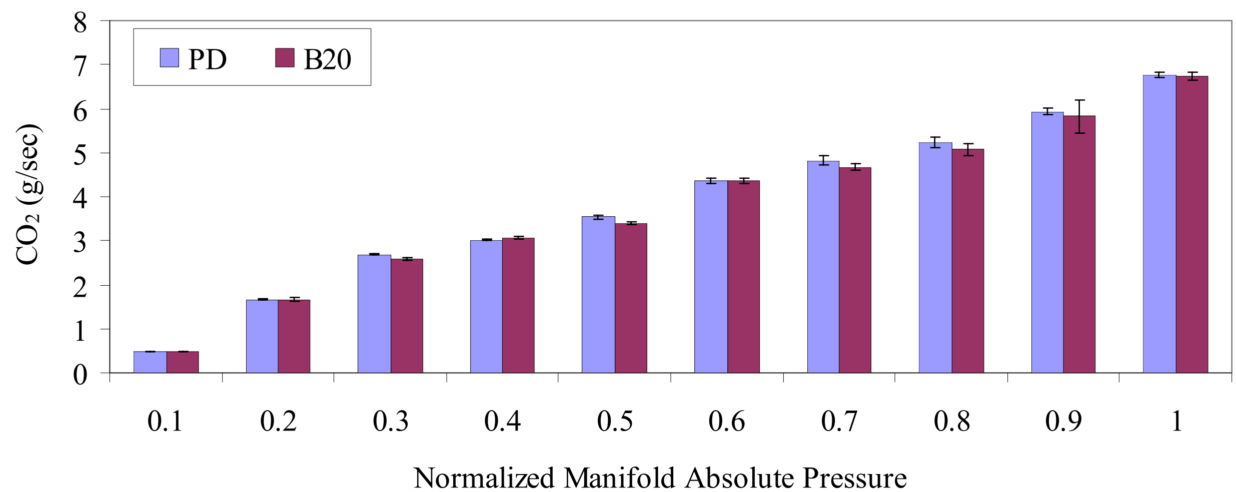
Table F1. Summary Table of Test Vehicle Information and Test Date

Vehicle Type	Test ID	Vehicle ID ([a])	Engine Type	Test Fuel Type	
				Petroleum Diesel	B20 Biodiesel
Motor Grader	MG1	955-0515 (5)	Tier 1	2/01/06	2/14/06
	MG2	955-0606 (4)	Tier 2	3/23/06	4/20/07
	MG3	955-0516 (5)	Tier 1	5/25/07	8/04/06
	MG4	948-6647 (5)	Tier 0	4/03/07	12/05/06
	MG5	955-0277 (4)	Tier 0	1/17/07	2/21/07
	MG6	955-0633 (5)	Tier 3	6/22/07	6/28/07
Backhoe	BH1	FDP20882 (5)	Tier 2	5/24/07 [c]	4/26/07 [c]
	BH2	803-0242 (5)	Tier 0	4/05/06 [b]	1/12/06 [b]
	BH3	803-0241 (4)	Tier 1	3/31/06 [b]	5/07/07 [c]
	BH4	808-0214(4)	Tier 1	4/13/07 [c]	5/01/07 [b]
	BH5	FDP22085 (5)	Tier 2	5/23/07 [c]	4/25/07 [c]
Front-End Loader	FL1	010-0249 (4)	Tier 1	3/08/06 [b]	5/08/07 [b]
	FL2	010-0301 (4)	Tier 1	4/07/06 [b]	4/10/07 [b]
	FL3	010-5074 (5)	Tier 1	5/18/07 [c]	7/21/06 [b]
	FL4	010-0388 (5)	Tier 2	5/22/07 [c]	5/17/07 [c]

[a] Division Number; [b] Actual Site Condition; [c] Maintenance Yard Condition

BACKHOE 1





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 79 ^{o}F and the relative humidity was 52 %. For the B20 biodiesel test, the ambient temperature was 77 ^{o}F and the relative humidity was 60 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F1. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Backhoe 1 (continued on next page)

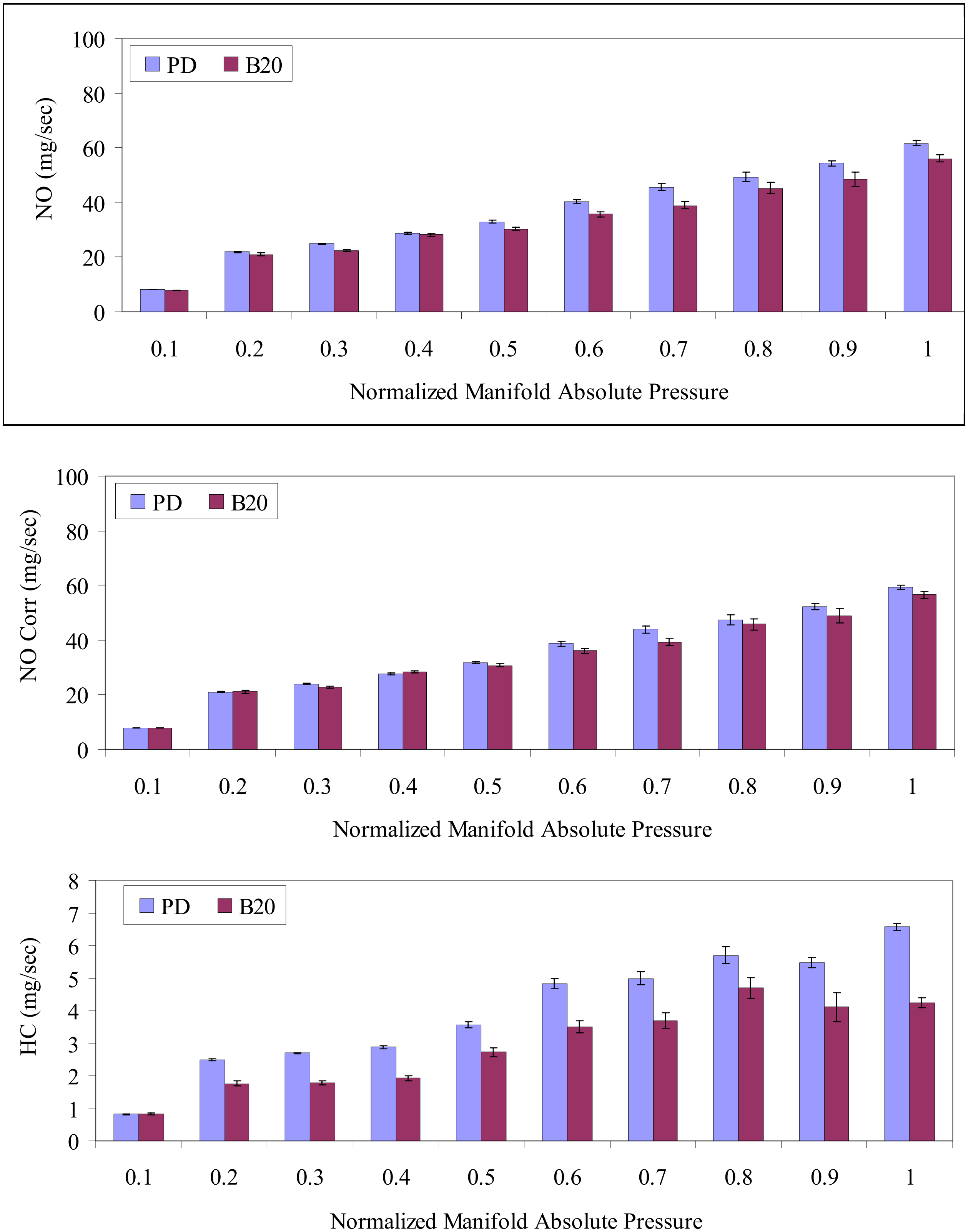


Figure F1. Continued

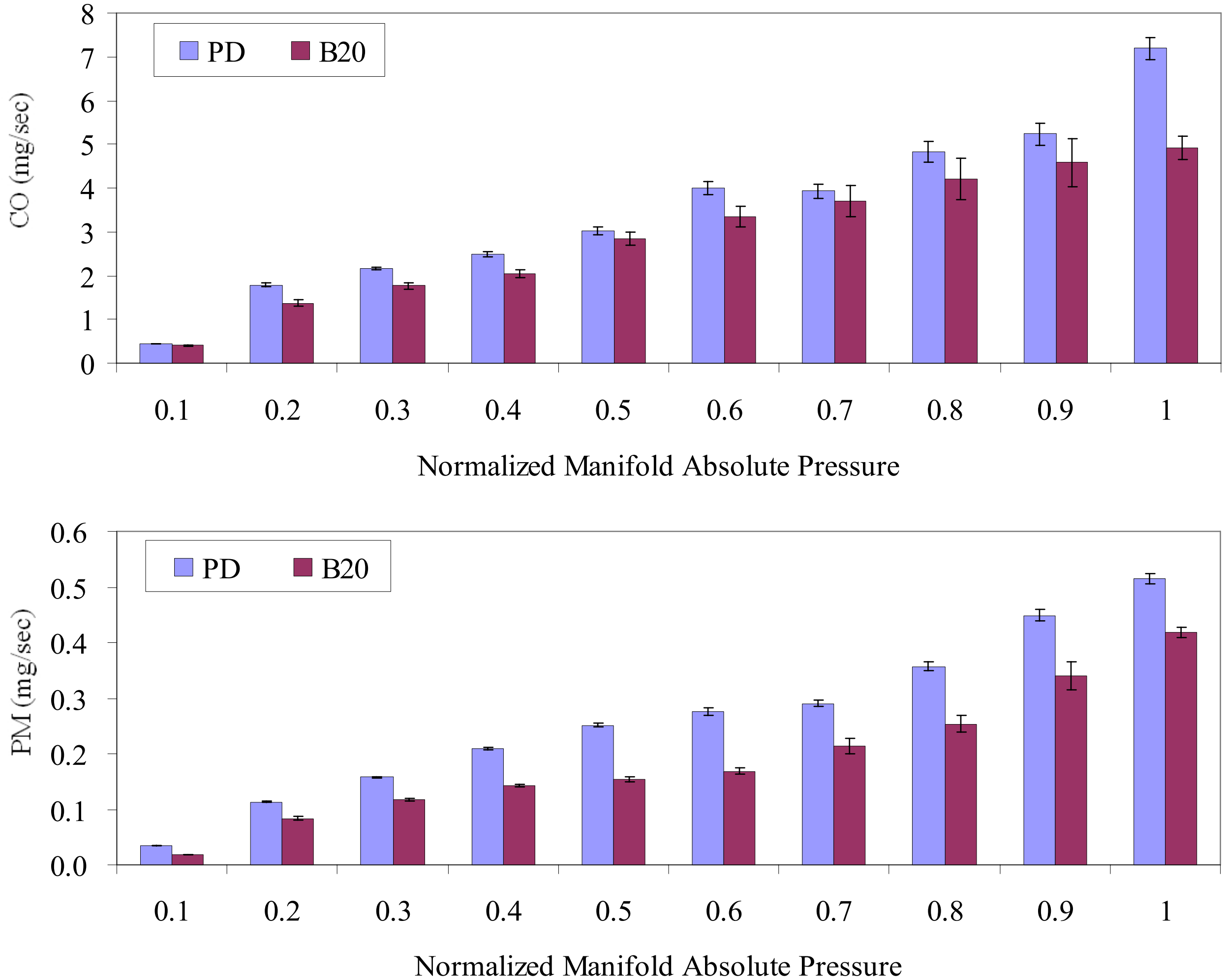
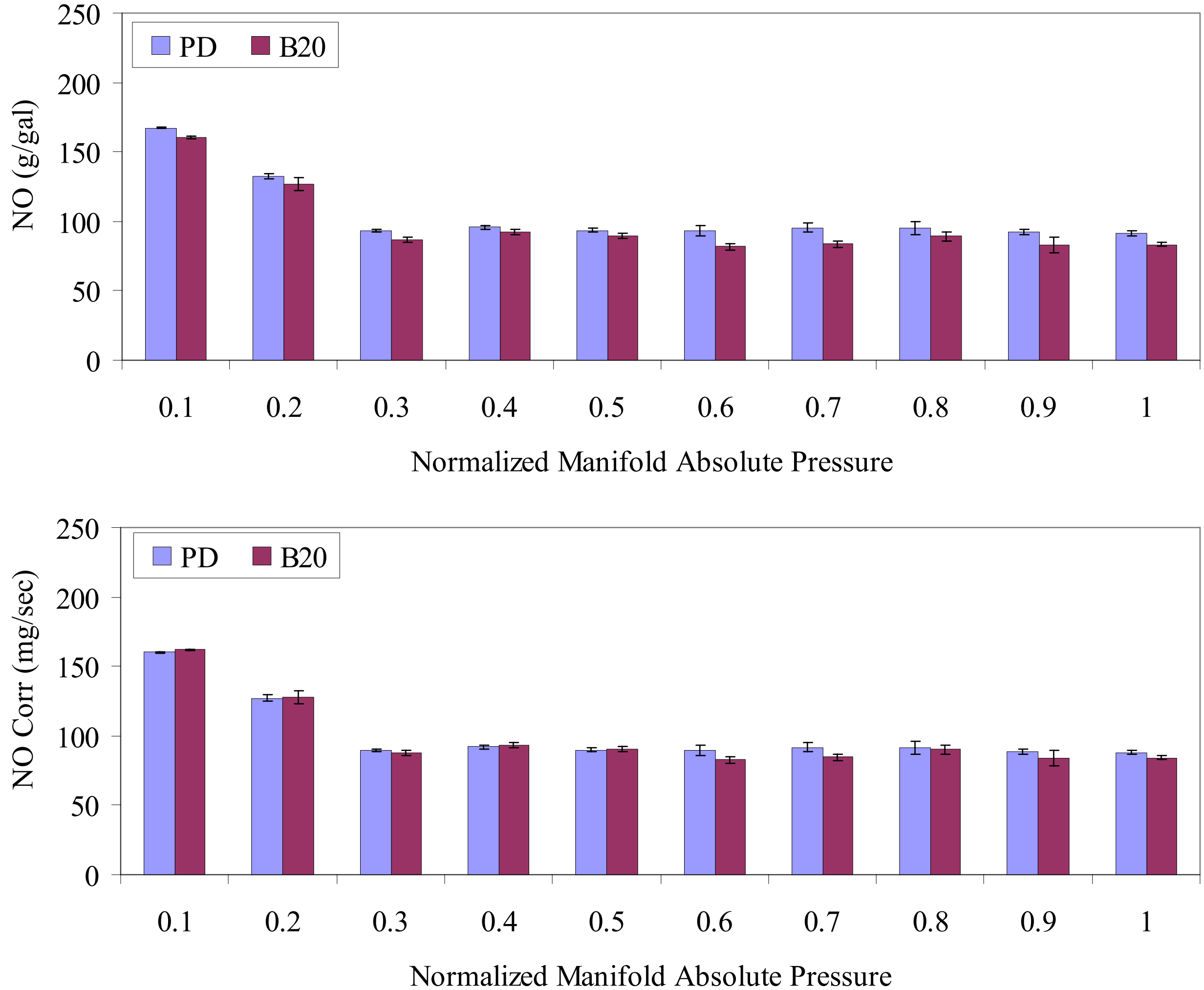


Figure F1. Continued



NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 79 ^{o}F and the relative humidity was 52 %. For the B20 biodiesel test, the ambient temperature was 77 ^{o}F and the relative humidity was 60 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F2. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Backhoe 1 (continued on next page)

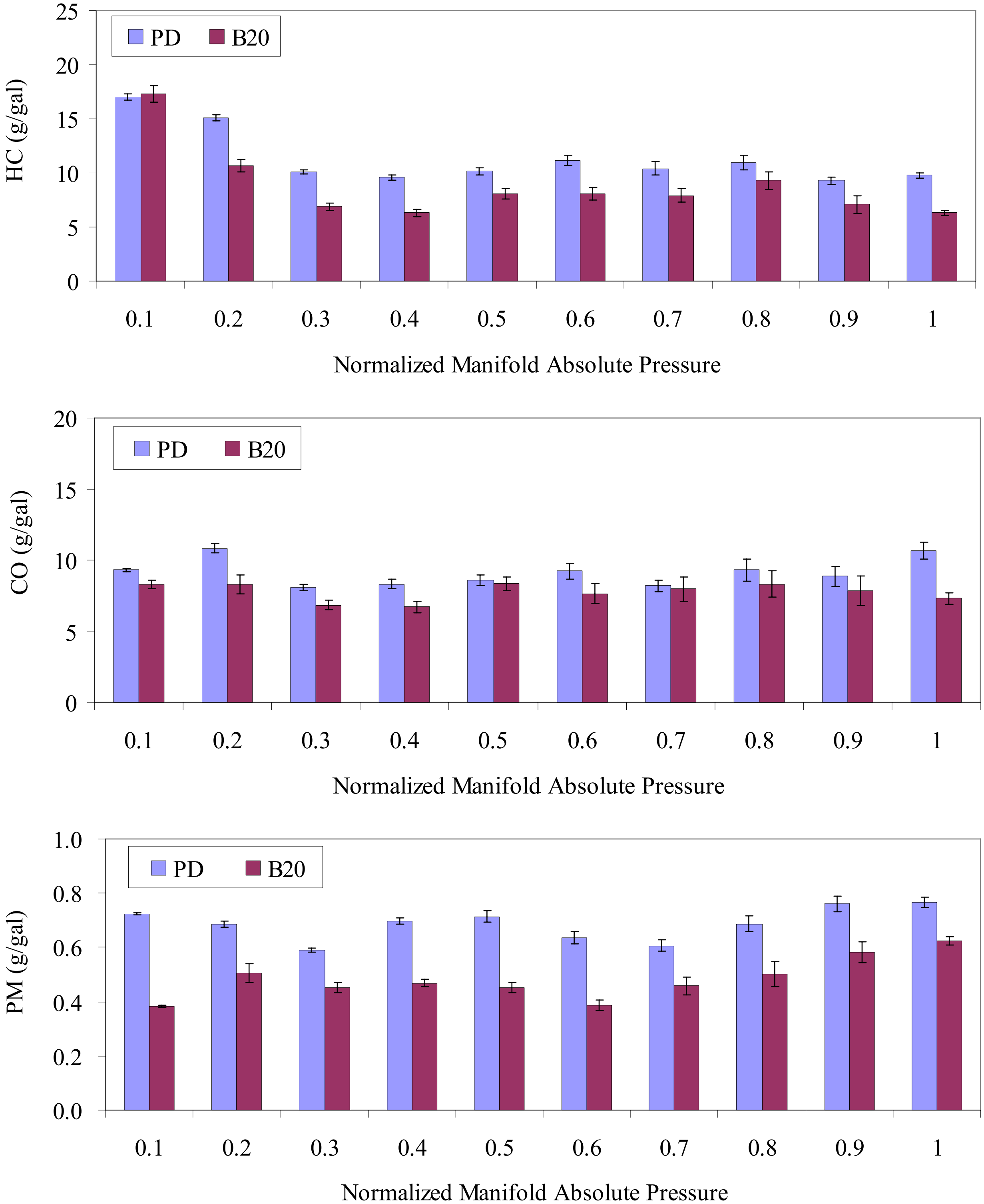
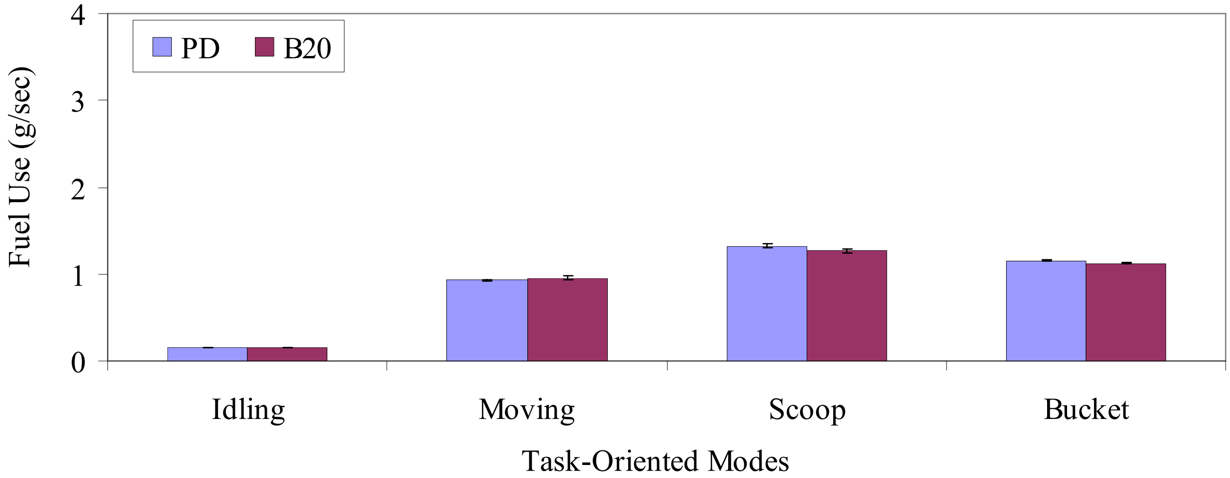
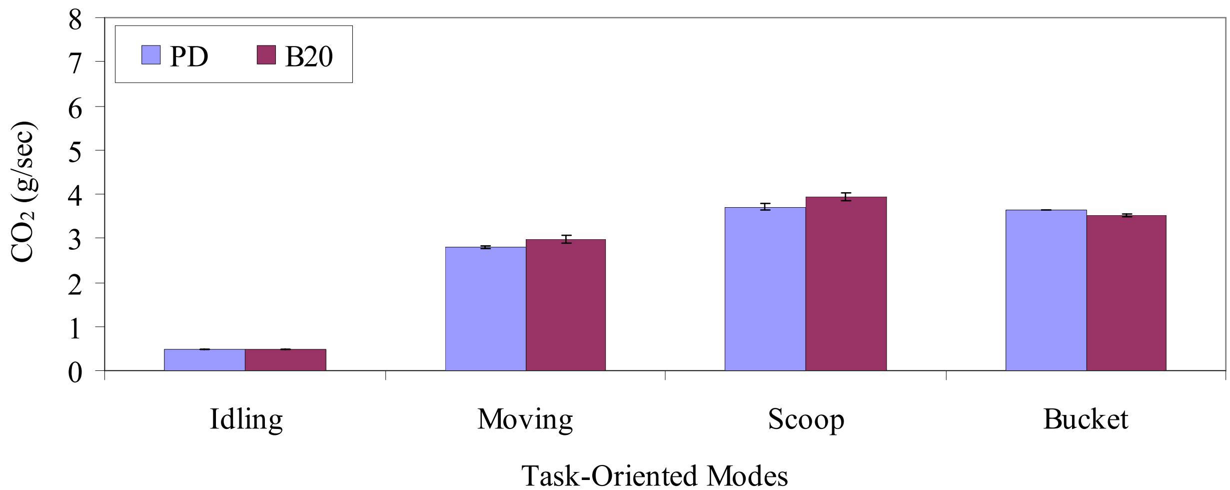


Figure F2. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 79 ^{o}F and the relative humidity was 52 %. For the B20 biodiesel test, the ambient temperature was 77 ^{o}F and the relative humidity was 60 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F3. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Backhoe 1 **(continued on next page)**

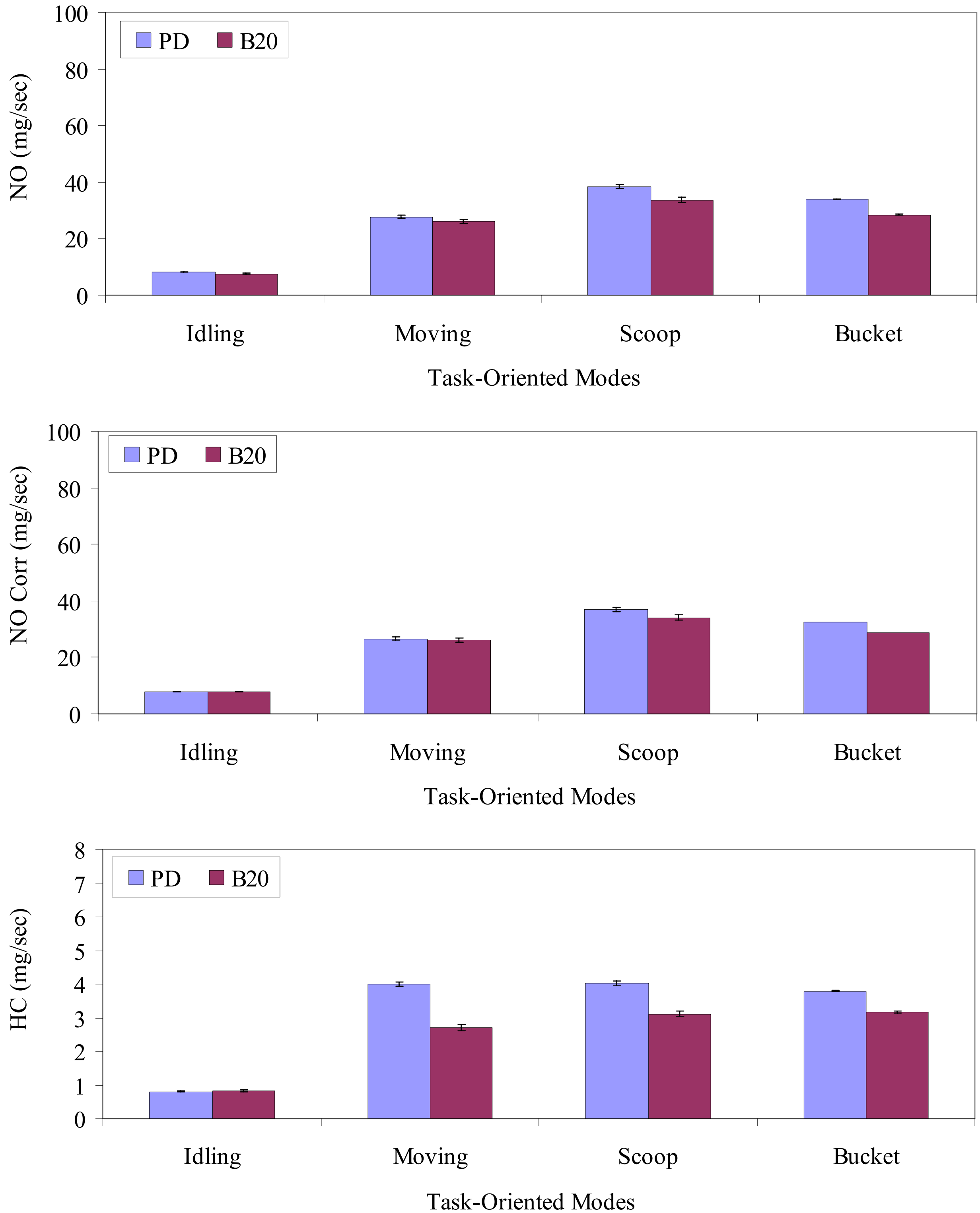
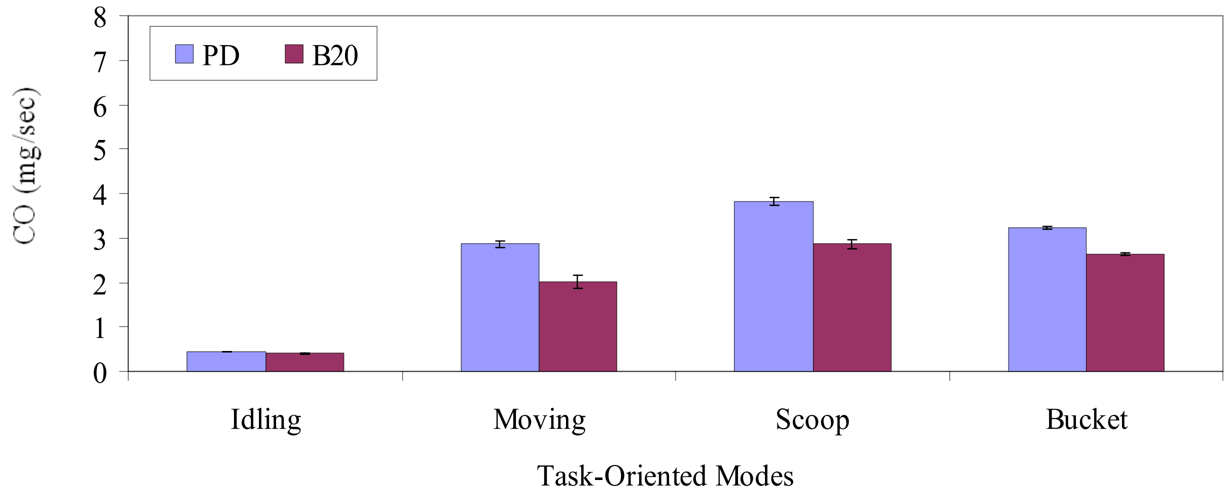


Figure F3. Continued



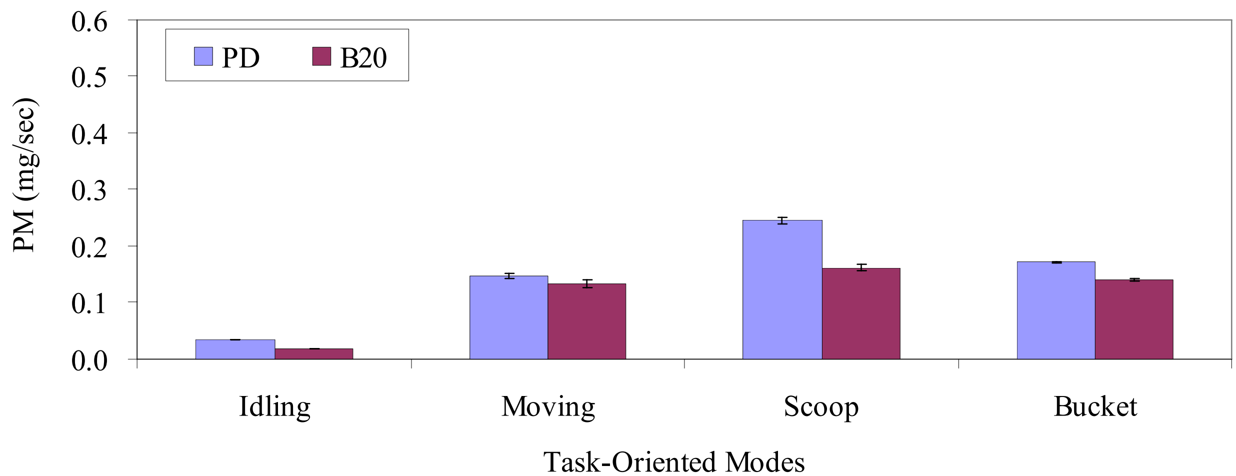
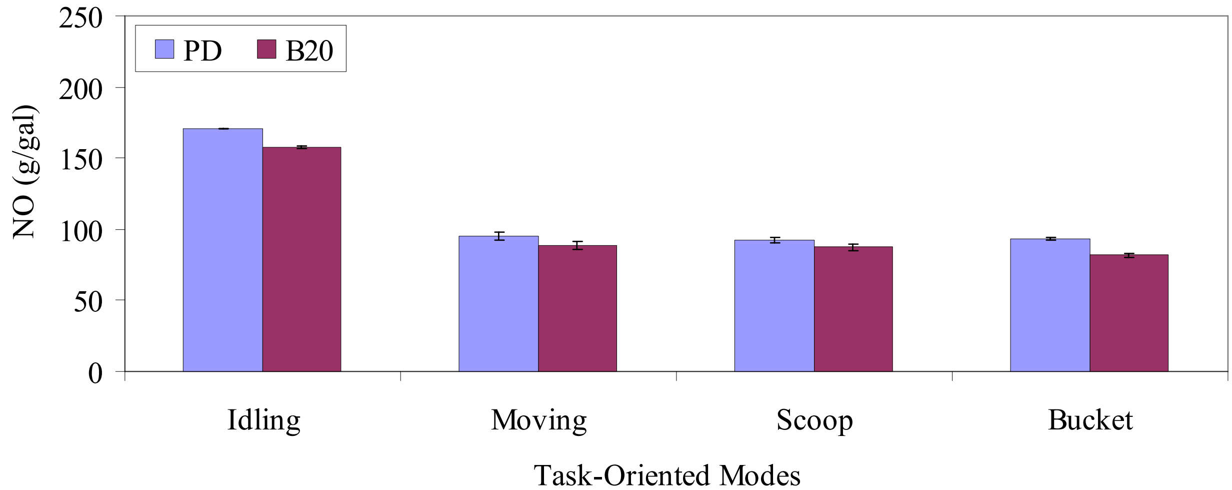
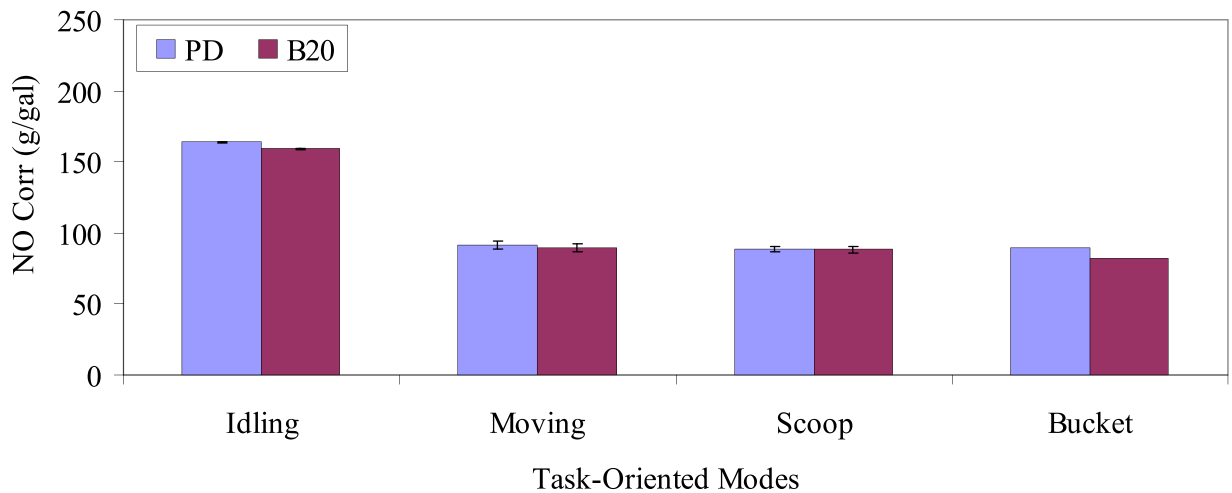


Figure F3. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 79 ^{o}F and the relative humidity was 52 %. For the B20 biodiesel test, the ambient temperature was 77 ^{o}F and the relative humidity was 60 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F4. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Backhoe 1 (continued on next page)

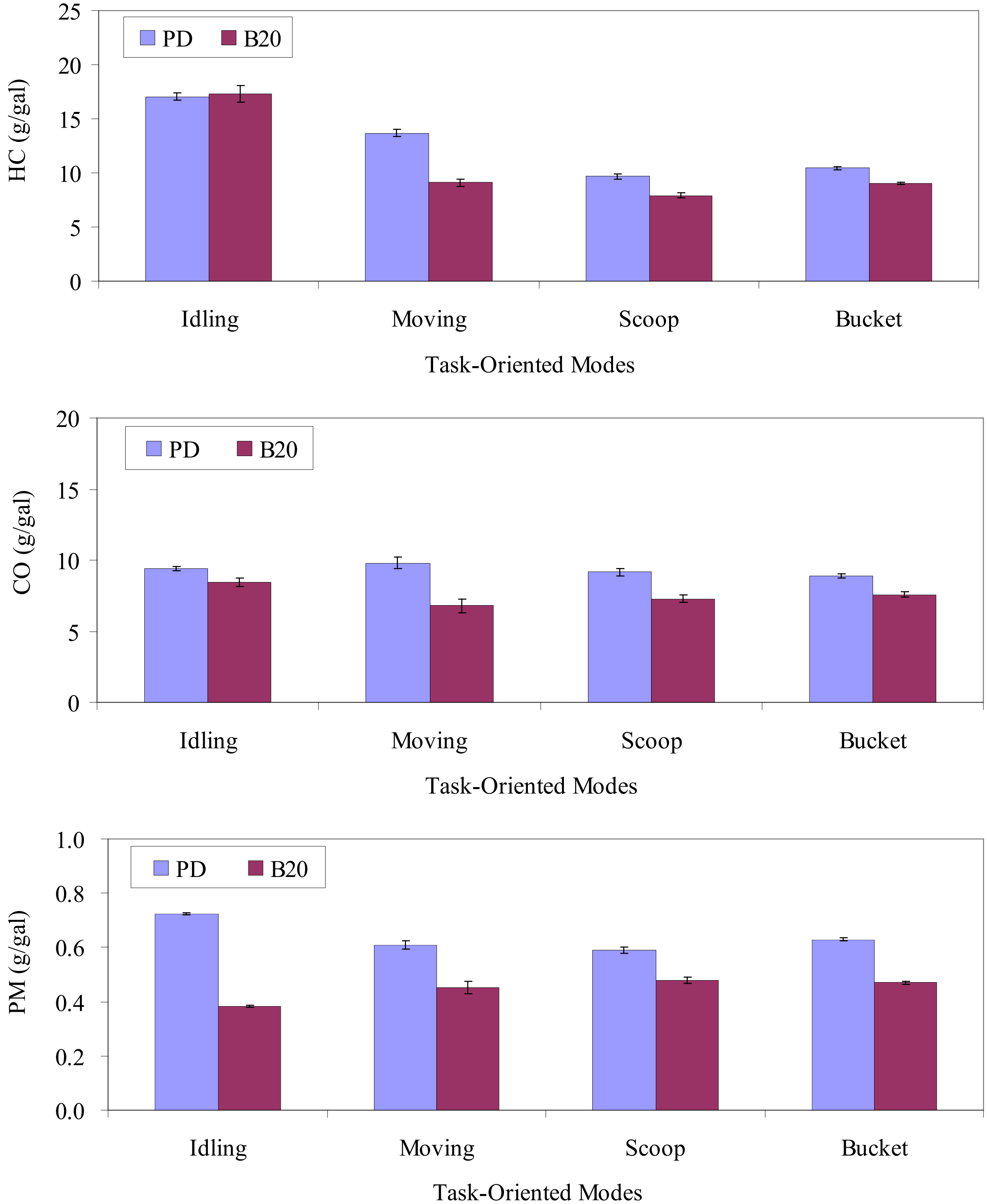
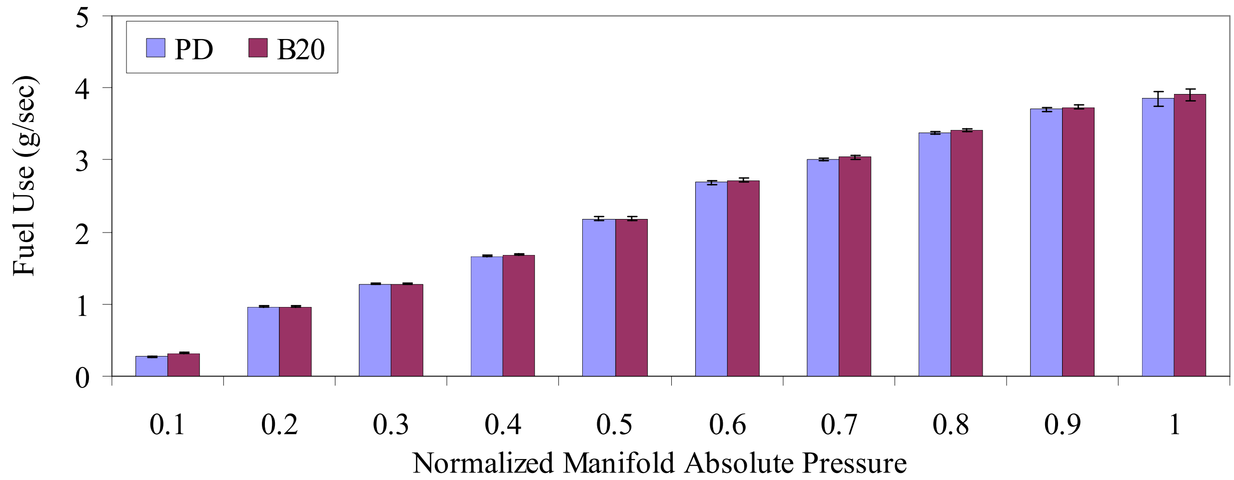
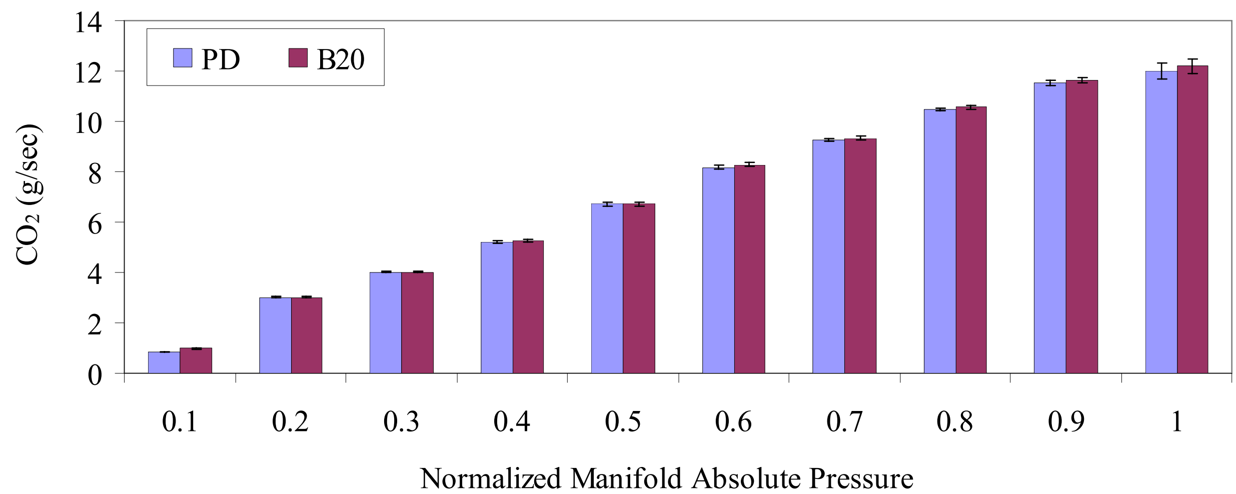


Figure F4. Continued

BACKHOE 2





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 60 ^oF and the relative humidity was 26 %. For the B20 biodiesel test, the ambient temperature was 58 ^oF and the relative humidity was 80 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F5. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Backhoe 2 (continued on next page)

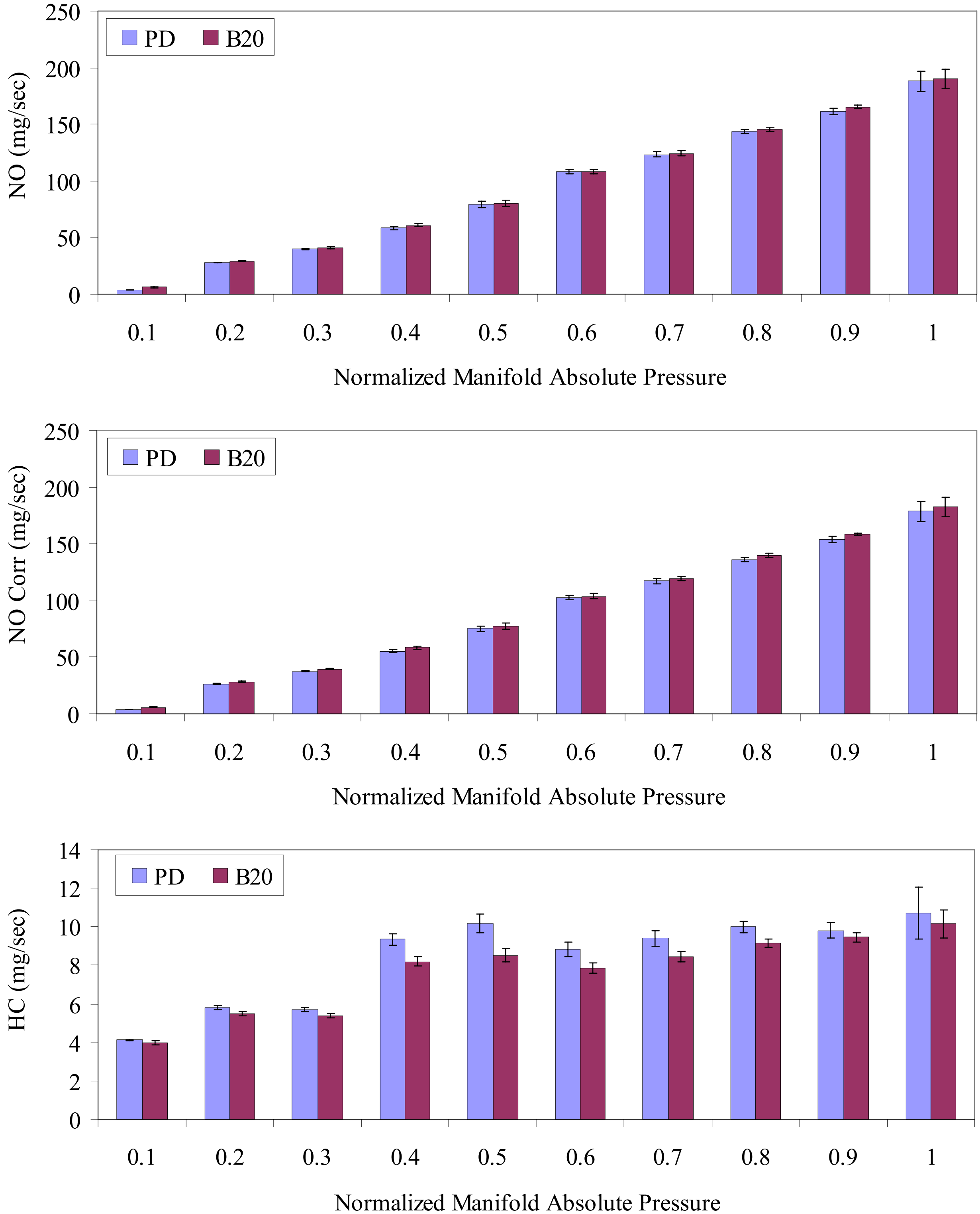
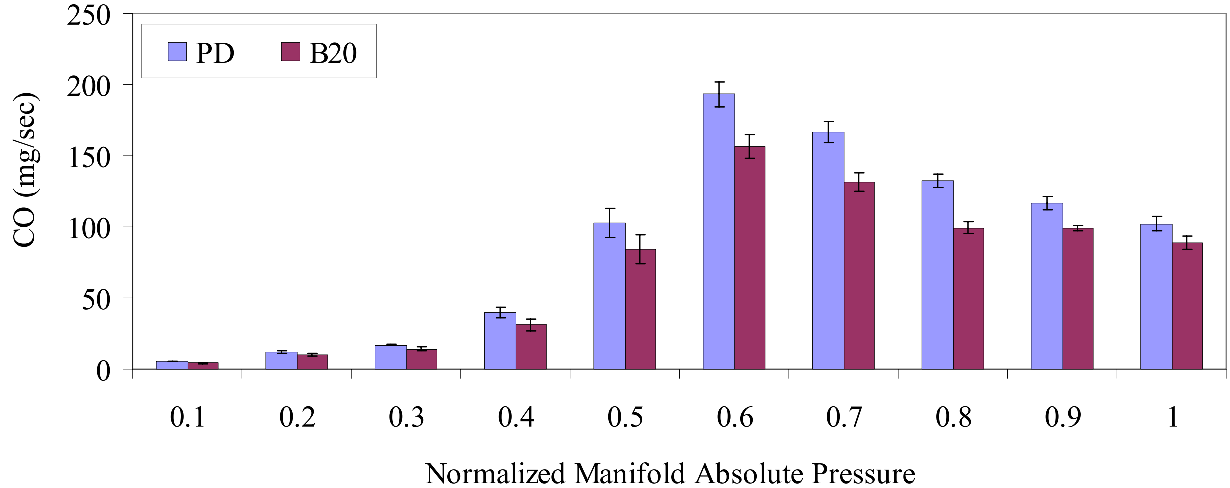


Figure F5. Continued



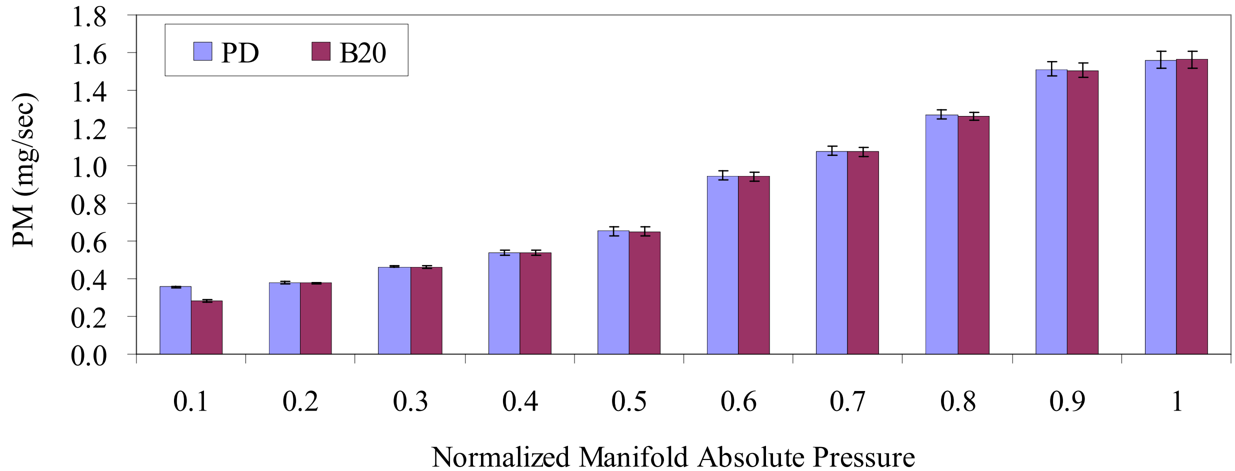
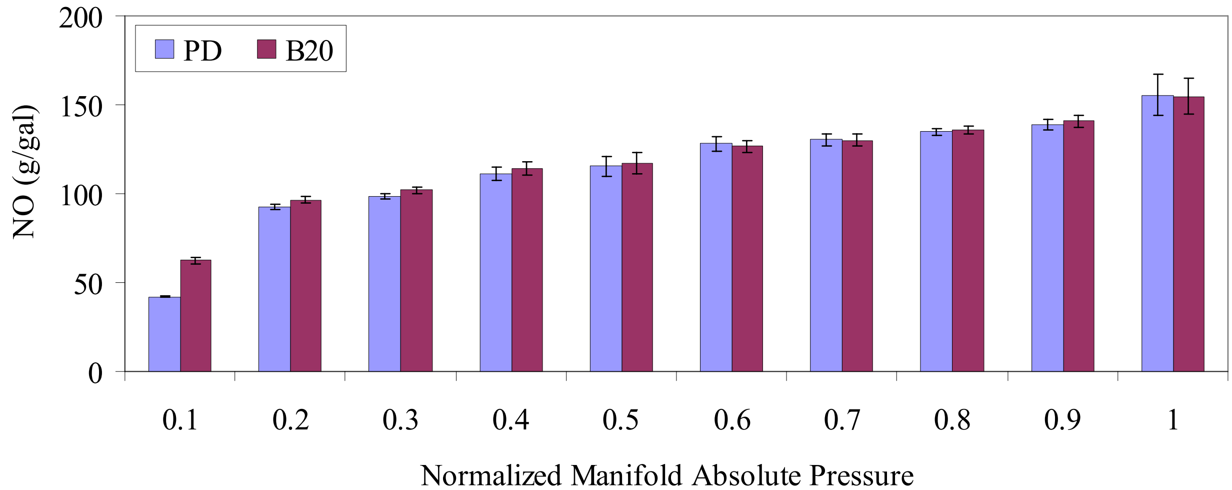
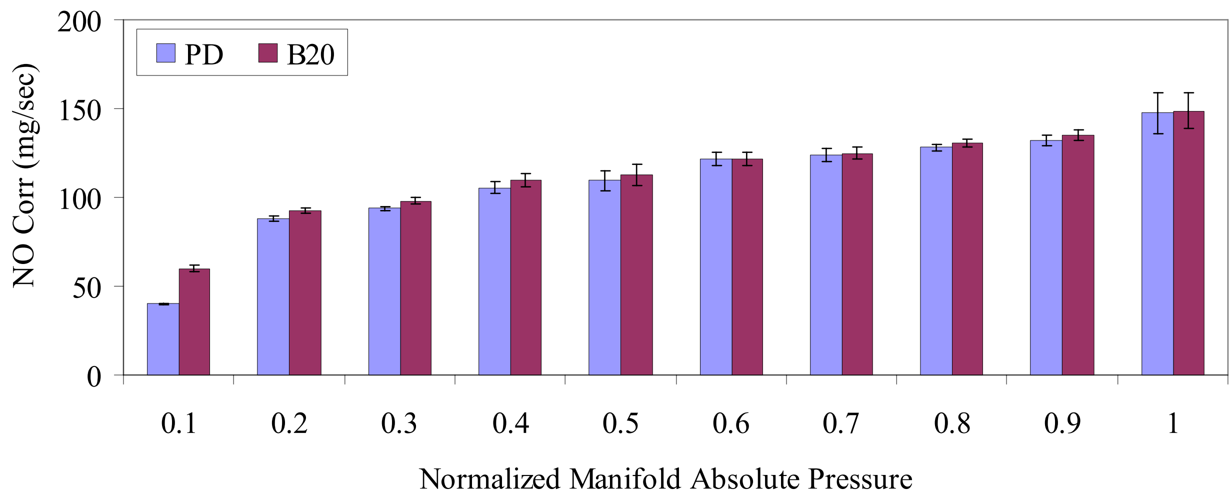


Figure F5. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 60 ^{o}F and the relative humidity was 26 %. For the B20 biodiesel test, the ambient temperature was 58 ^{o}F and the relative humidity was 80 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F6. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Backhoe 2 (continued on next page)

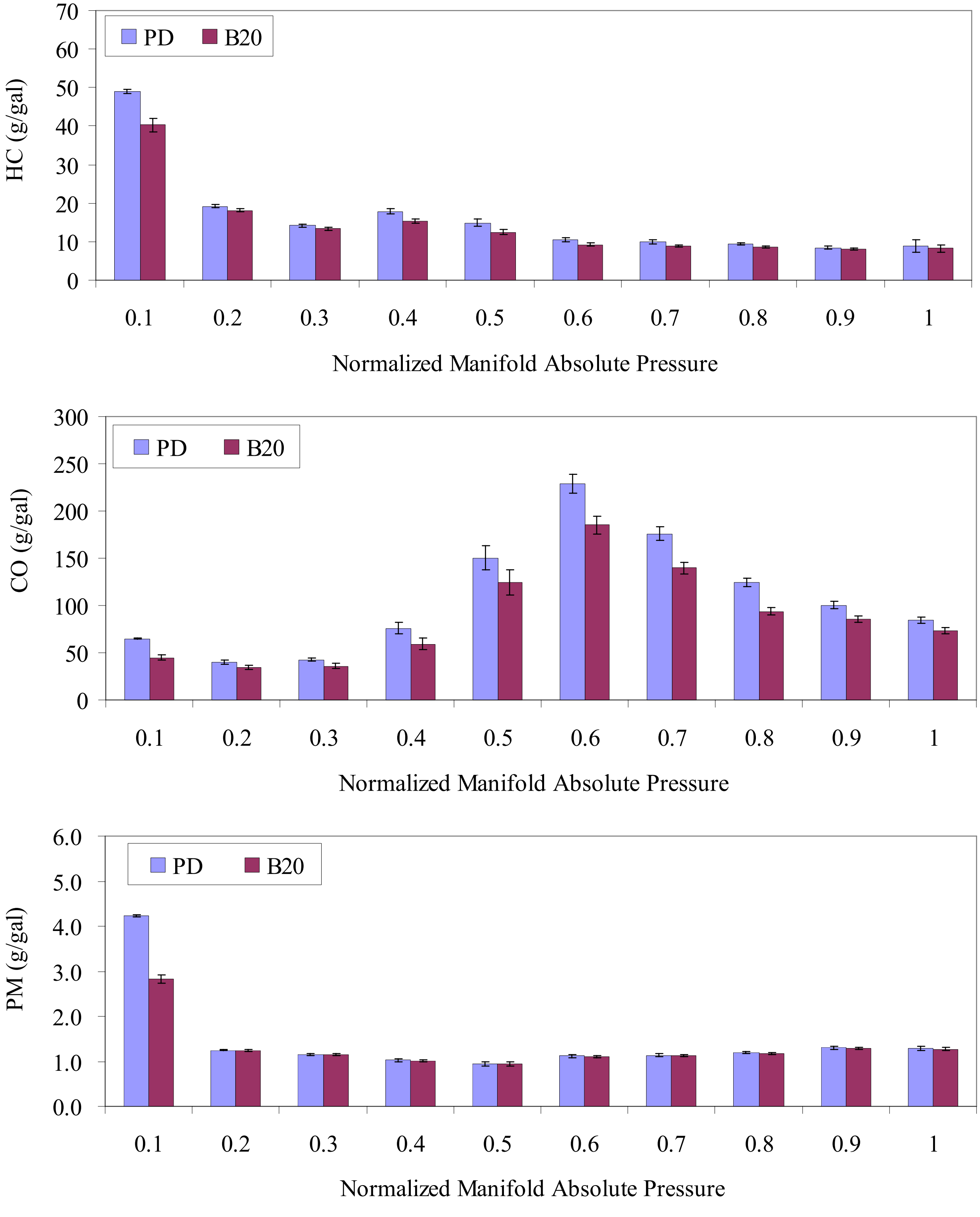
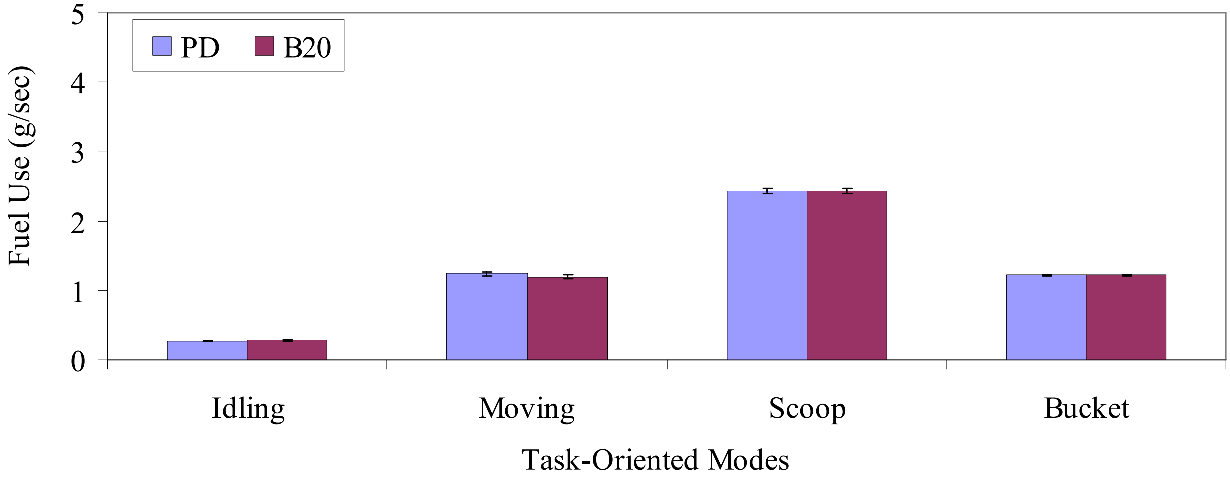
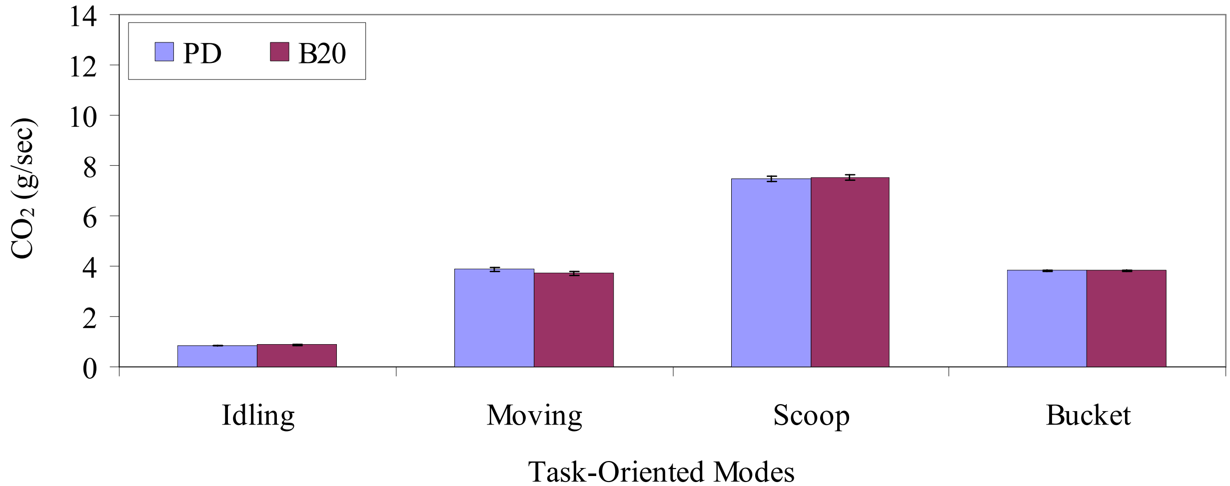


Figure F6. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 60 ^{o}F and the relative humidity was 26 %. For the B20 biodiesel test, the ambient temperature was 58 ^{o}F and the relative humidity was 80 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F7. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Backhoe 2 (continued on next page)

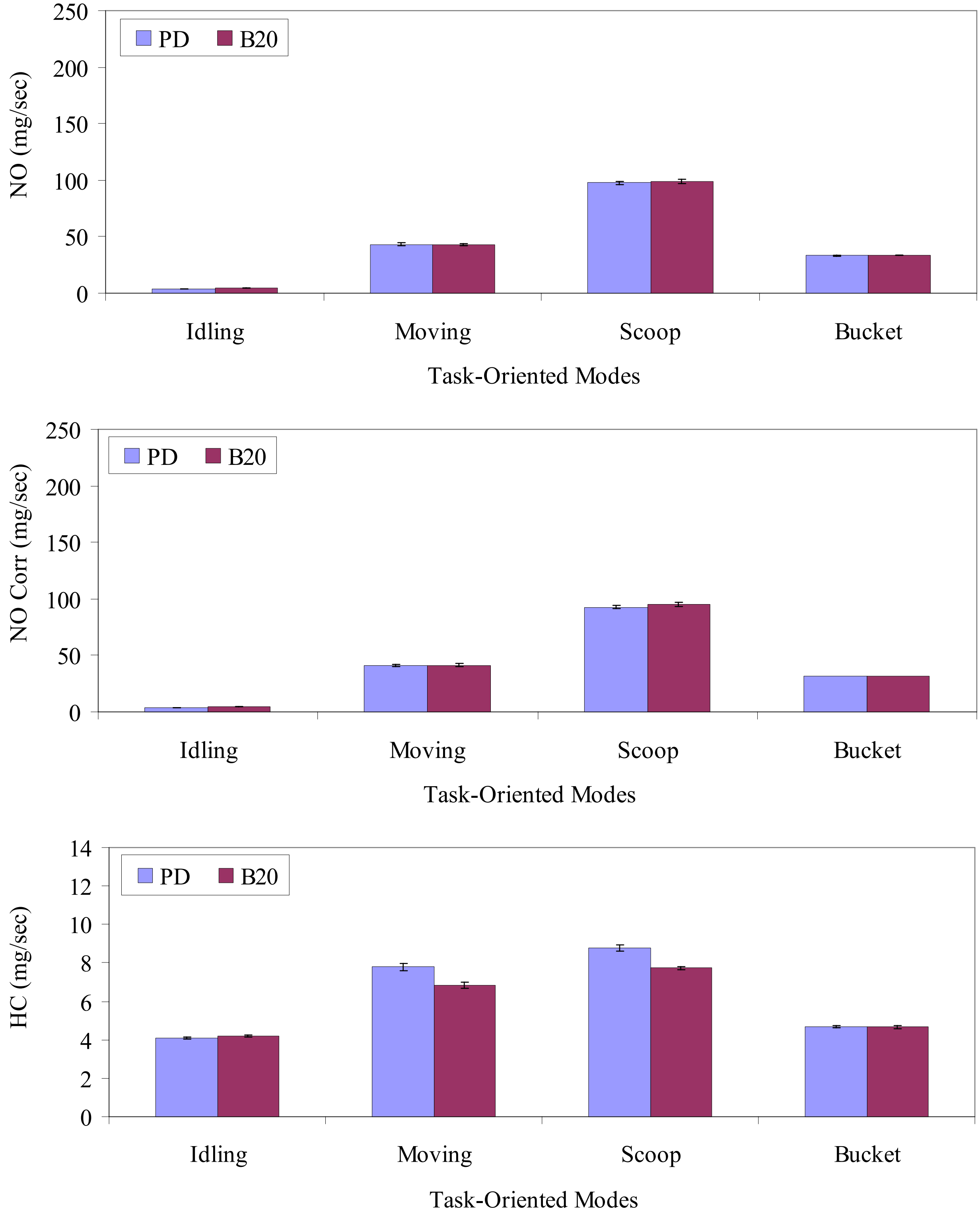
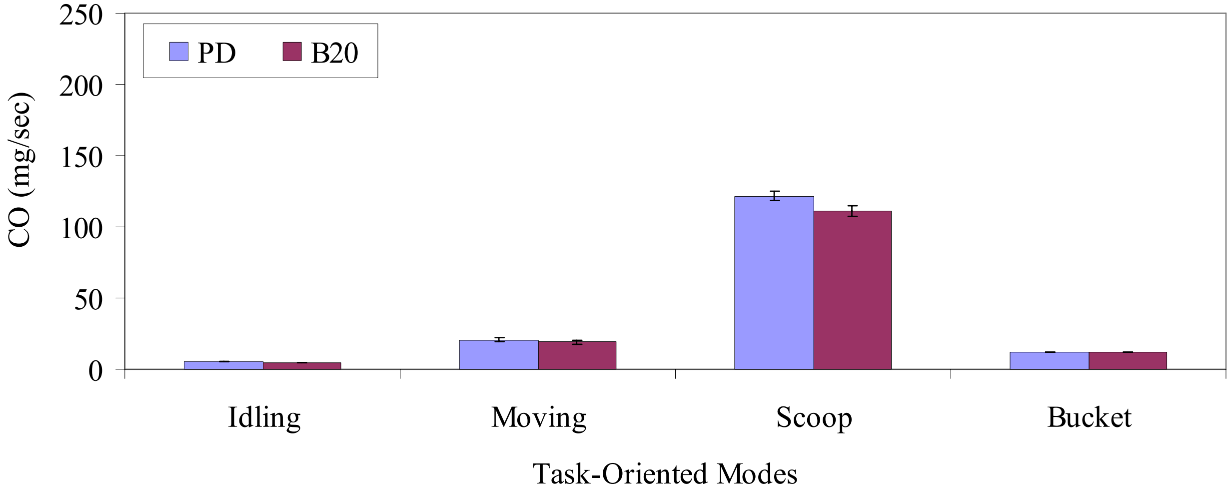


Figure F7. Continued



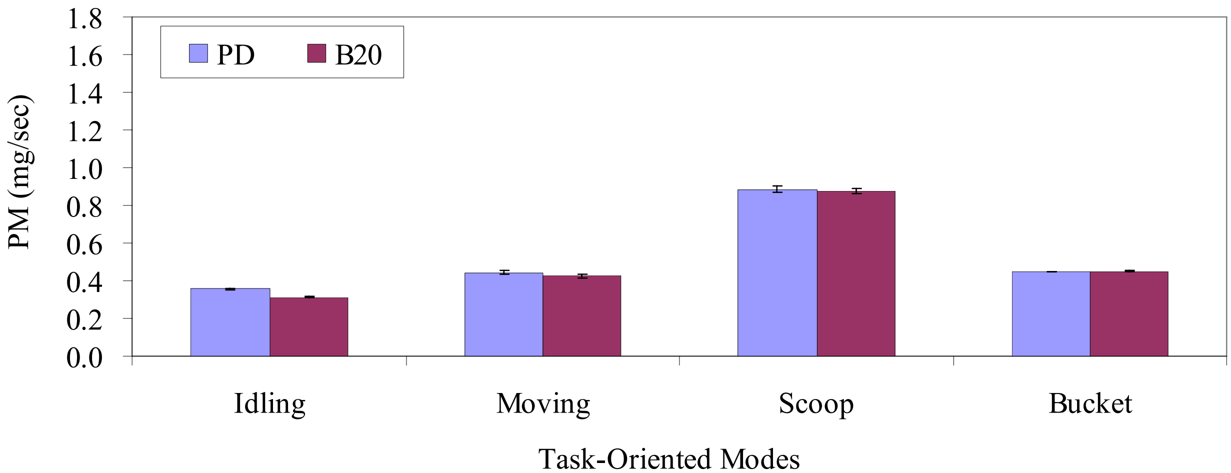
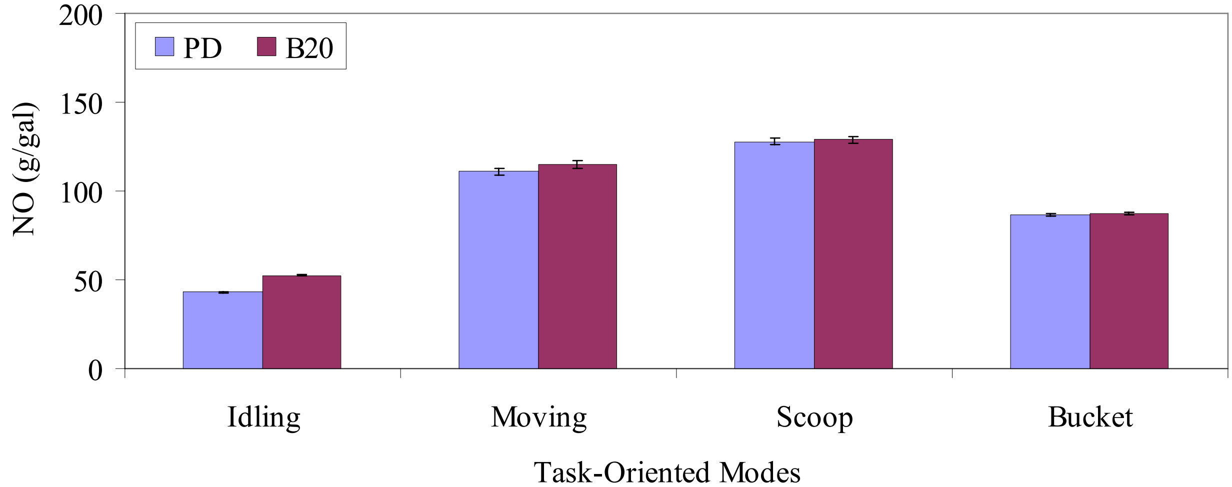
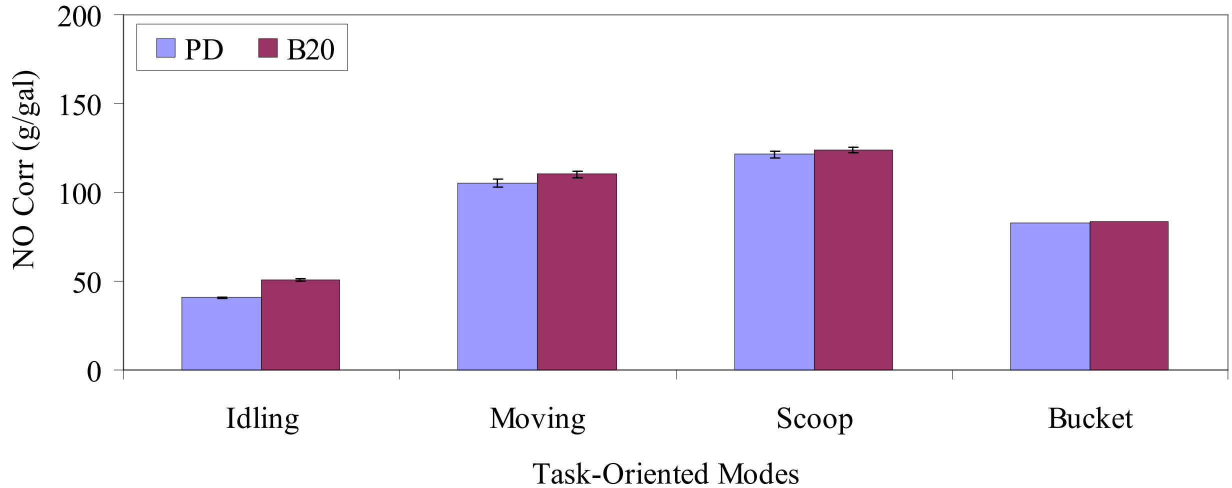


Figure F7. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 60 ^{o}F and the relative humidity was 26 %. For the B20 biodiesel test, the ambient temperature was 58 ^{o}F and the relative humidity was 80 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F8. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Backhoe 2 (continued on next page)

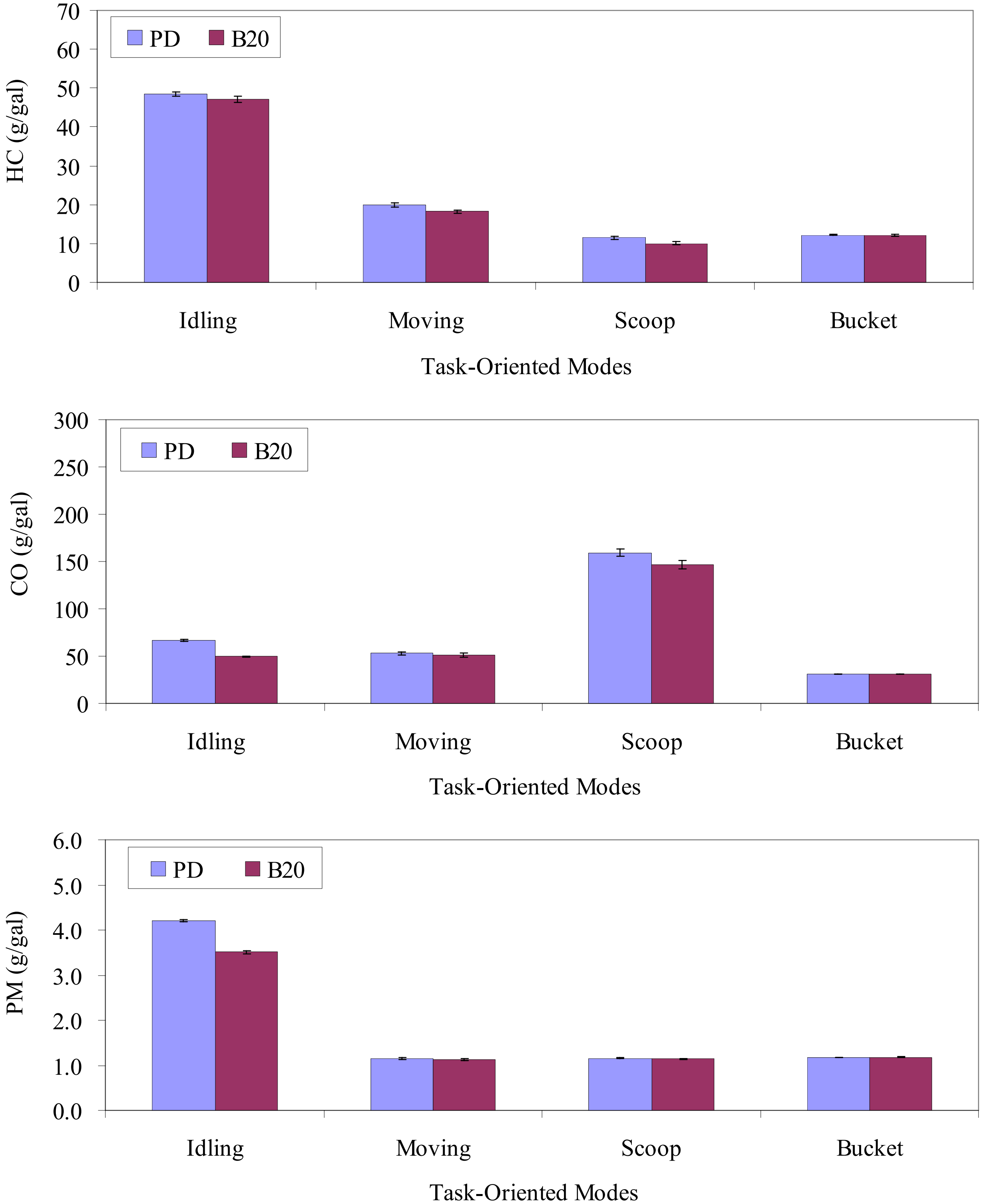
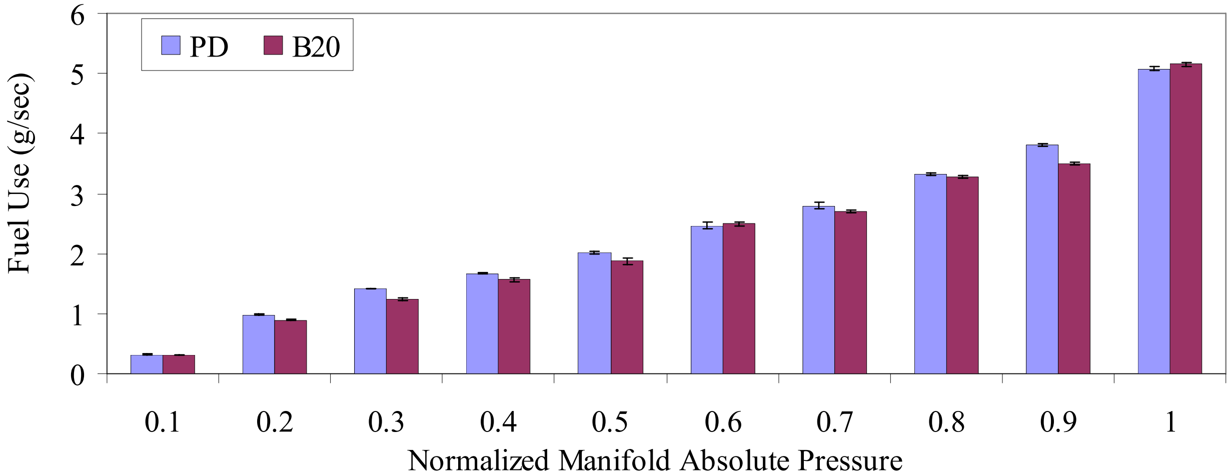
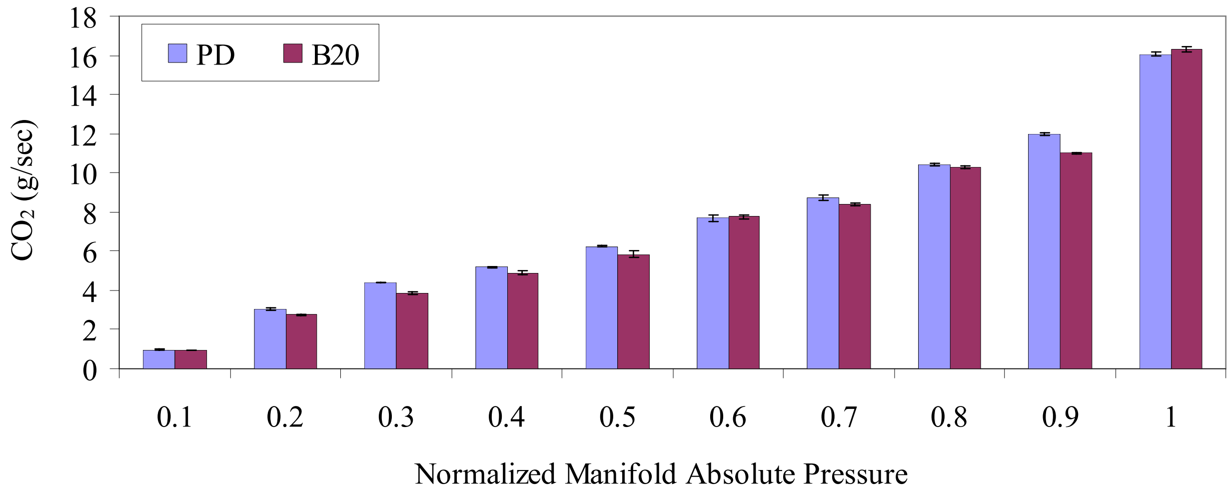


Figure F8. Continued

BACKHOE 3





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 67 ^oF and the relative humidity was 50 %. For the B20 biodiesel test, the ambient temperature was 63 ^oF and the relative humidity was 36 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F9. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Backhoe 3 (continued on next page)

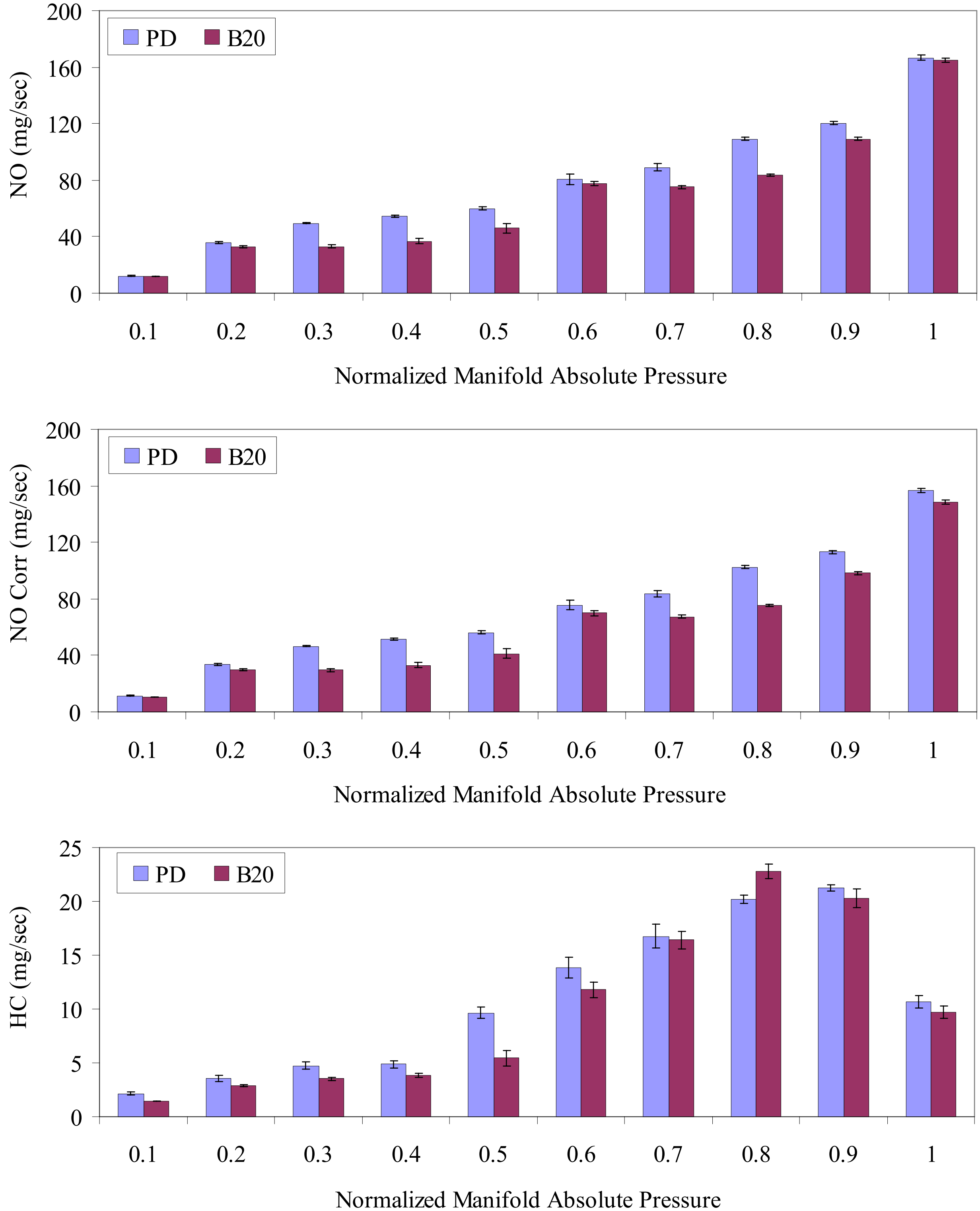
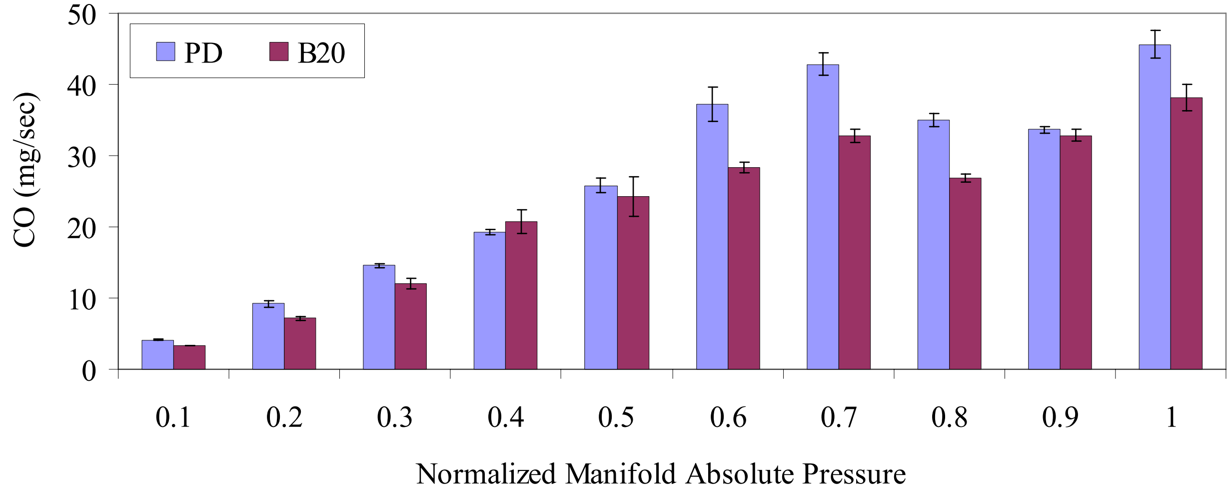


Figure F9. Continued



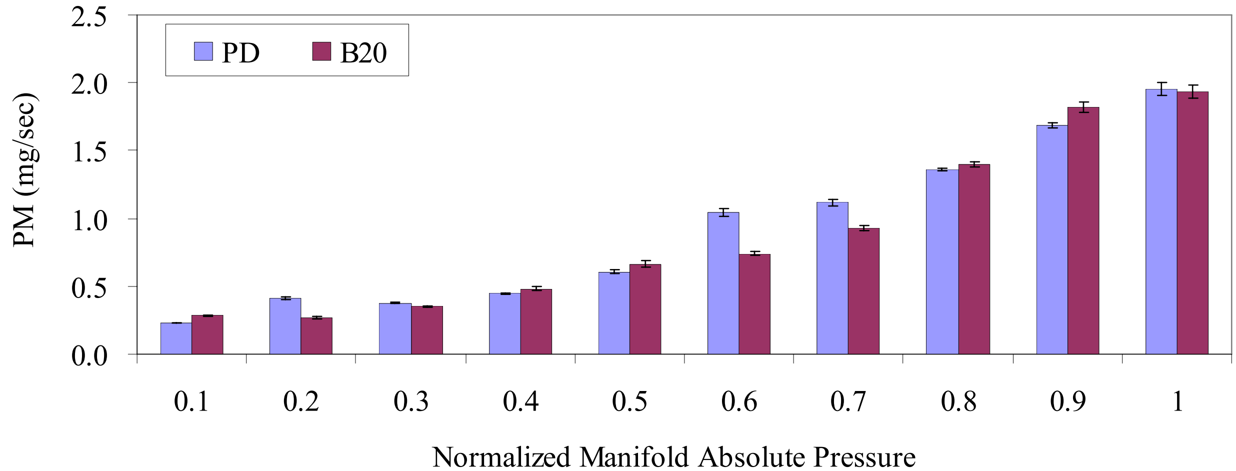
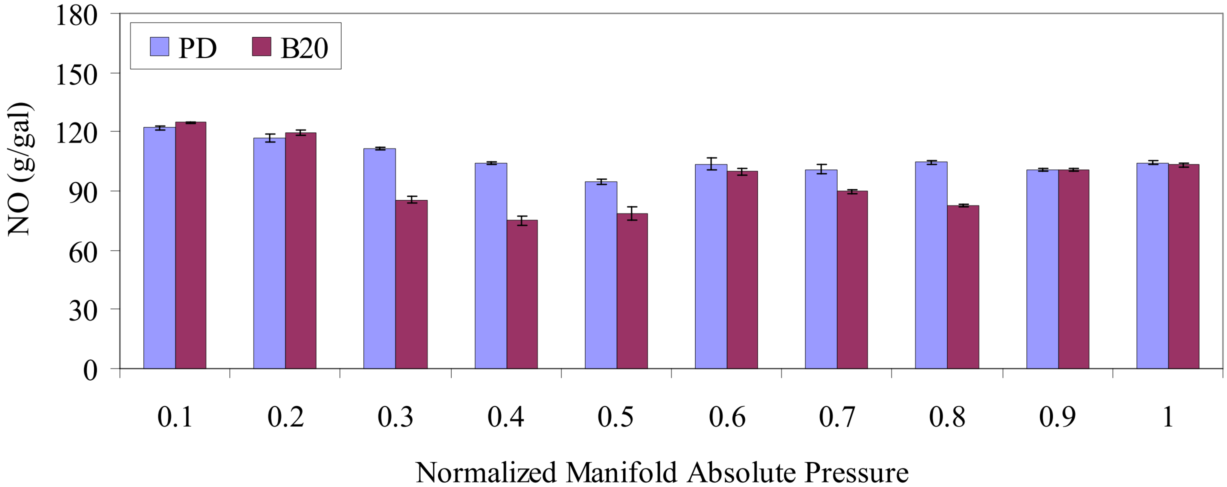
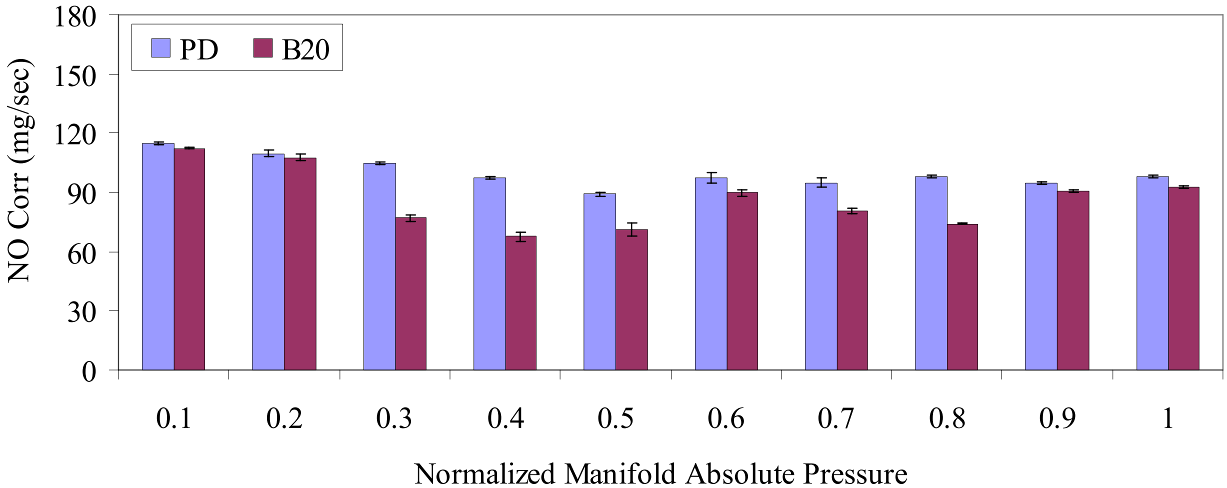


Figure F9. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 67 ^oF and the relative humidity was 50 %. For the B20 biodiesel test, the ambient temperature was 63 ^oF and the relative humidity was 36 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F10. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Backhoe 3 (continued on next page)

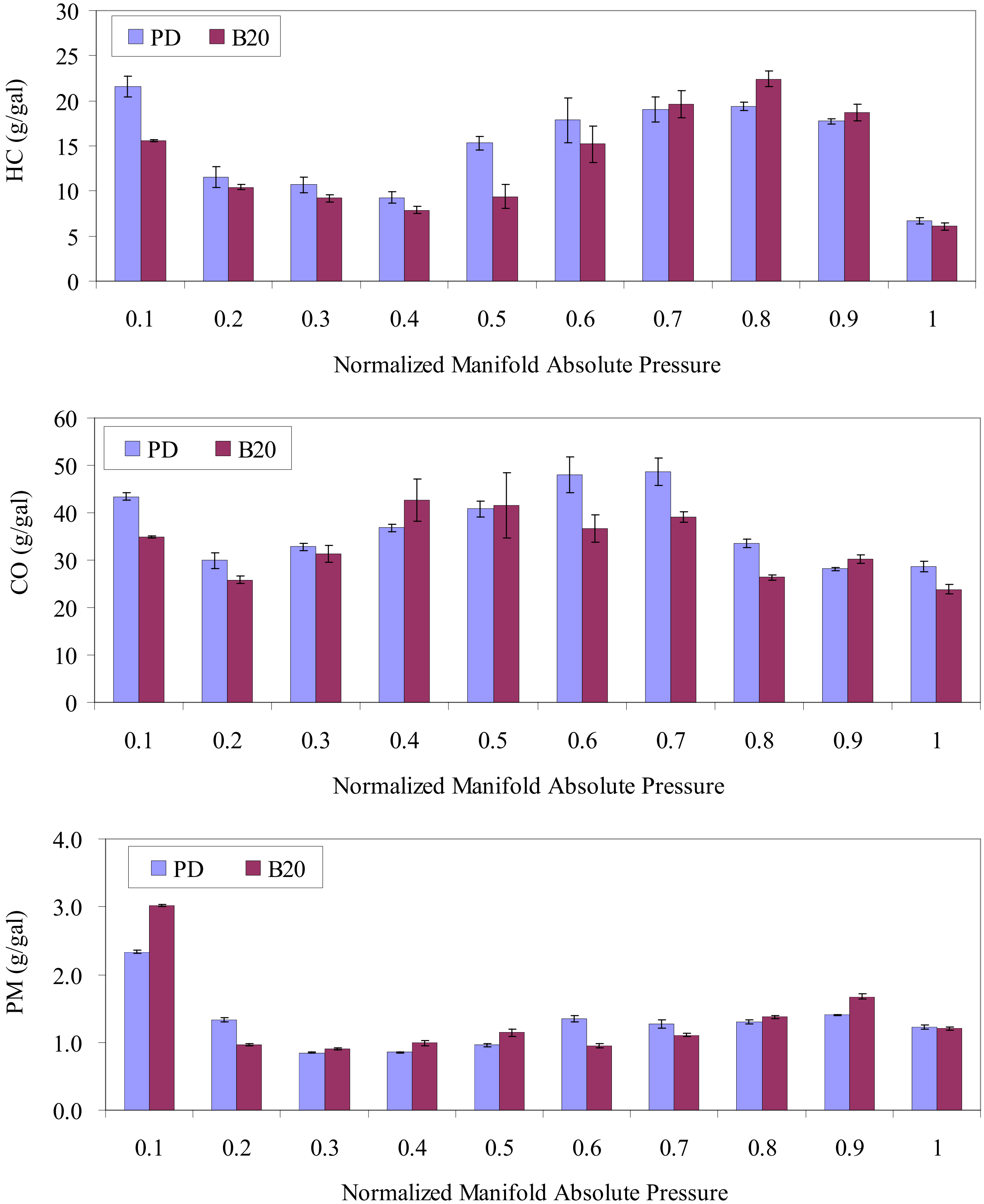
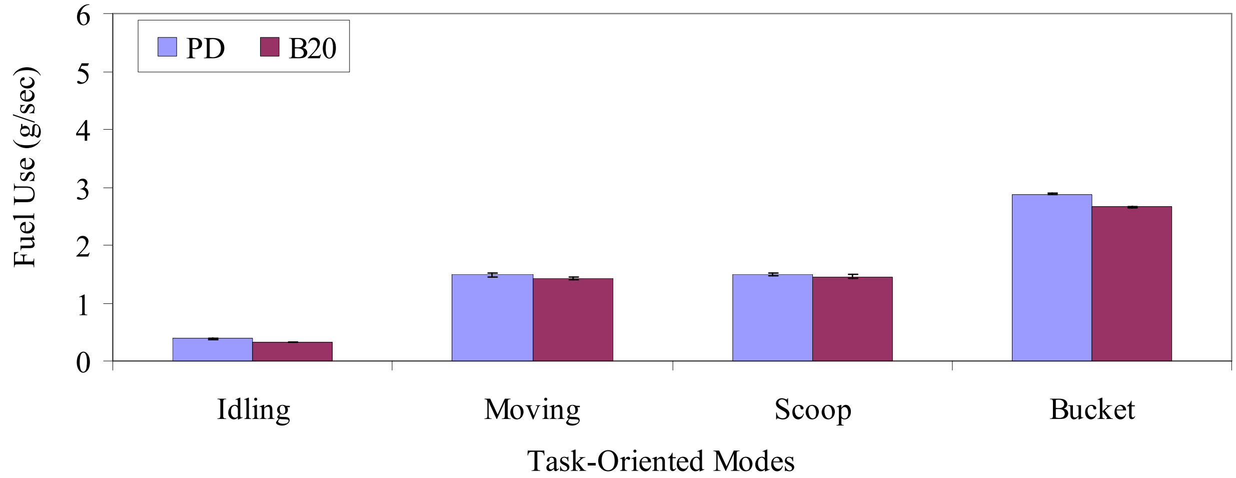
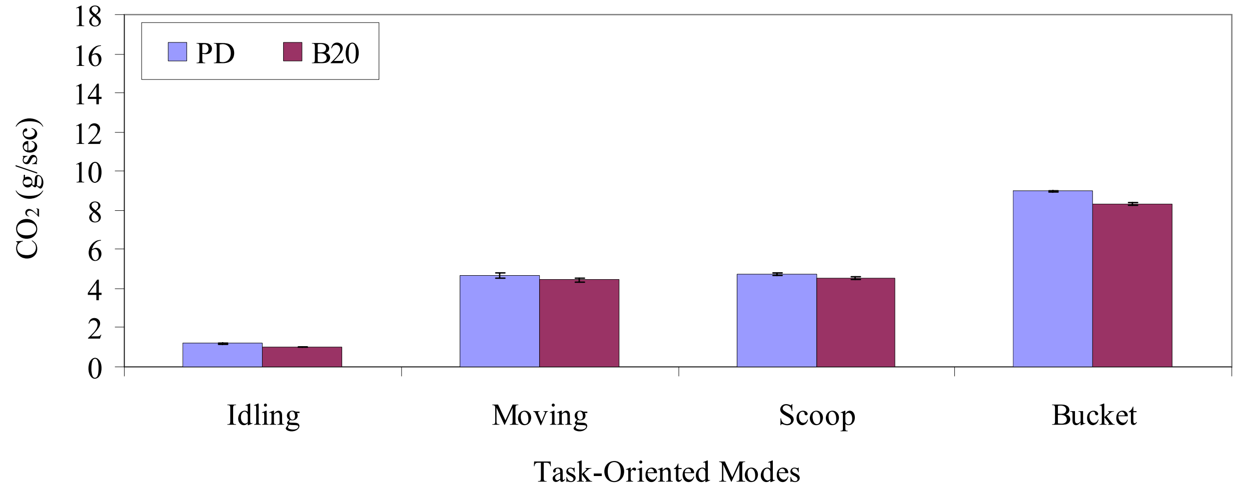


Figure F10. Continued

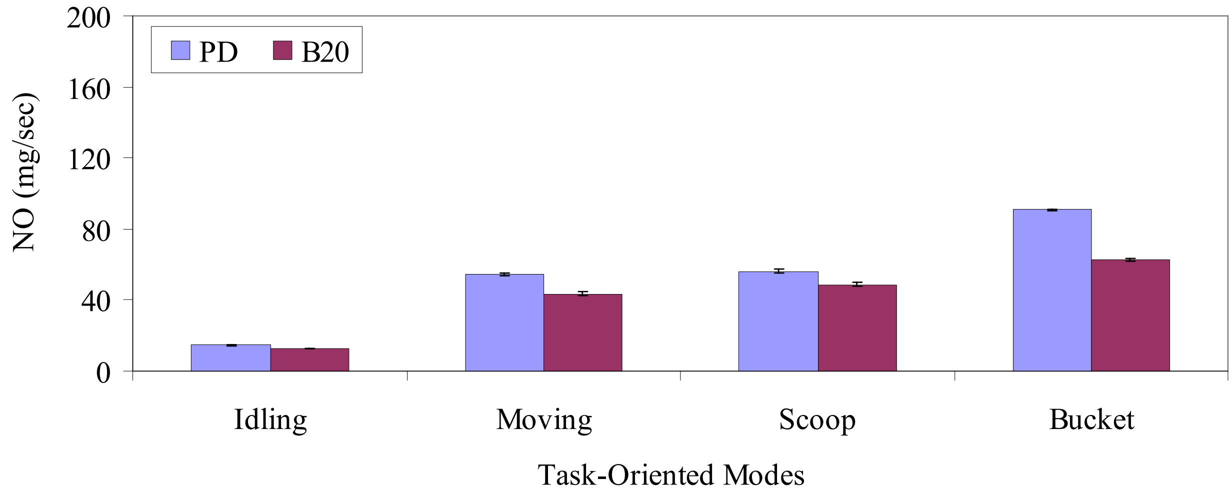


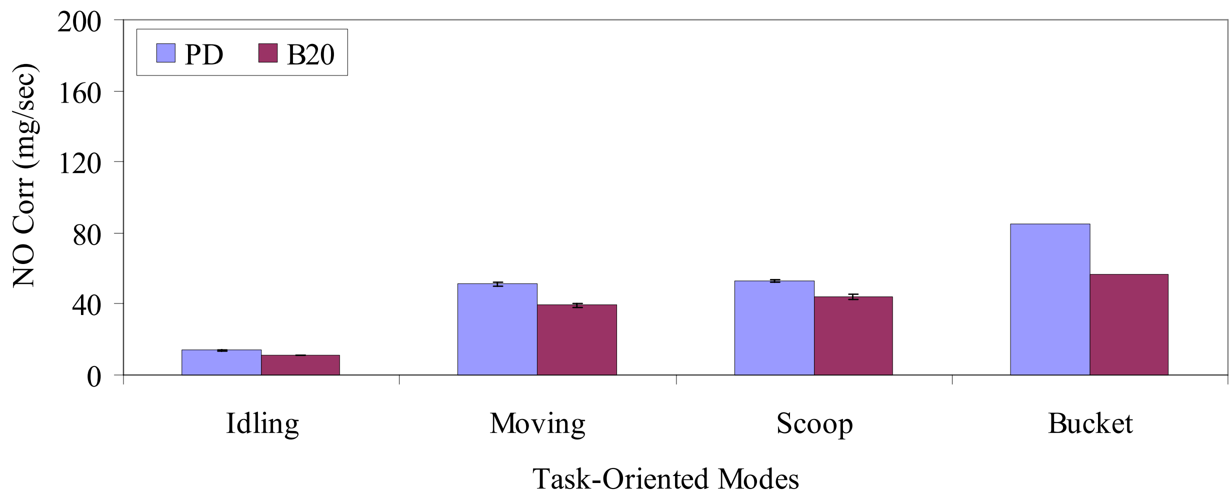


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 67 ^{o}F and the relative humidity was 50 %. For the B20 biodiesel test, the ambient temperature was 63 ^{o}F and the relative humidity was 36 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F11. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Backhoe 3 (continued on next page)





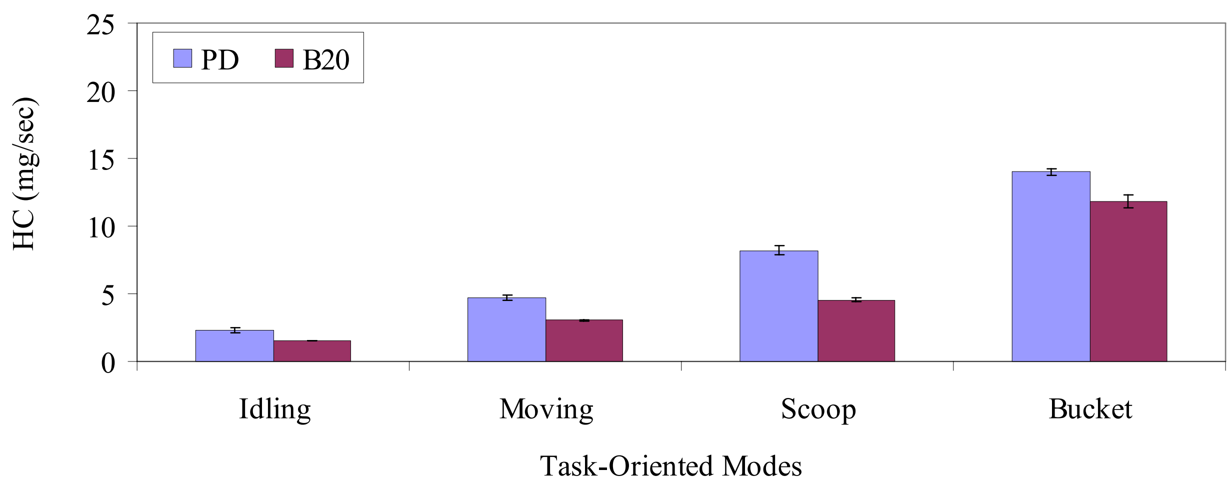
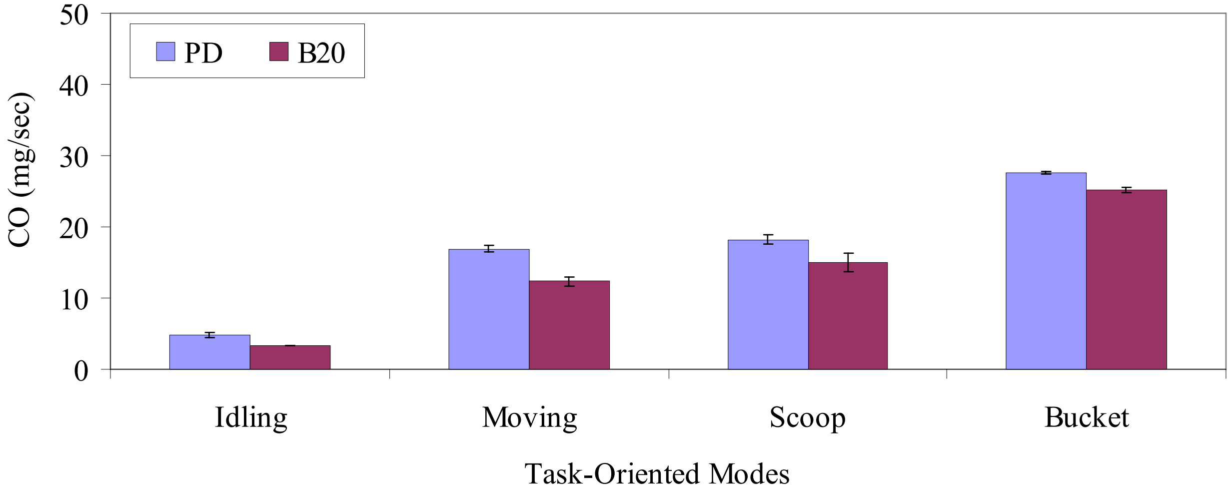


Figure F11. Continued



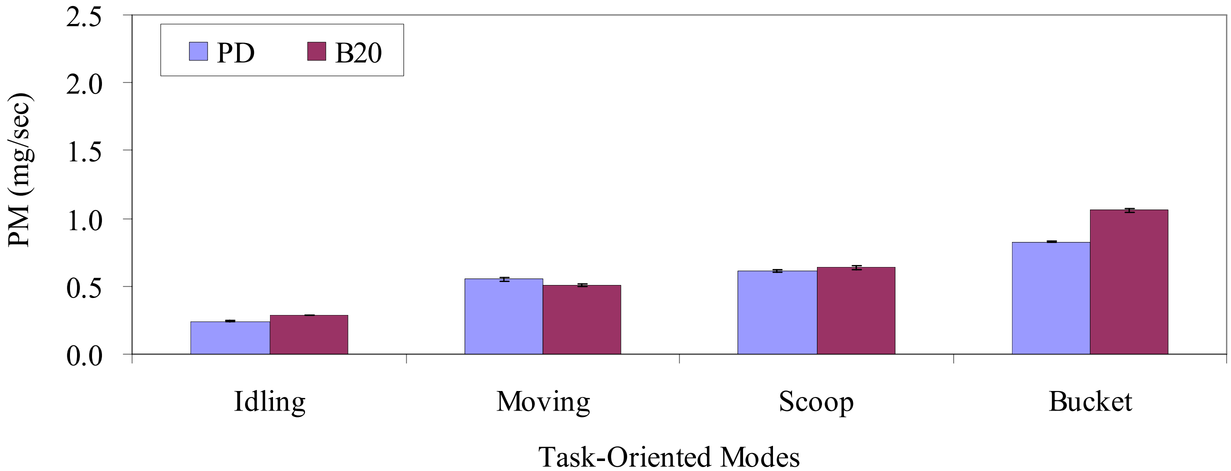
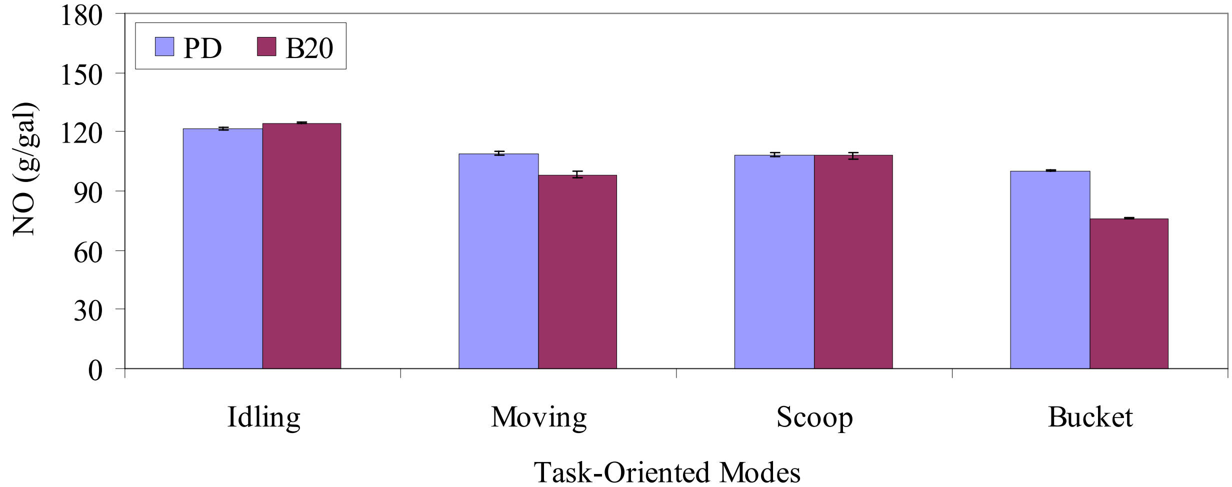
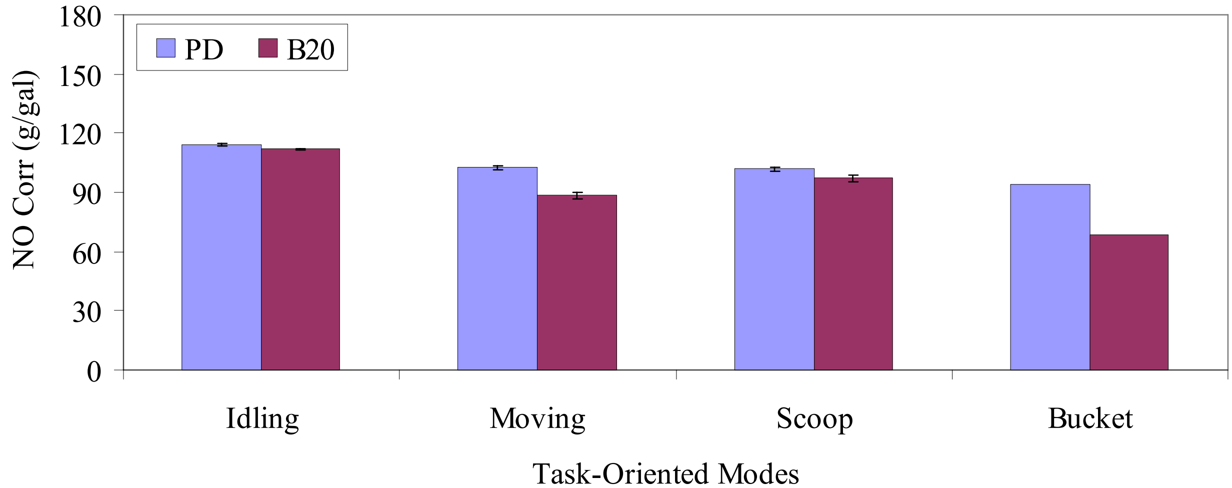


Figure F11. Continued

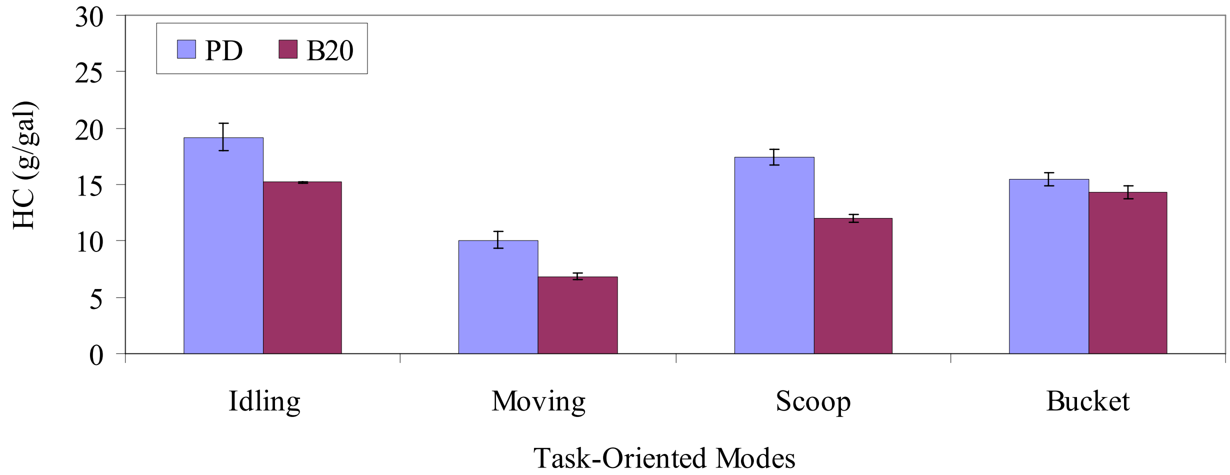


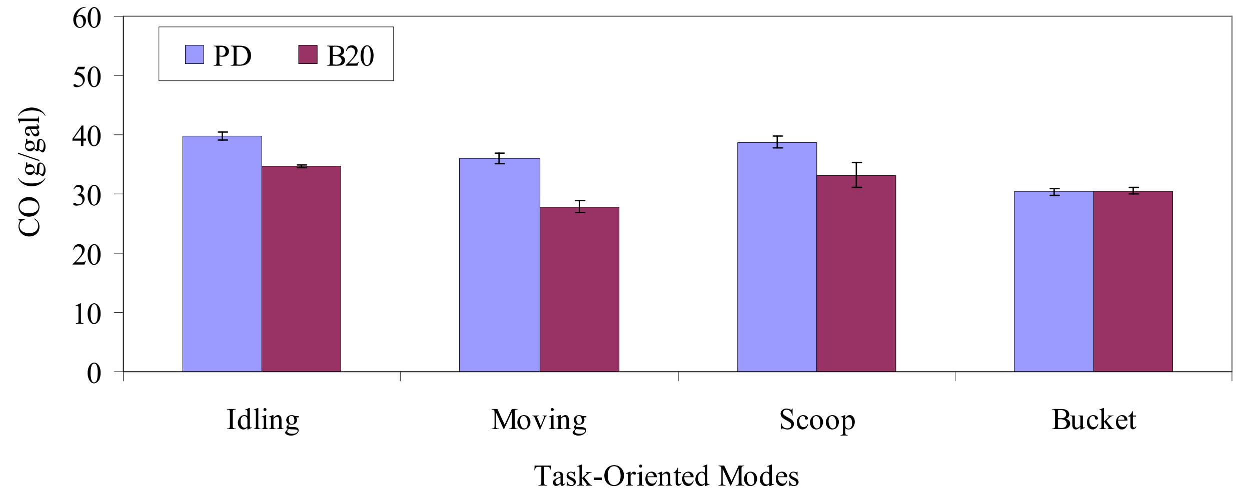


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 67 ^{o}F and the relative humidity was 50 %. For the B20 biodiesel tests, the ambient temperature was 63 ^{o}F and the relative humidity was 36 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F12. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Backhoe 3 (continued on next page)





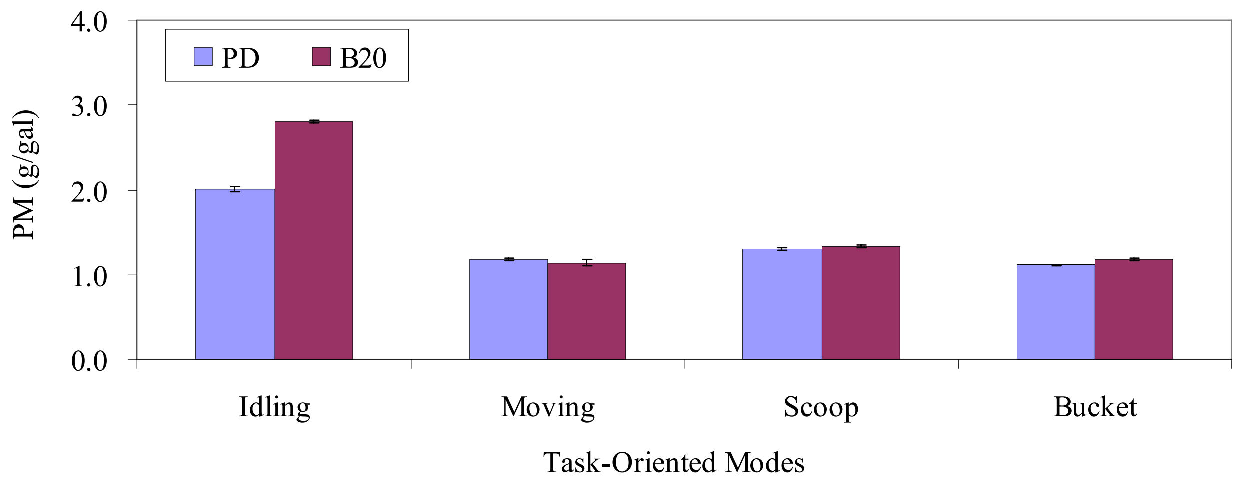
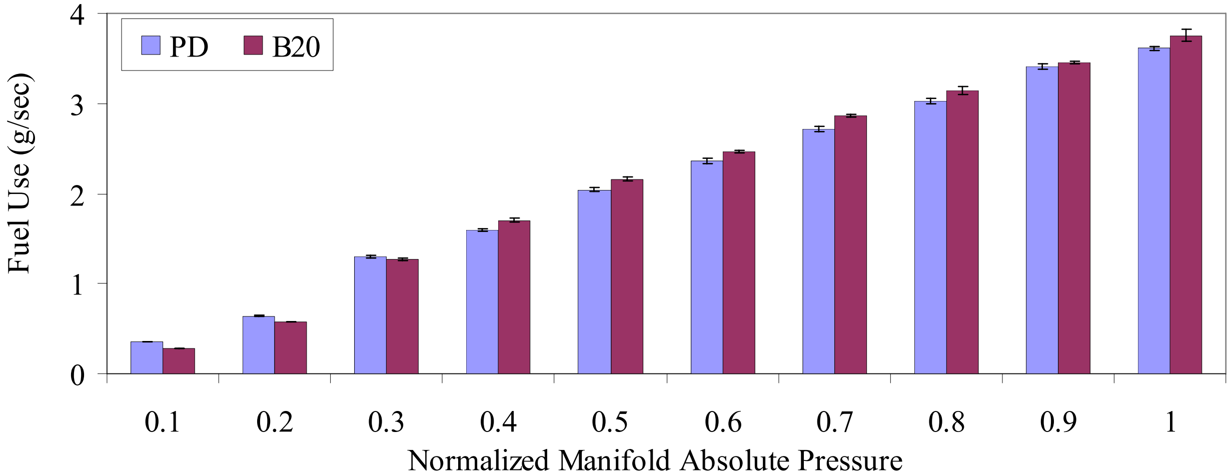
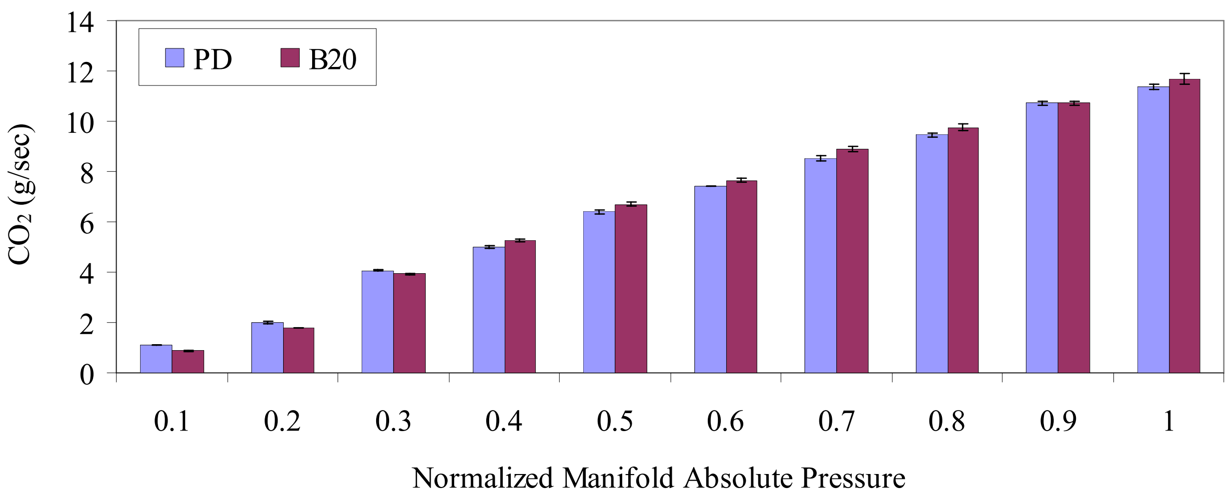


Figure F12. Continued

BACKHOE 4





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 54 ^{o}F and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 83 ^{o}F and the relative humidity was 38 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F13. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Backhoe 4 (continued on next page)

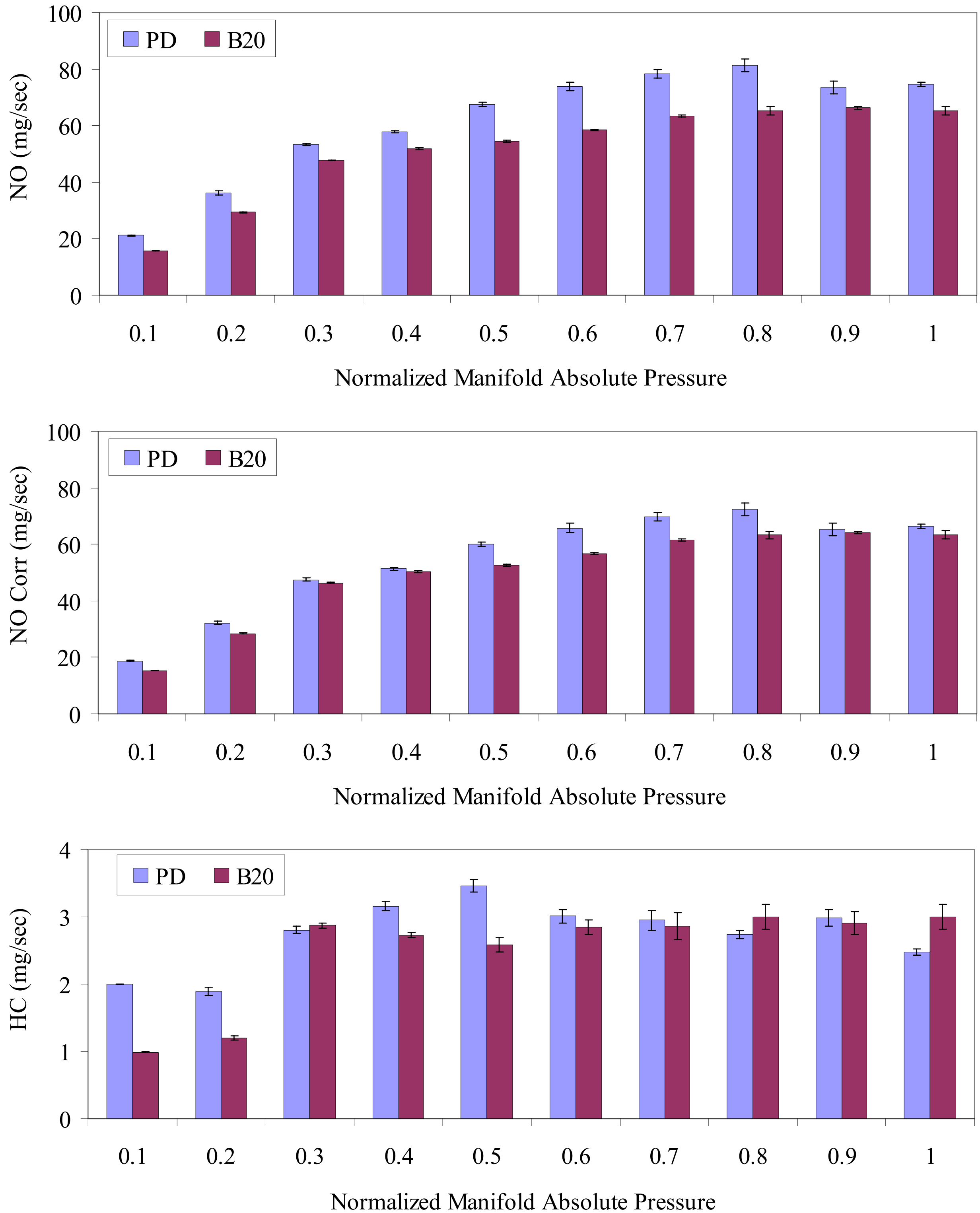
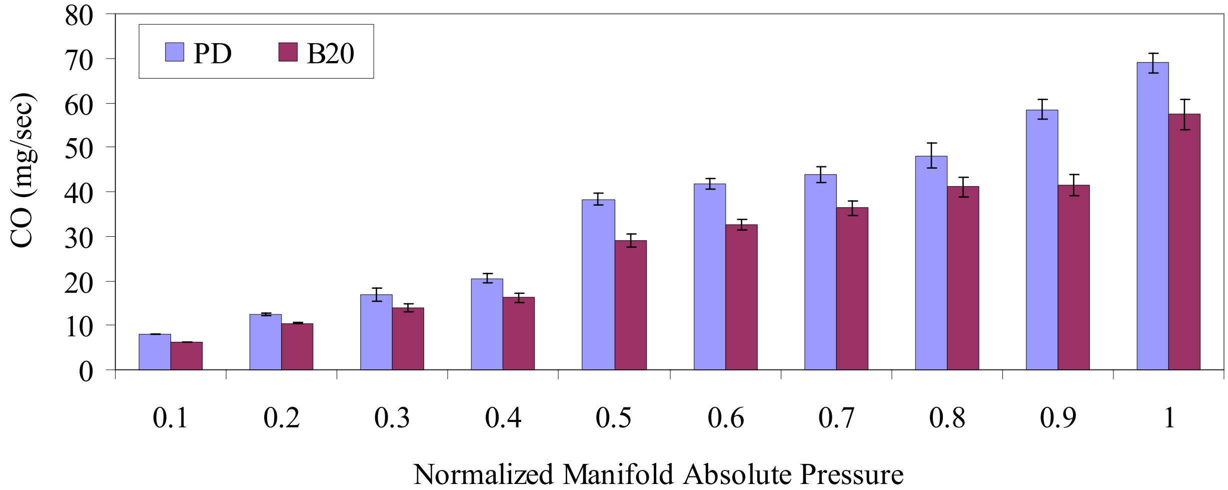


Figure F13. Continued



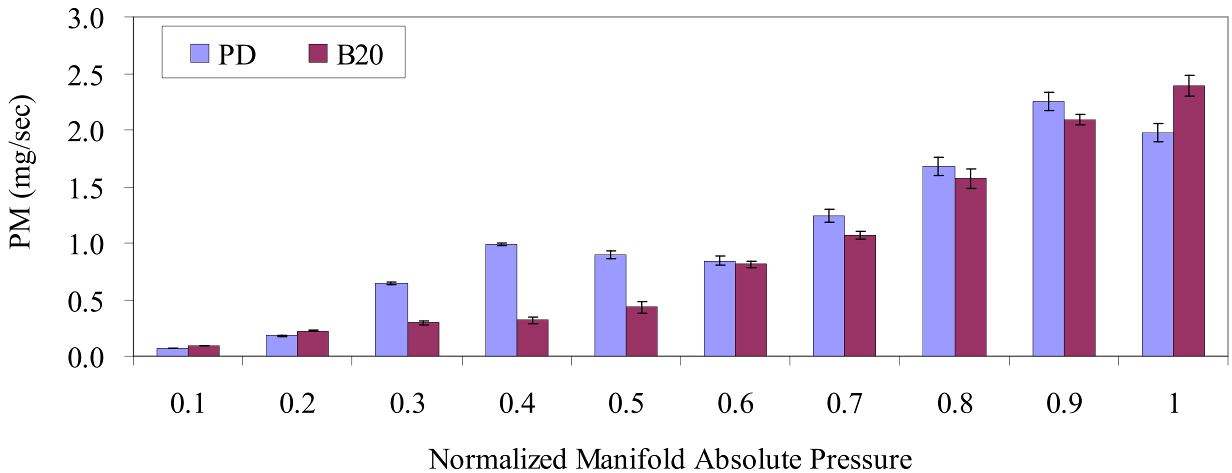
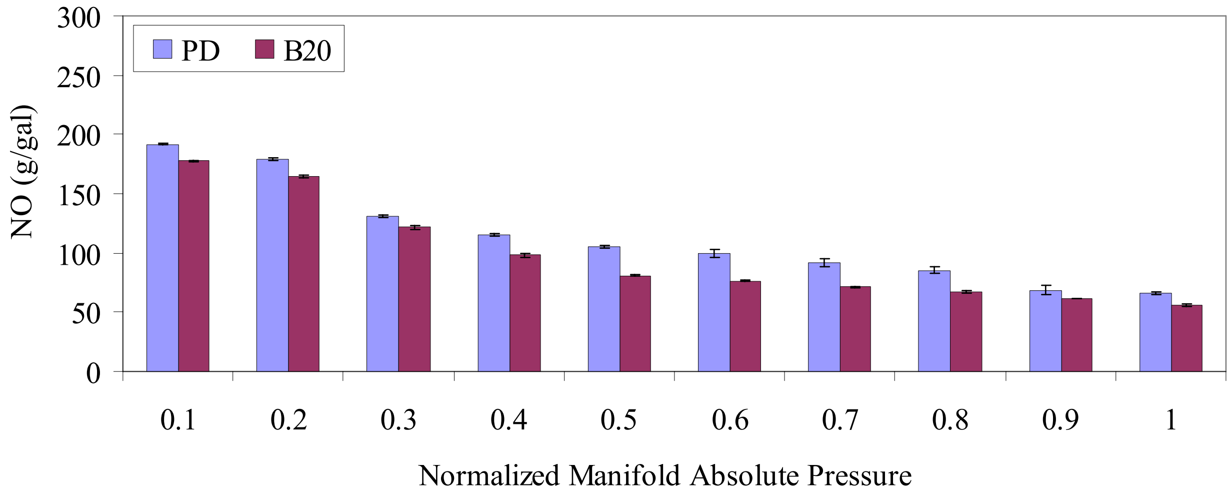
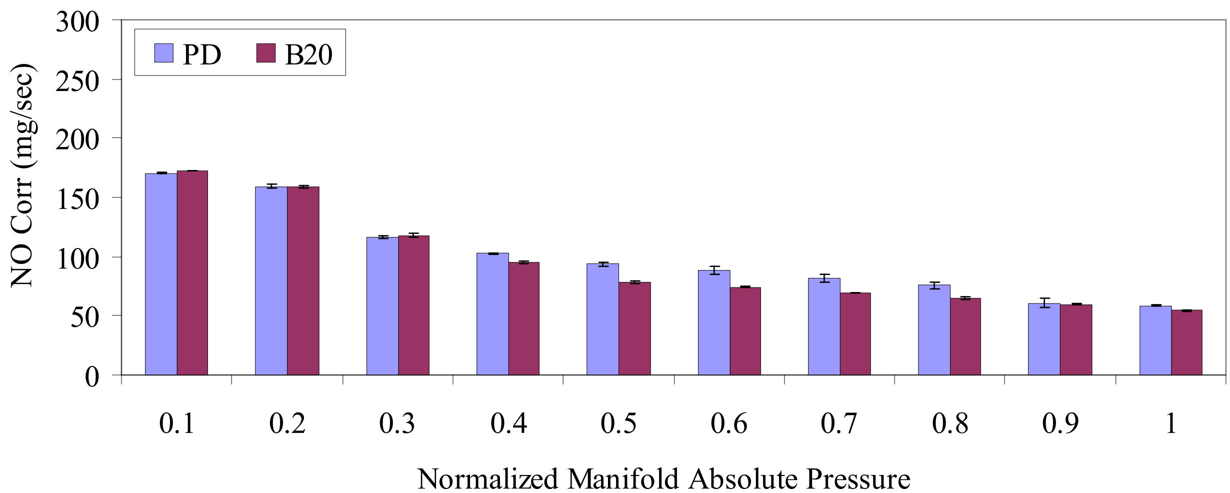


Figure F13. Continued

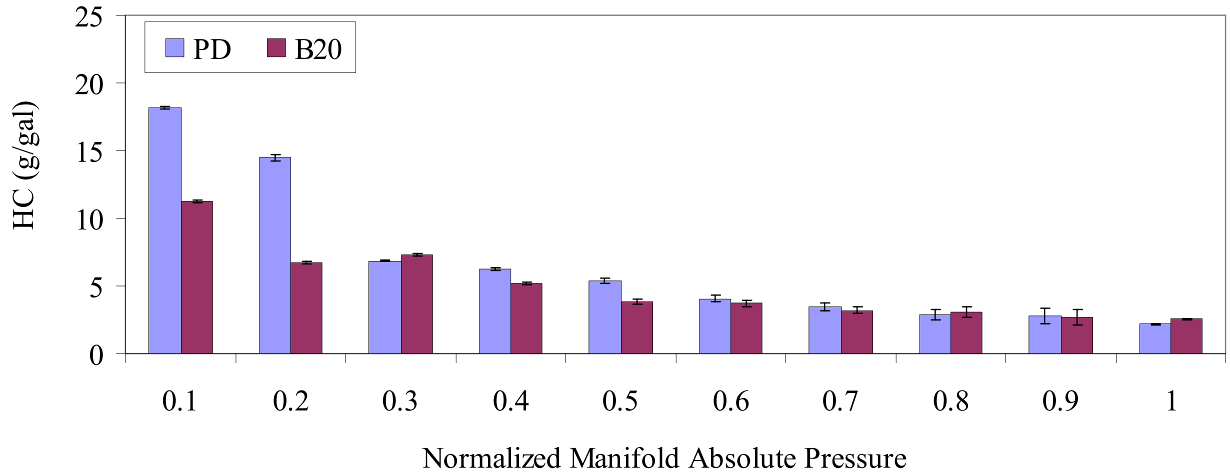


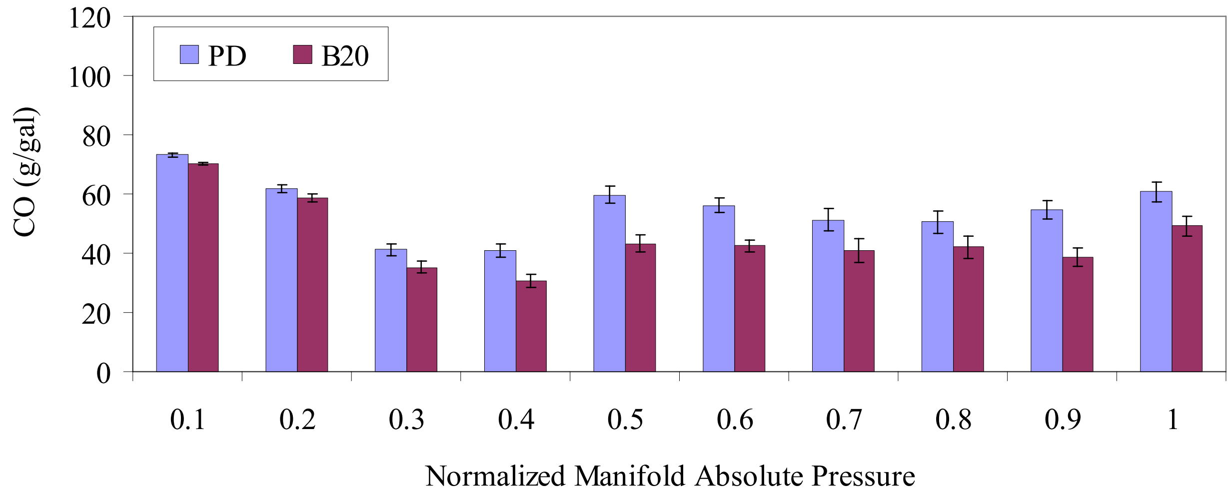


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 54 ^oF and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 83 ^oF and the relative humidity was 38 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F14. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Backhoe 4 (continued on next page)





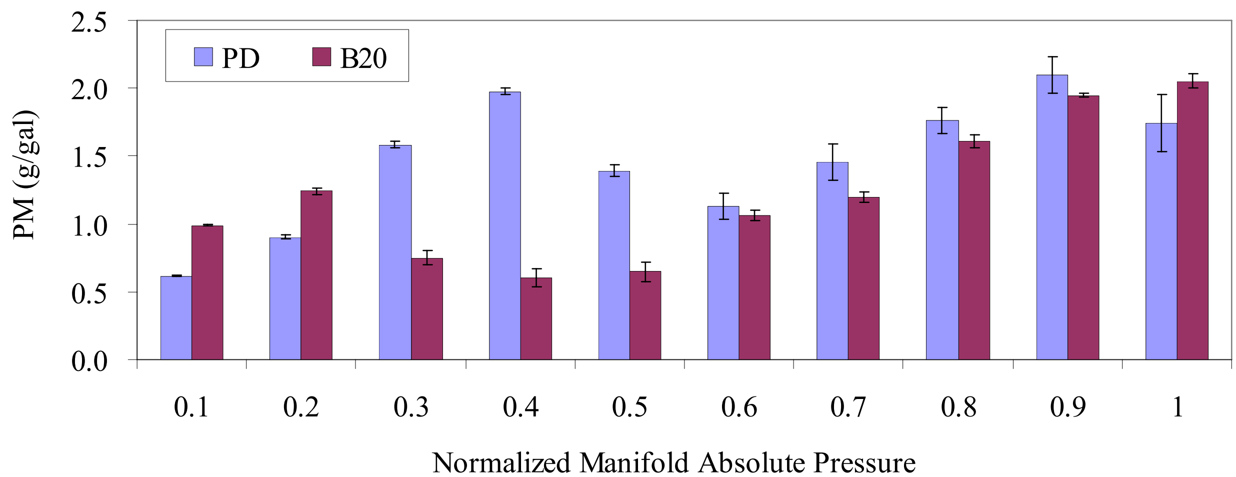
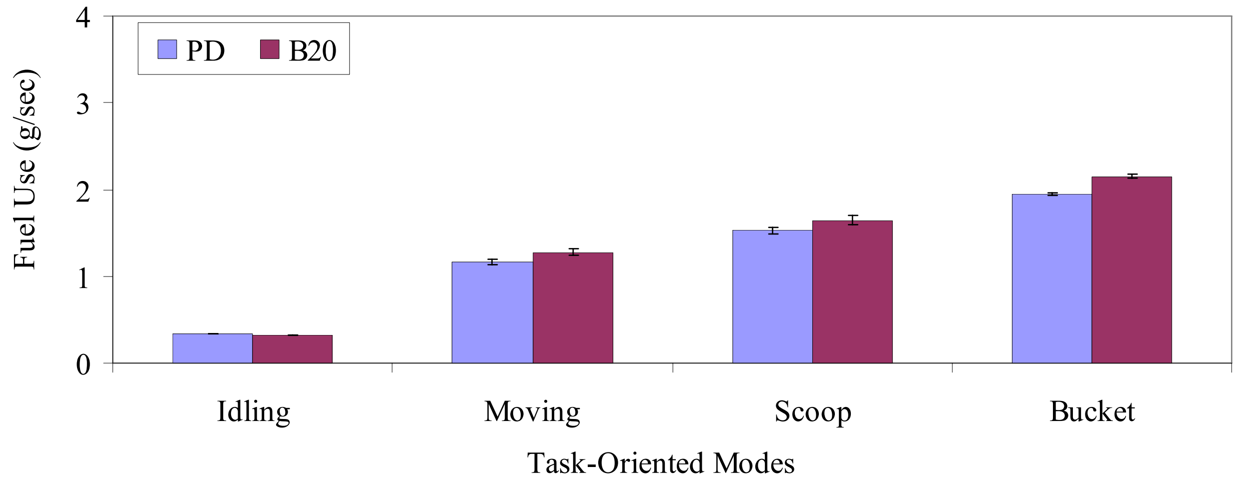
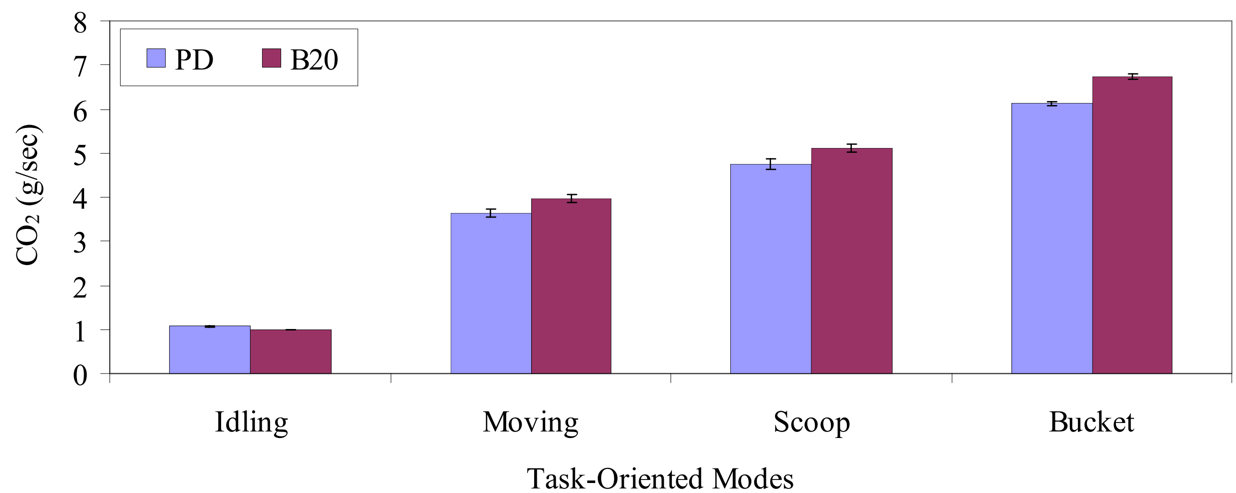


Figure F14. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 54 ^{o}F and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 83 ^{o}F and the relative humidity was 38 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F15. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Backhoe 4 (continued on next page)

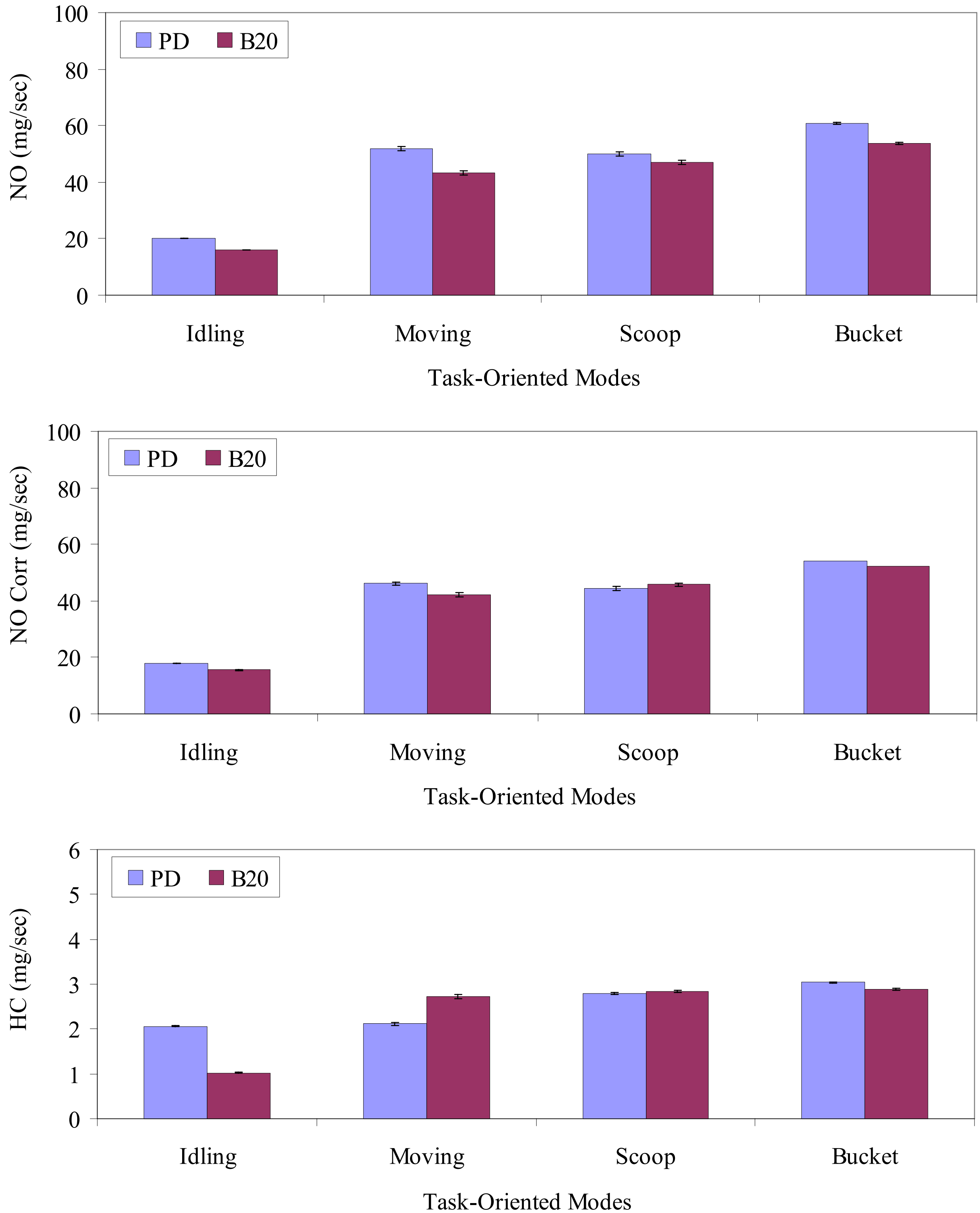


Figure F15. Continued

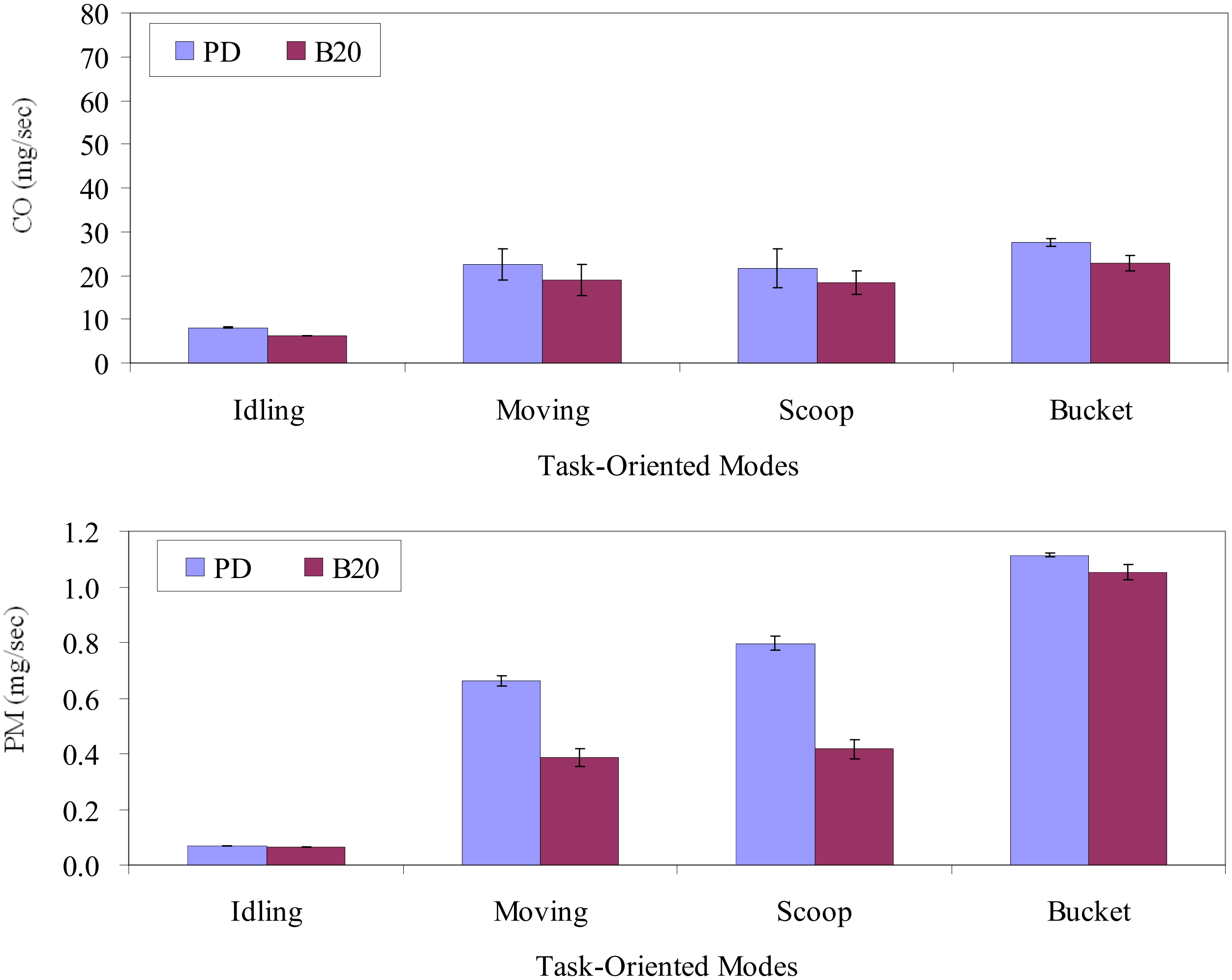
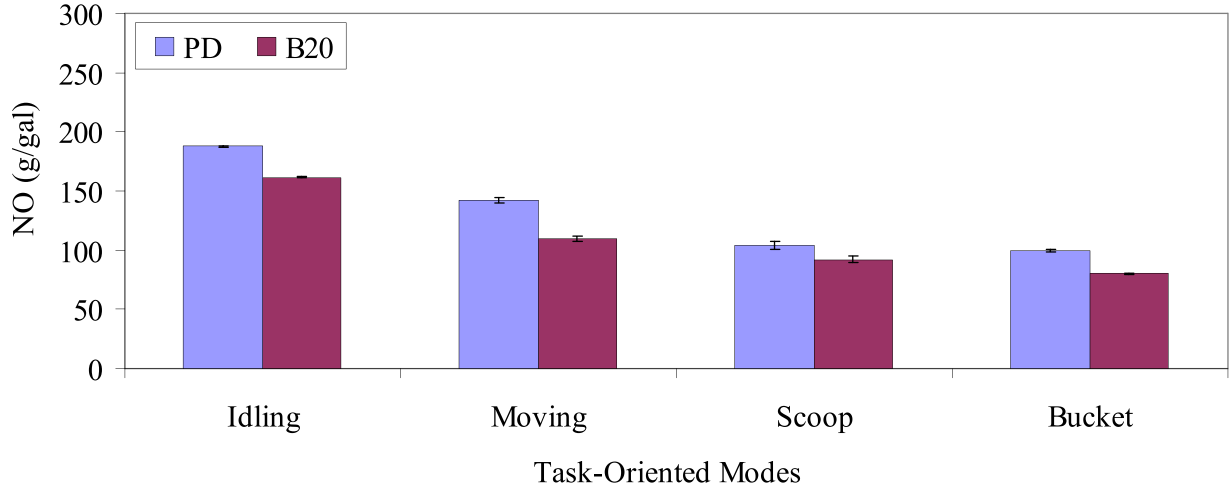
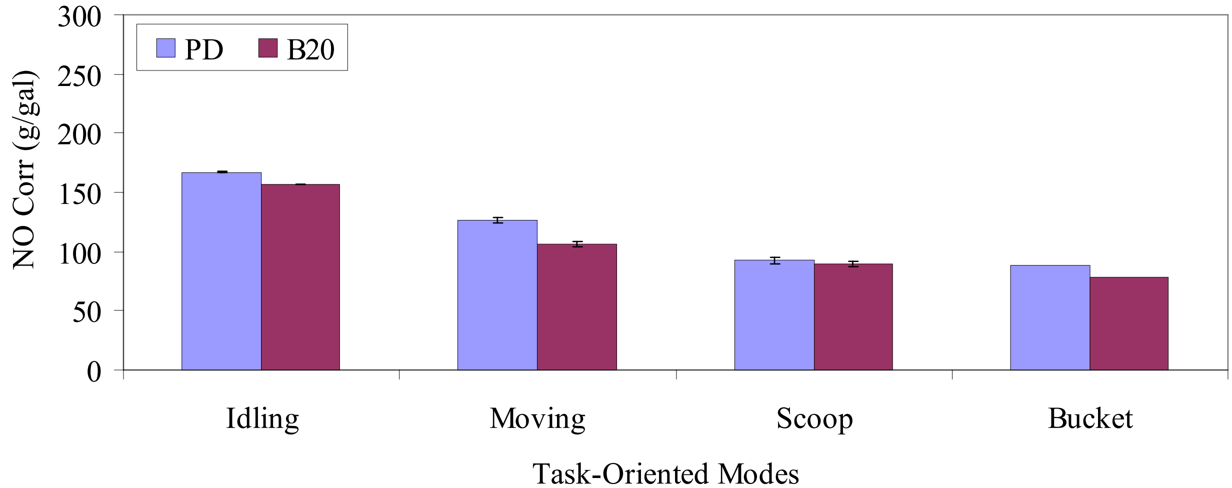


Figure F15. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 54 ^oF and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 83 ^oF and the relative humidity was 38 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F16. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Backhoe 4 (continued on next page)

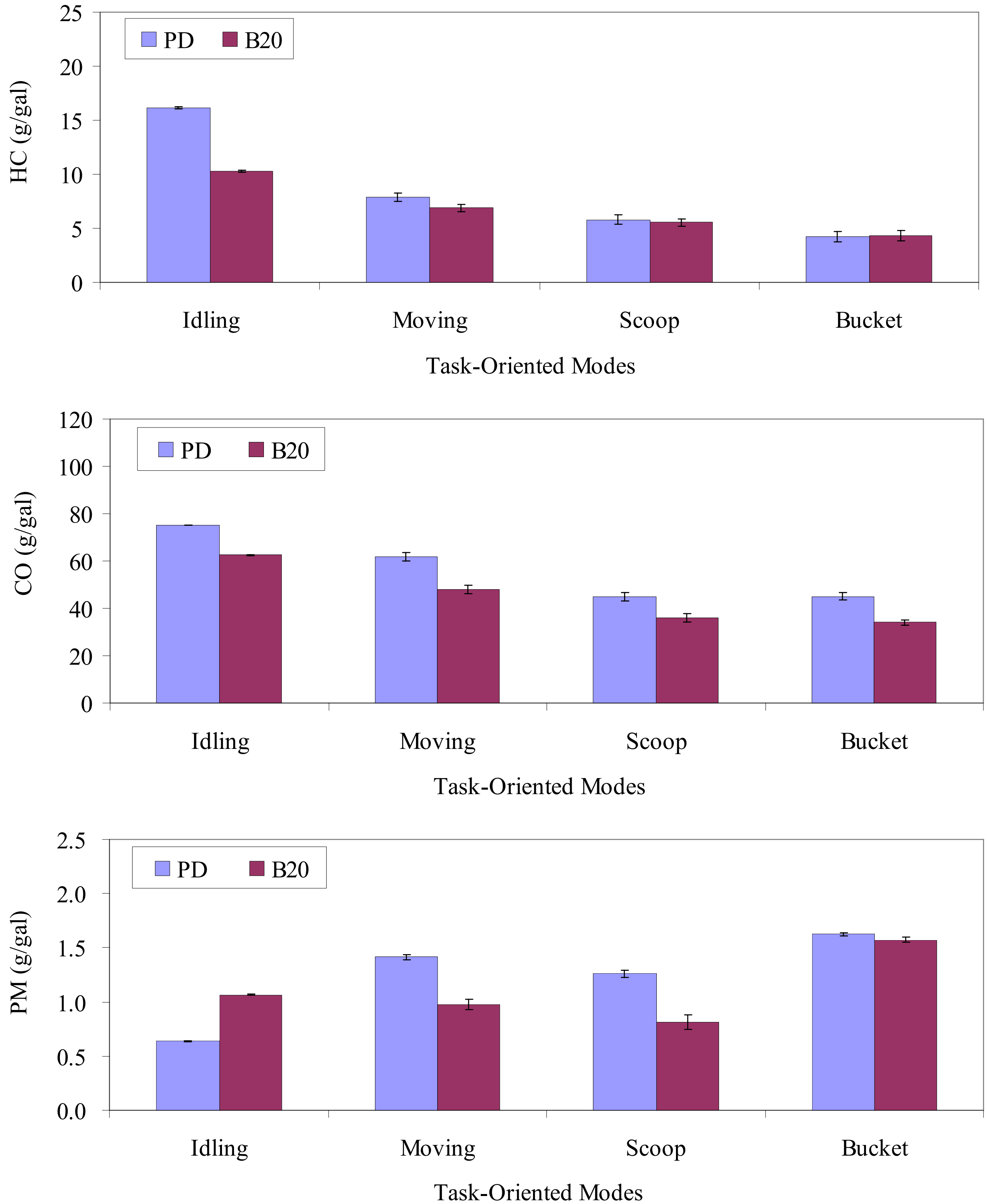
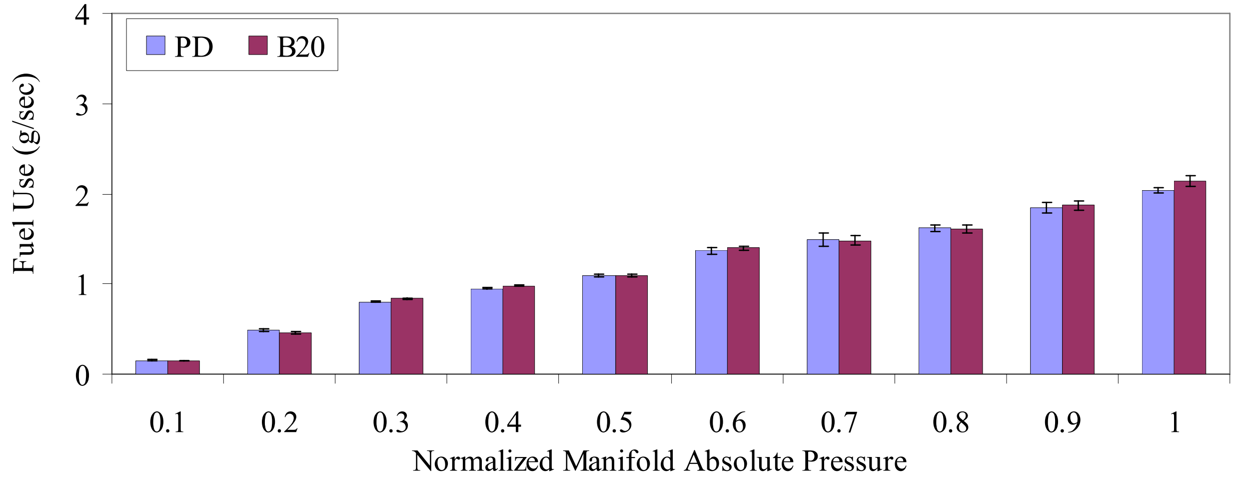
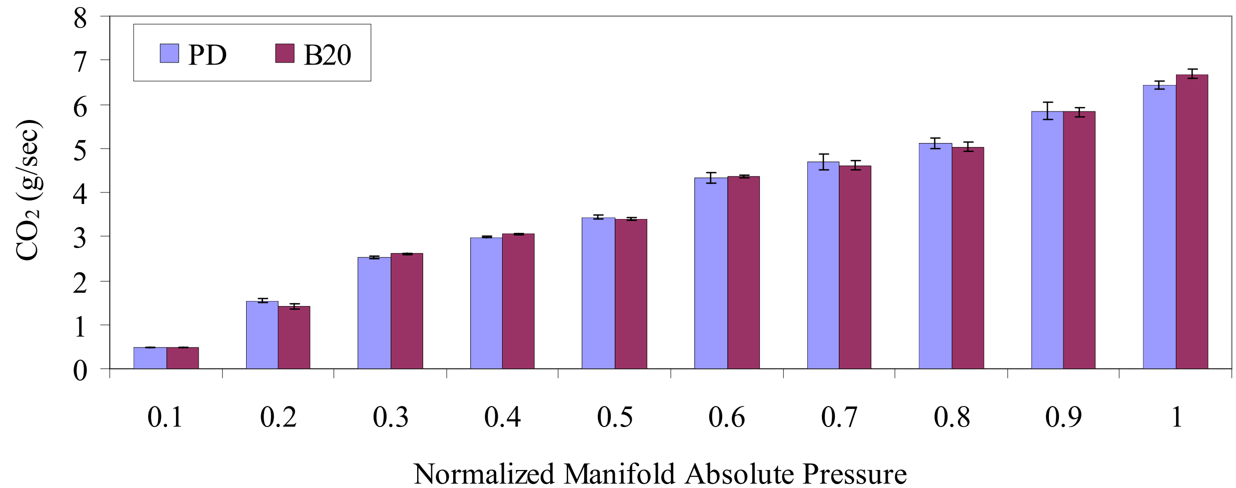


Figure F16. Continued

BACKHOE 5





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 70 ^oF and the relative humidity was 56 %. For the B20 biodiesel tests the ambient temperature was 76 ^oF and the relative humidity was 61 %.

Values shown in the figure are the upper end of the range: "0.1" = $0 \leq$ Normalized MAP < 0.1; "0.2" = $0.1 \leq$ Normalized MAP < 0.2, and so on.

Figure F17. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Backhoe 5 (continued on next page)

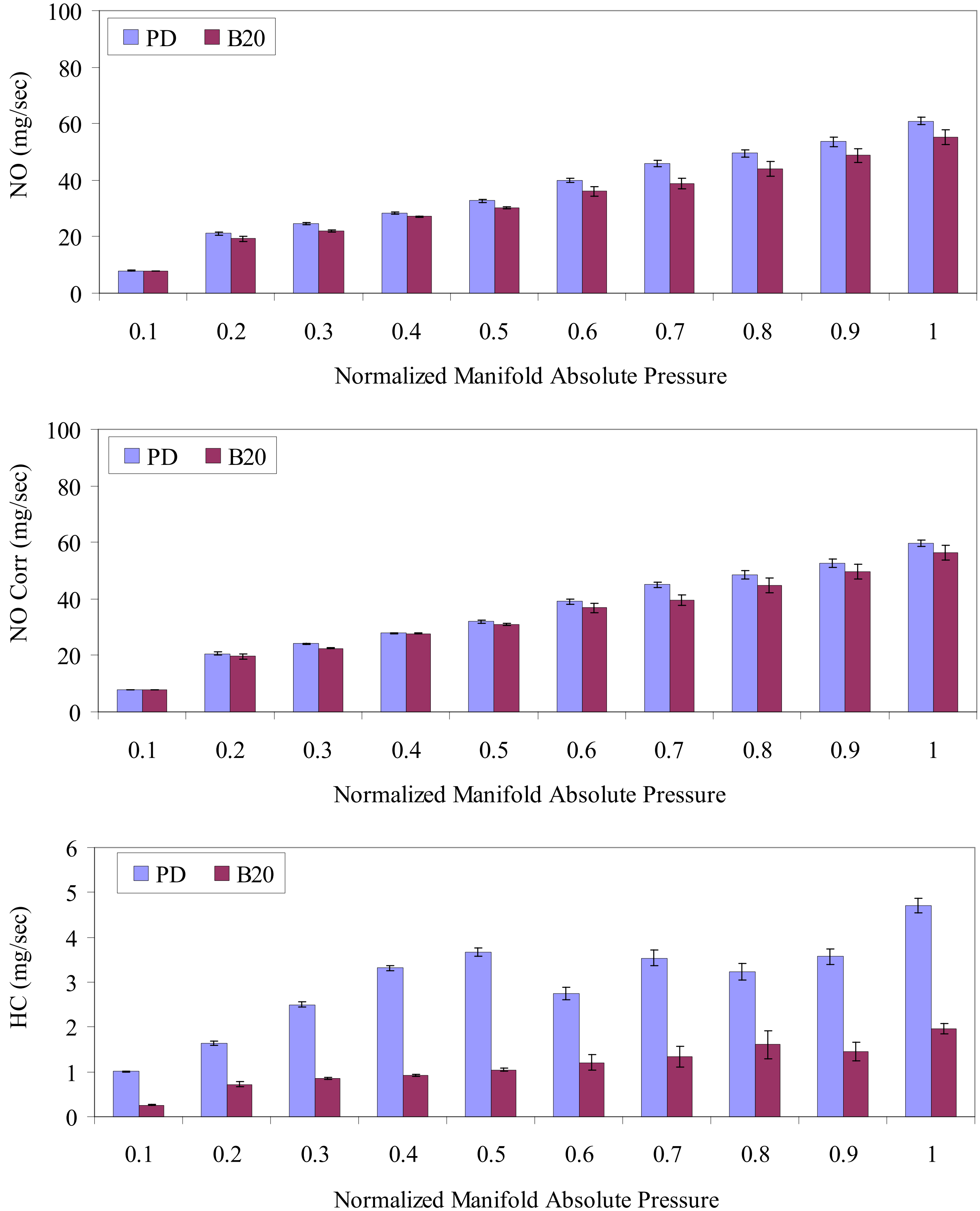
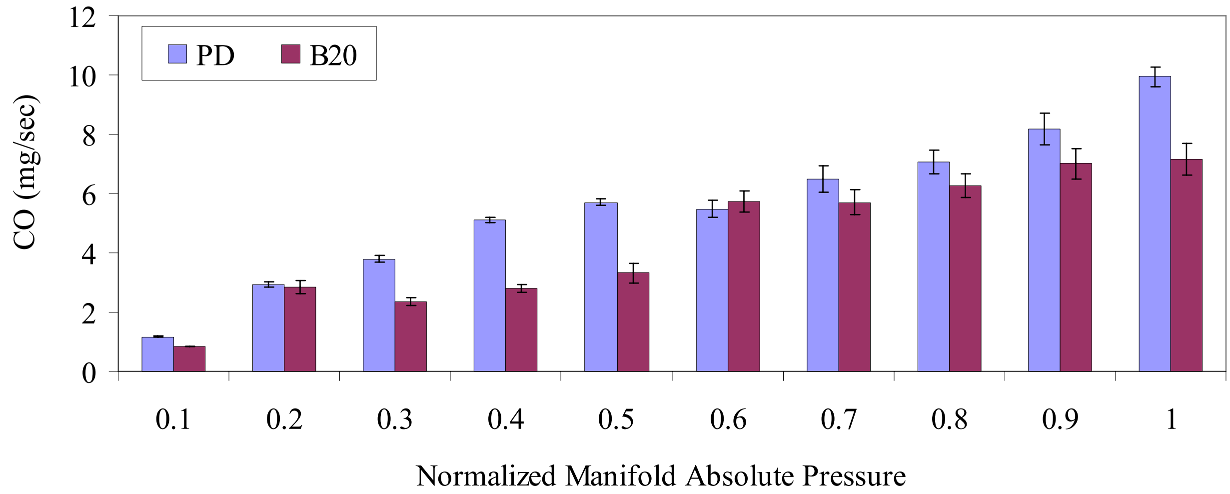


Figure F17. Continued



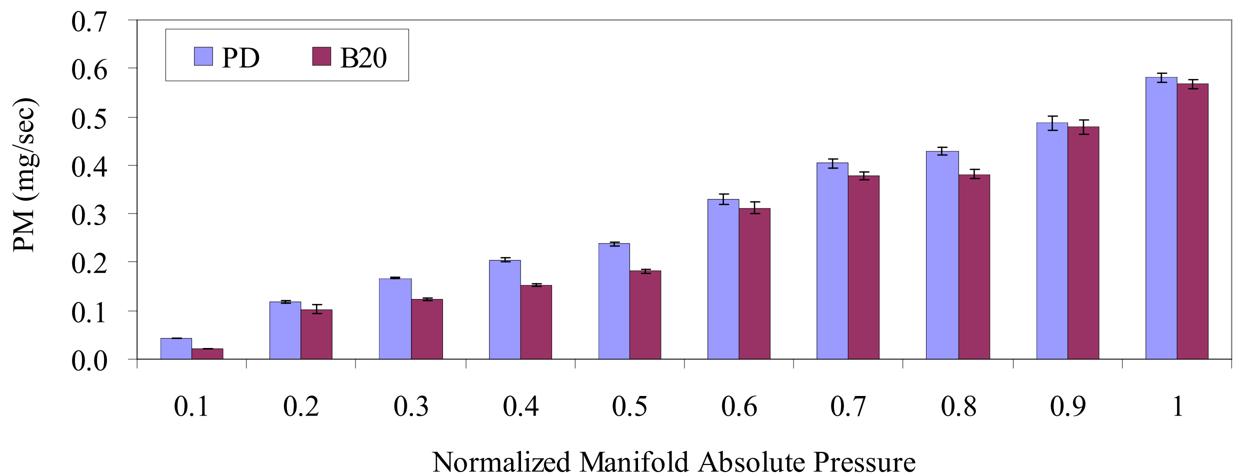
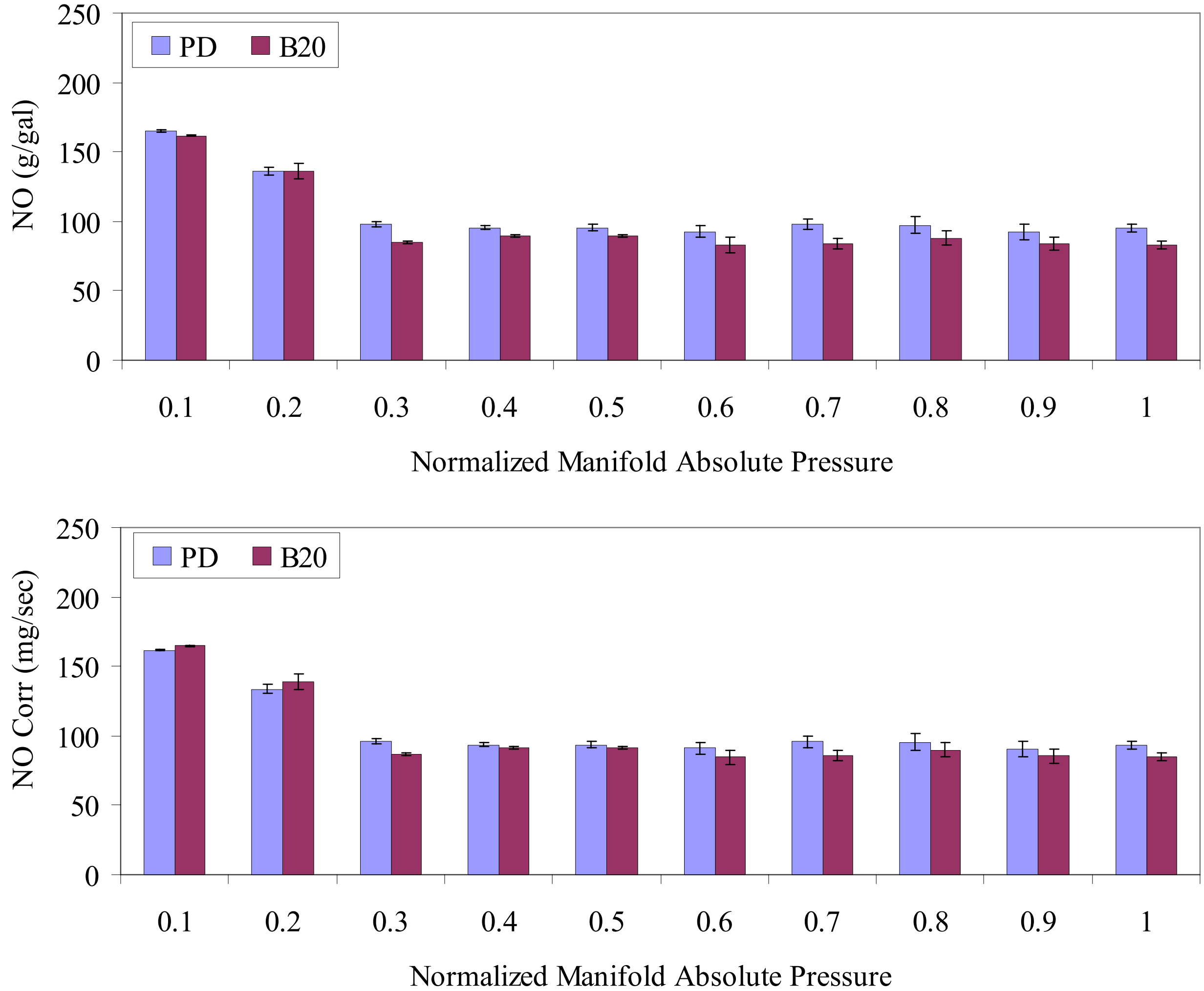


Figure F17. Continued



NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 70 ^oF and the relative humidity was 56 %. For the B20 biodiesel test, the ambient temperature was 76 ^oF and the relative humidity was 61 %.

Values shown in the figure are the upper end of the range: “0.1” = 0 ≤ Normalized MAP < 0.1; “0.2” = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F18. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Backhoe 5 (continued on next page)

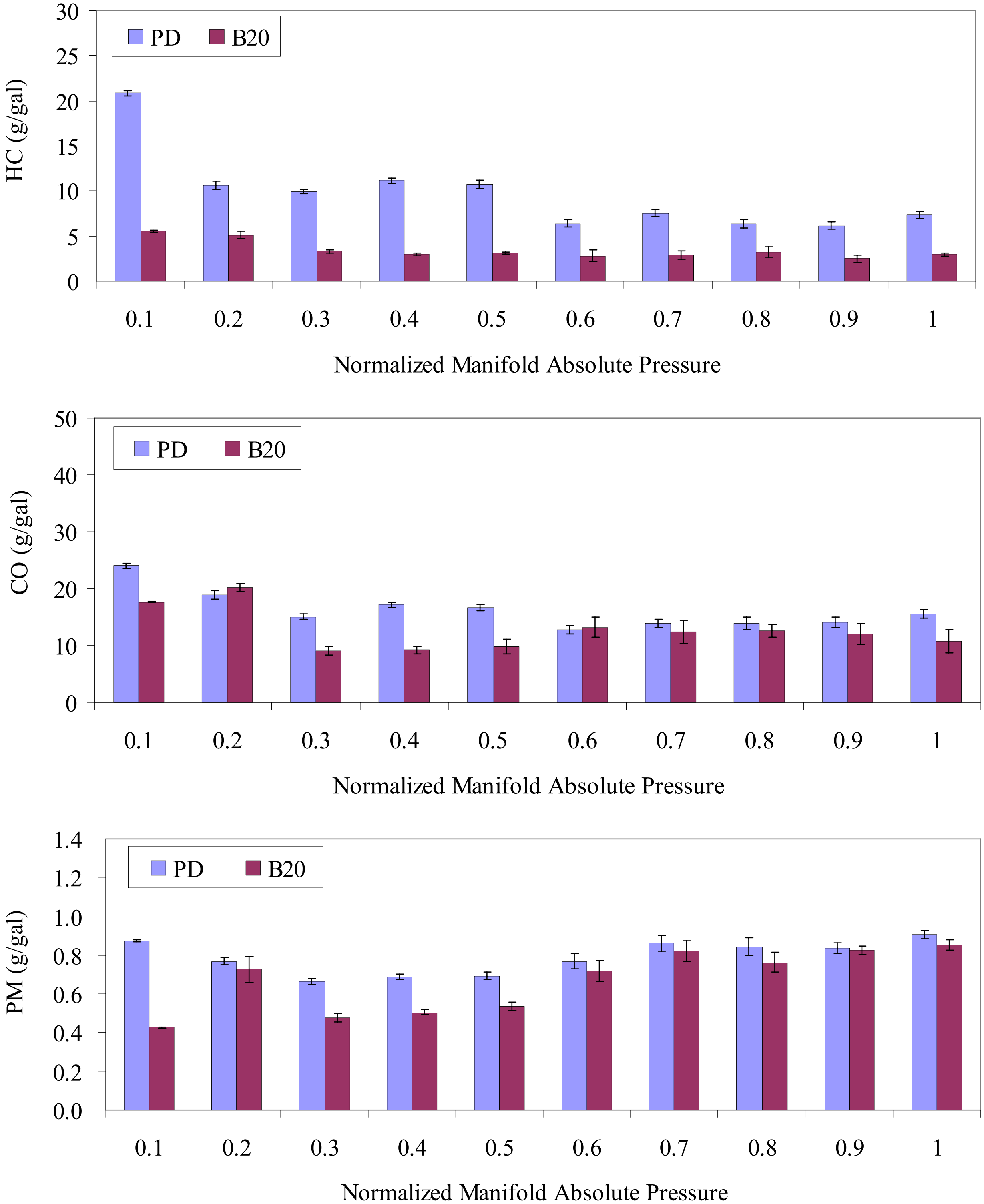
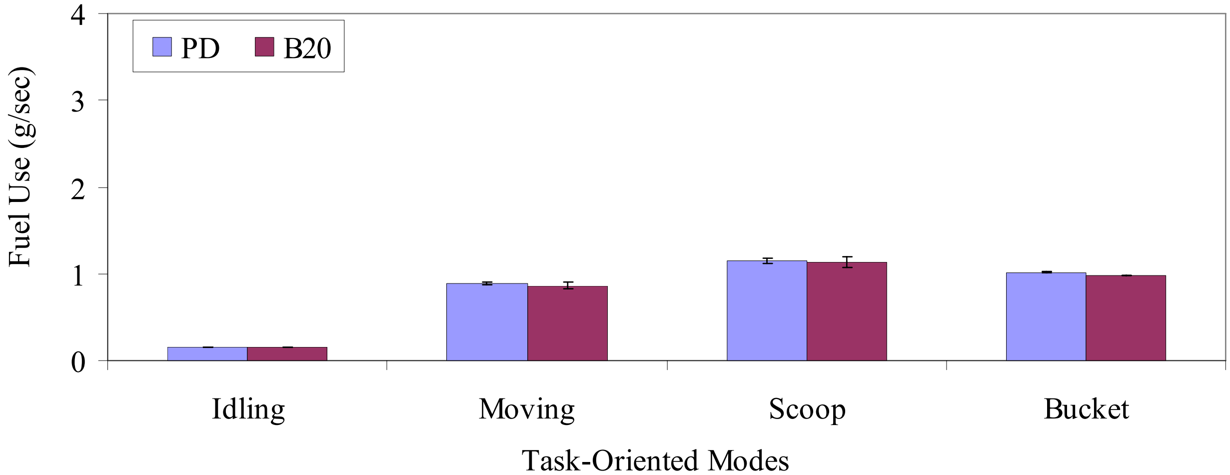
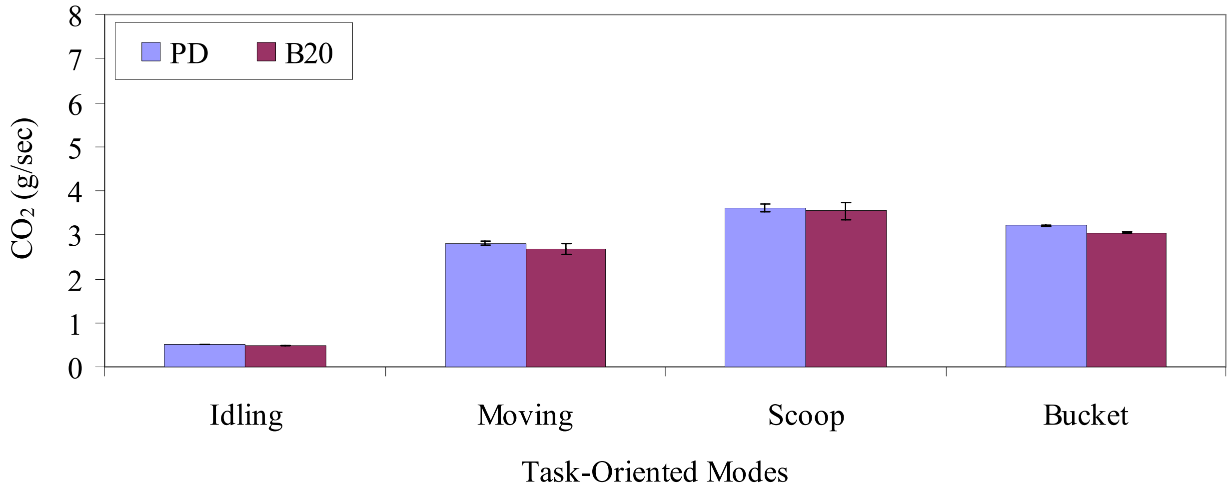


Figure F18. Continued

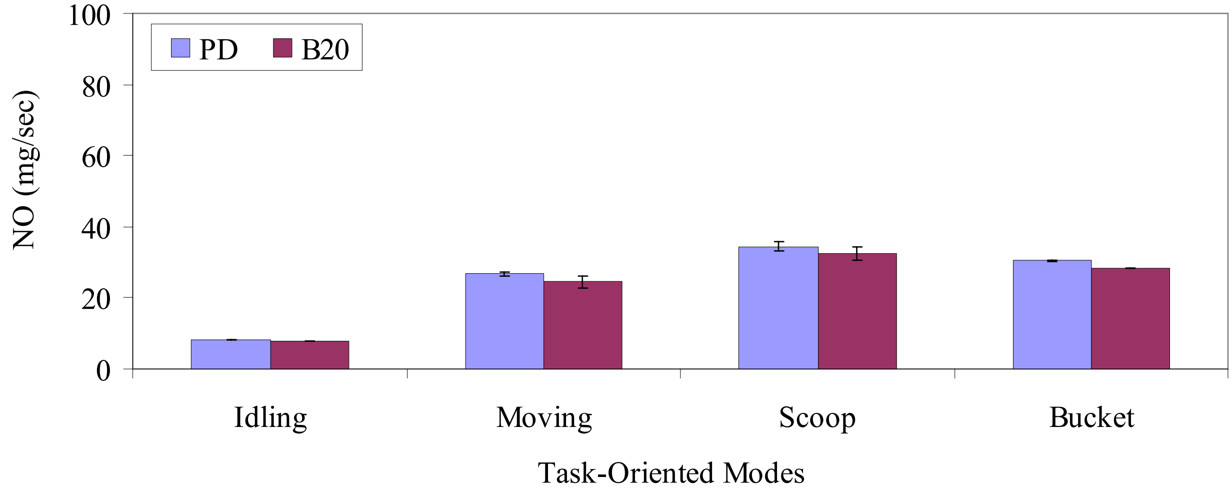


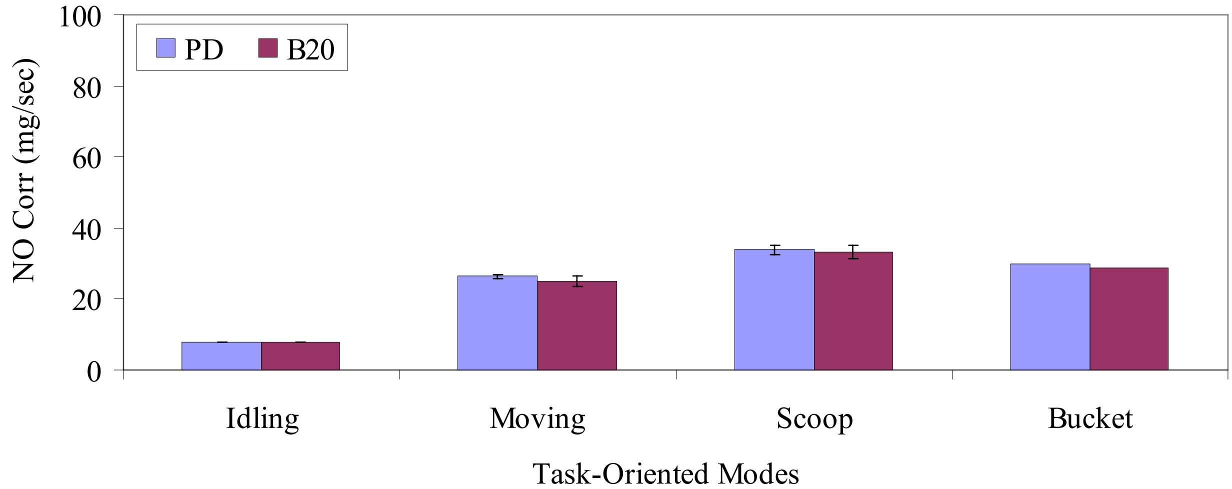


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 70 ^oF and the relative humidity was 56 %. For the B20 biodiesel test, the ambient temperature was 76 ^oF and the relative humidity was 61 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F19. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Backhoe 5 (continued on next page)





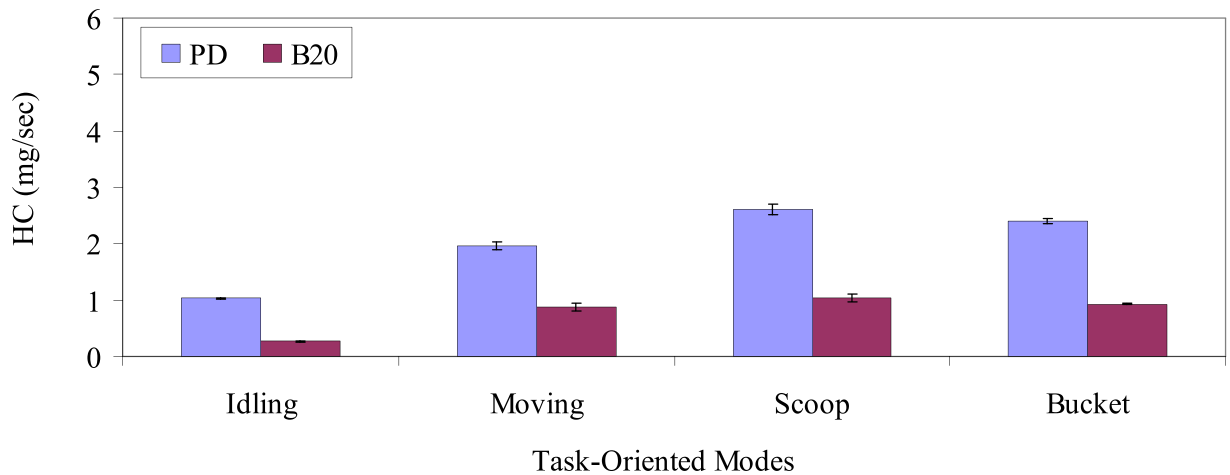
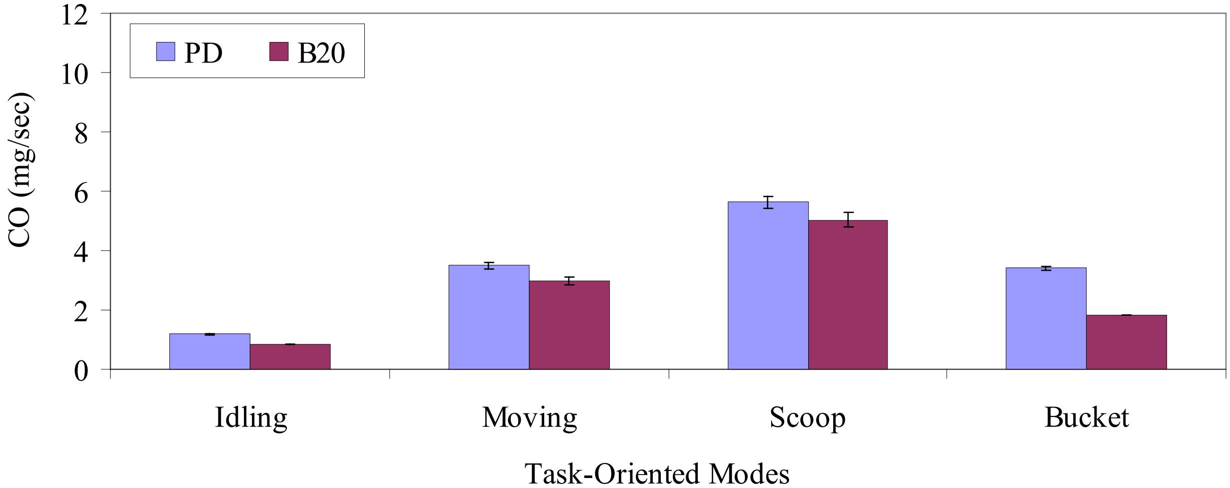


Figure F19. Continued



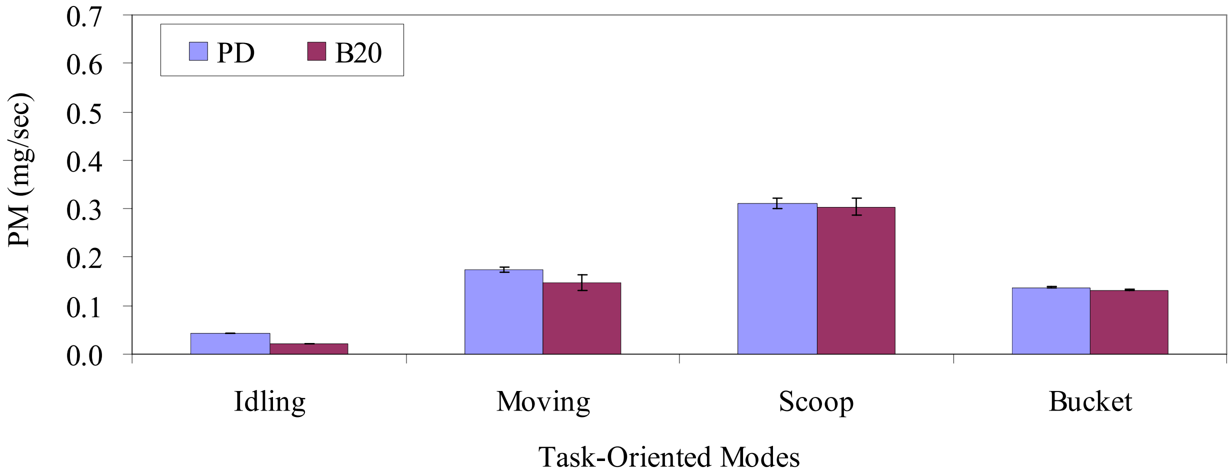
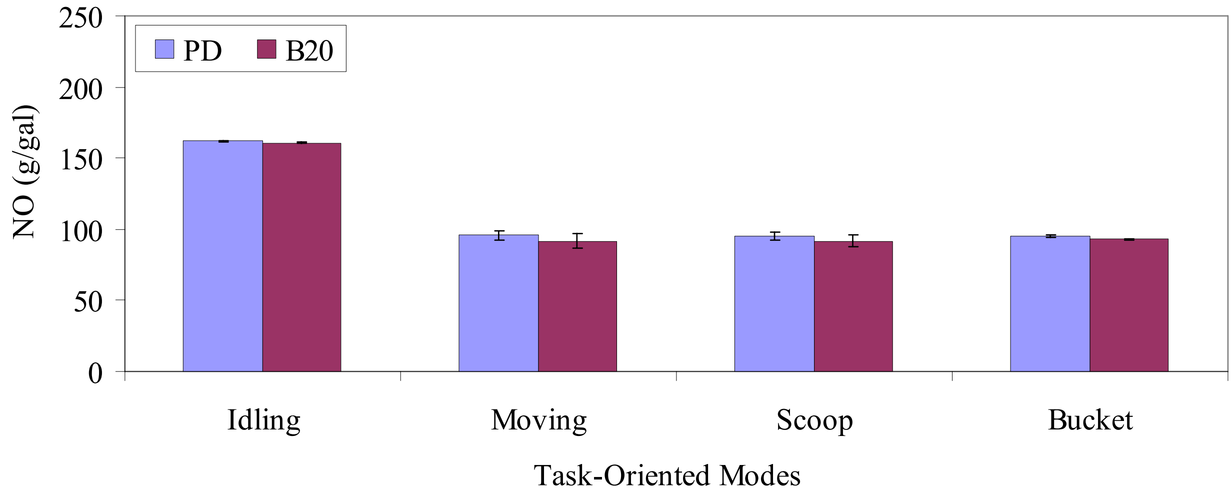
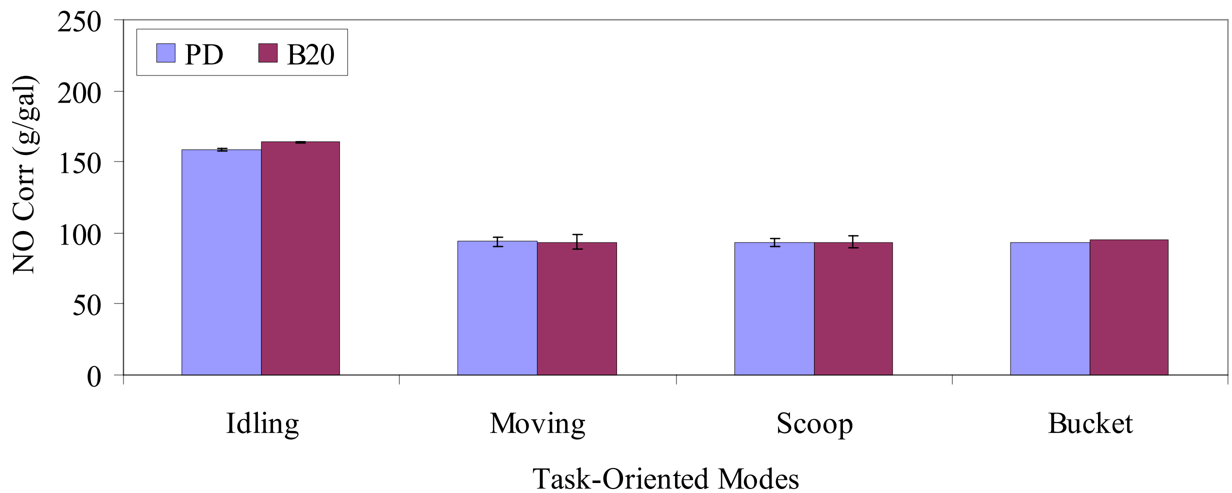


Figure F19. Continued

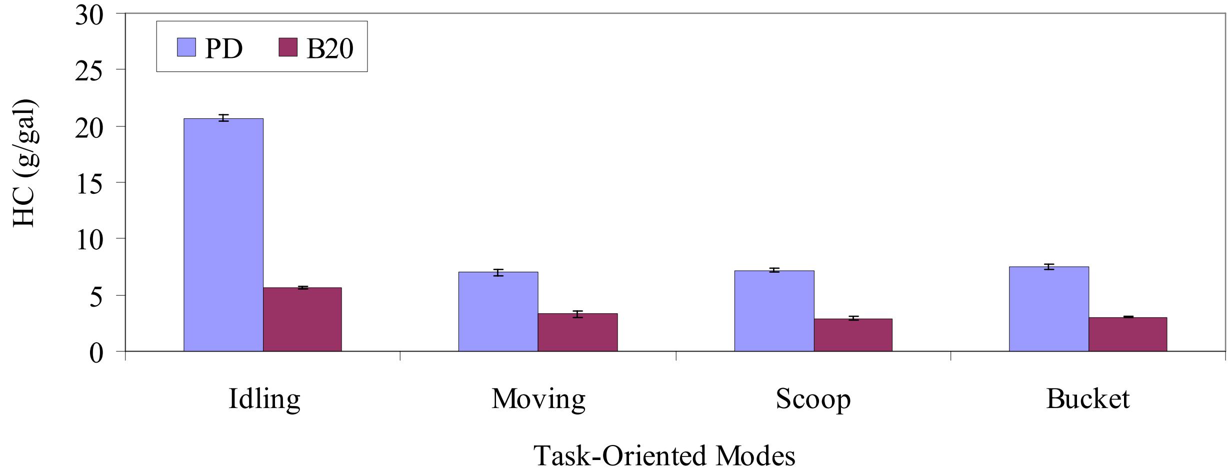


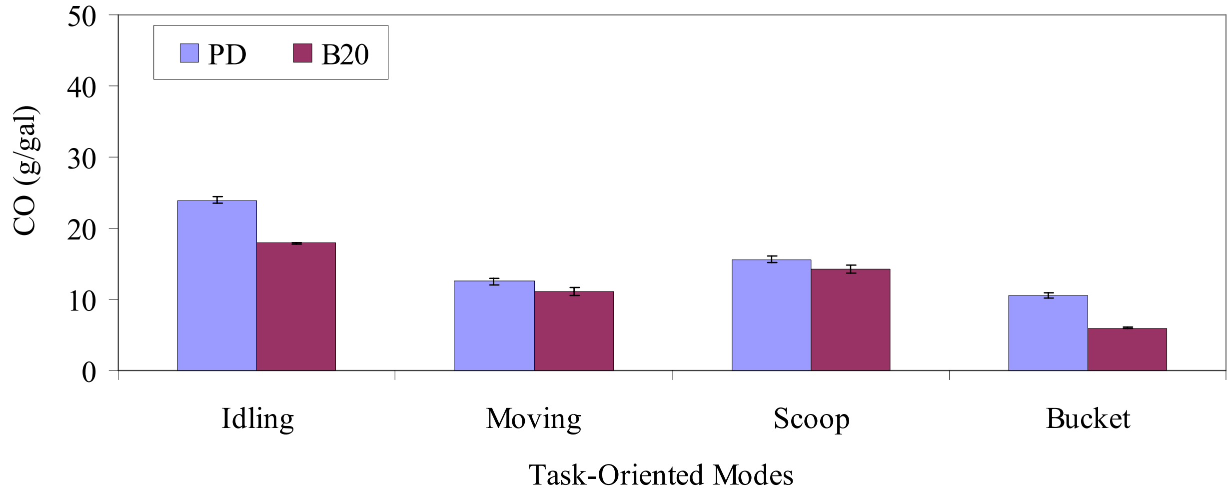


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 70 ^{o}F and the relative humidity was 56 %. For the B20 biodiesel test, the ambient temperature was 76 ^{o}F and the relative humidity was 61 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the backhoe when the loader bucket is not in contact with the ground (forward or backward); *scoop*: movement of the backhoe when the loader bucket is in contact with the ground; *bucket*: digging, swing, and dumping with excavator bucket.

Figure F20. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Backhoe 5 (continued on next page)





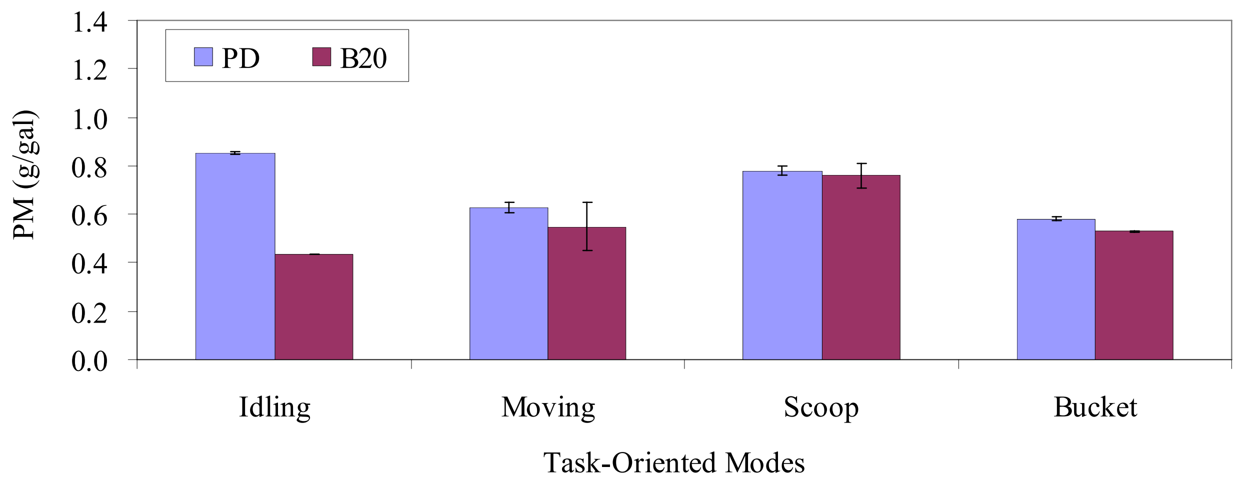
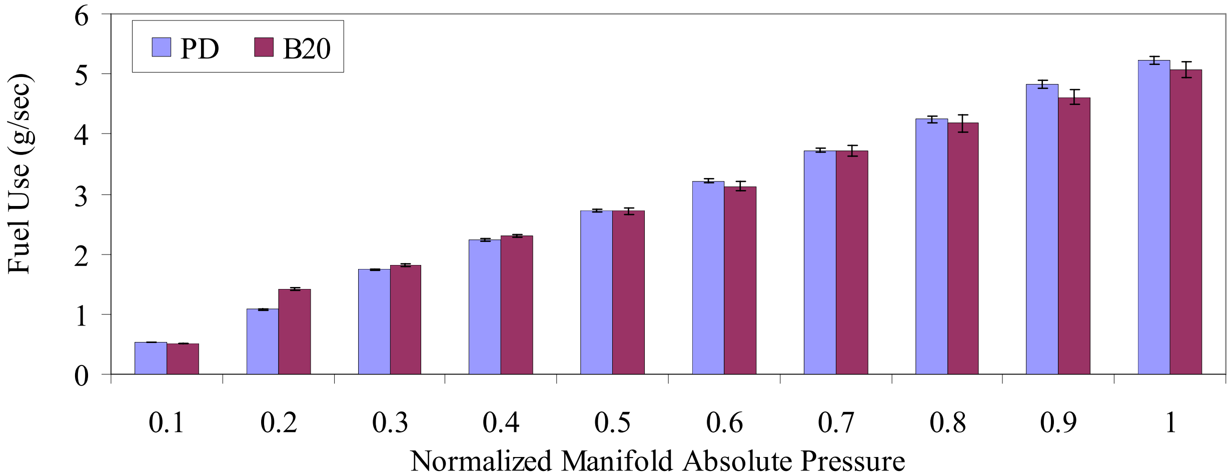
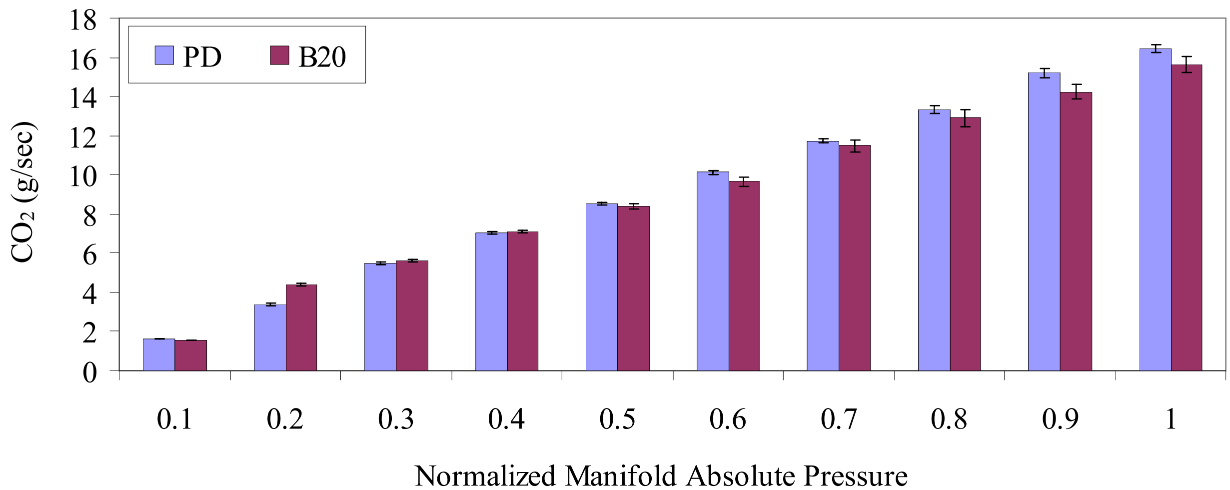


Figure F20. Continued

FRONT-END LOADER 1





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^{o}F and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^{o}F and the relative humidity was 74 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F21. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Front-End Loader 1 (continued on next page)

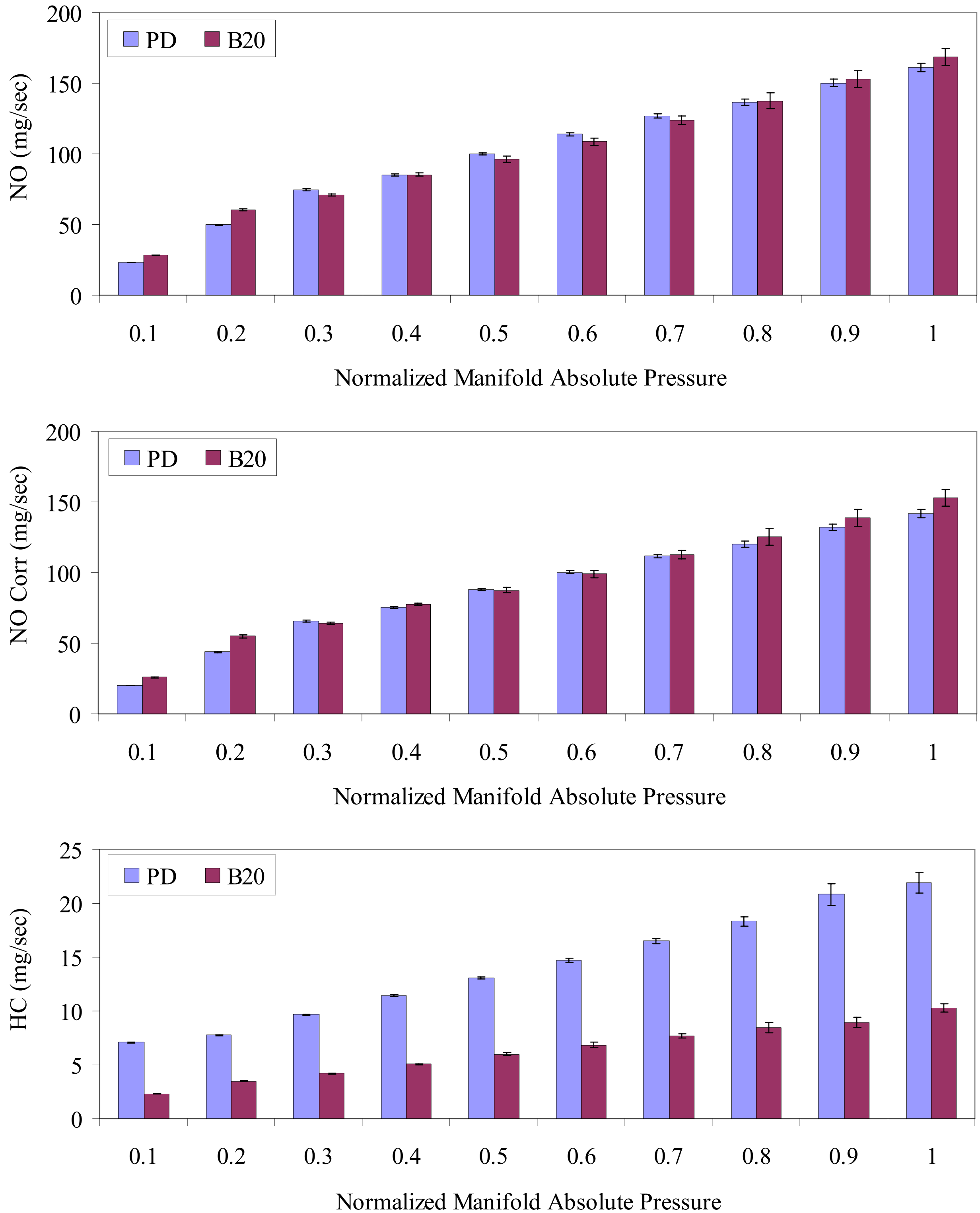
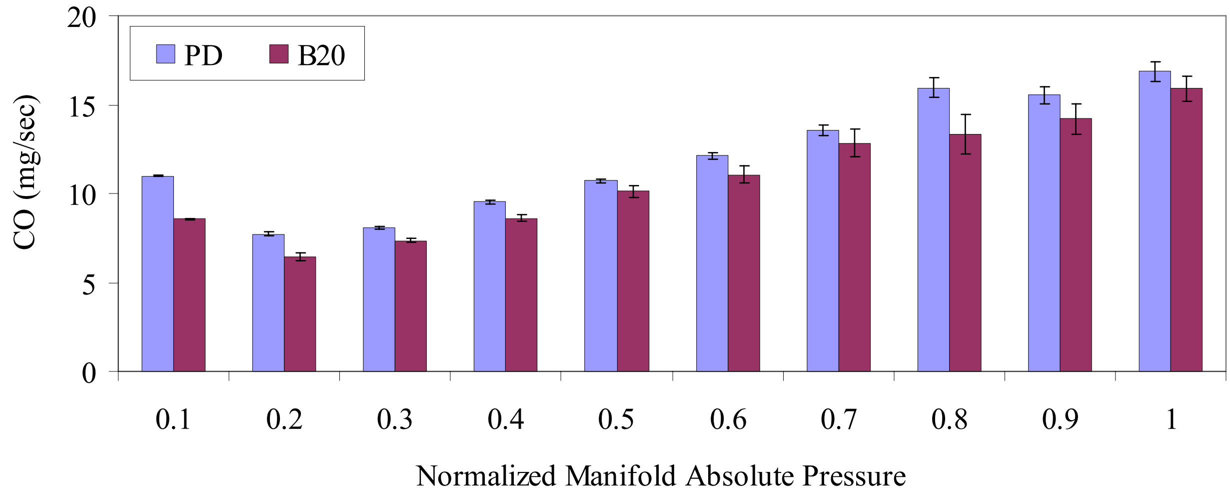


Figure F21. Continued



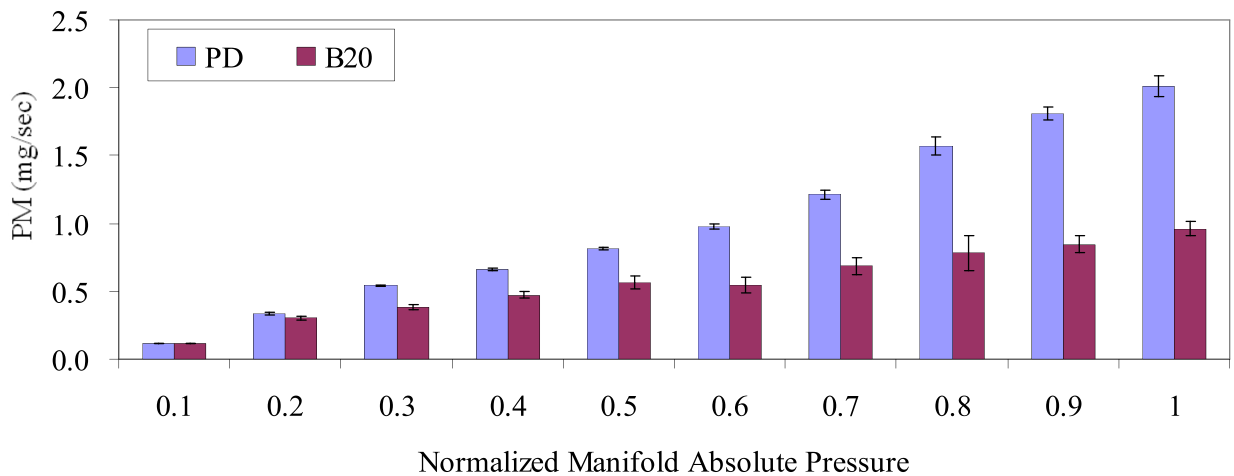
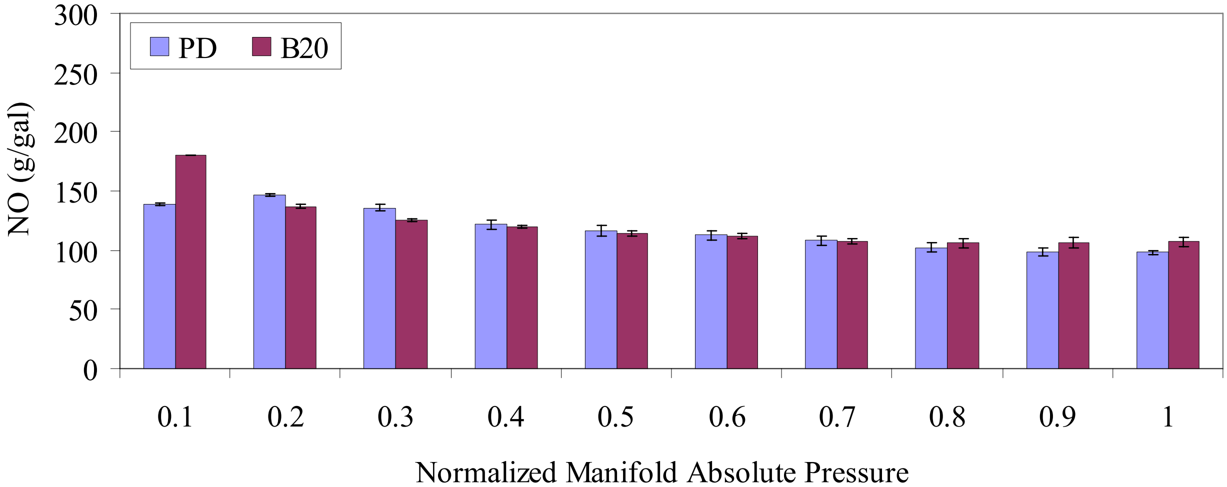
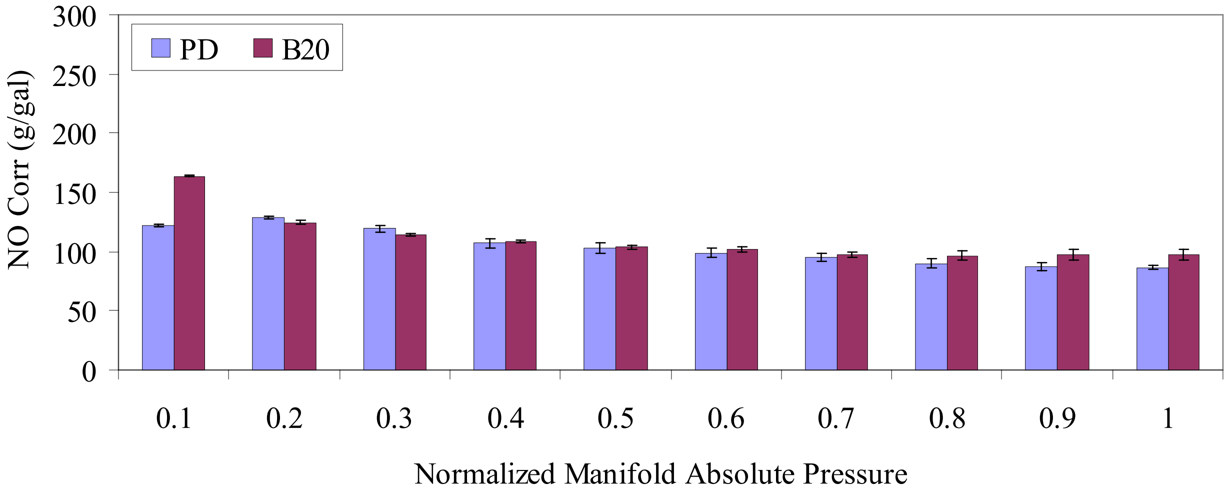


Figure F21. Continued

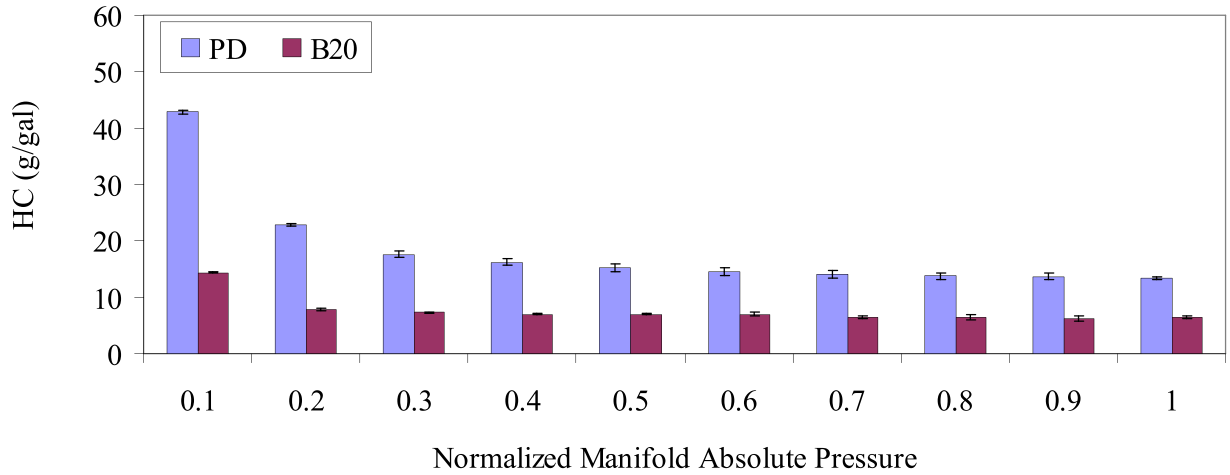


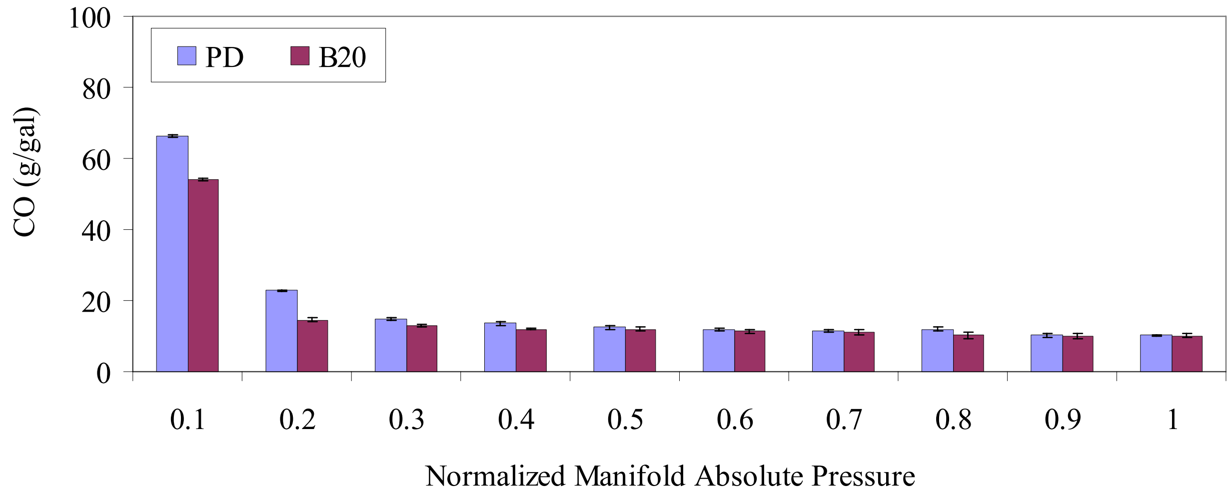


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^{o}F and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^{o}F and the relative humidity was 74 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F22. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Front-End Loader 1 (continued on next page)





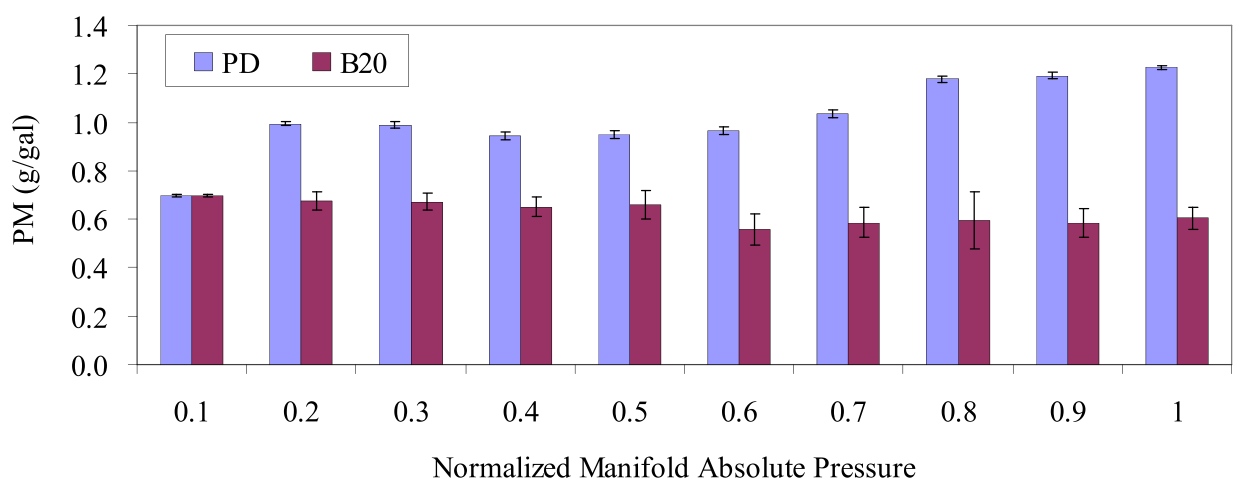
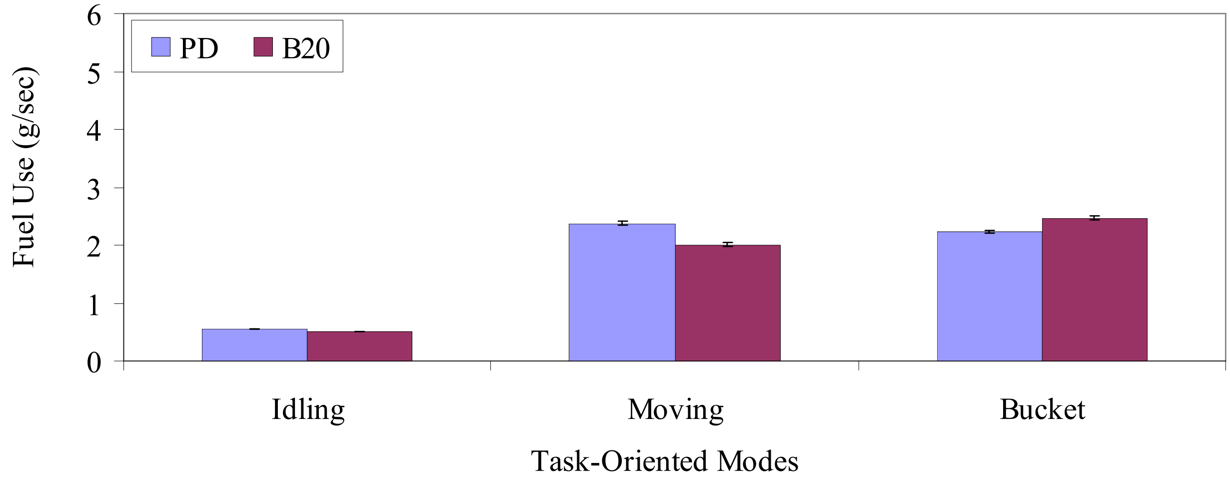
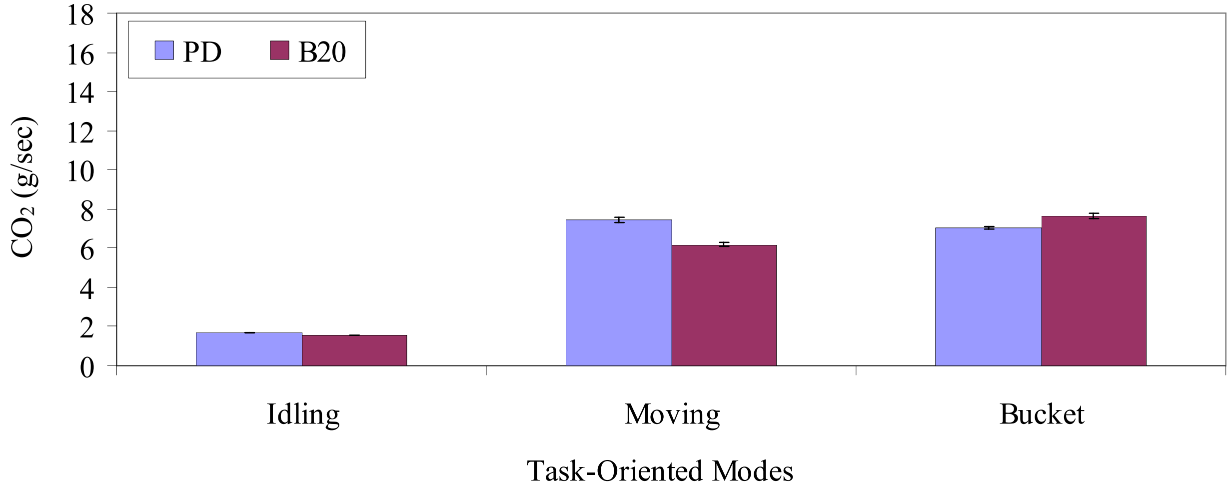


Figure F22. Continued

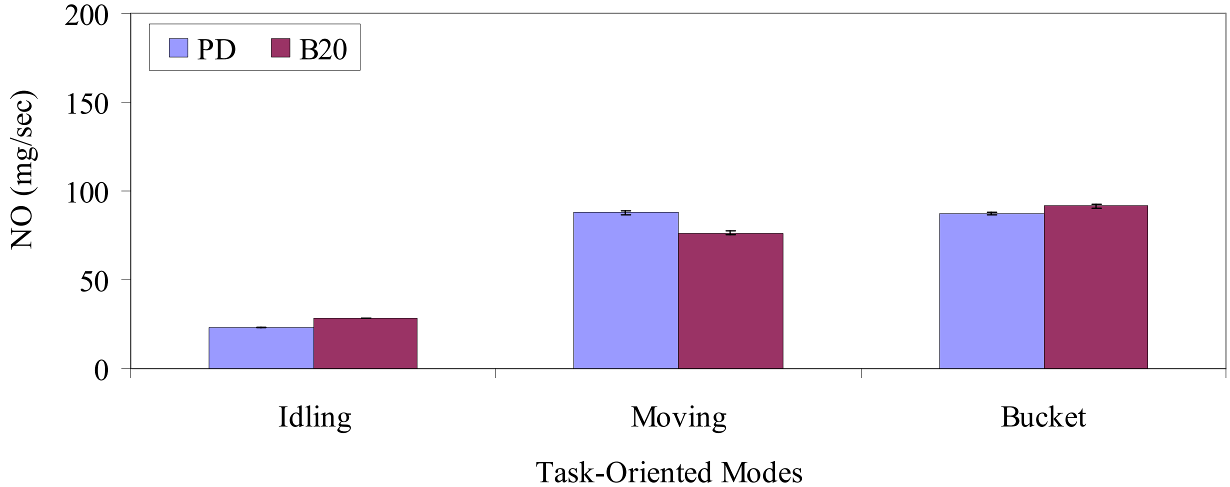


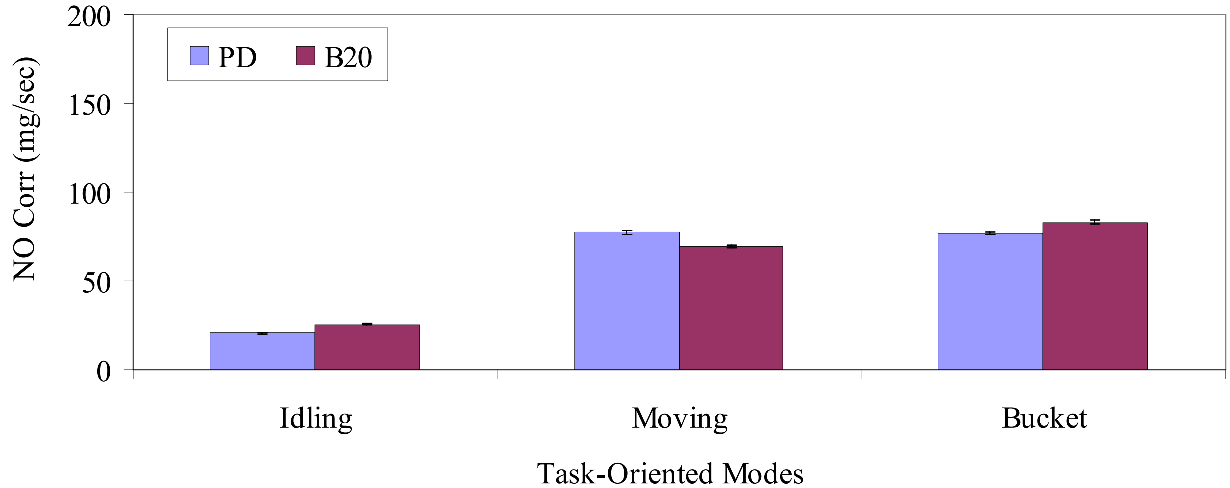


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^oF and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^oF and the relative humidity was 74 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F23. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Front-End Loader 1 (continued on next page)





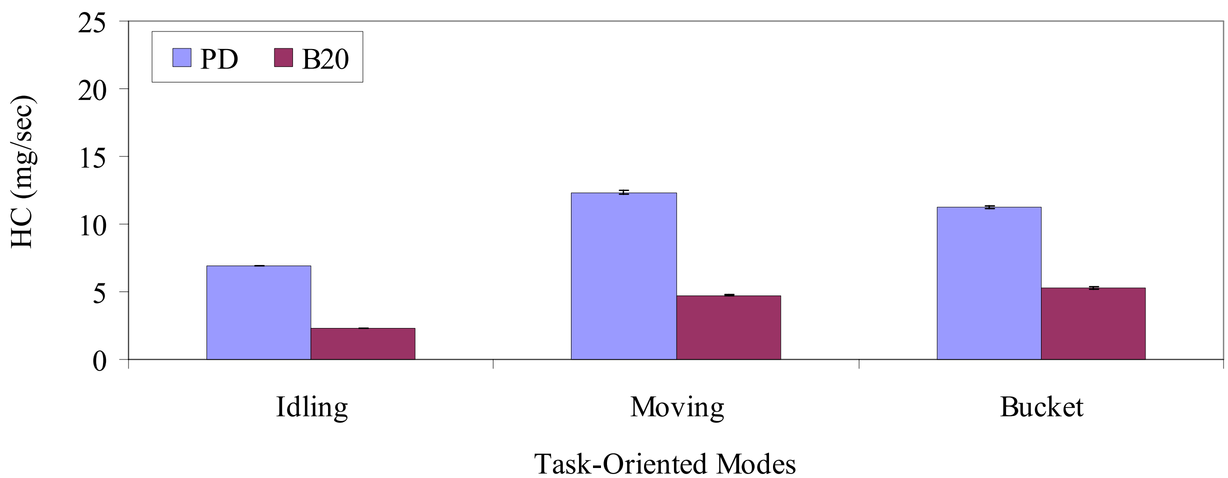
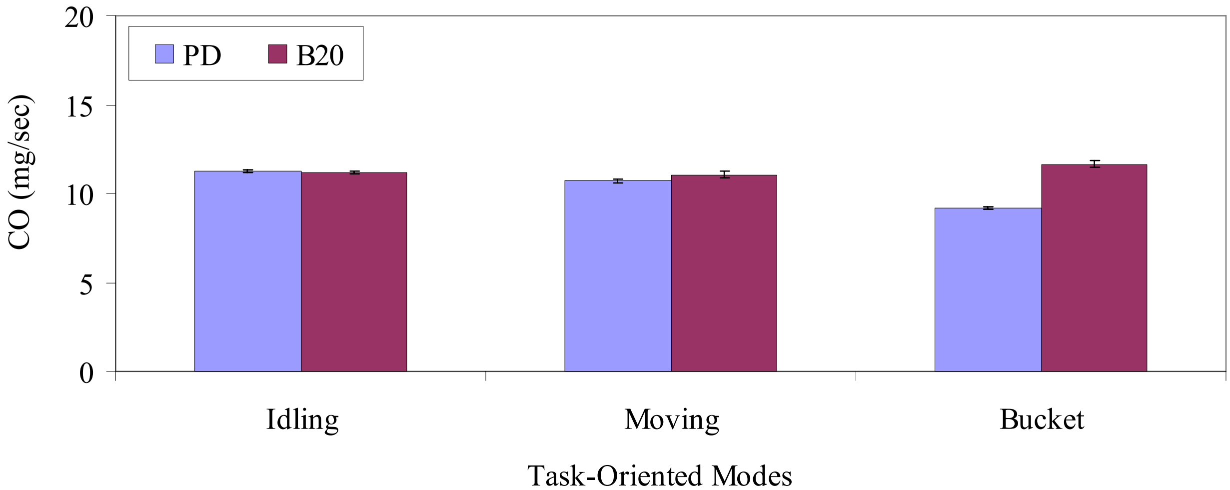


Figure F23. Continued



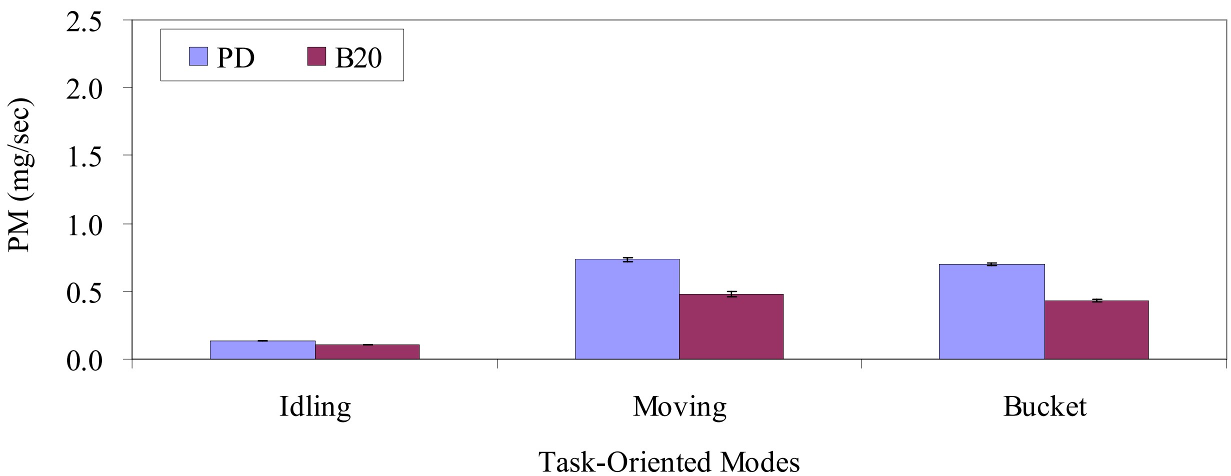
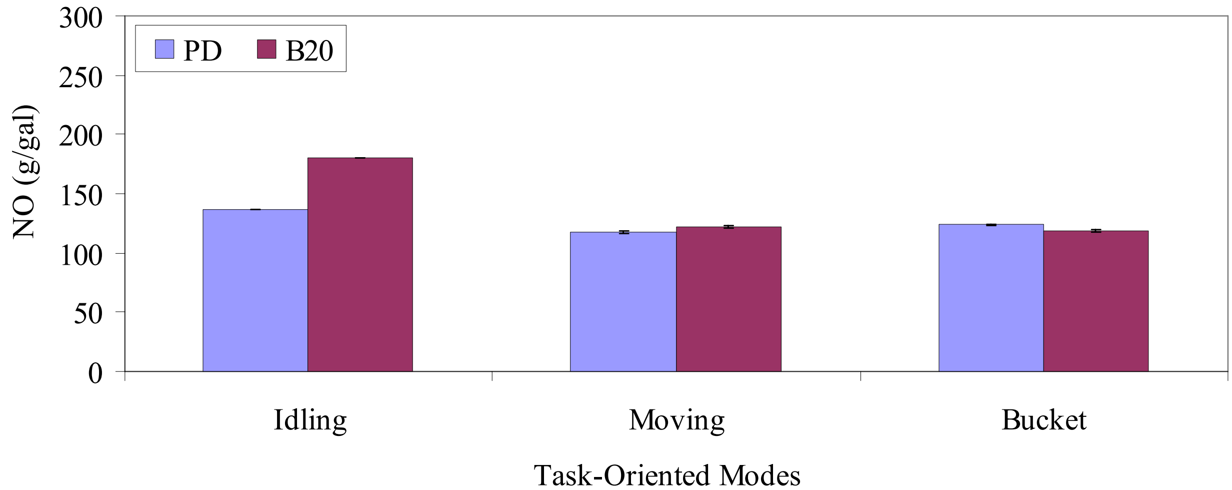
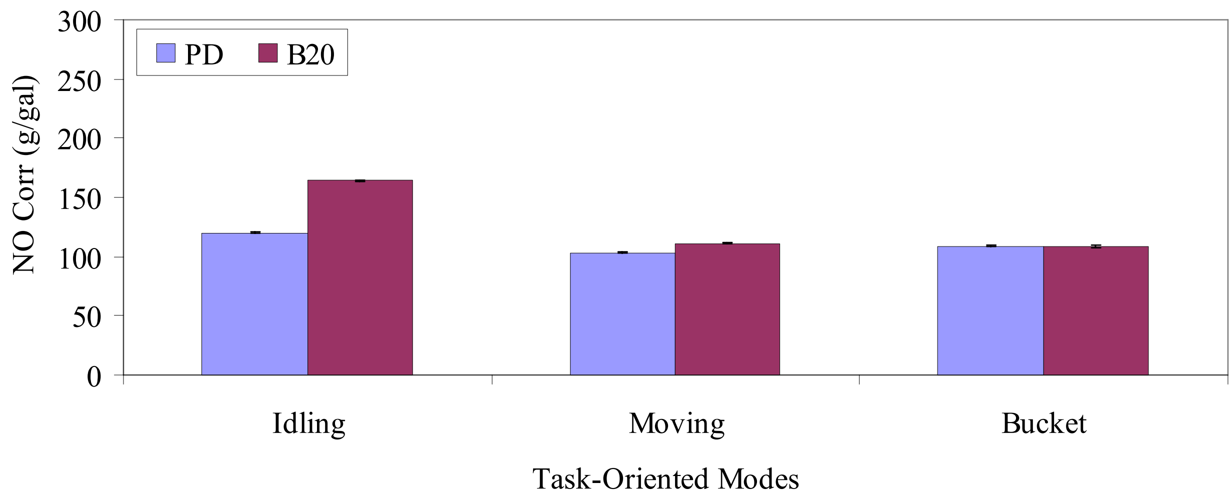


Figure F23. Continued

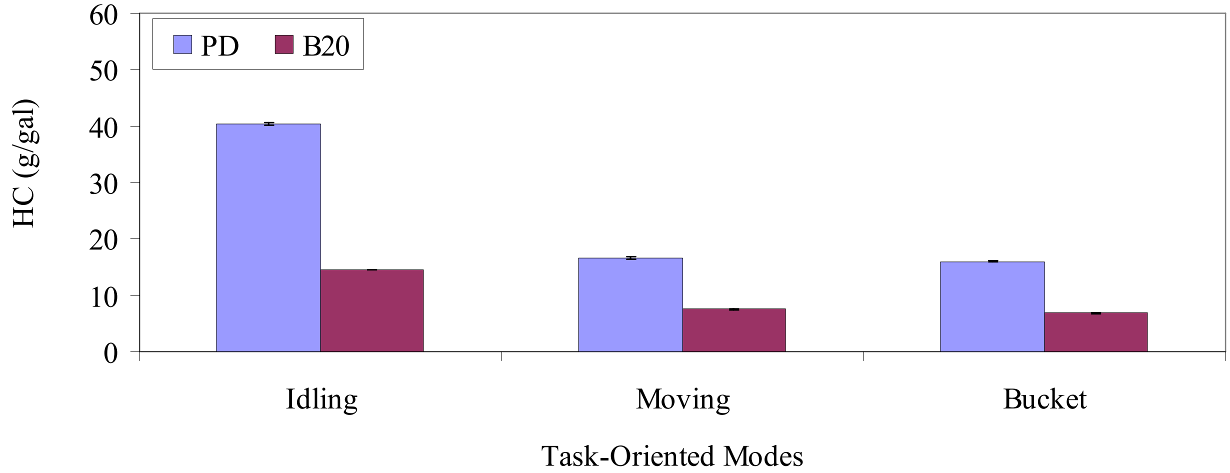


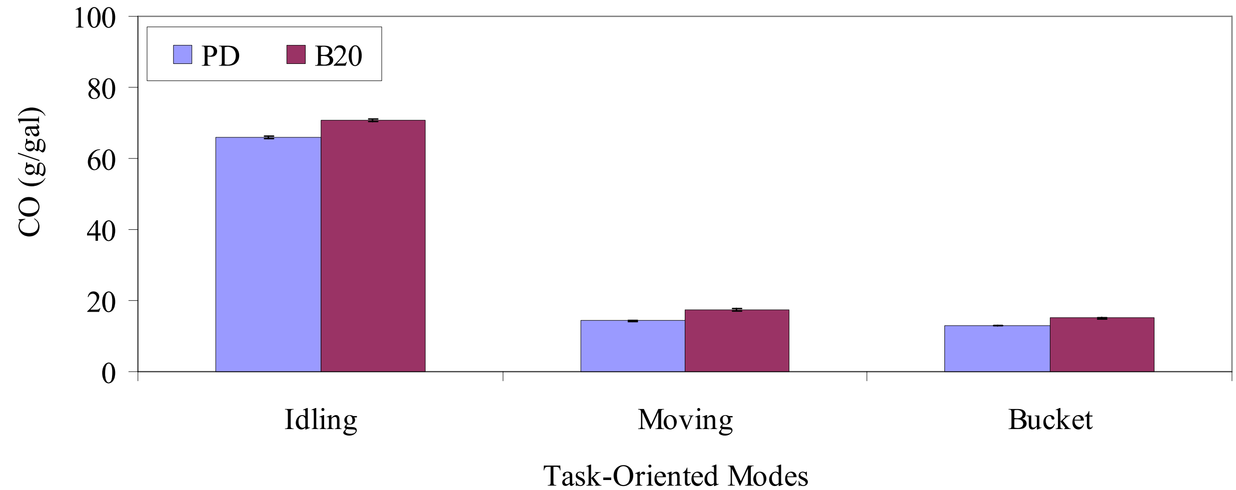


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^oF and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^oF and the relative humidity was 74 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F24. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Front-End Loader 1 (continued on next page)





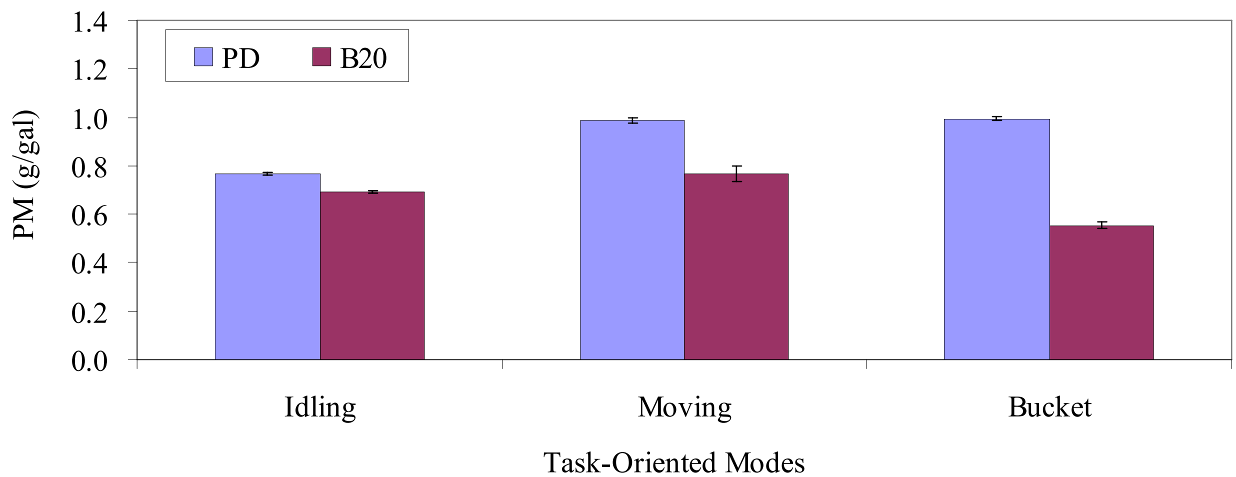
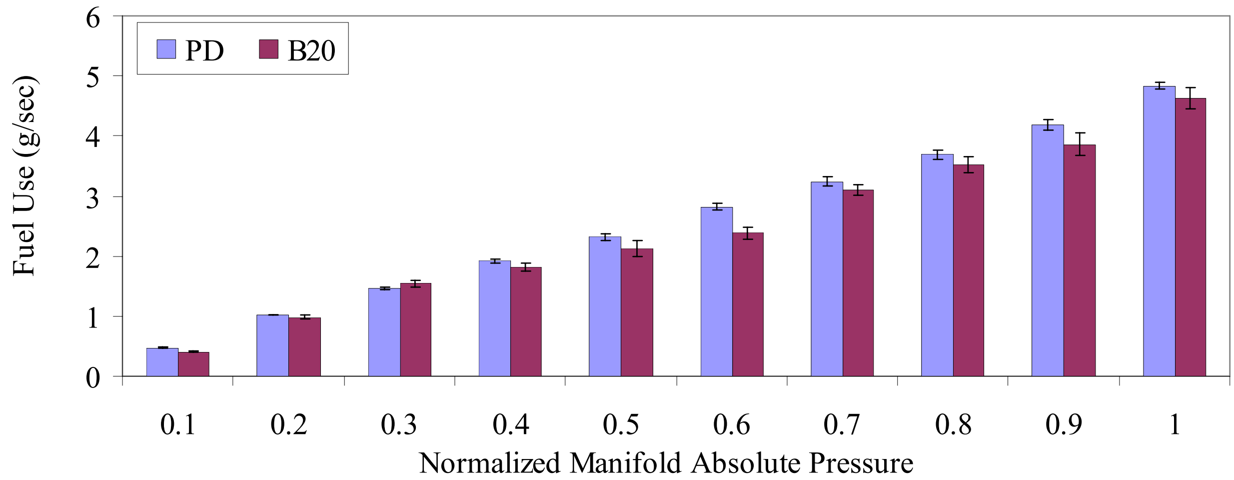
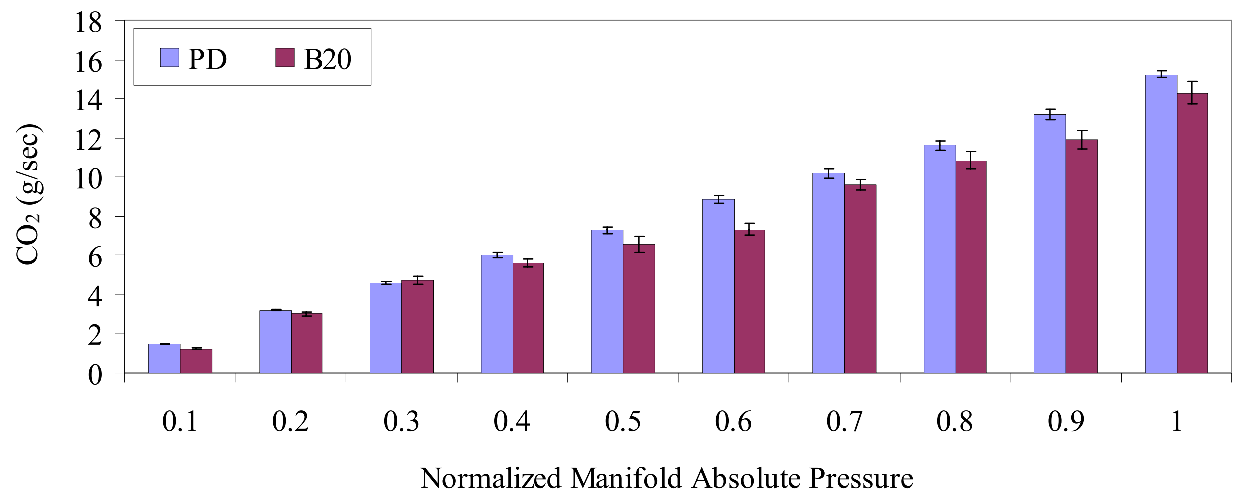


Figure F24. Continued

FRONT-END LOADER 2

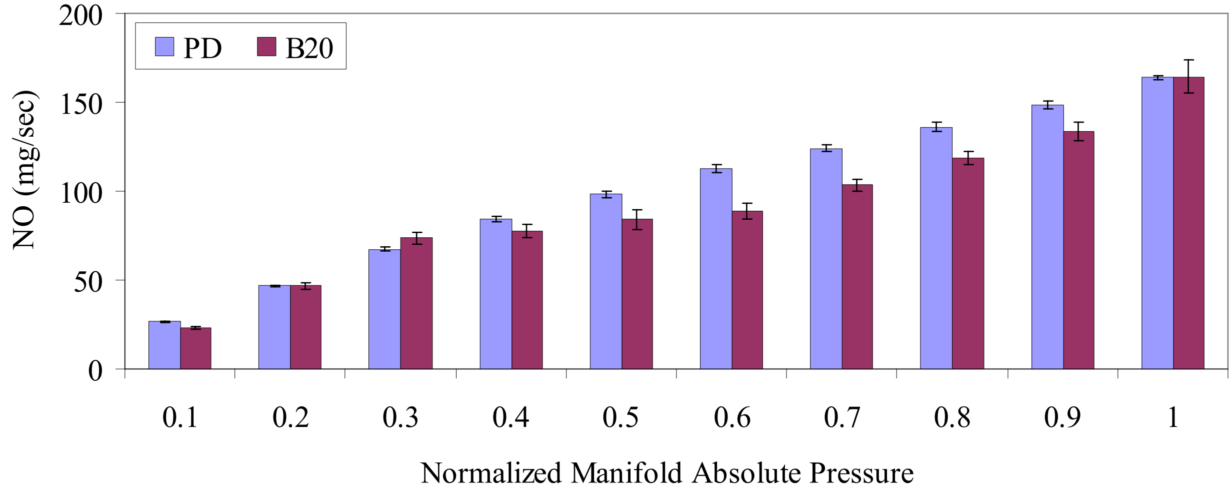


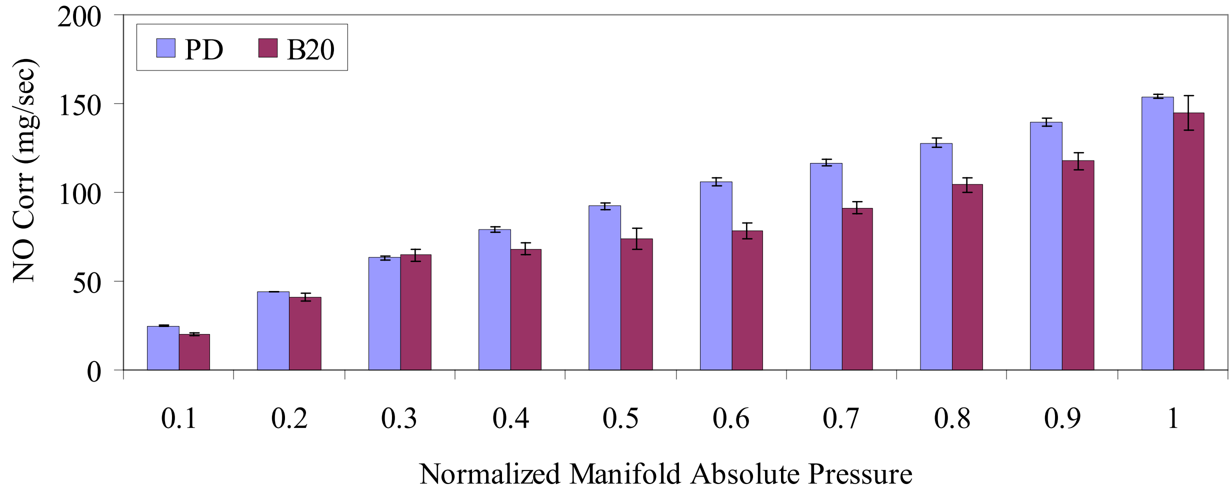


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 71 ^oF and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 50 ^oF and the relative humidity was 46 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F25. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Front-End Loader 2 (continued on next page)





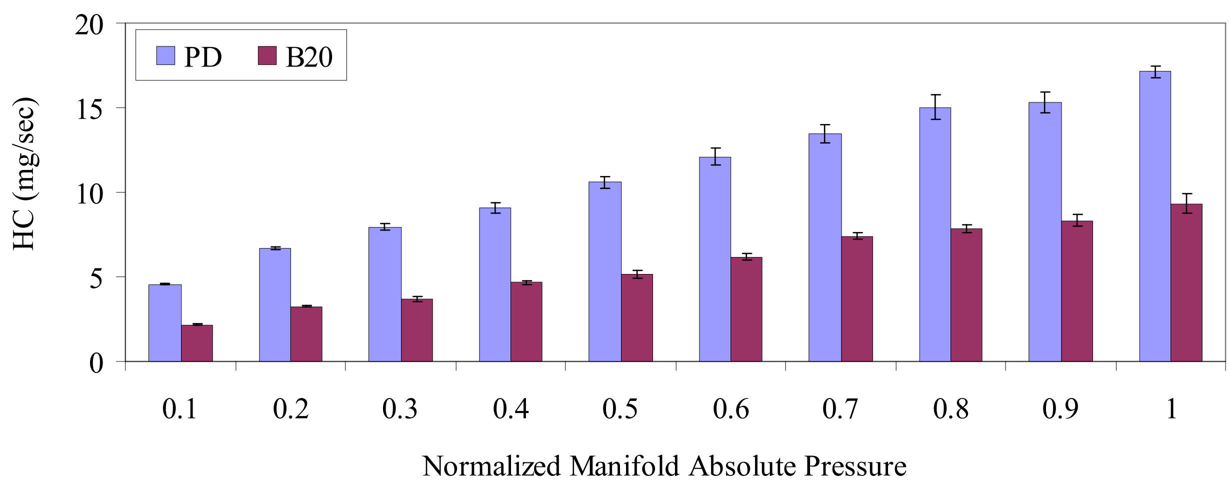
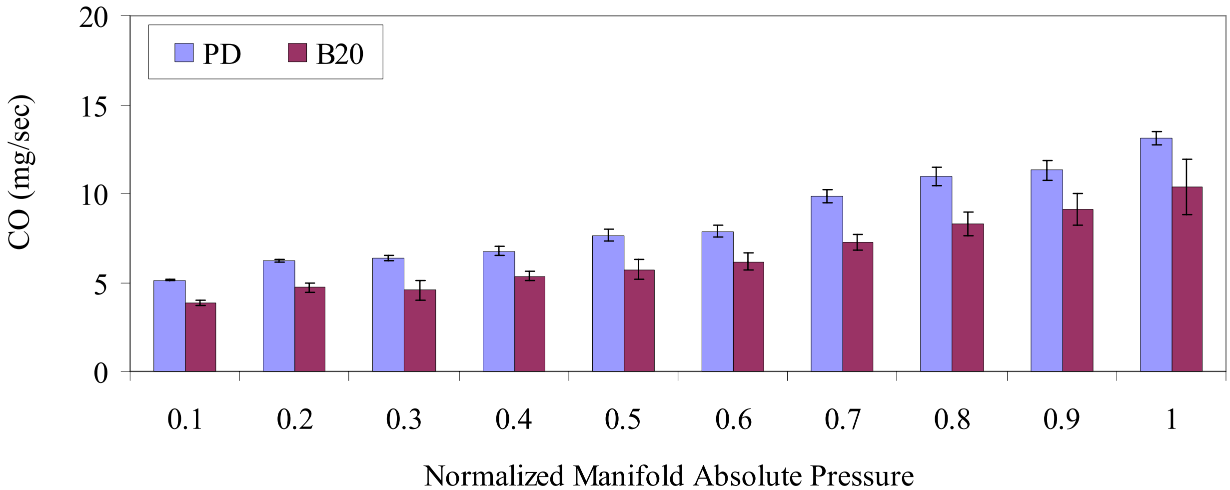


Figure F25. Continued



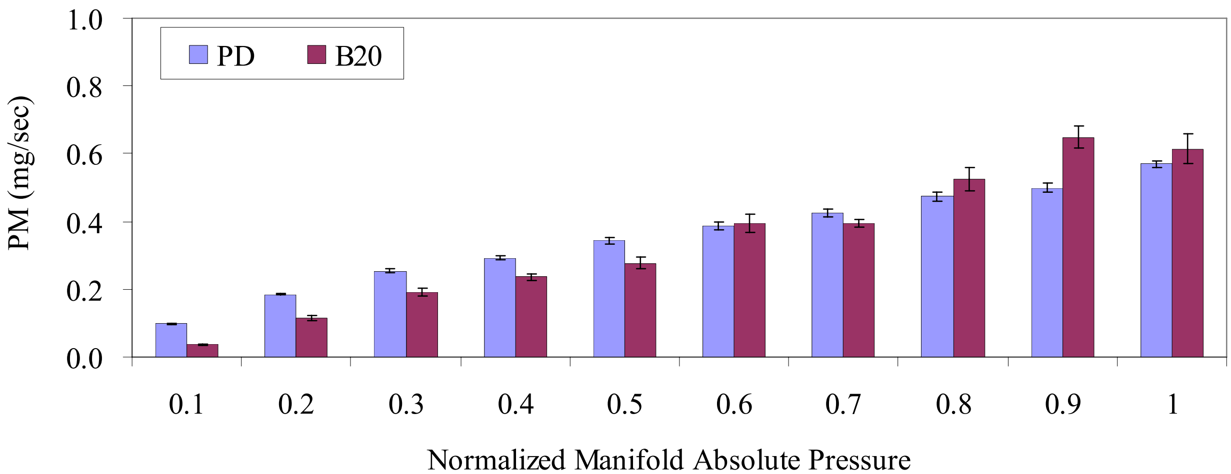
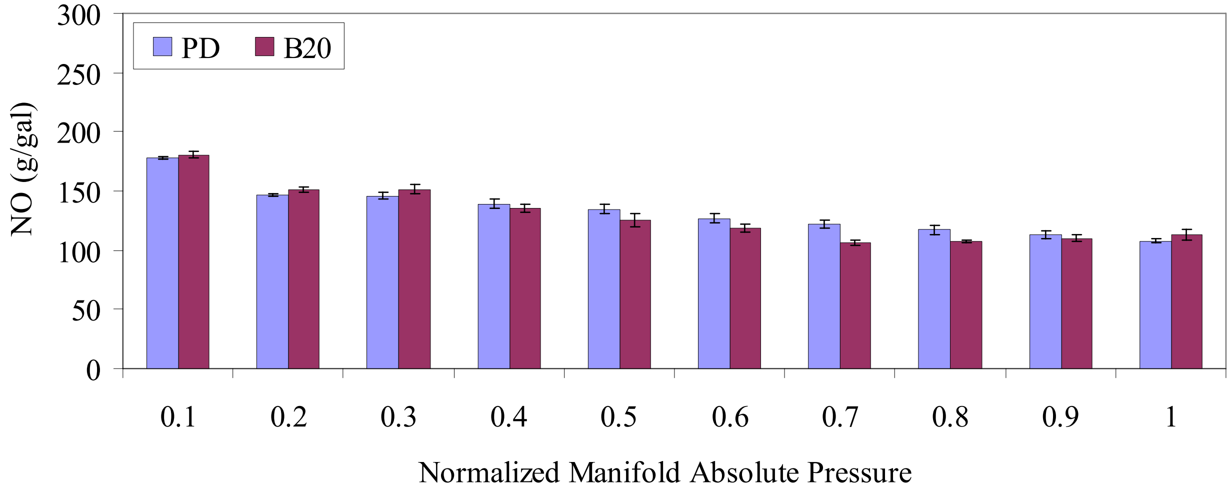
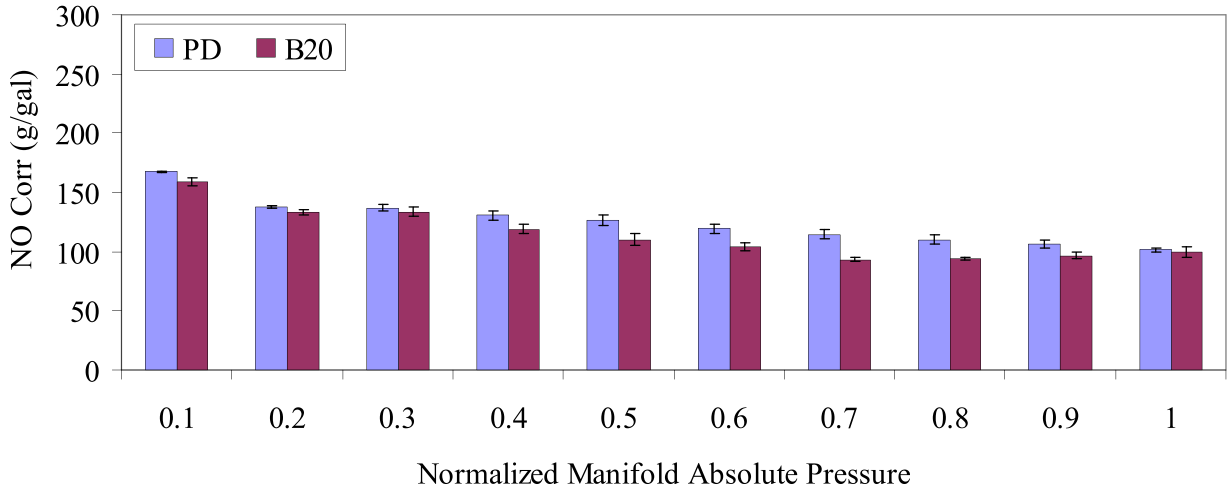


Figure F25. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 71 ^oF and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 50 ^oF and the relative humidity was 46 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 $\leq$ Normalized MAP < 0.1; "0.2" = 0.1 $\leq$ Normalized MAP < 0.2, and so on.

Figure F26. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Front-End Loader 2 (continued on next page)

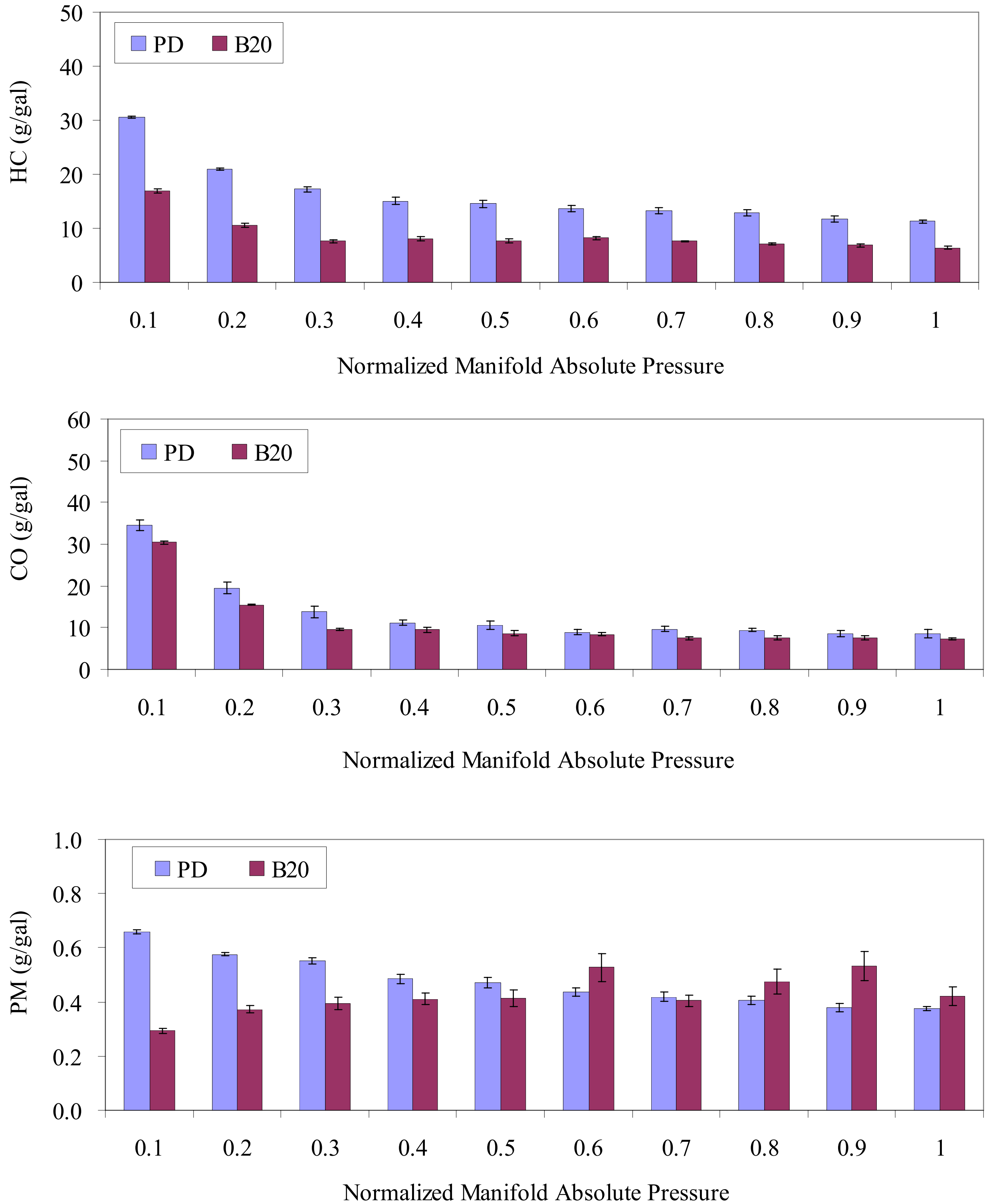
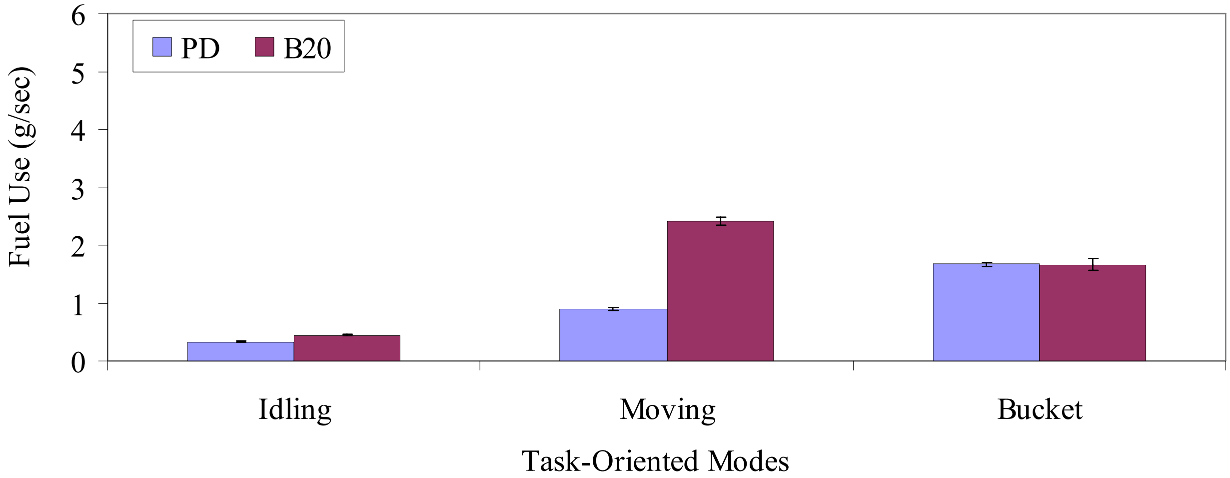
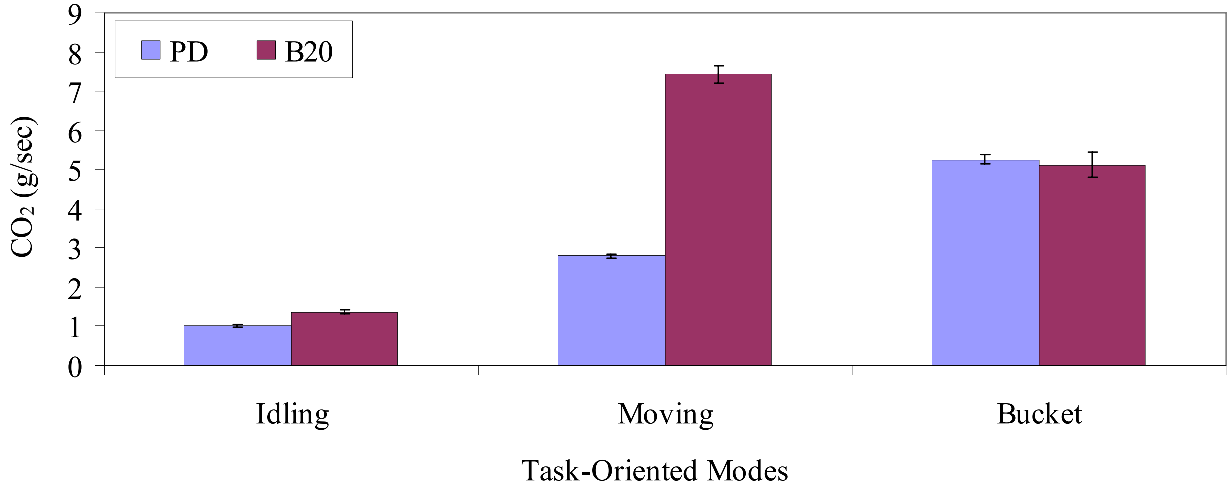


Figure F26. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 71 ^{o}F and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 50 ^{o}F and the relative humidity was 46 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F27. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Front-End Loader 2 (continued on next page)

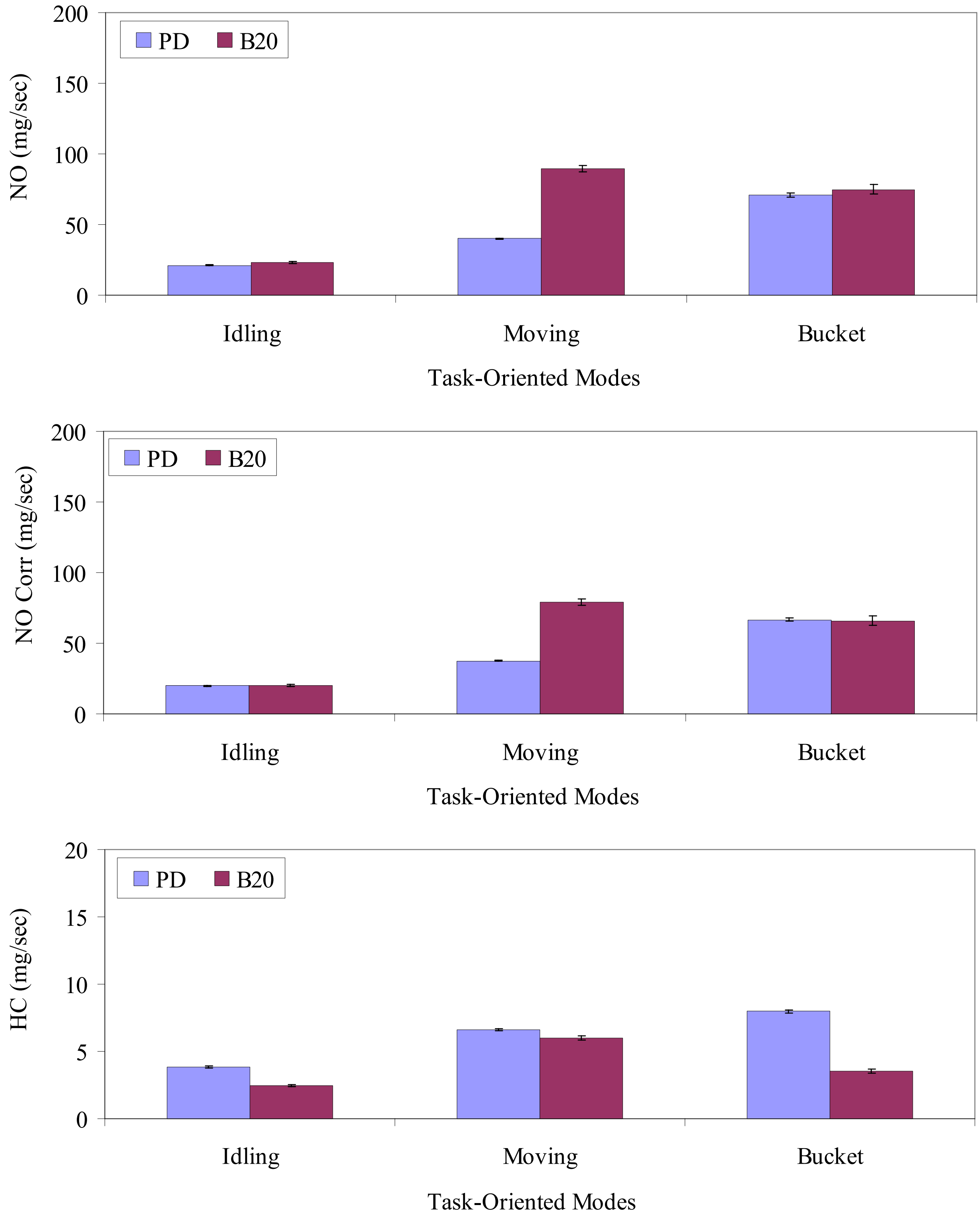
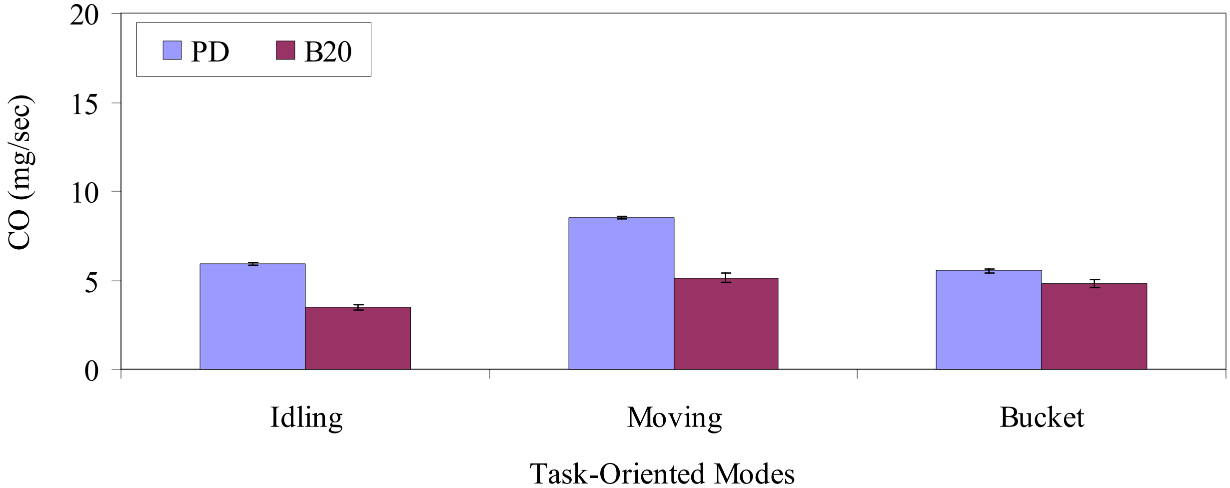


Figure F27. Continued



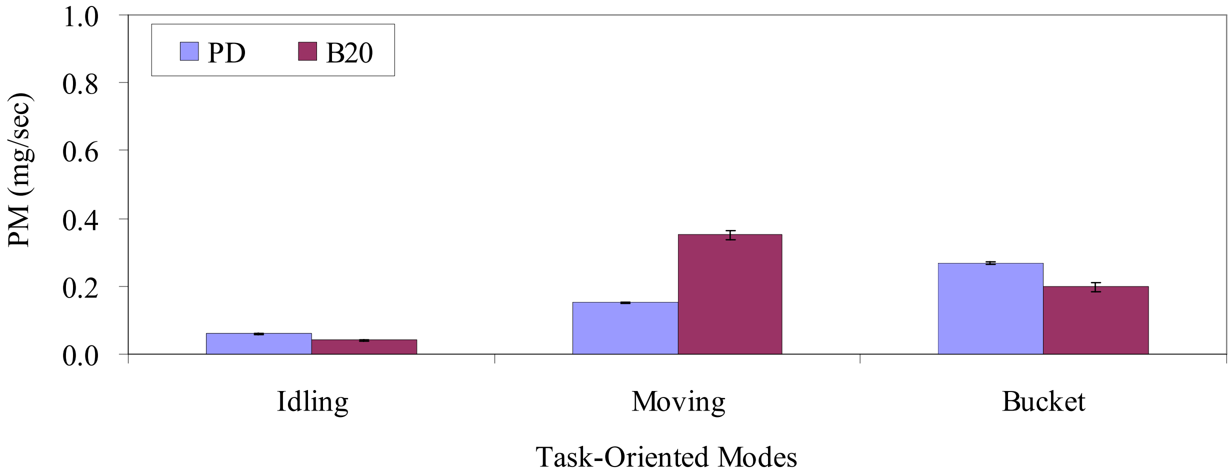
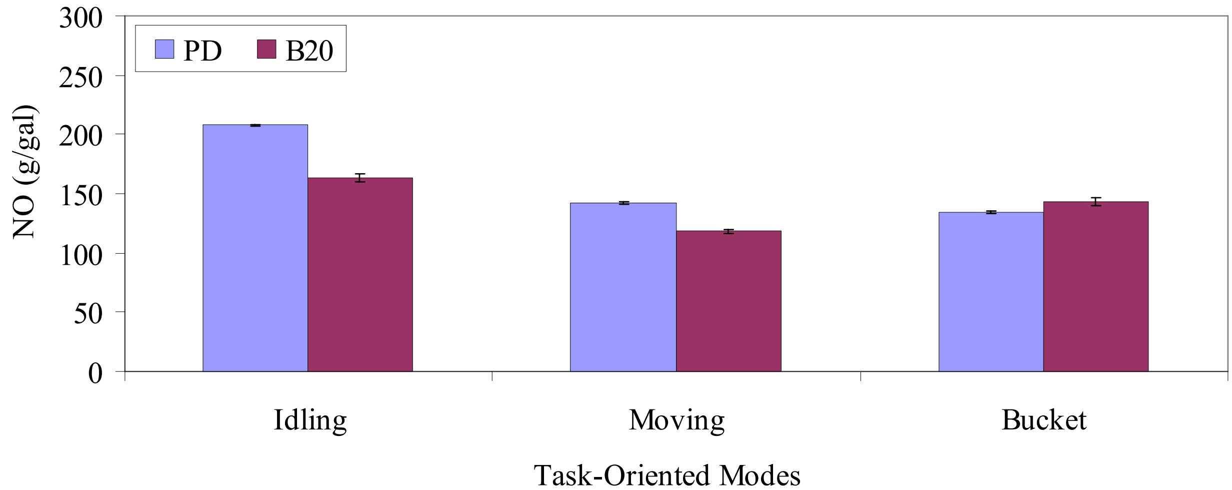
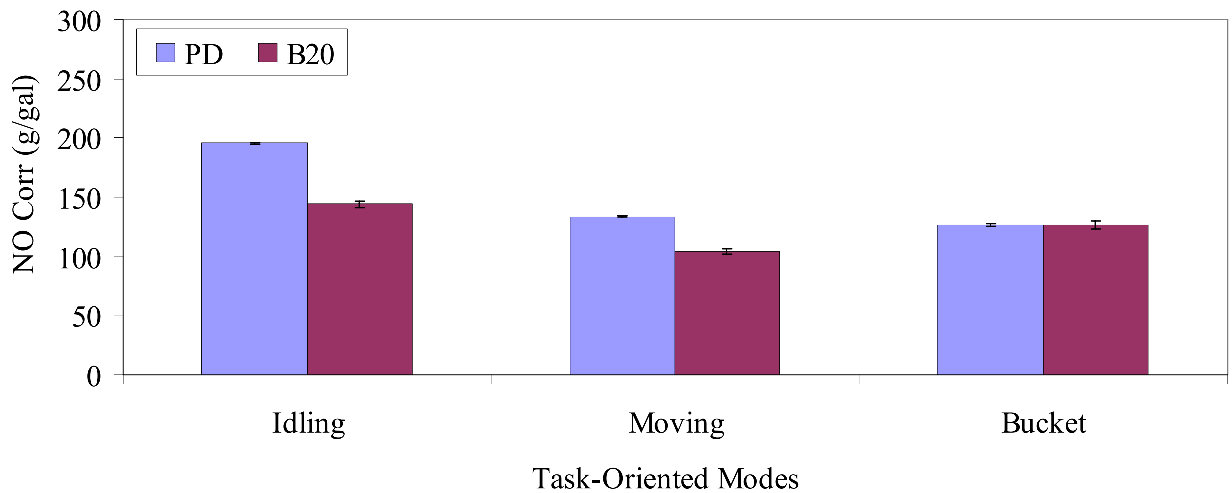


Figure F27. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 71 ^{o}F and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 50 ^{o}F and the relative humidity was 46 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F28. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Front-End Loader 2 (continued on next page)

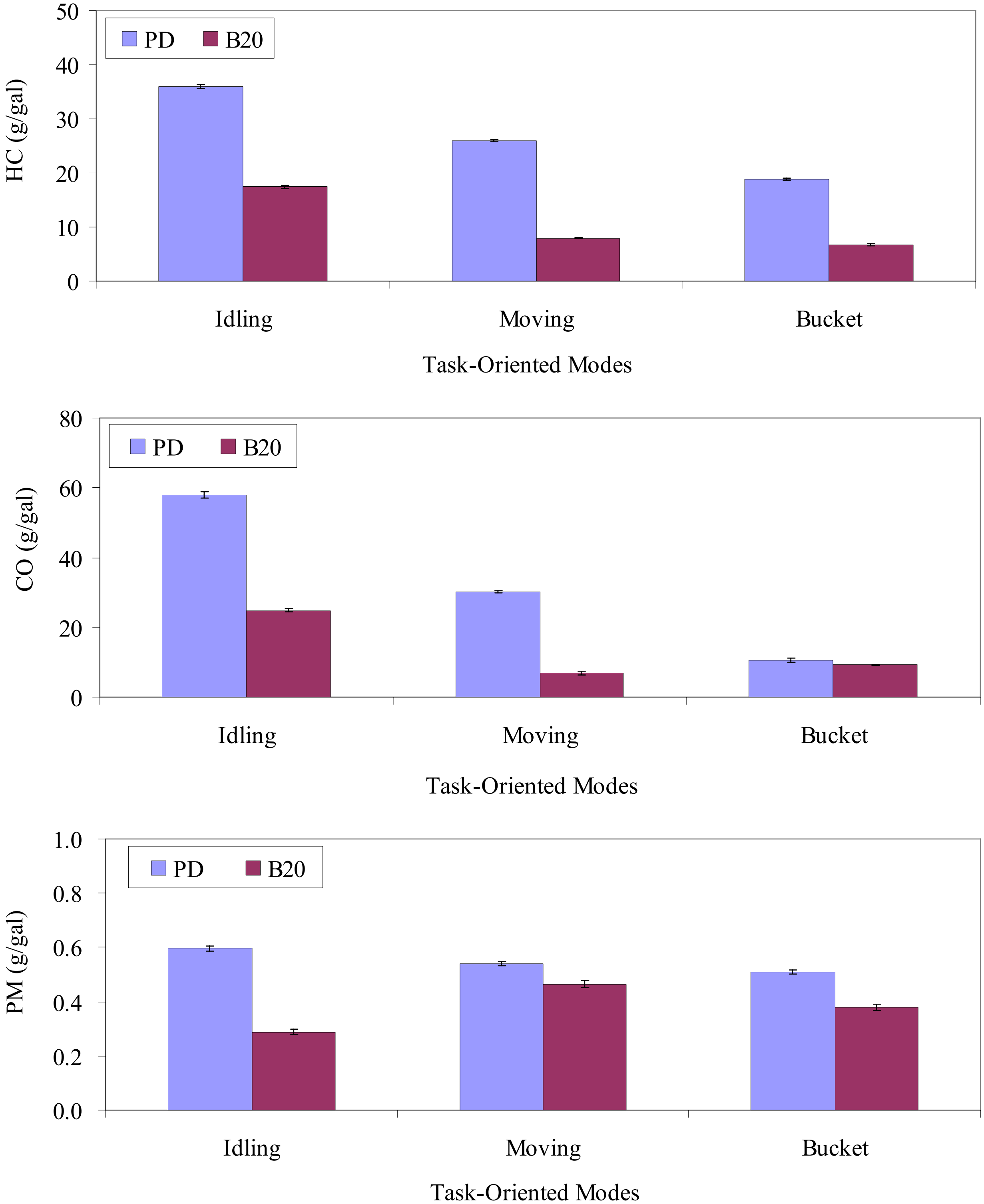
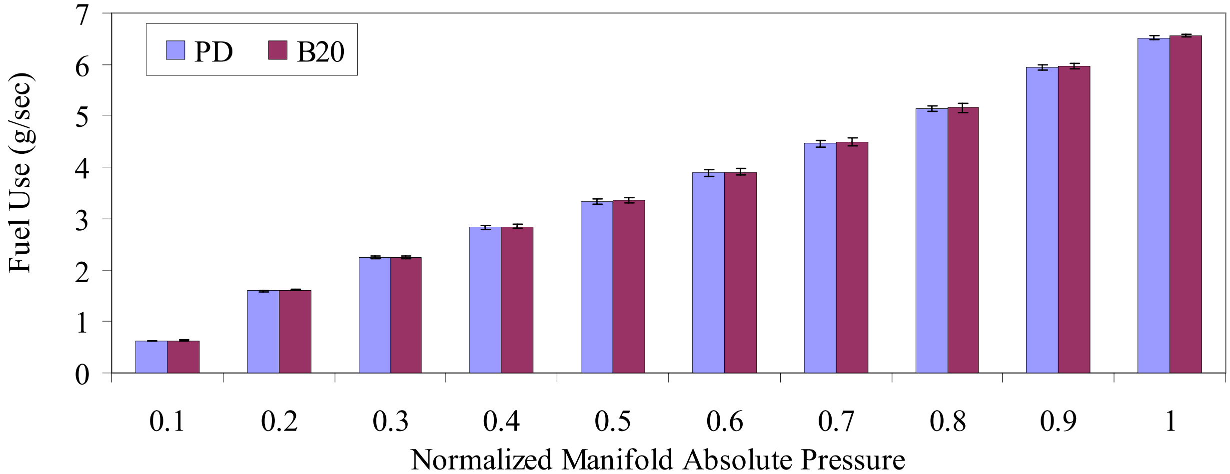
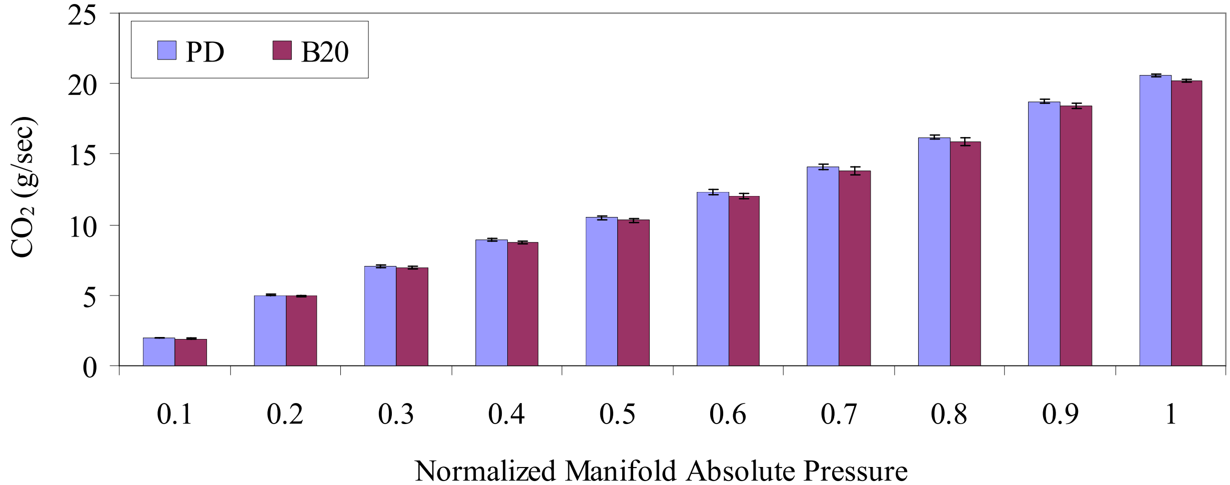


Figure F28. Continued

FRONT-END LOADER 3

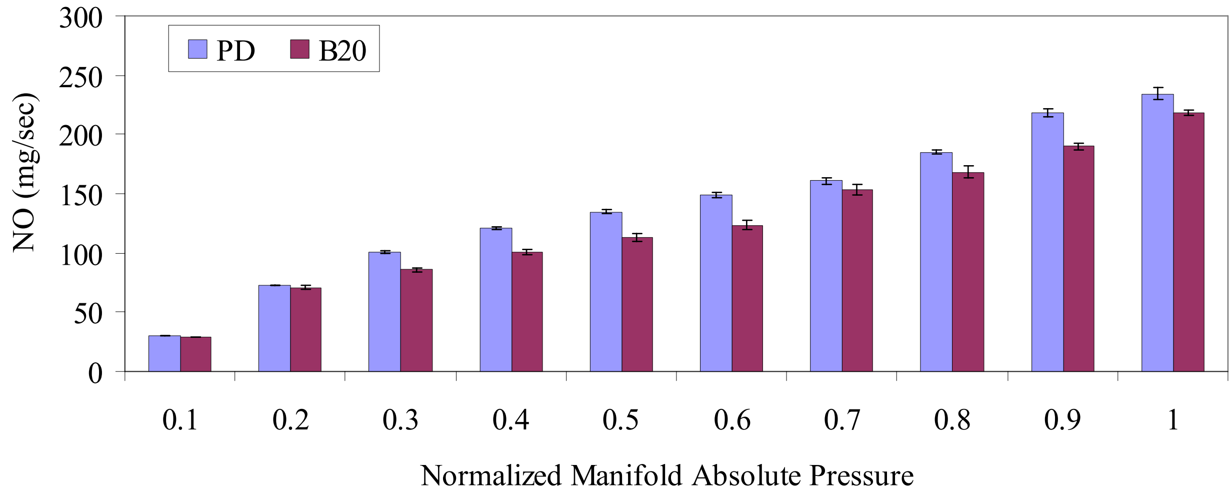


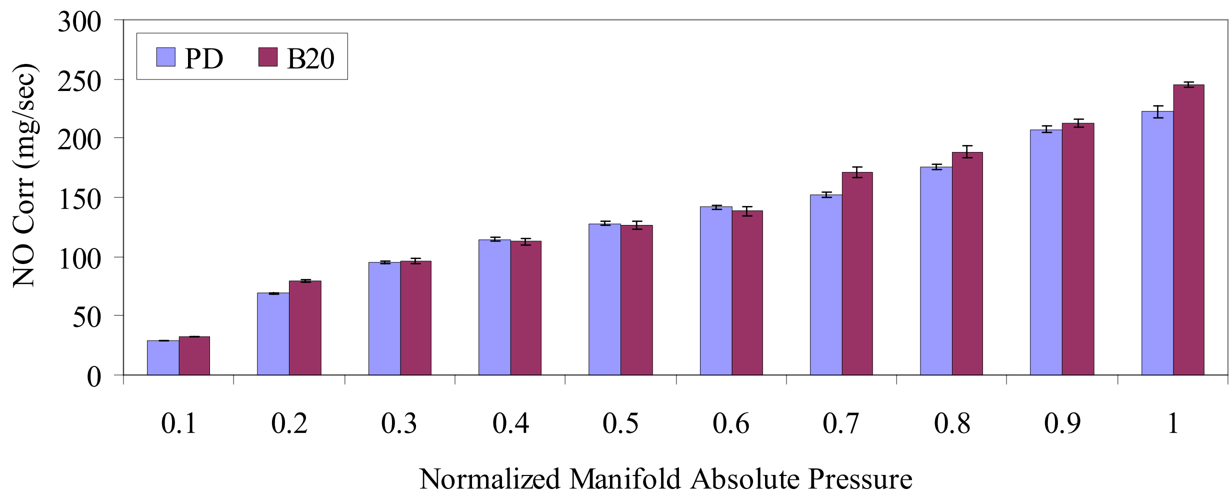


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 64 ^oF and the relative humidity was 63 %. For the B20 biodiesel test, the ambient temperature was 85 ^oF and the relative humidity was 64 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F29. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Front-End Loader 3 (continued on next page)





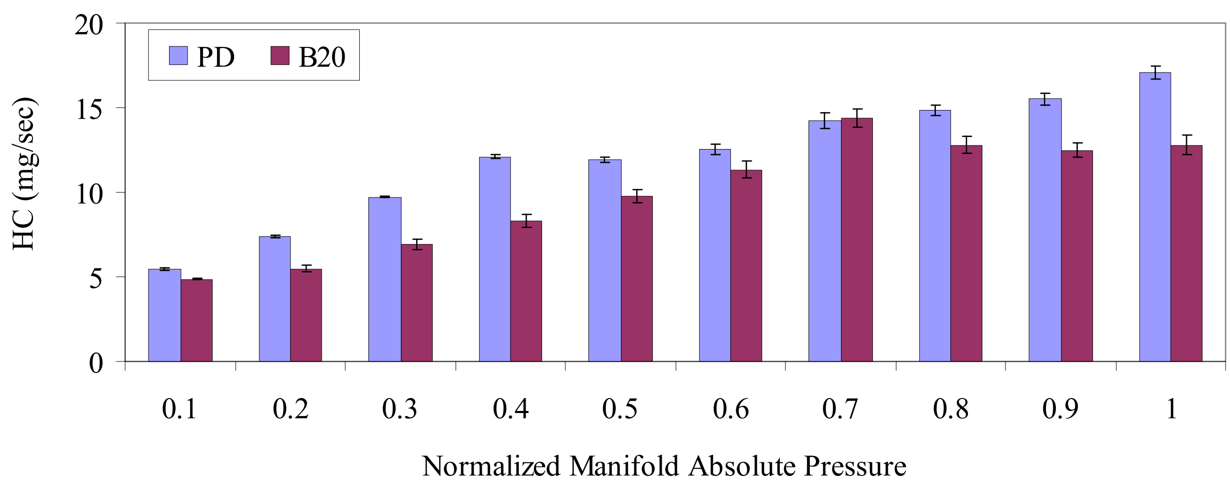


Figure F29. Continued

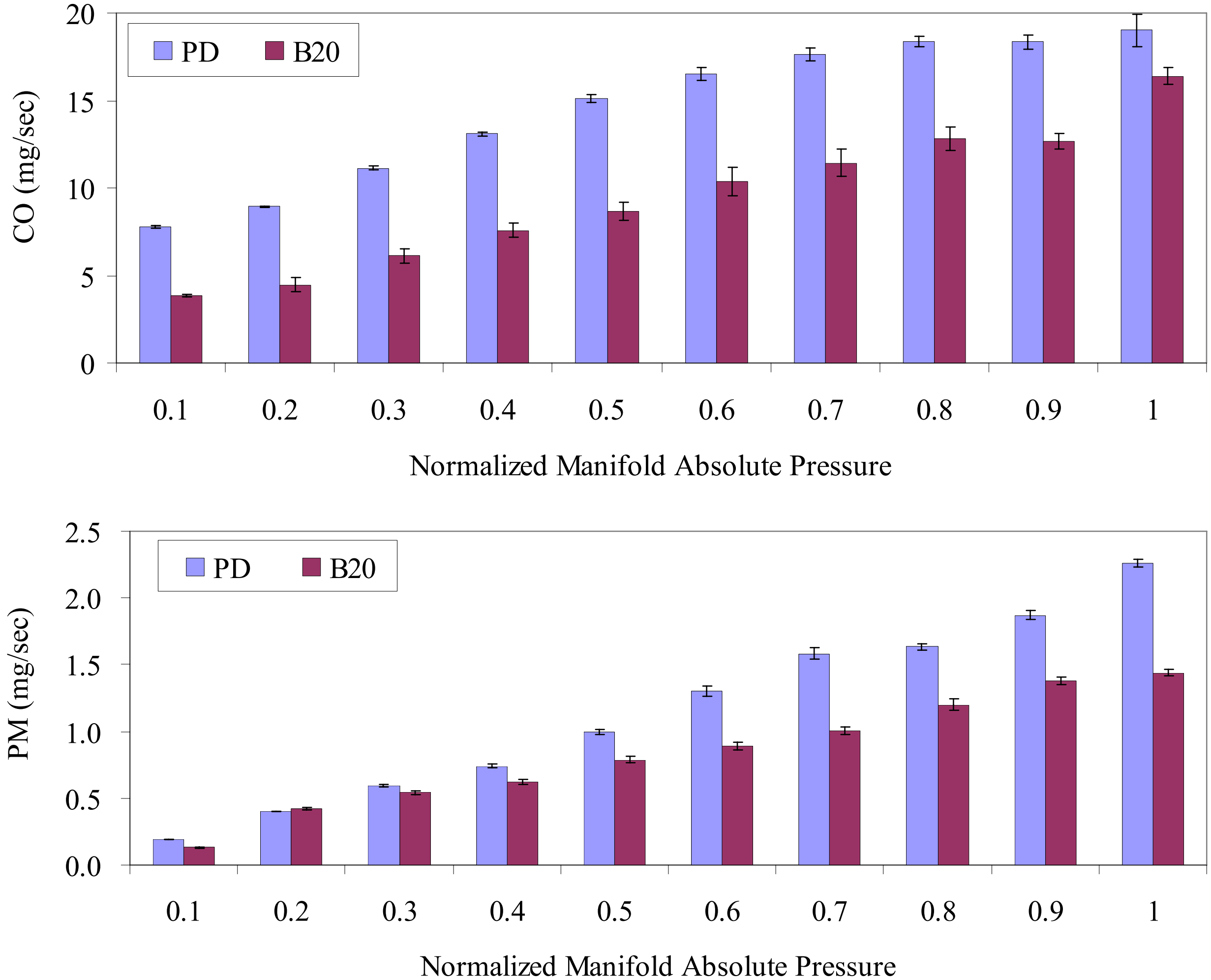
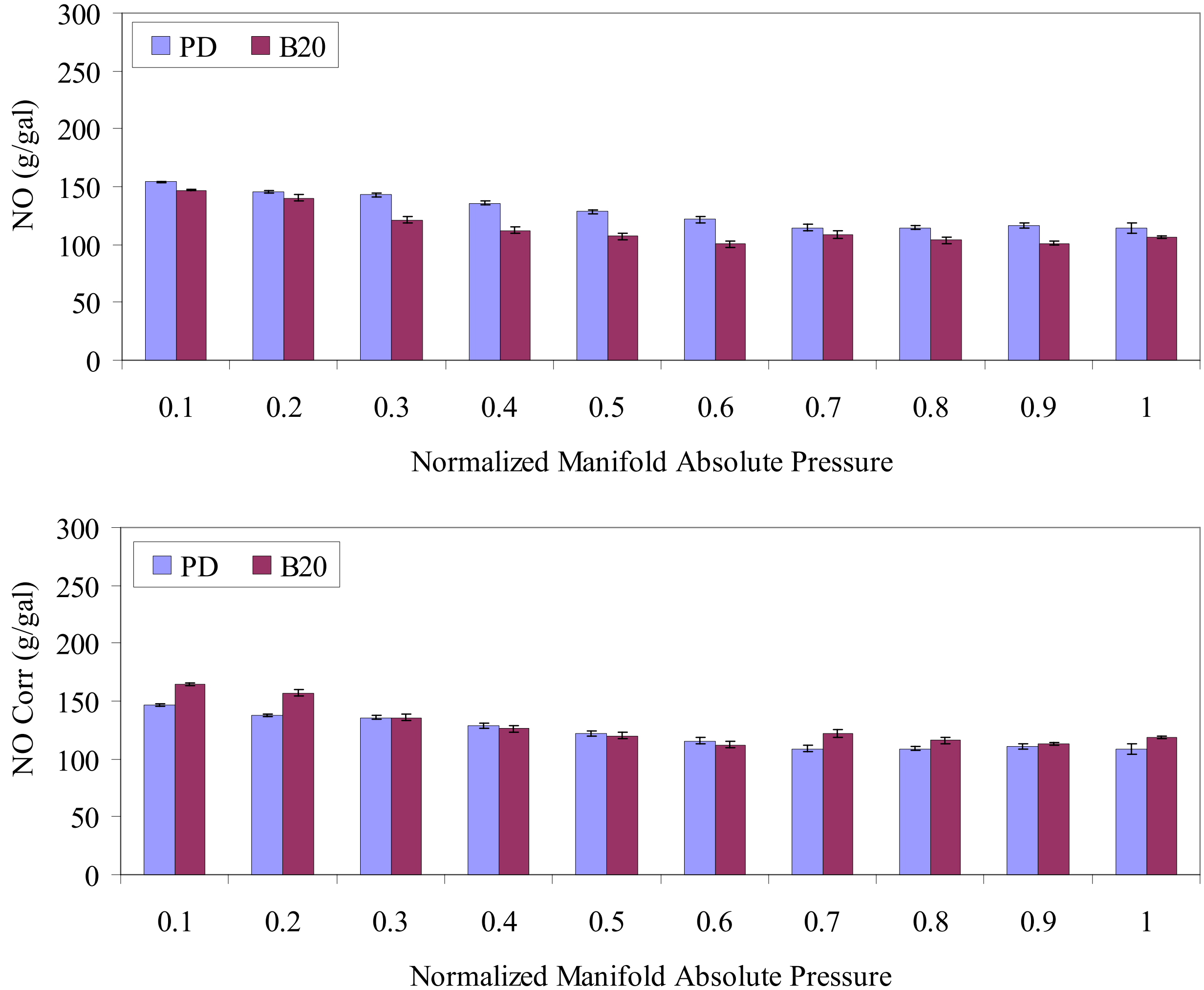


Figure F29. Continued



NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 64 ^oF and the relative humidity was 63 %. For the B20 biodiesel test, the ambient temperature was 85 ^oF and the relative humidity was 64 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F30. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Front-End Loader 3 (continued on next page)

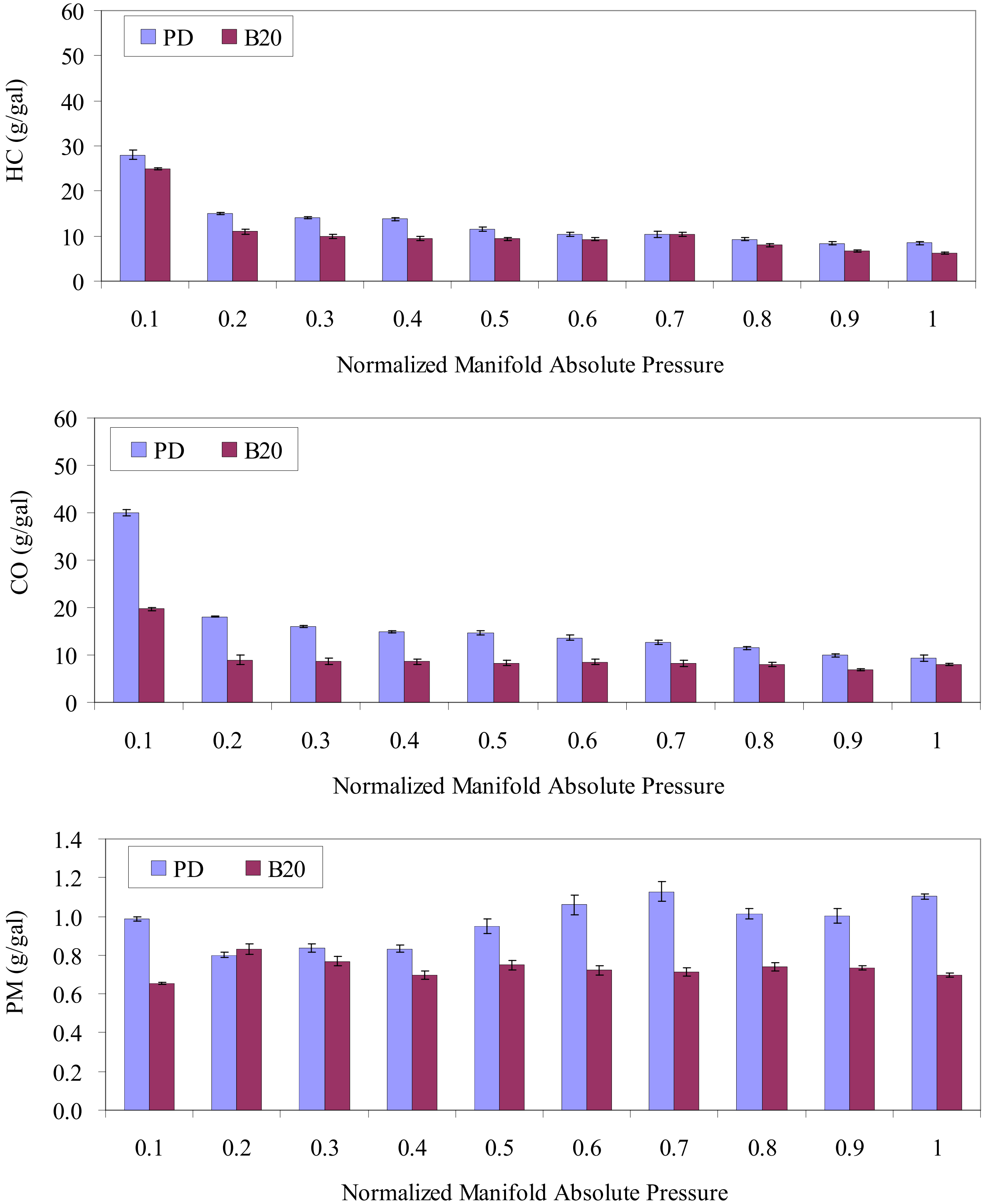
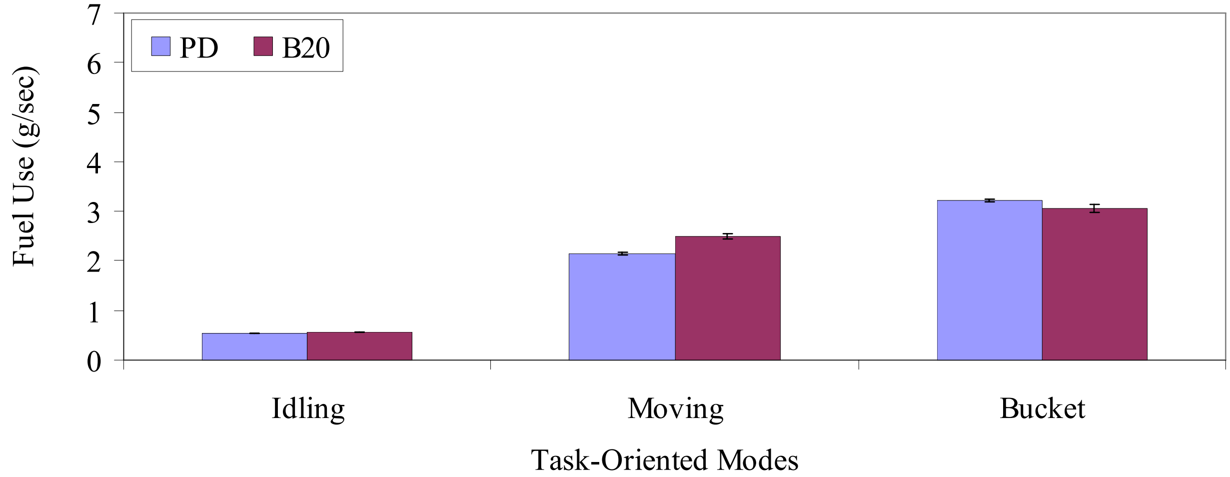
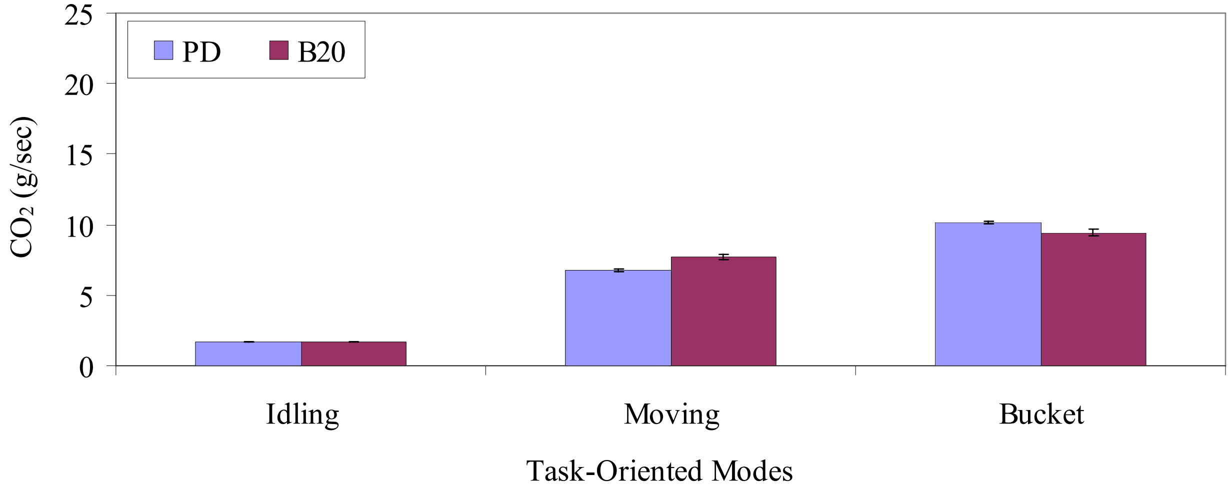


Figure F30. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 64 ^oF and the relative humidity was 63 %. For the B20 biodiesel test, the ambient temperature was 85 ^oF and the relative humidity was 64 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F31. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Front-End Loader 3 (continued on next page)

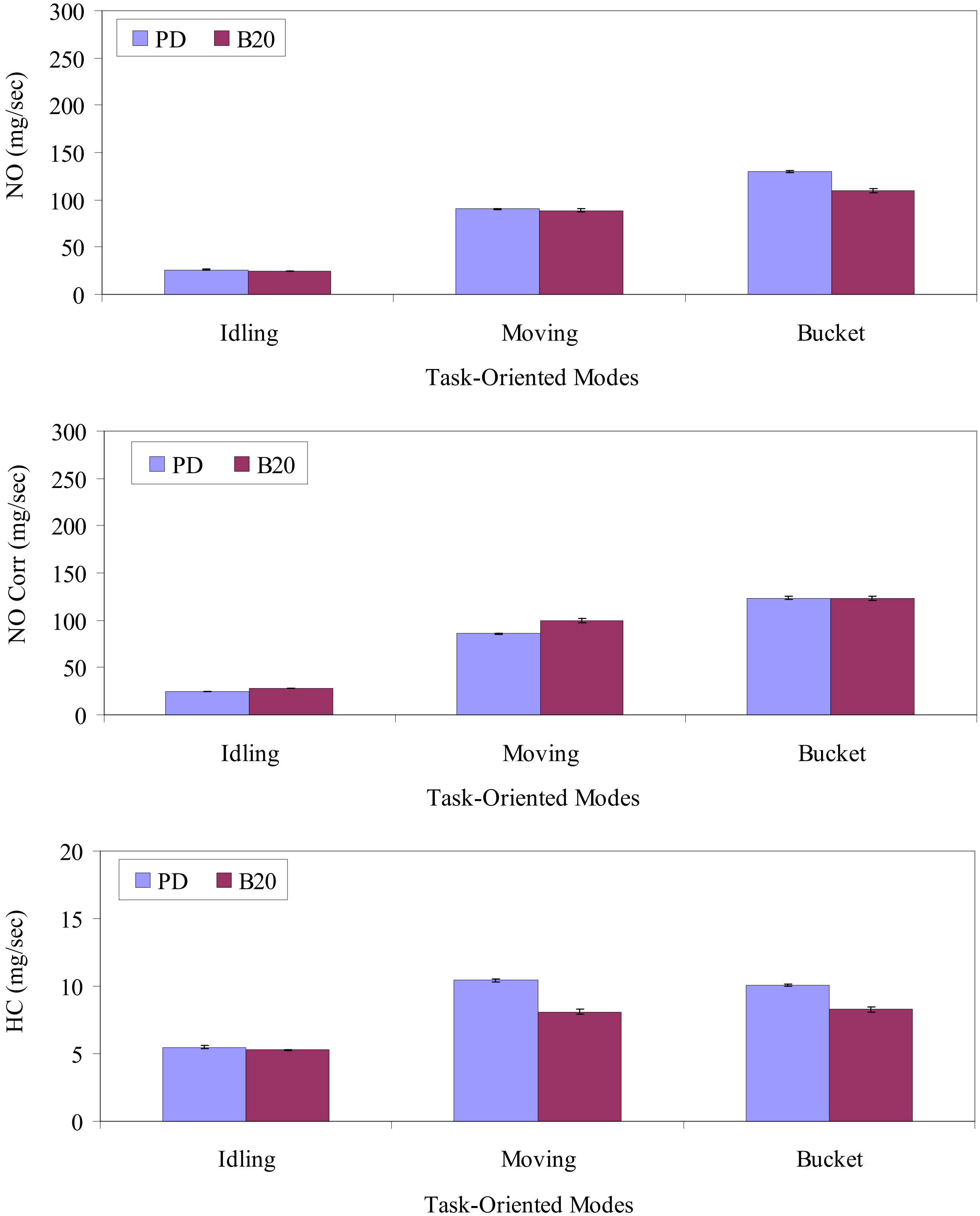
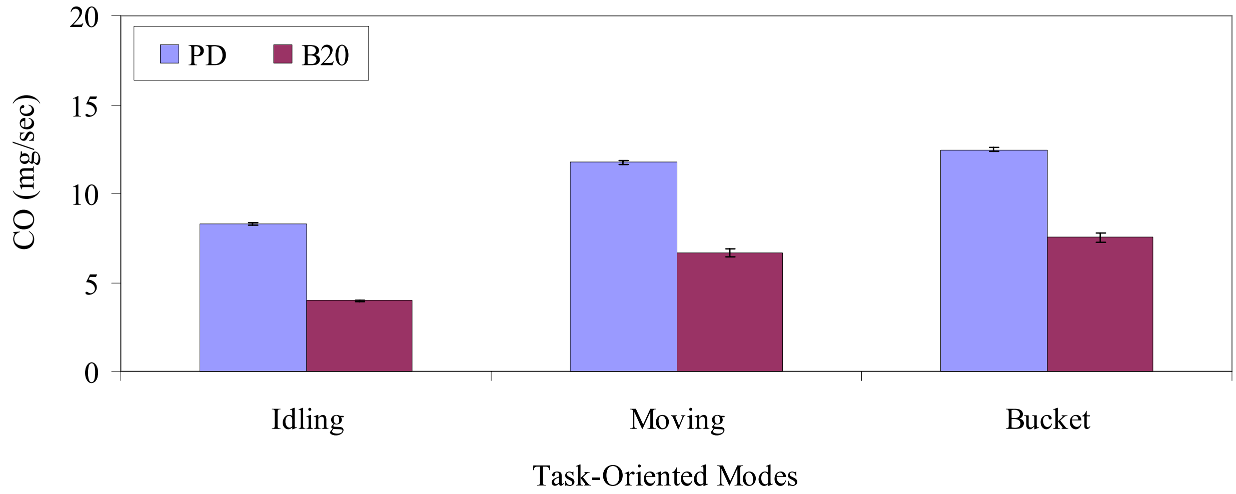


Figure F31. Continued



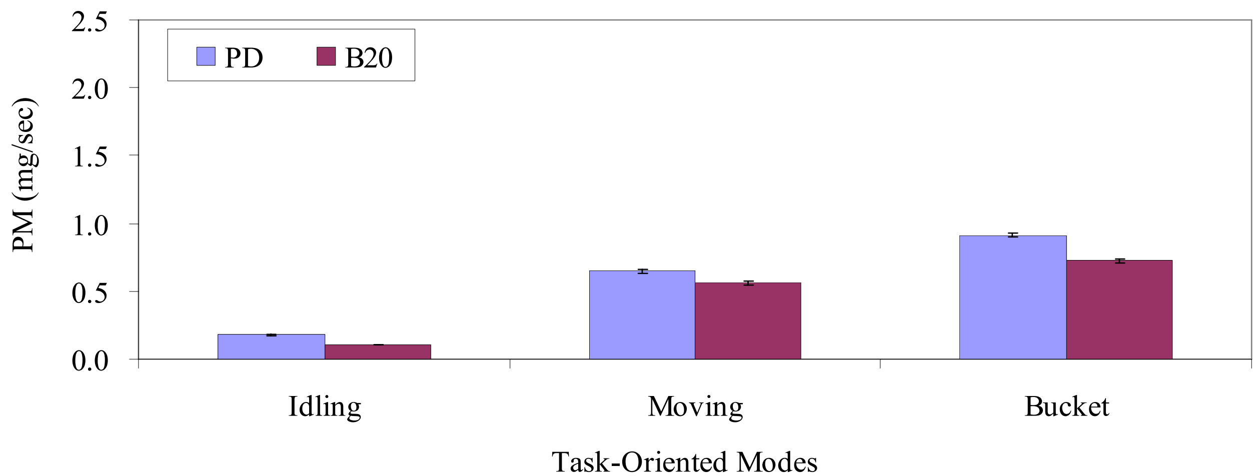
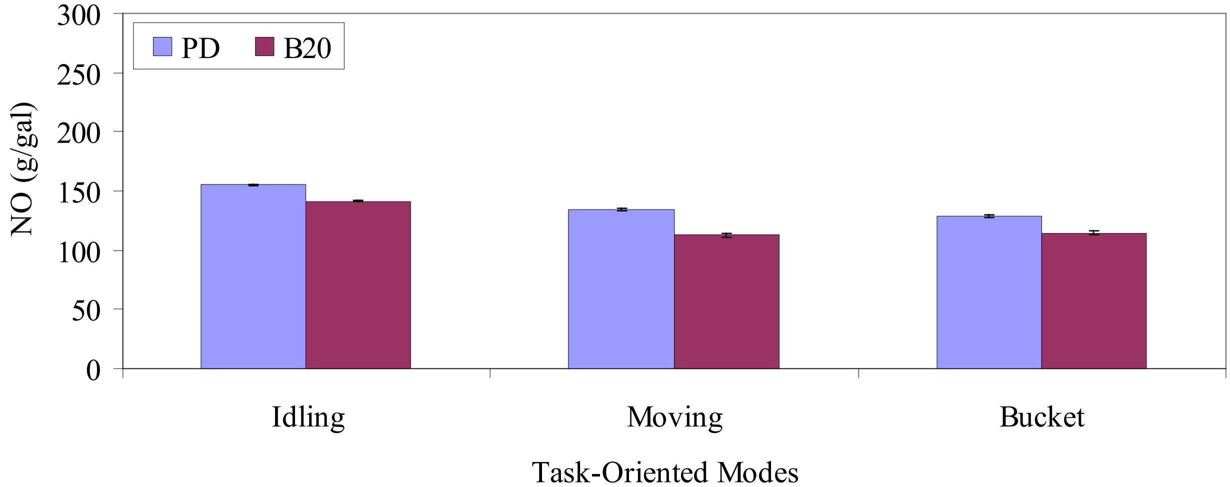
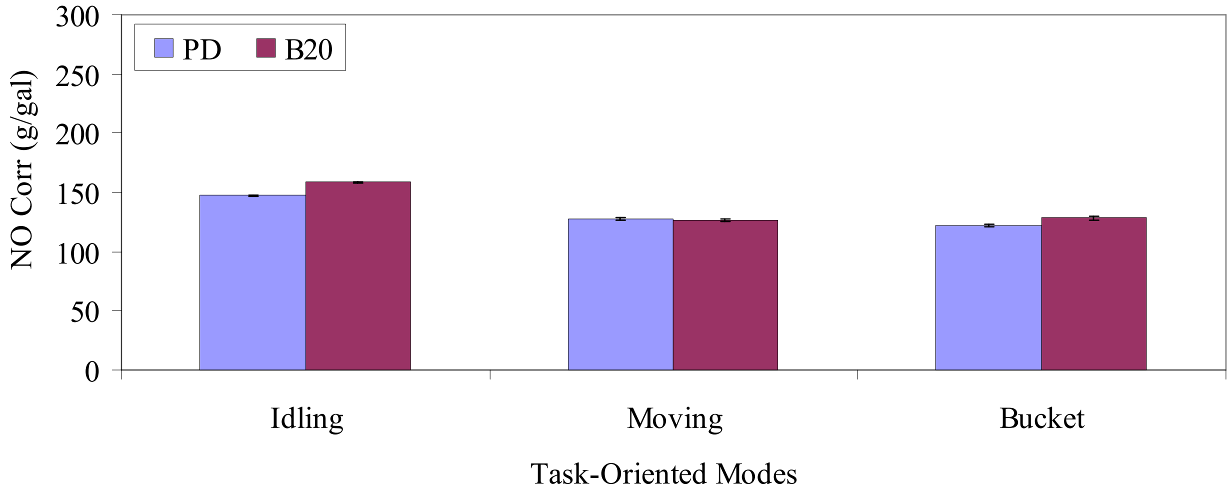


Figure F31. Continued

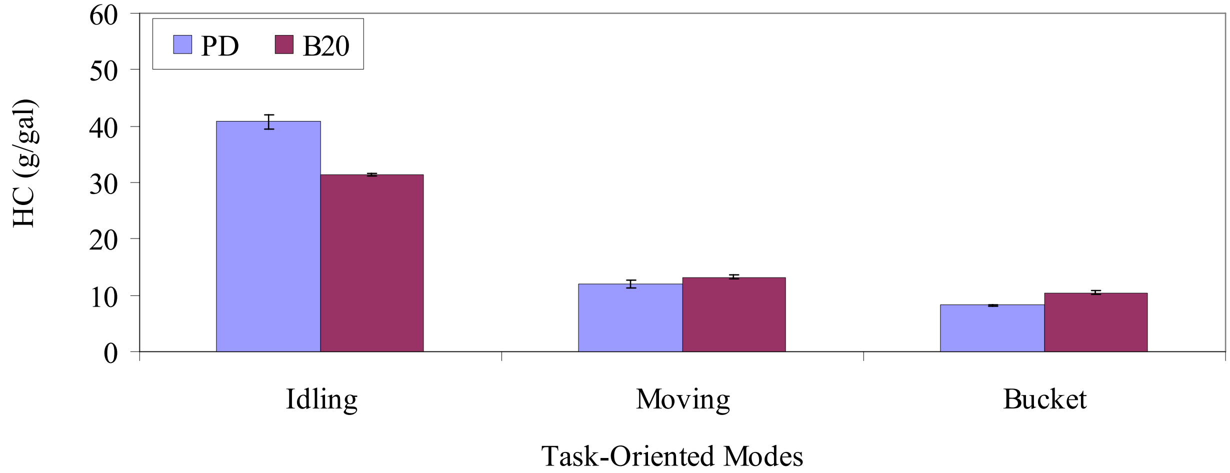


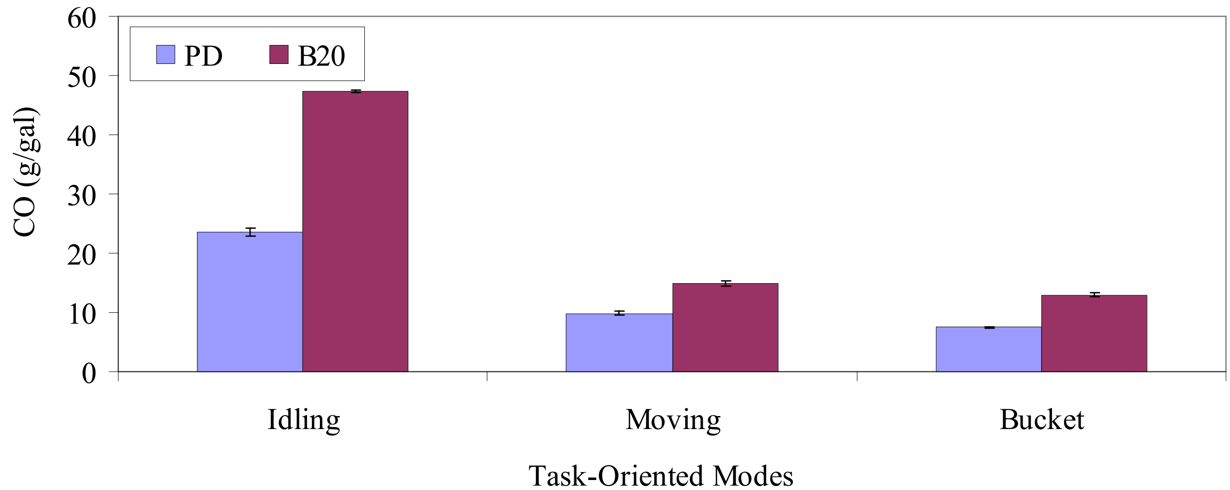


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 64 ^{o}F and the relative humidity was 63 %. For the B20 biodiesel test, the ambient temperature was 85 ^{o}F and the relative humidity was 64 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F32. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Front-End Loader 3 (continued on next page)





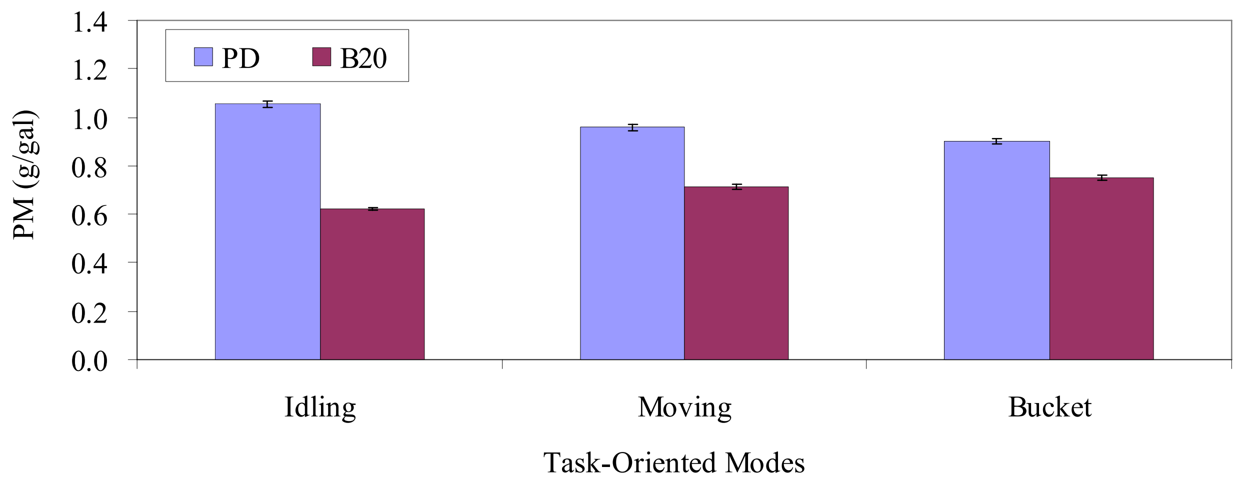
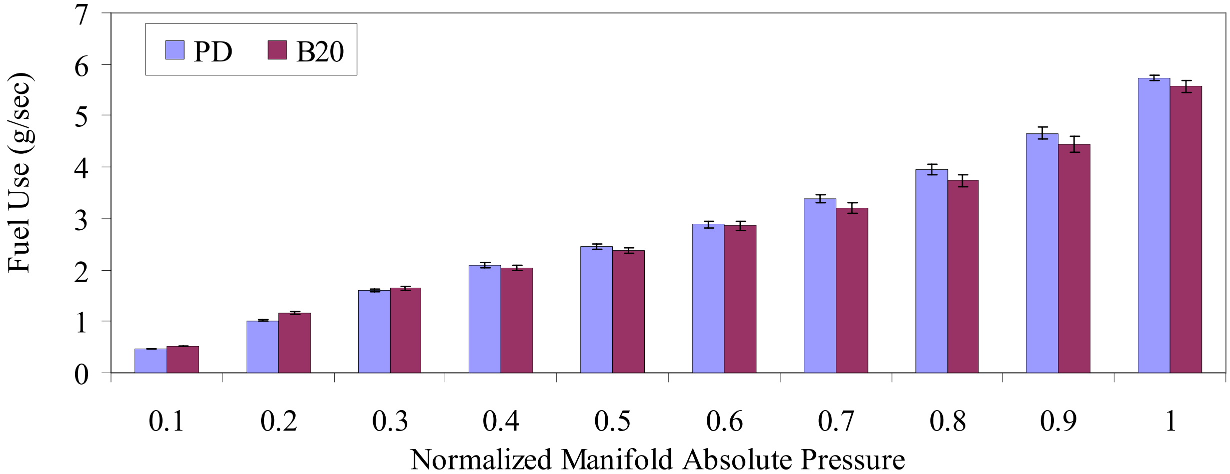
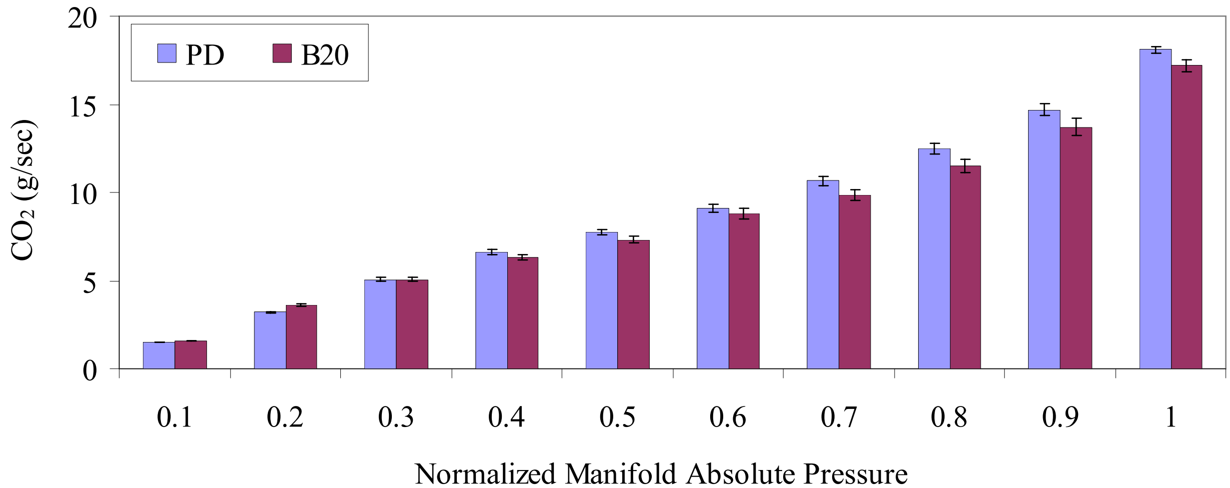


Figure F32. Continued

FRONT-END LOADER 4

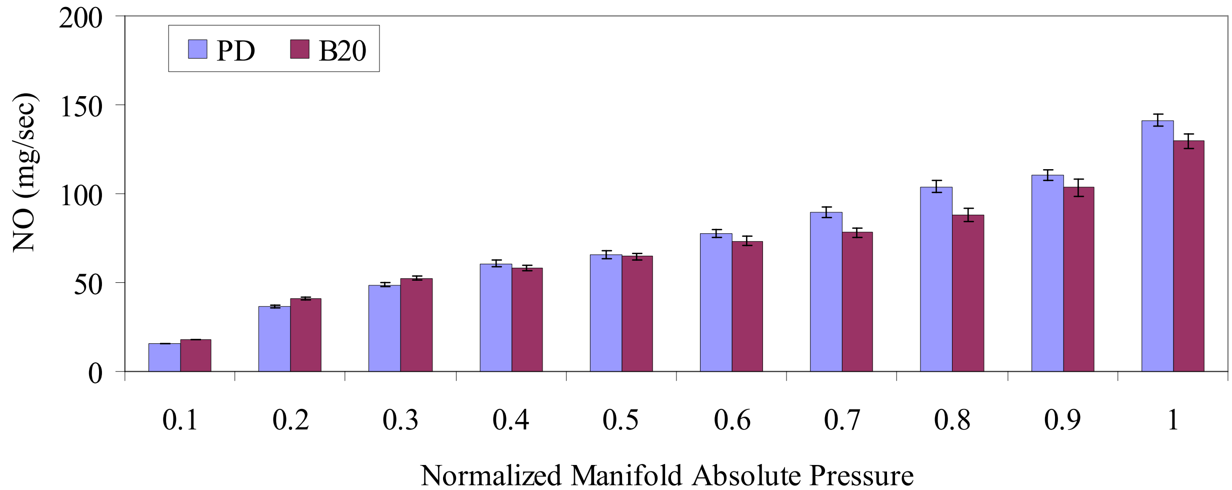


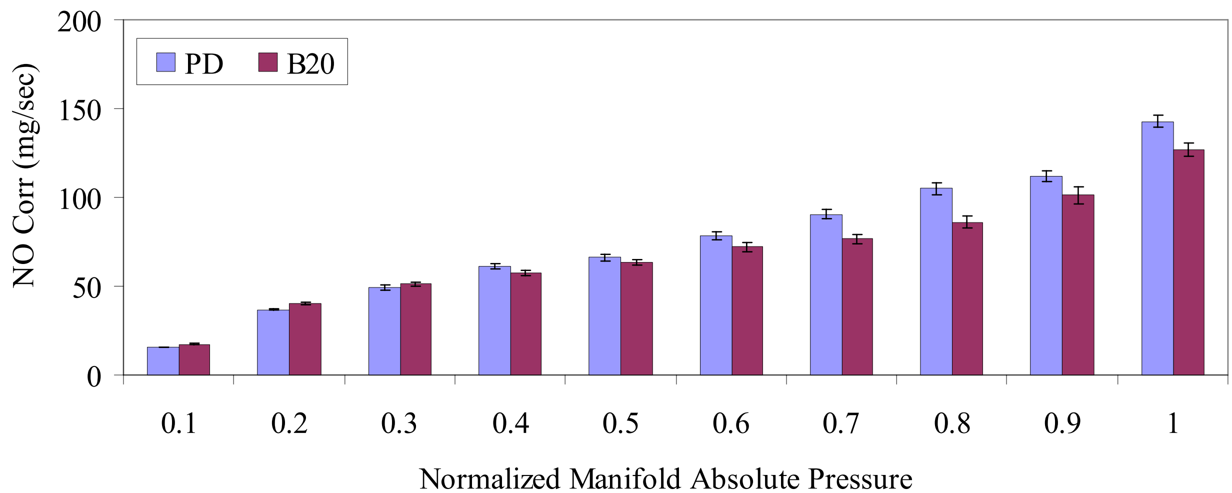


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^oF and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^oF and the relative humidity was 74 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F33. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Front-End Loader 4 (continued on next page)





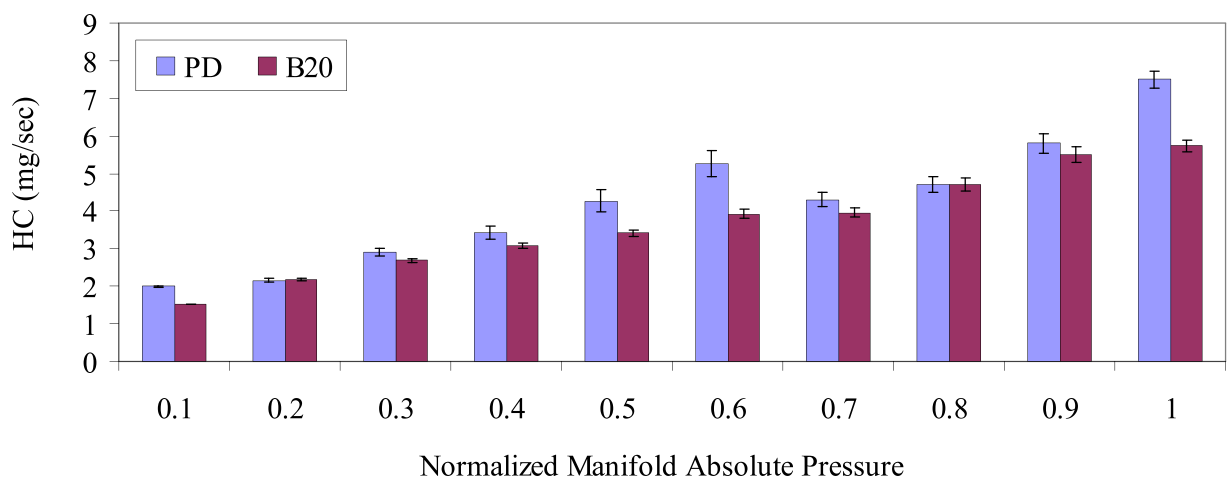
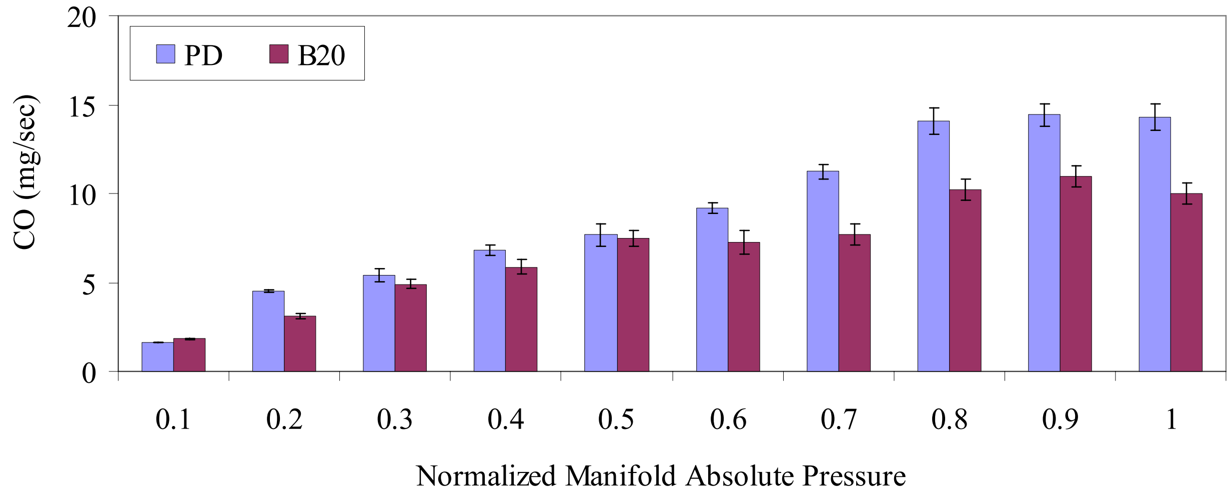


Figure F33. Continued



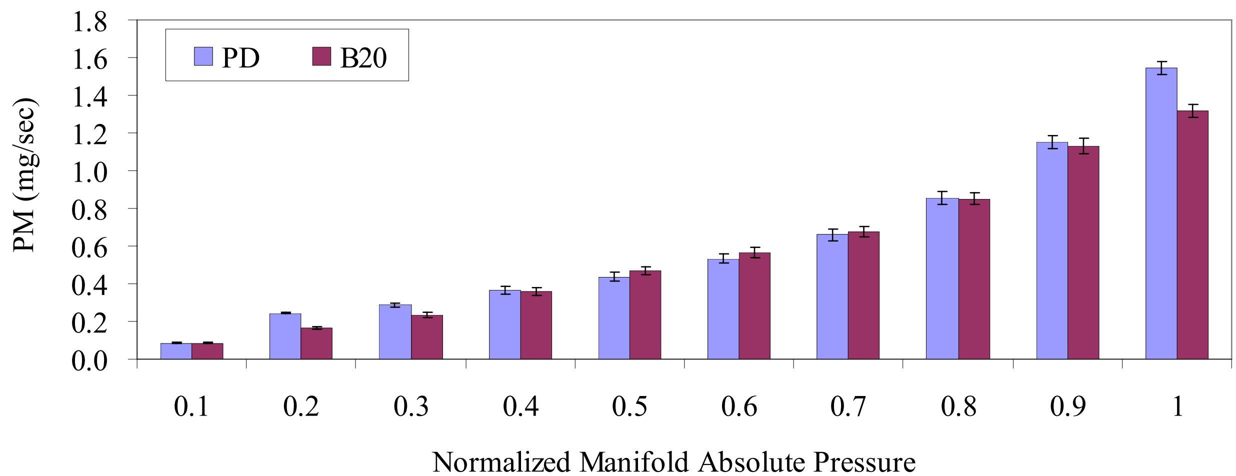
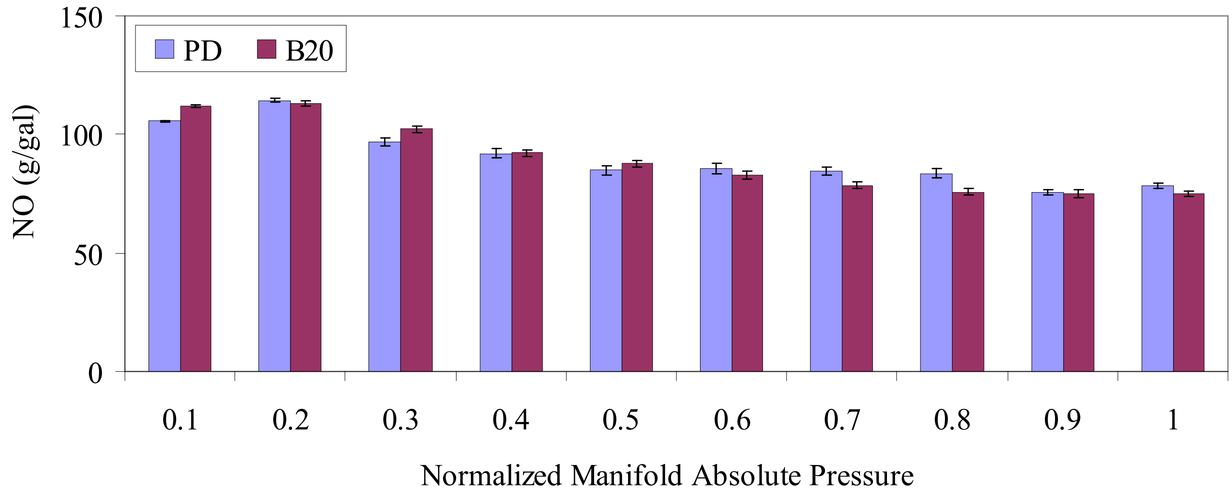
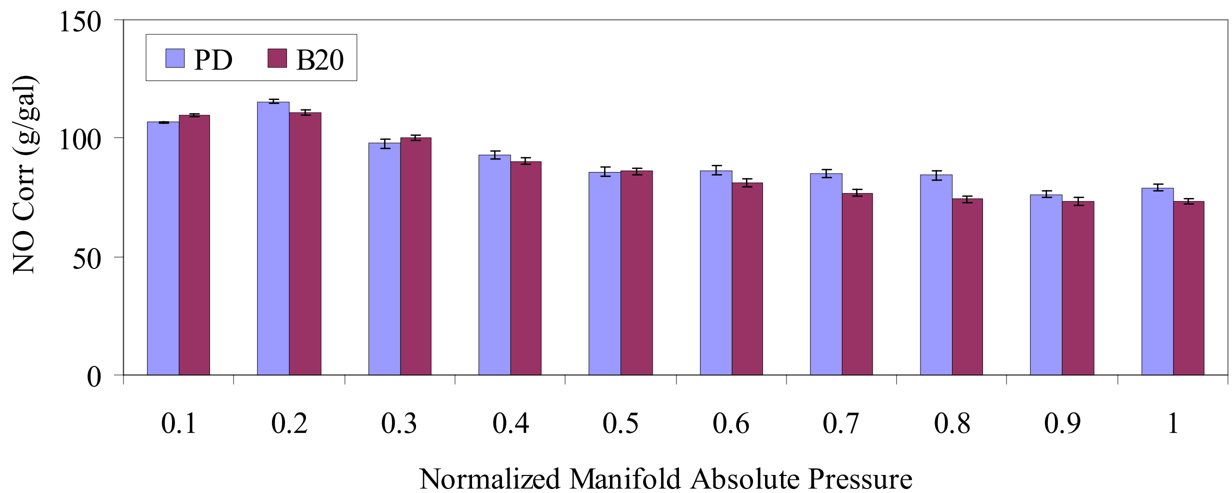


Figure F33. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^{o}F and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^{o}F and the relative humidity was 74 %.

Values shown in the figure are the upper end of the range: “0.1” = 0 ≤ Normalized MAP < 0.1; “0.2” = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F34. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Front-End Loader 4 (continued on next page)

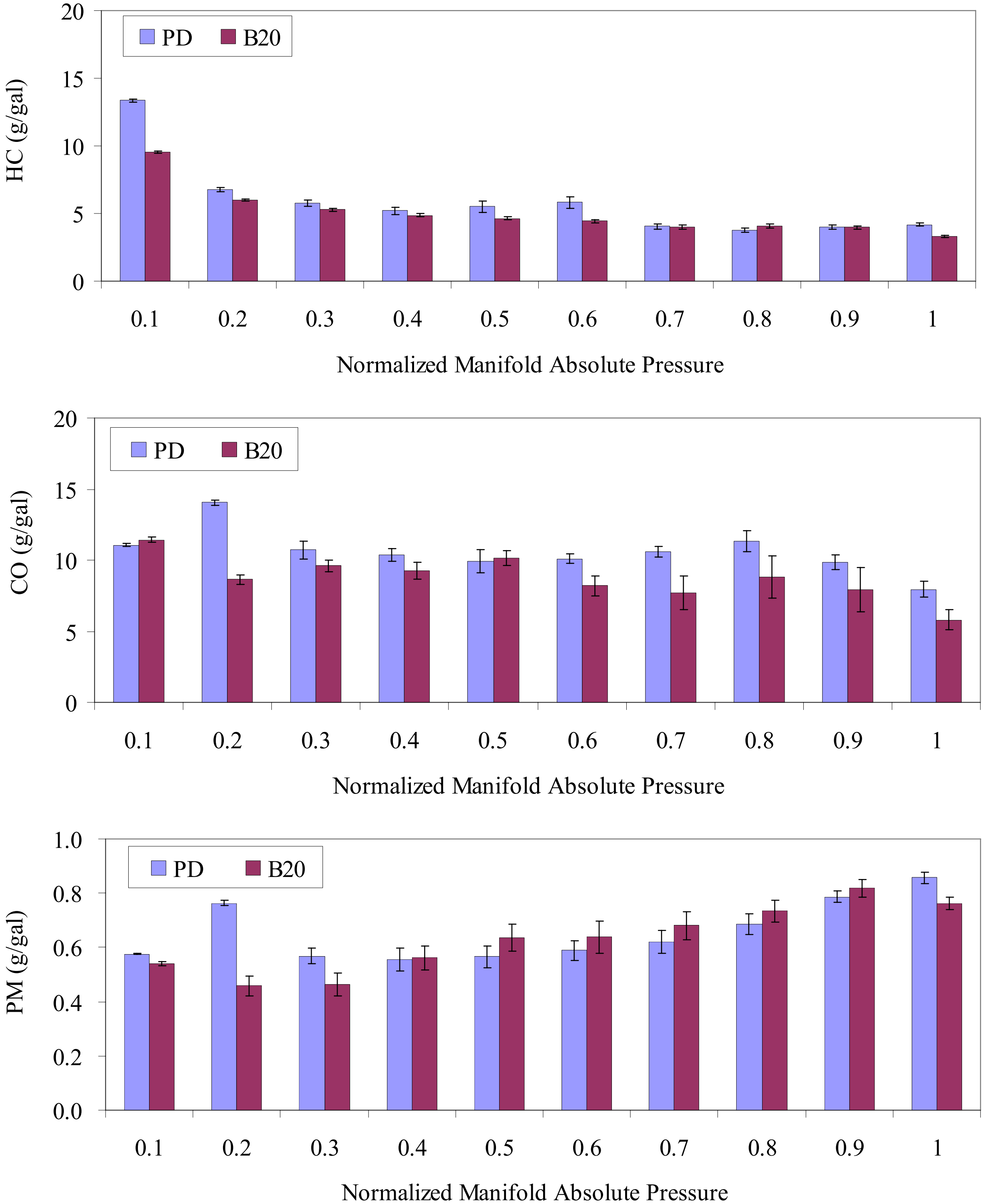
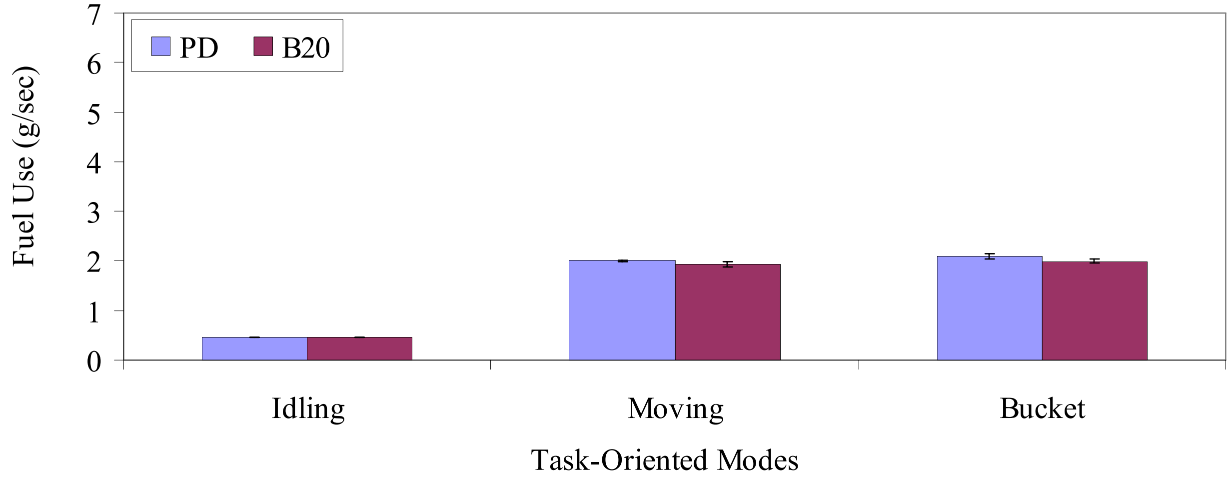
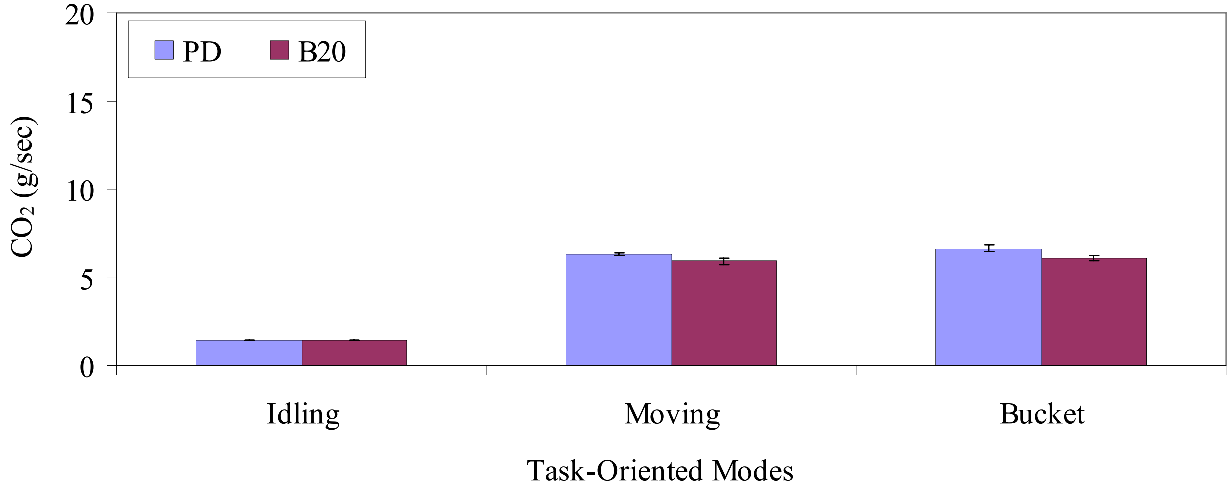


Figure F34. Continued

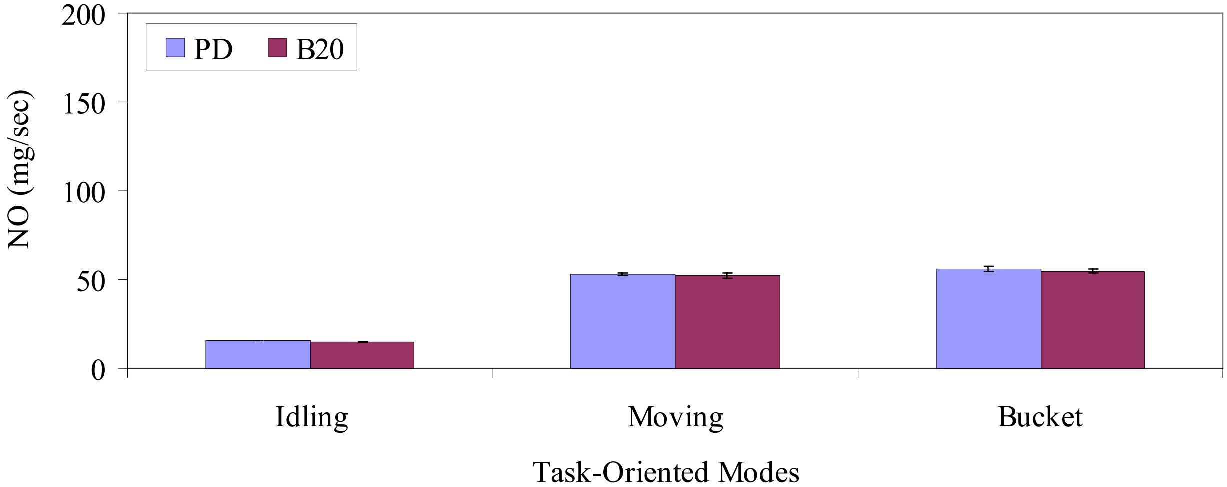


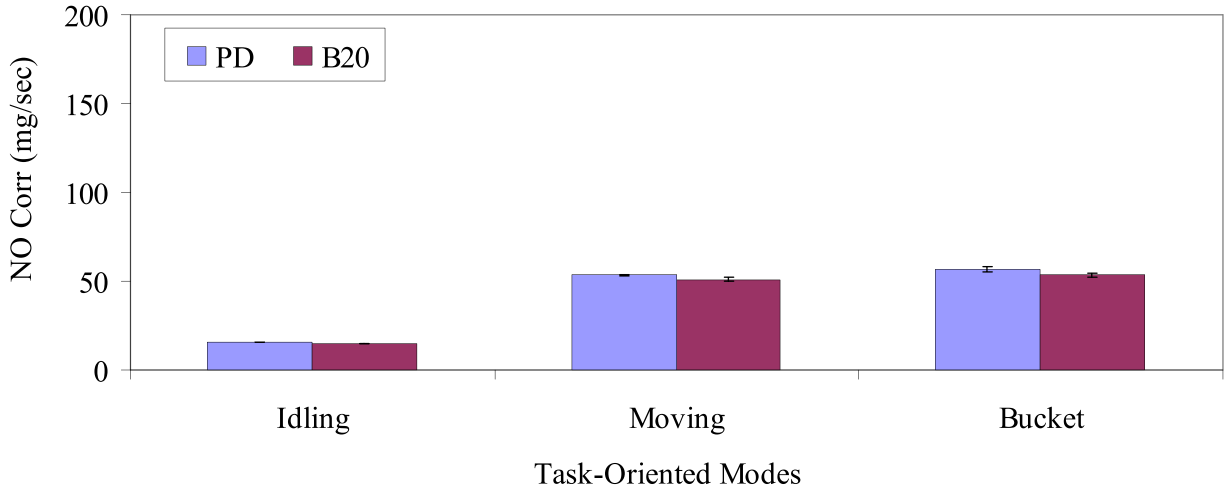


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^oF and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^oF and the relative humidity was 74 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F35. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Front-End Loader 4 (continued on next page)





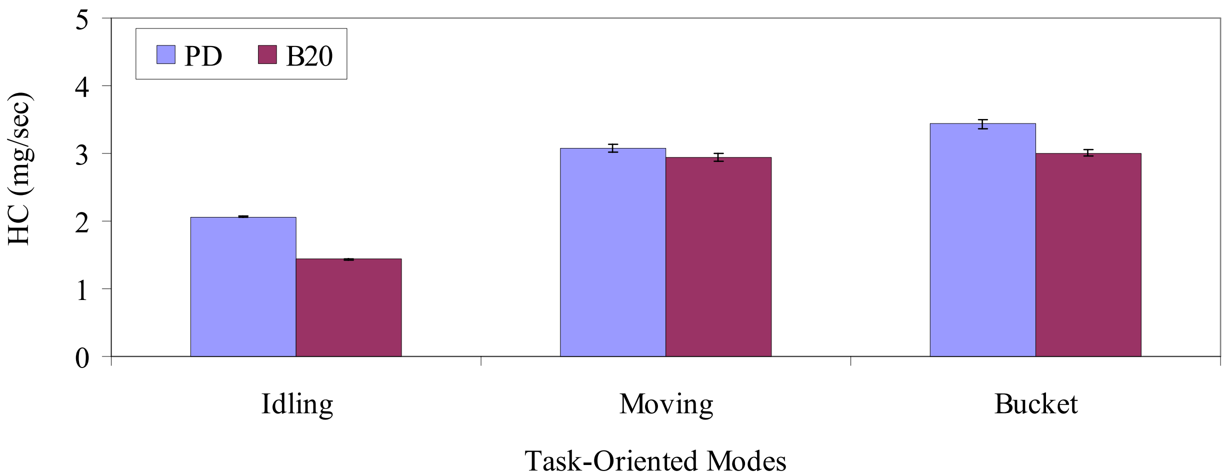
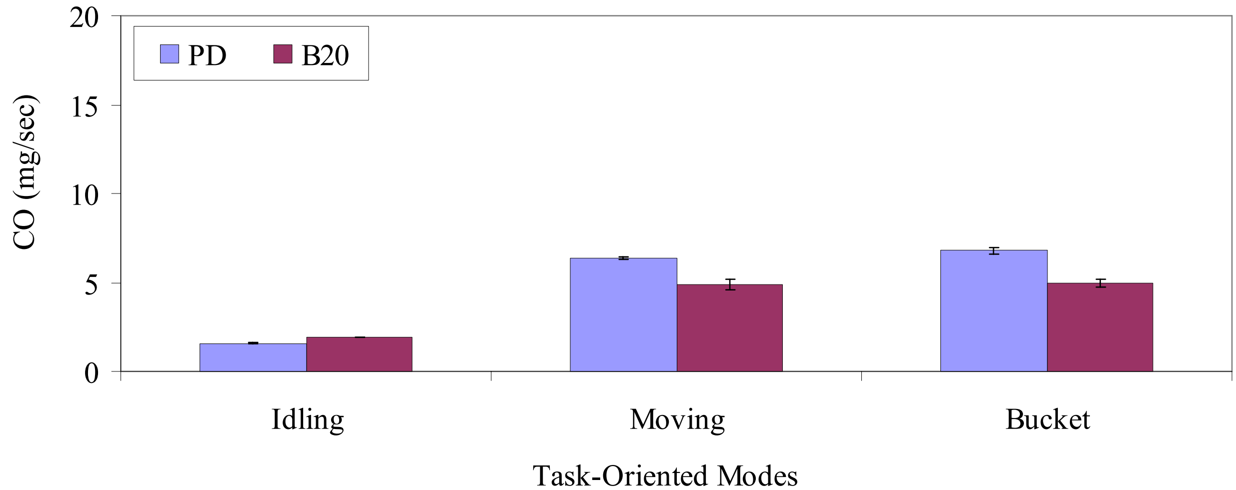


Figure F35. Continued



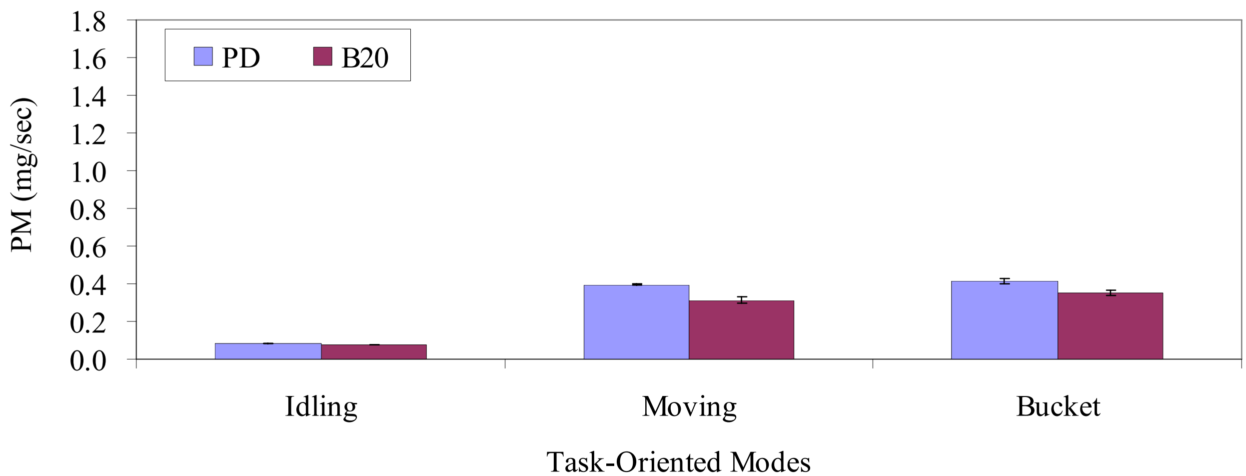
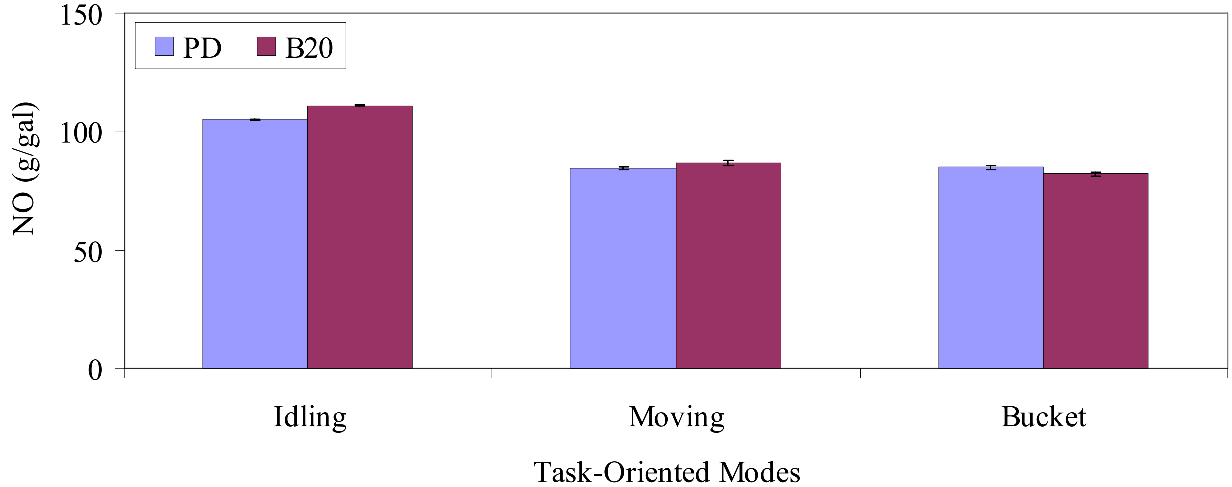
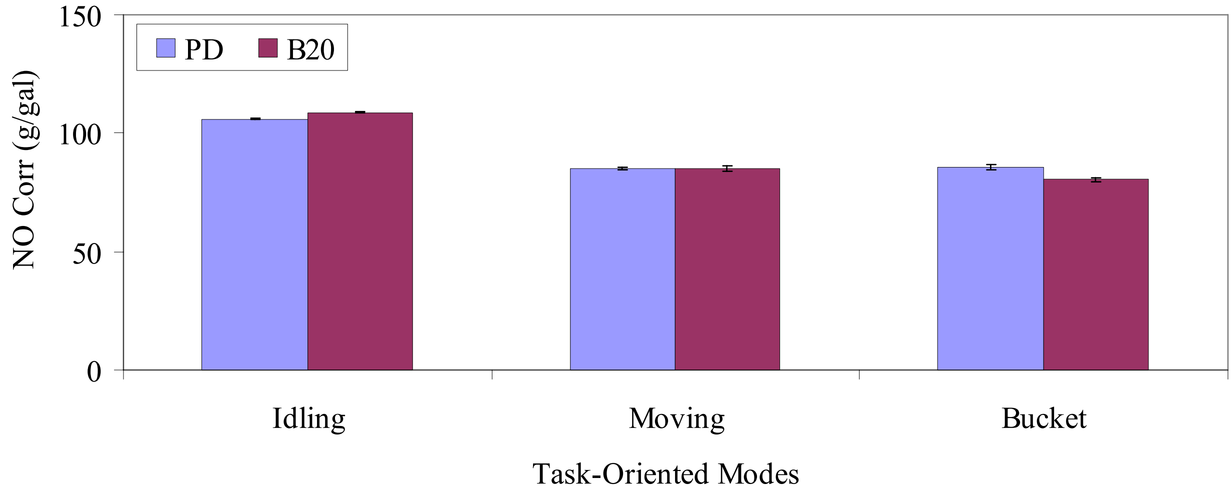


Figure F35. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 50 ^{o}F and the relative humidity was 40 %. For the B20 biodiesel test, the ambient temperature was 49 ^{o}F and the relative humidity was 74 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the front-end loader when the bucket is not in contact with the ground (forward or backward); *bucket*: movement of the front-end loader when the bucket is in contact with the ground.

Figure F36. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Front-End Loader 4 (continued on next page)

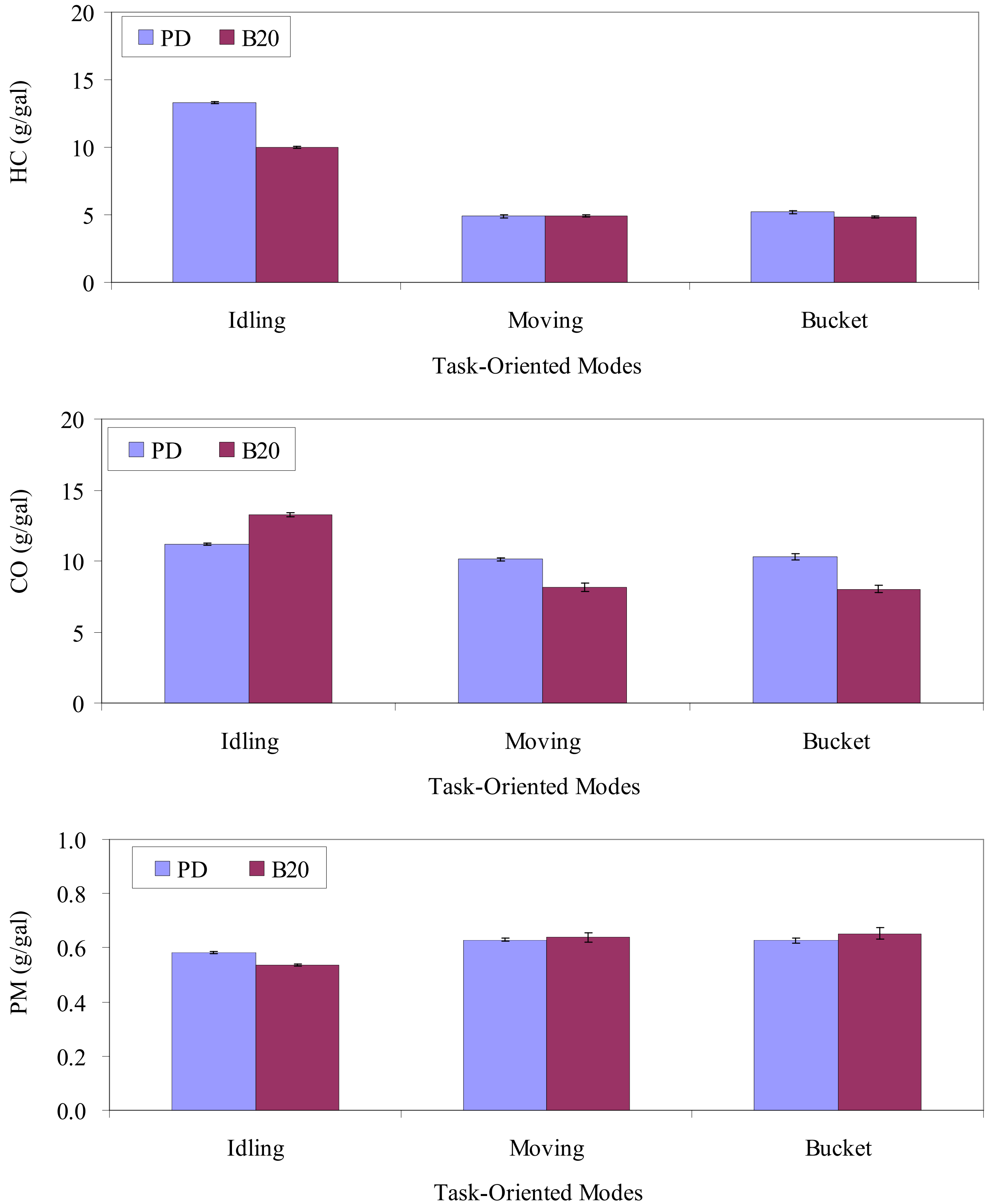
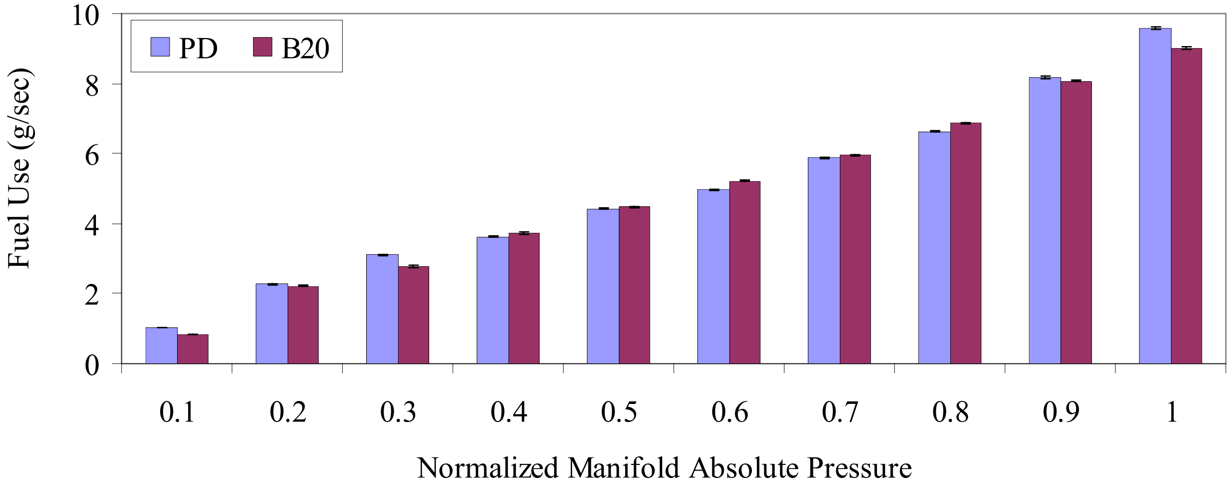
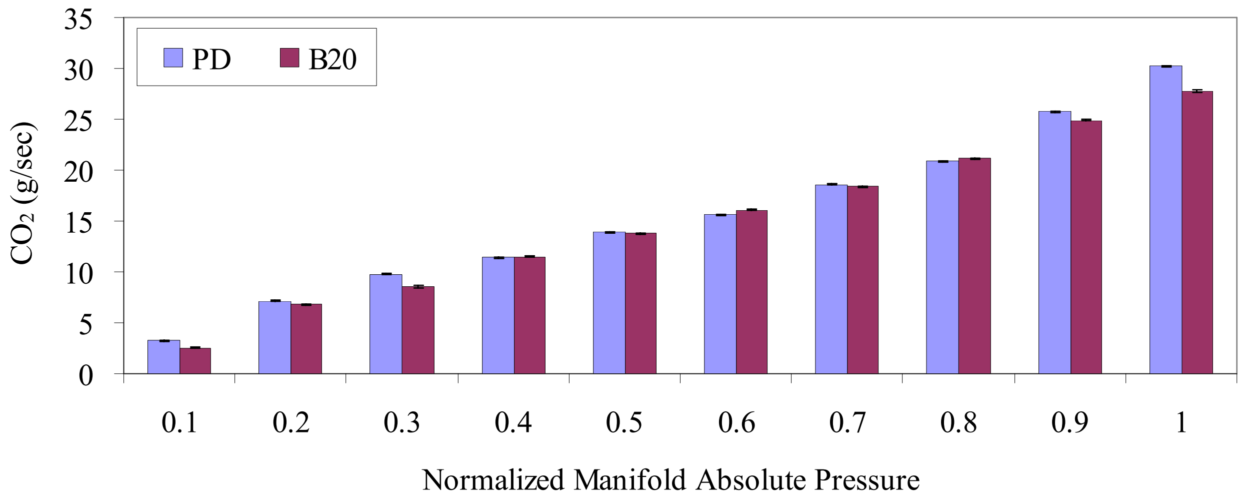


Figure F36. Continued

MOTOR GRADER 1

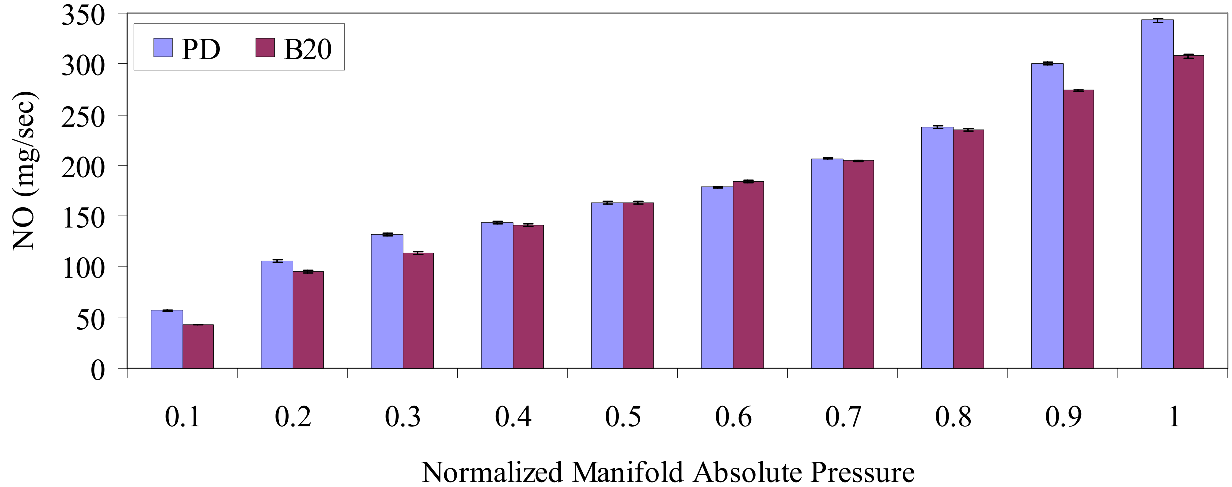


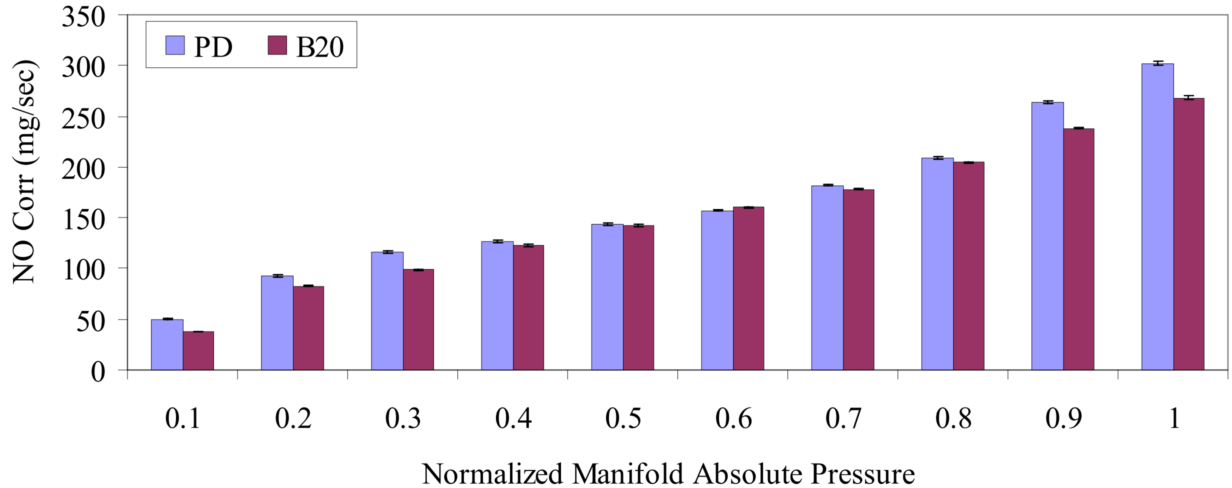


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 48 ^oF and the relative humidity was 43 %. For the B20 biodiesel test, the ambient temperature was 48 ^oF and the relative humidity was 38 %.

Values shown in the figure are the upper end of the range: “0.1” = 0 ≤ Normalized MAP < 0.1; “0.2” = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F37. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Motor Grader 1 (continued on next page)





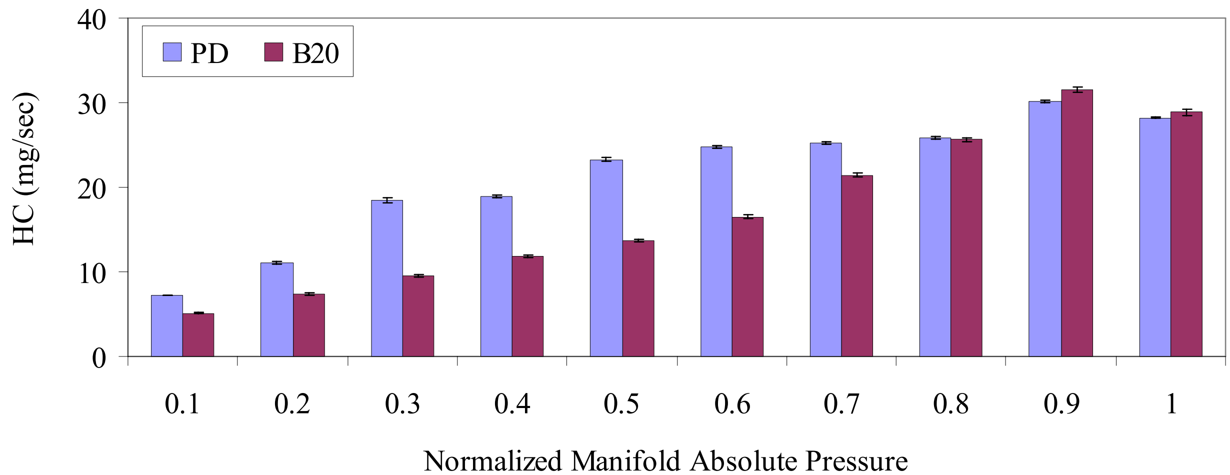
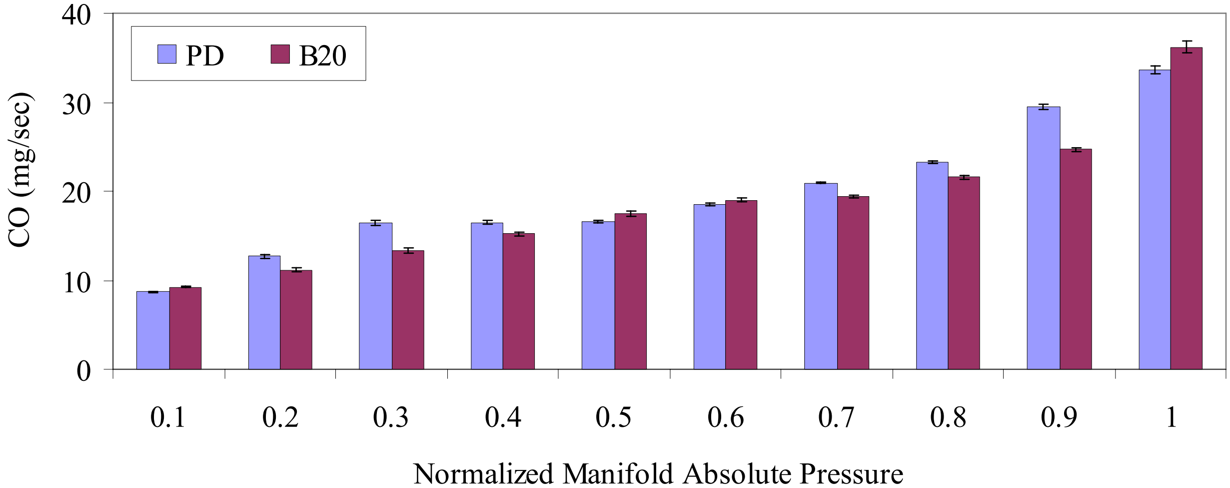


Figure F37. Continued



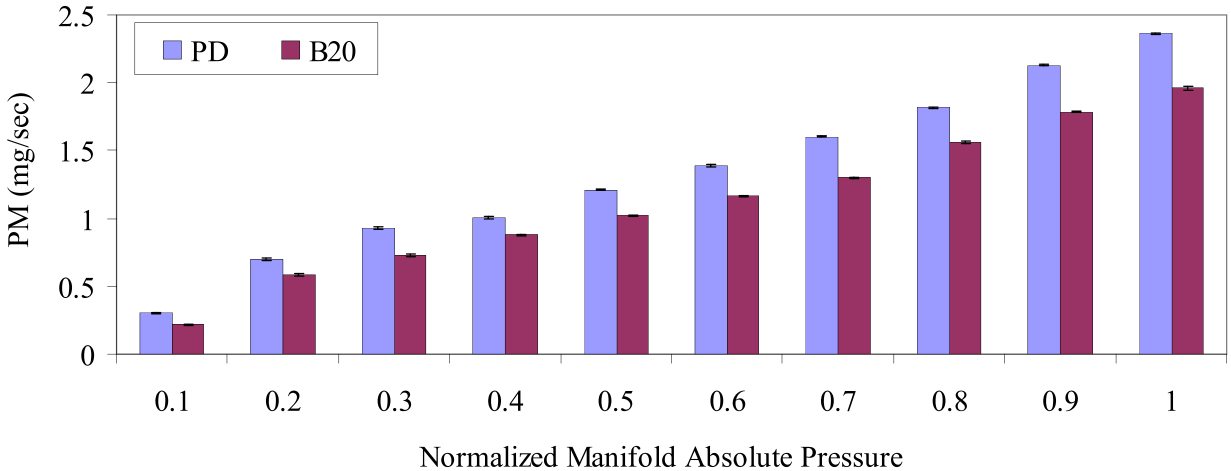
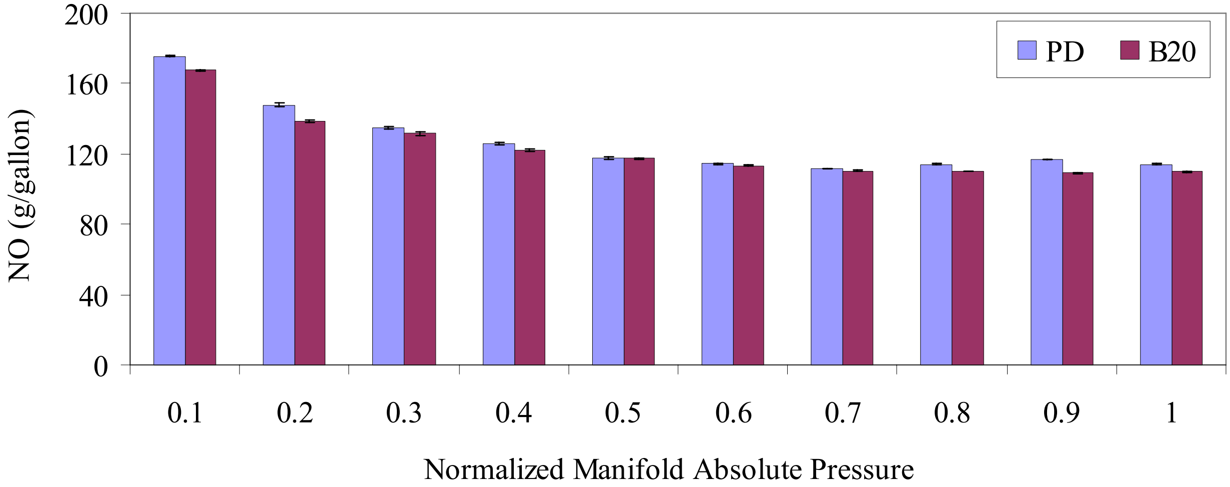
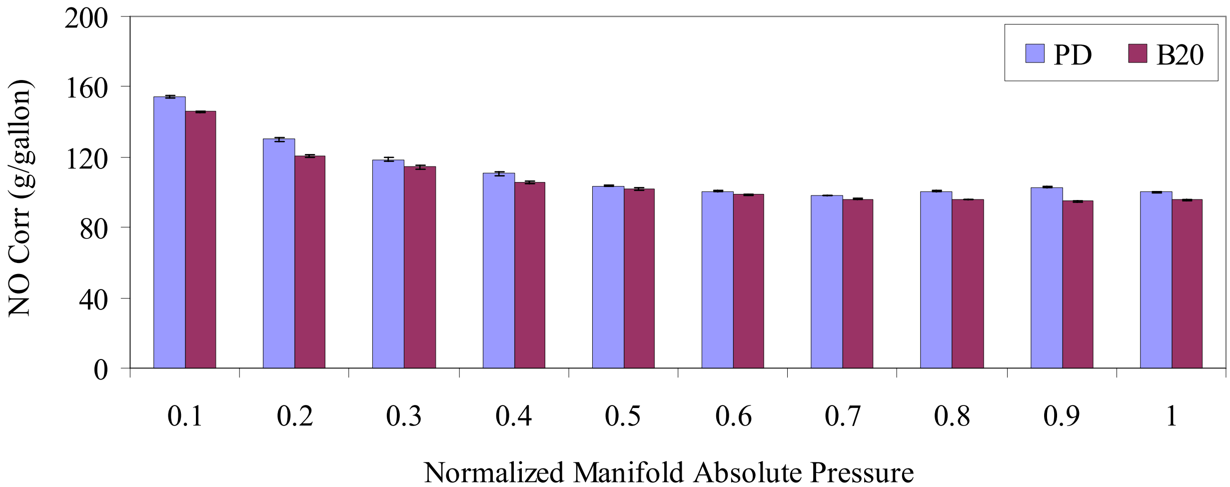


Figure F37. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 48 ^oF and the relative humidity was 43 %. For the B20 biodiesel test, the ambient temperature was 48 ^oF and the relative humidity was 38 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F38. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Motor Grader 1 (continued on next page)

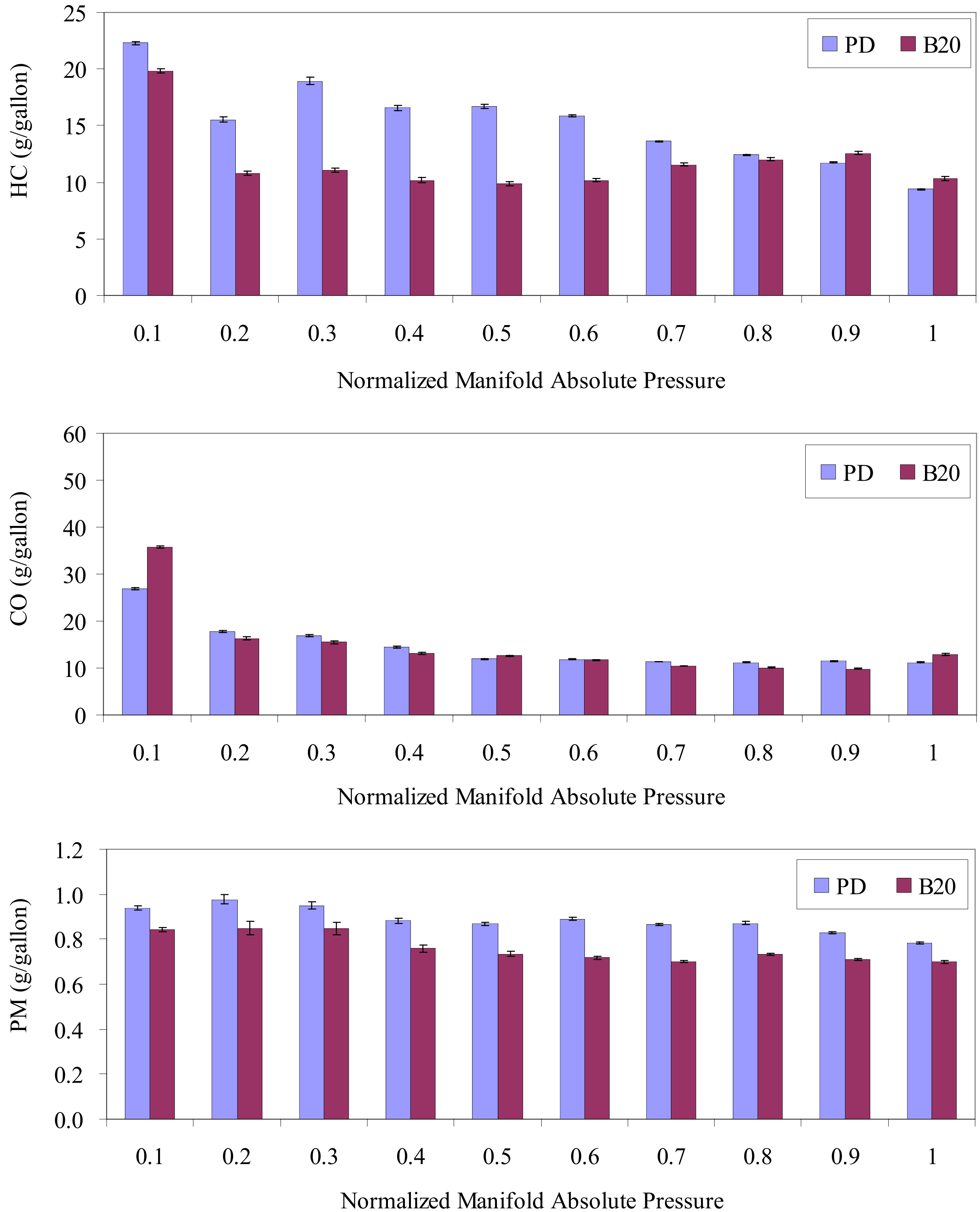
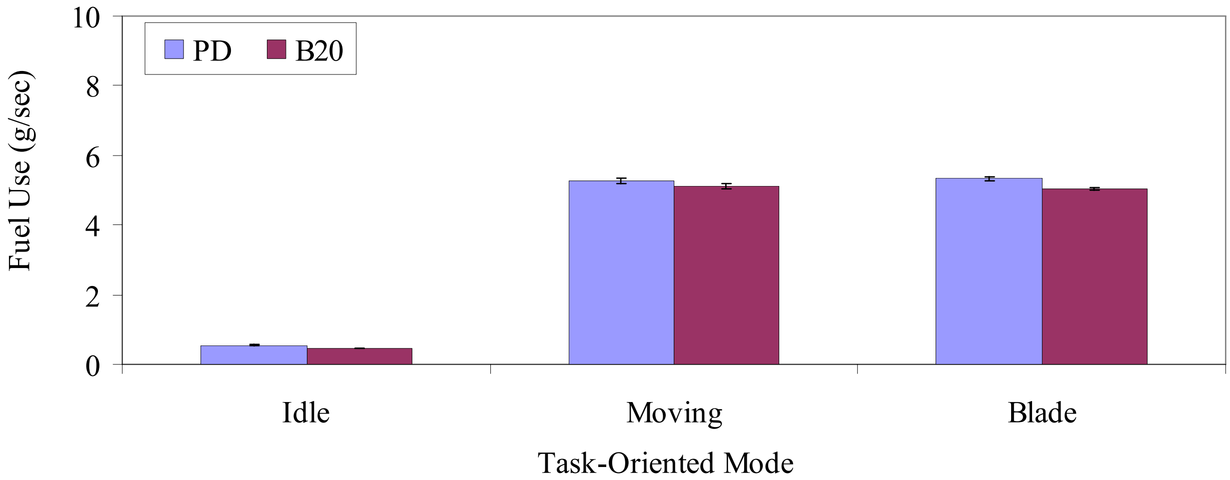
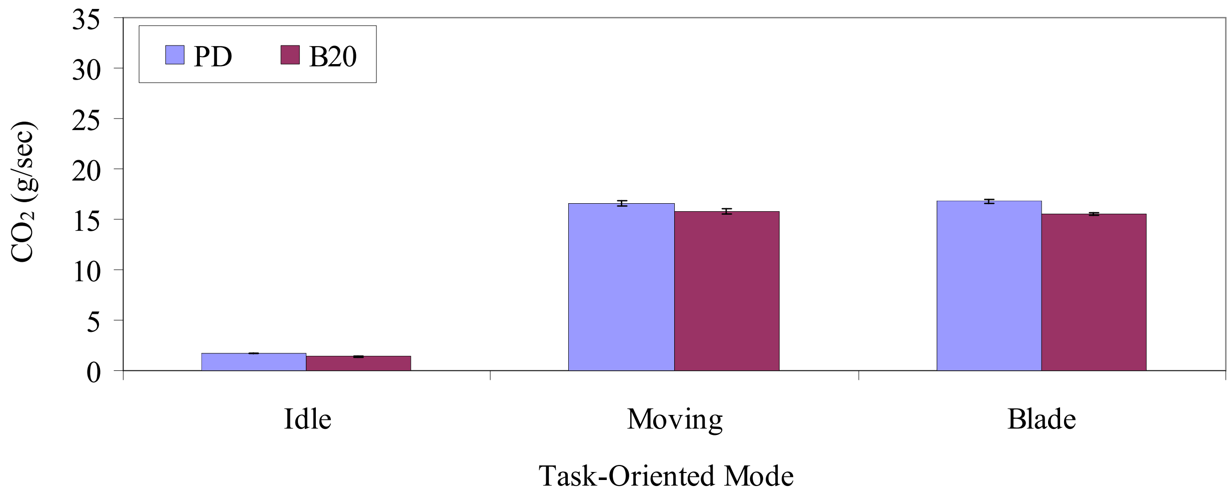


Figure F38. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 48 ^oF and the relative humidity was 43 %. For the B20 biodiesel test, the ambient temperature was 48 ^oF and the relative humidity was 38 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F39. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Motor Grader 1 (continued on next page)

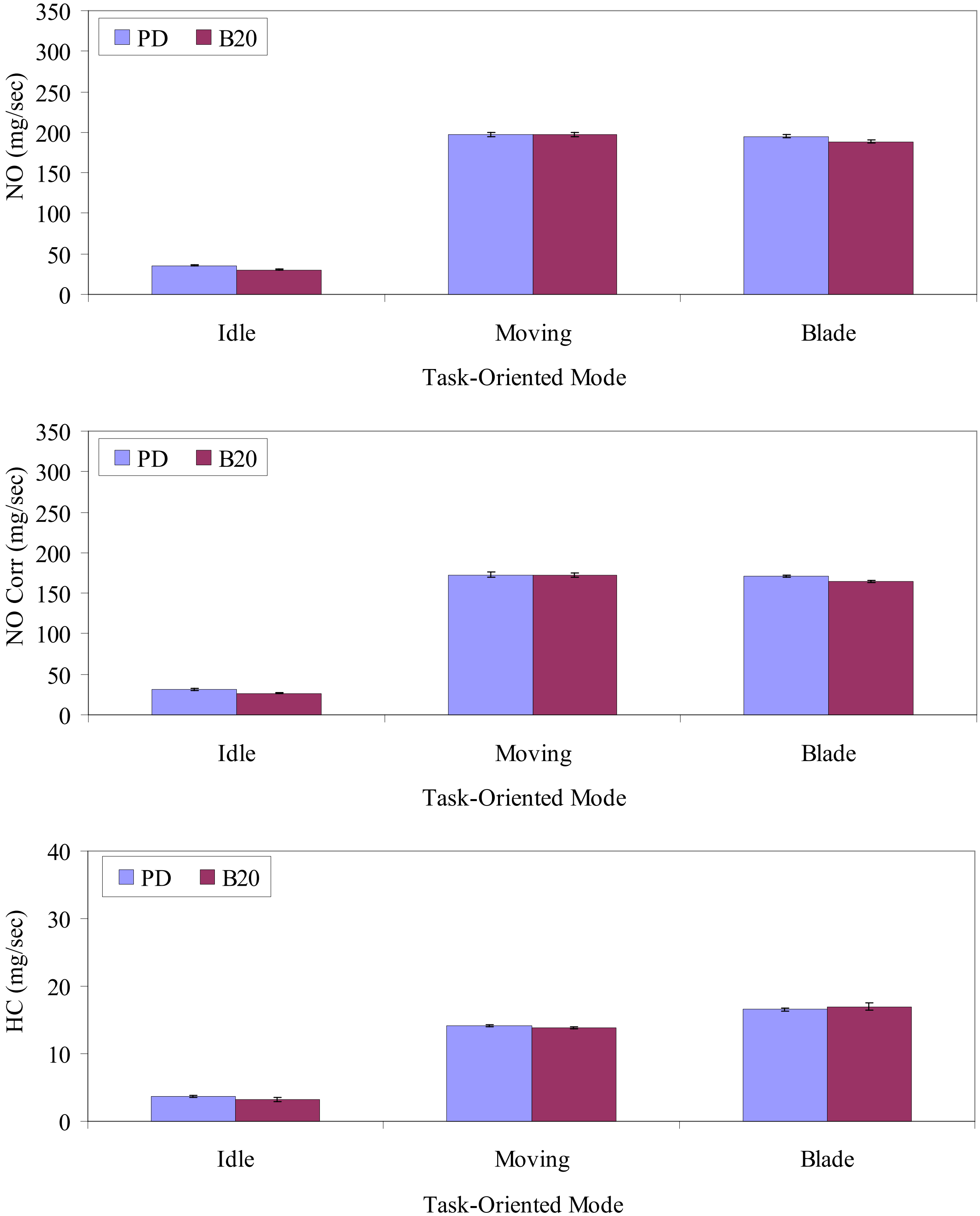
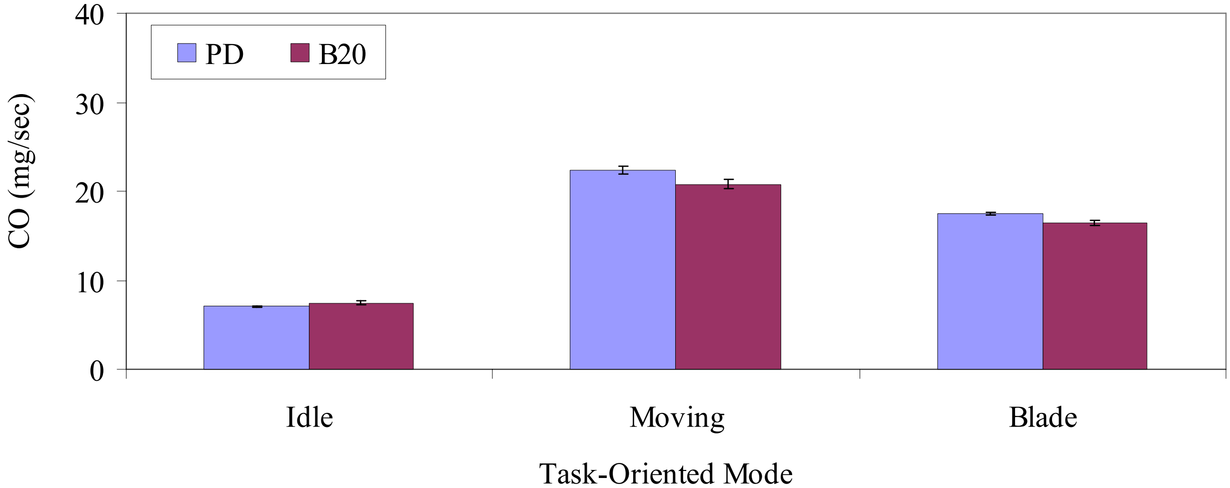


Figure F39. Continued



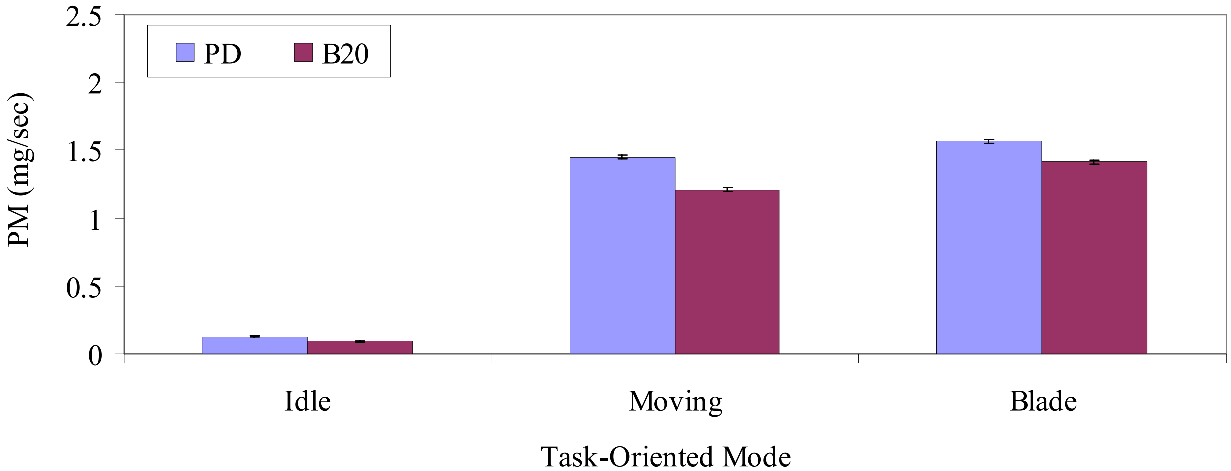
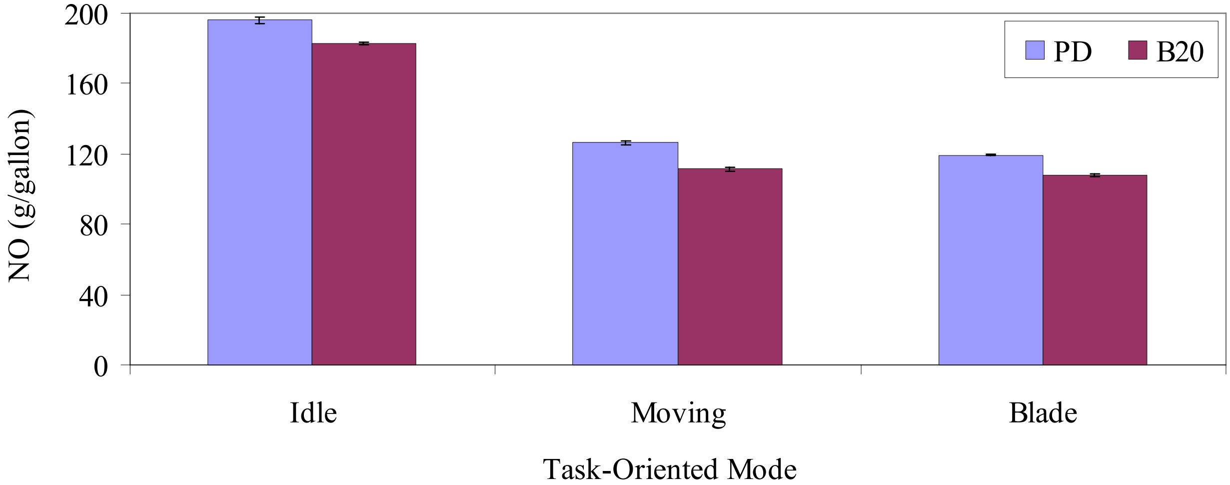
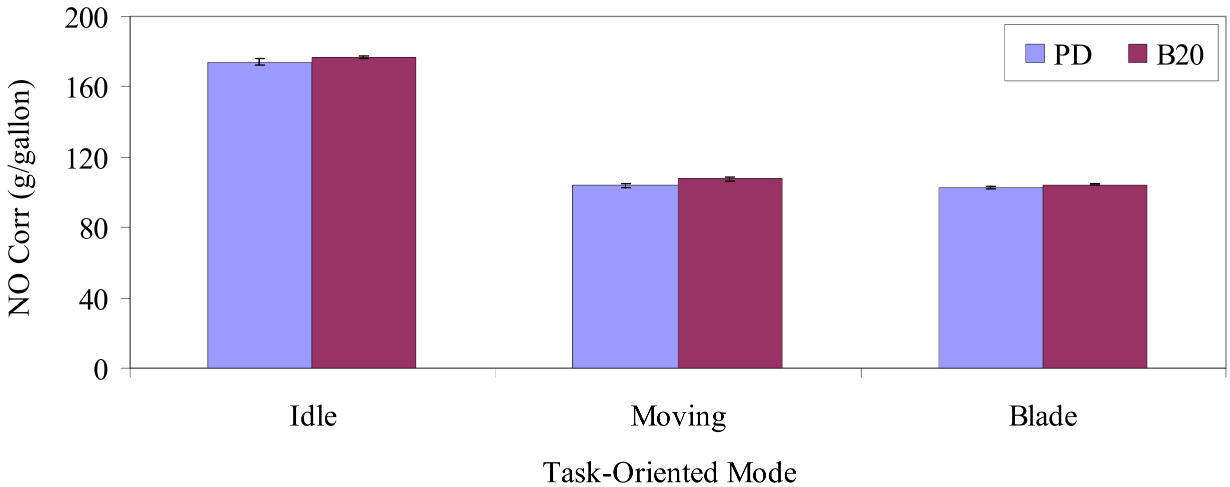


Figure F39. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 48 ^{o}F and the relative humidity was 43 %. For the B20 biodiesel test, the ambient temperature was 48 ^{o}F and the relative humidity was 38 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F40. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Motor Grader 1 (continued on next page)

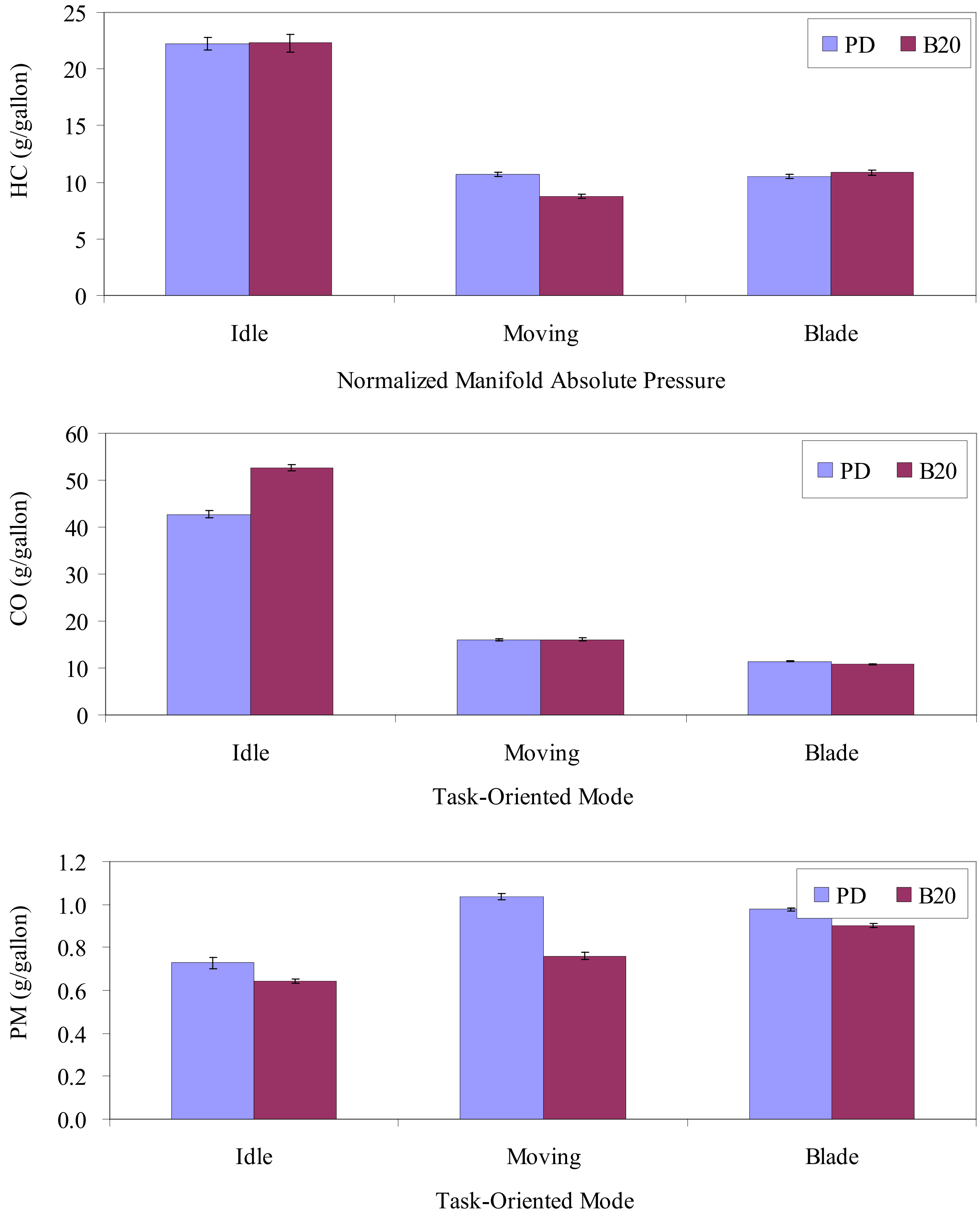
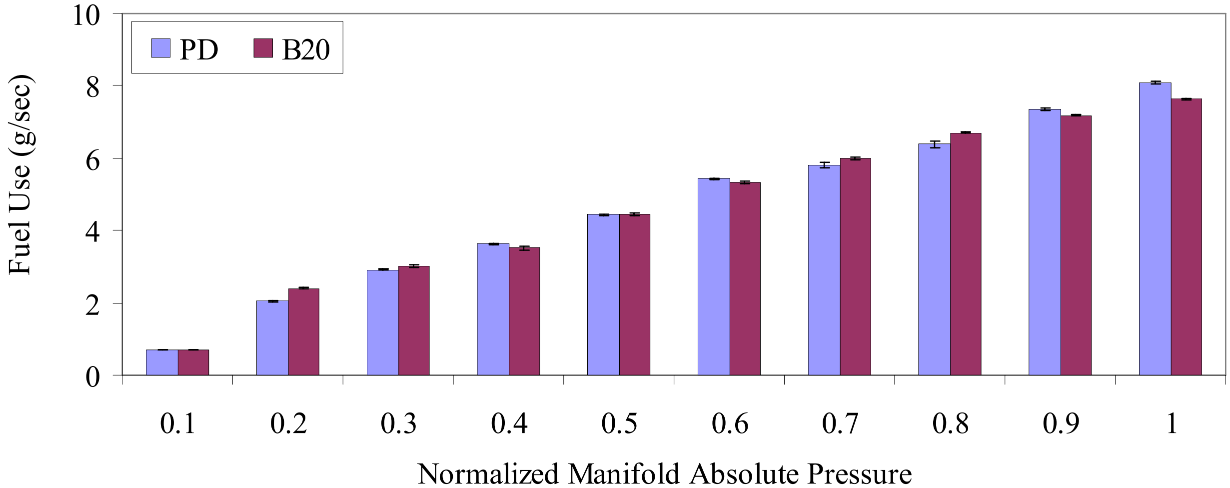
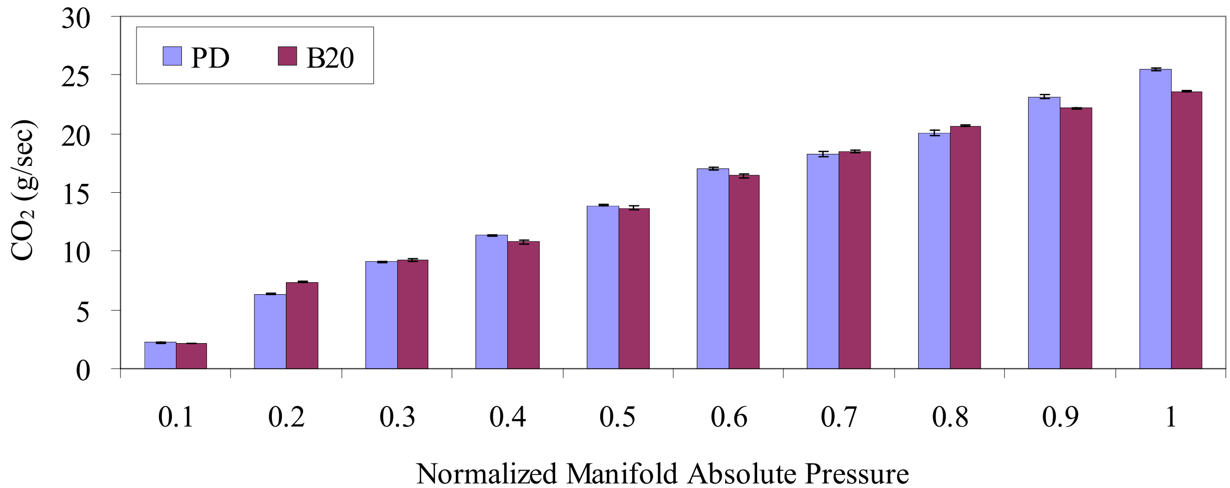


Figure F40. Continued

MOTOR GRADER 2

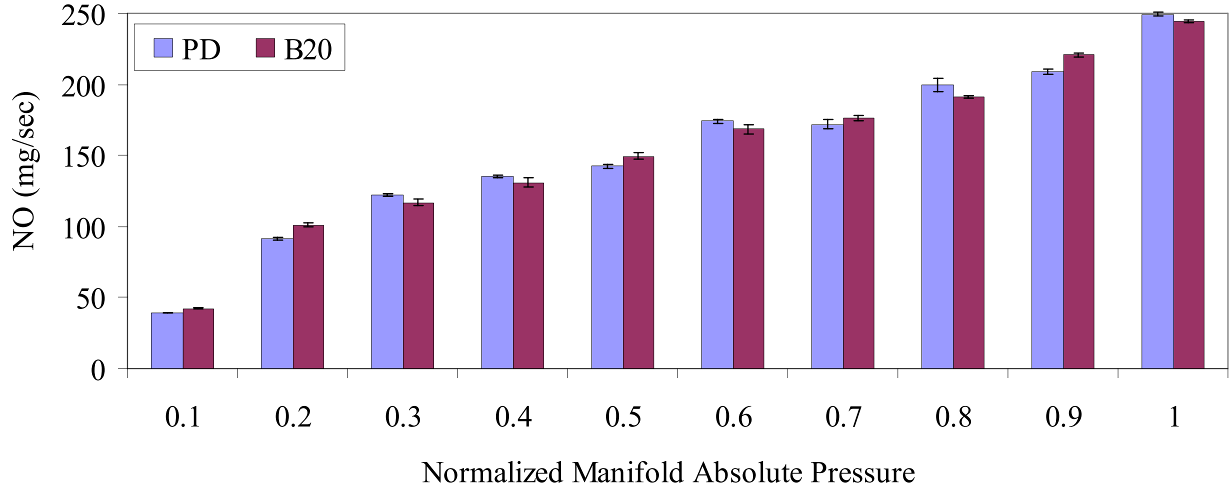


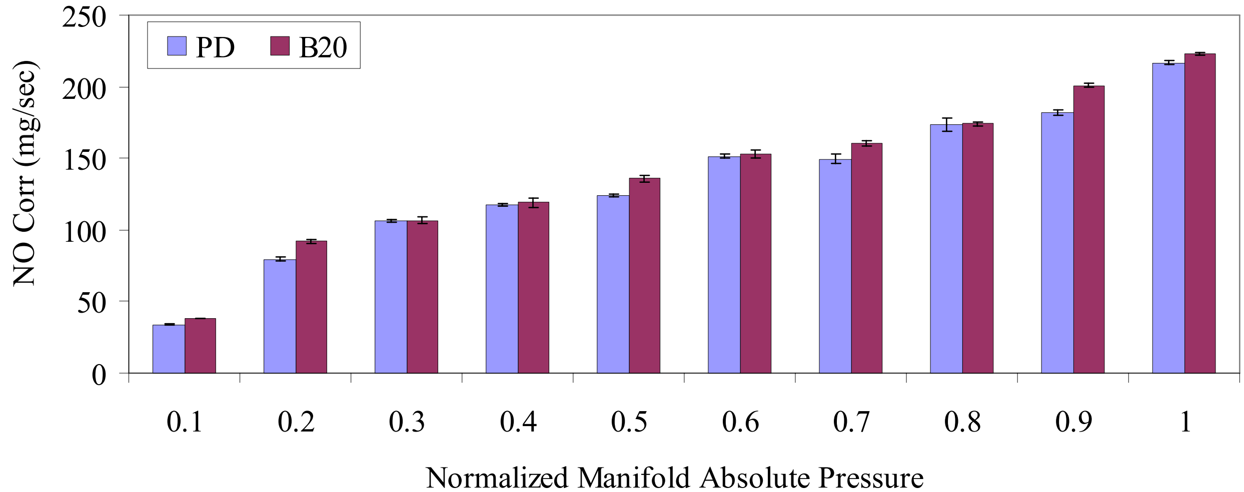


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 47 ^oF and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 64 ^oF and the relative humidity was 44 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F41. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Motor Grader 2 (continued on next page)





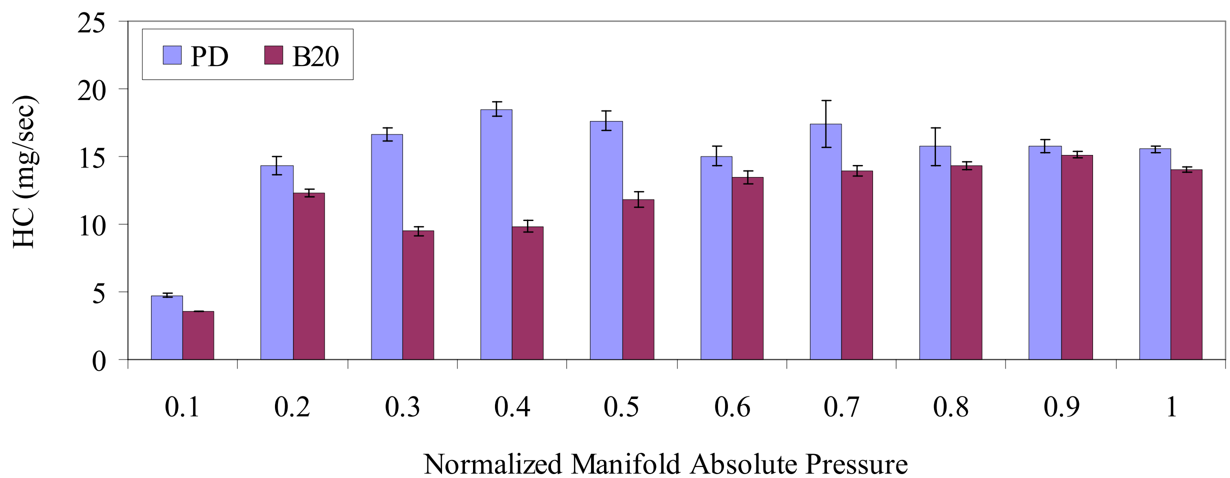


Figure F41. Continued

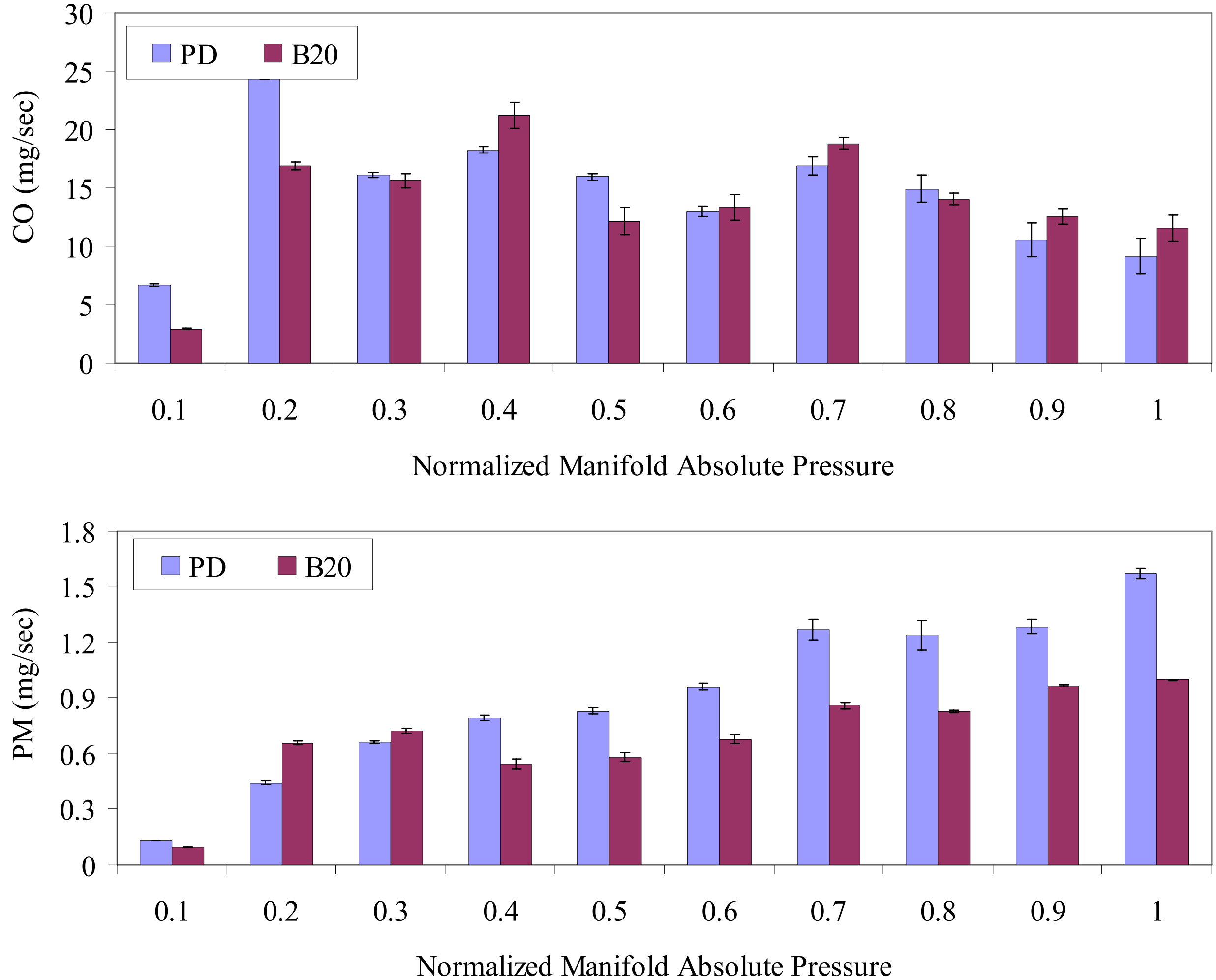
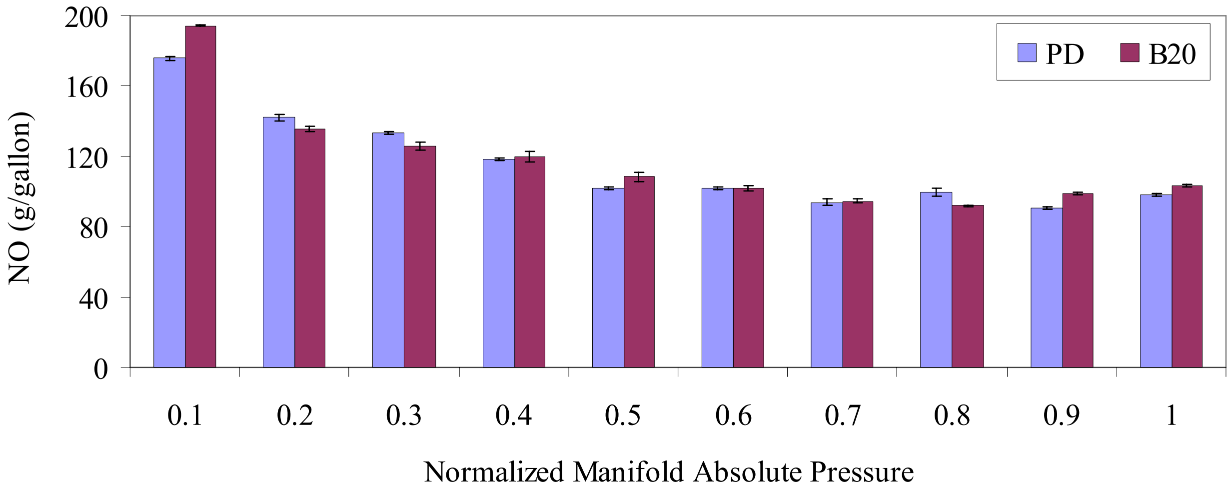
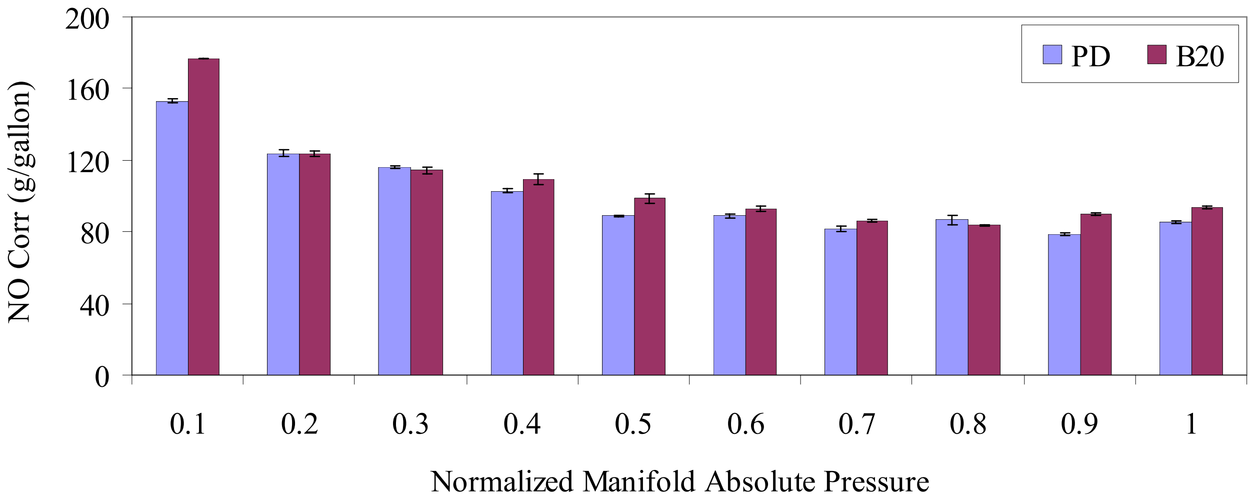


Figure F41. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 47 ^oF and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 64 ^oF and the relative humidity was 44 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F42. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Motor Grader 2 (continued on next page)

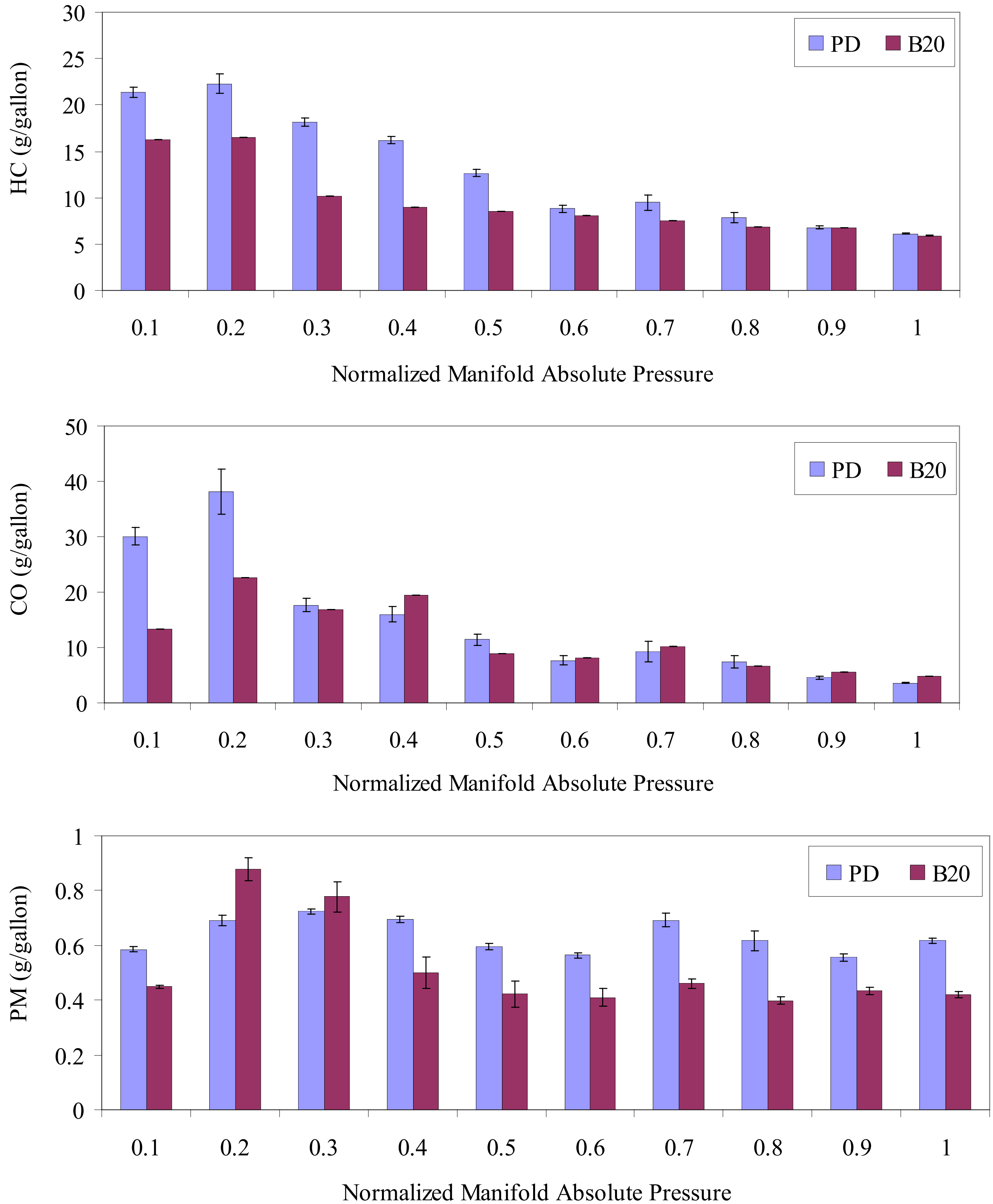
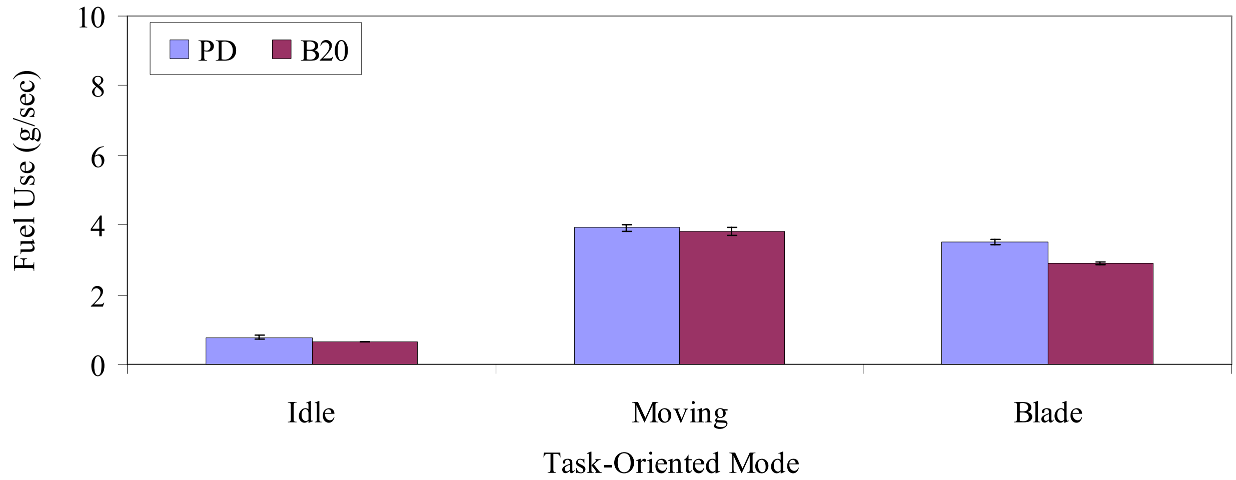
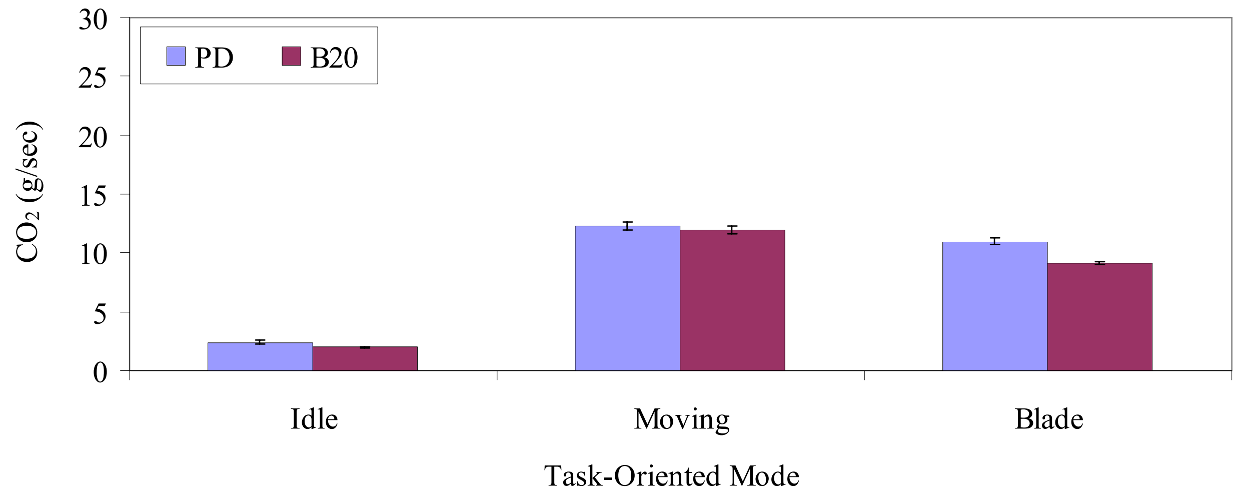


Figure F42. Continued

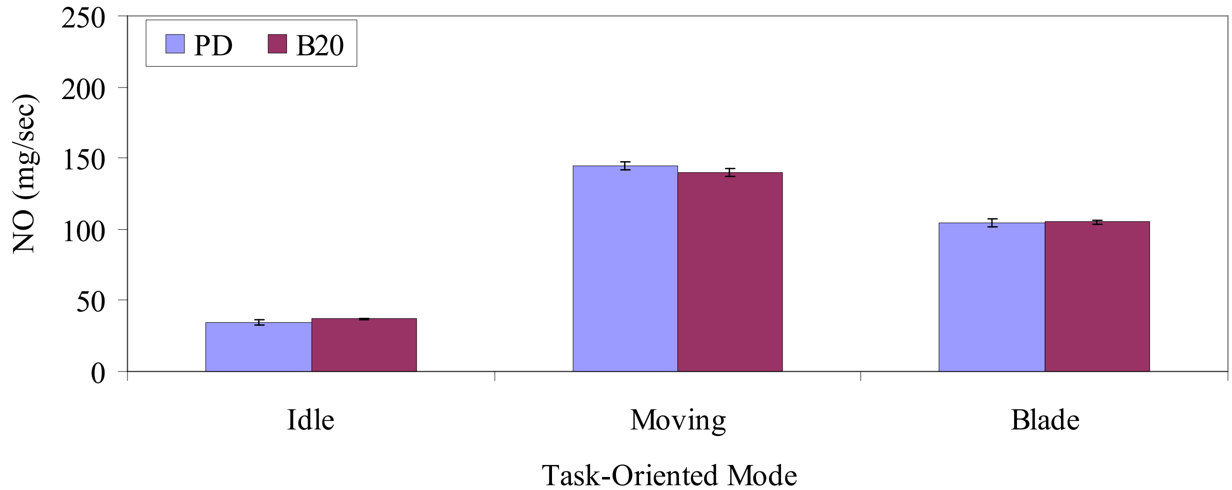


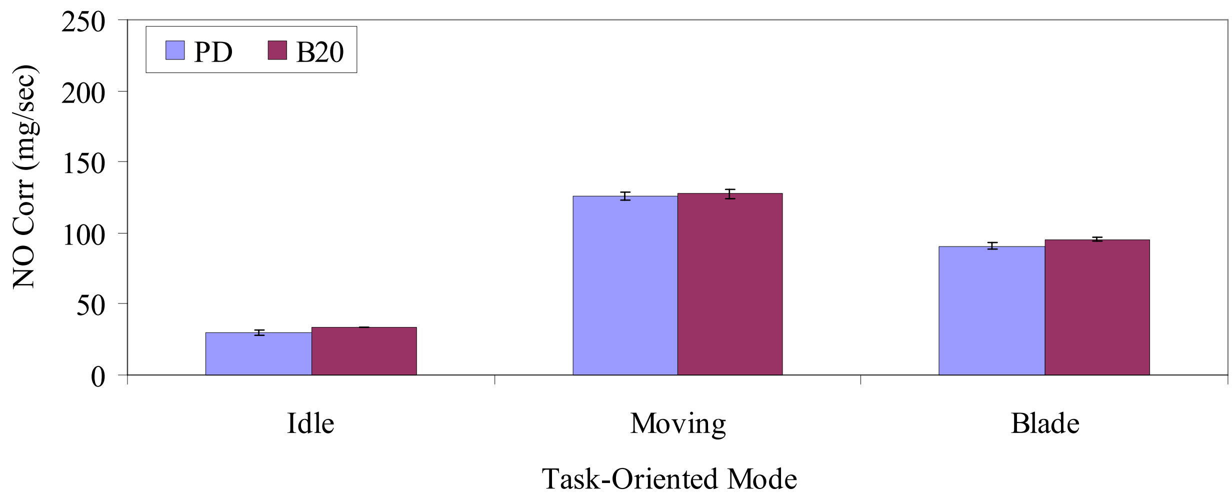


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 47 ^{o}F and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 64 ^{o}F and the relative humidity was 44 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F43. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Motor Grader 2 (continued on next page)





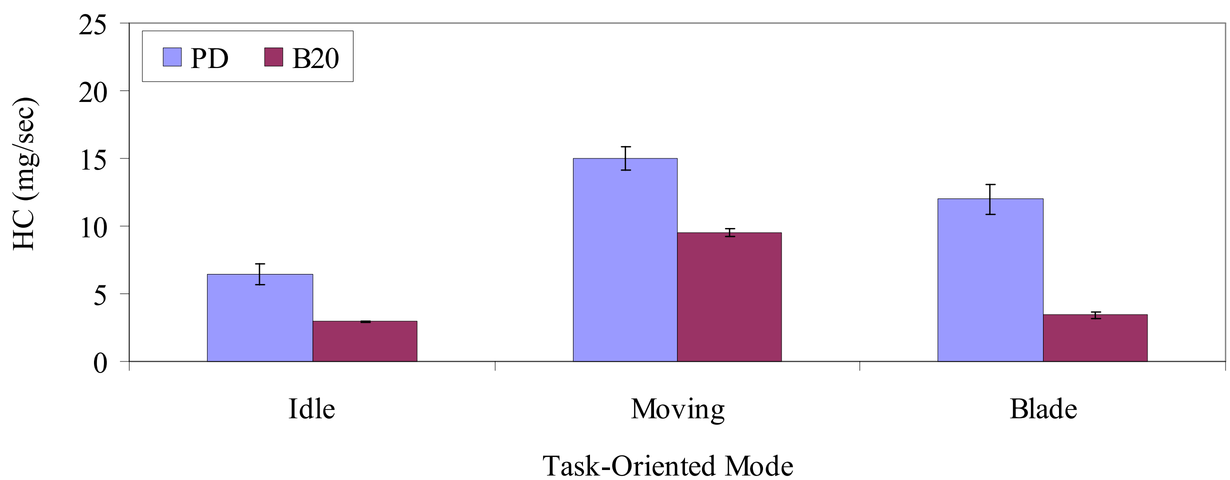
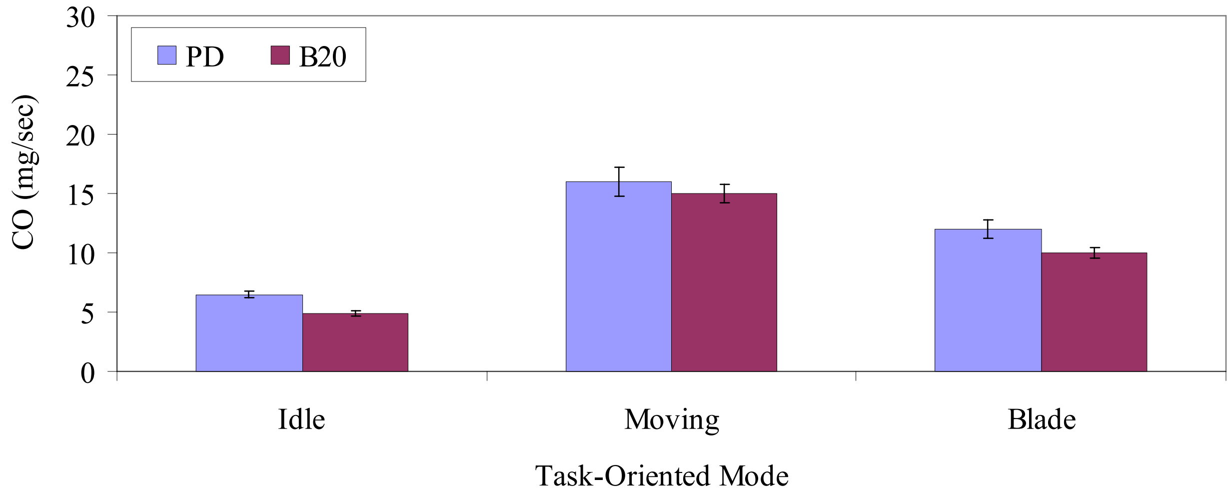


Figure F43. Continued



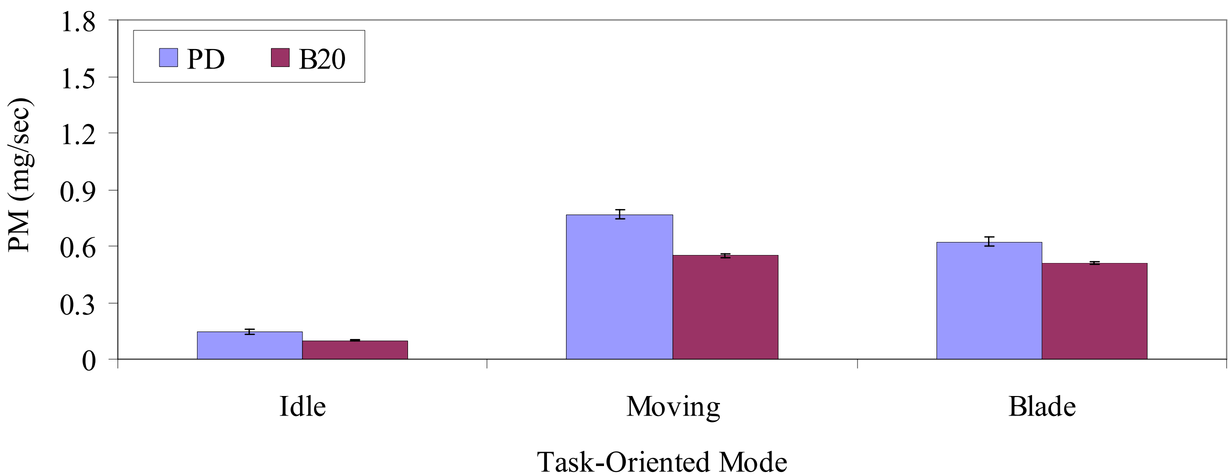
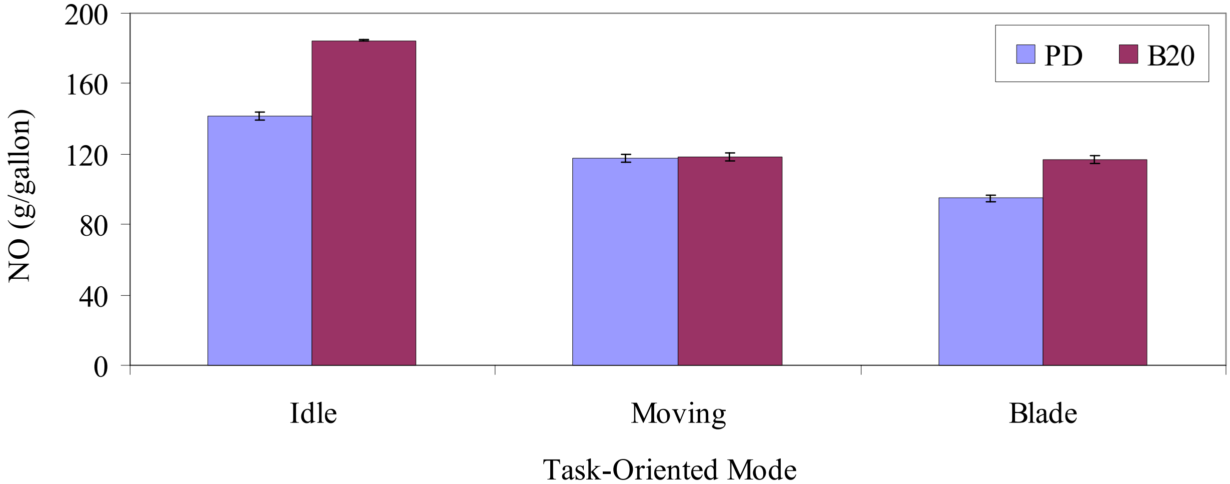
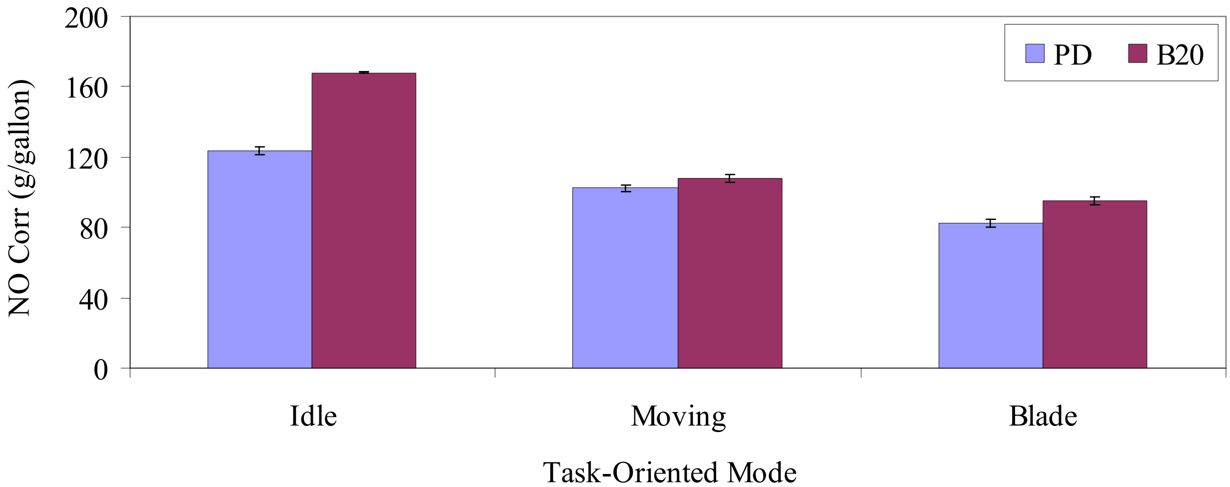


Figure F43. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 47 ^{o}F and the relative humidity was 42 %. For the B20 biodiesel test, the ambient temperature was 64 ^{o}F and the relative humidity was 44 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F44. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Motor Grader 2 (continued on next page)

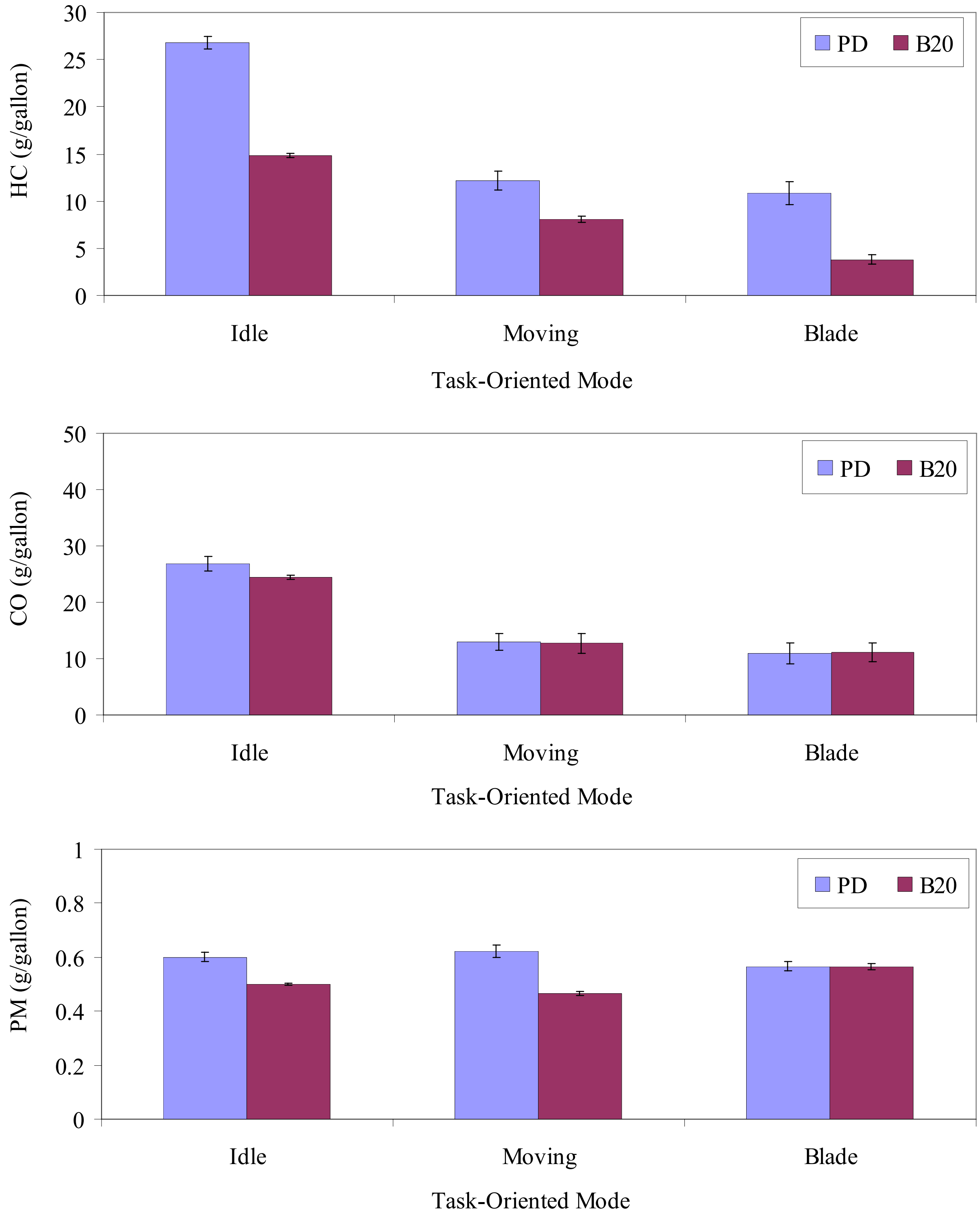
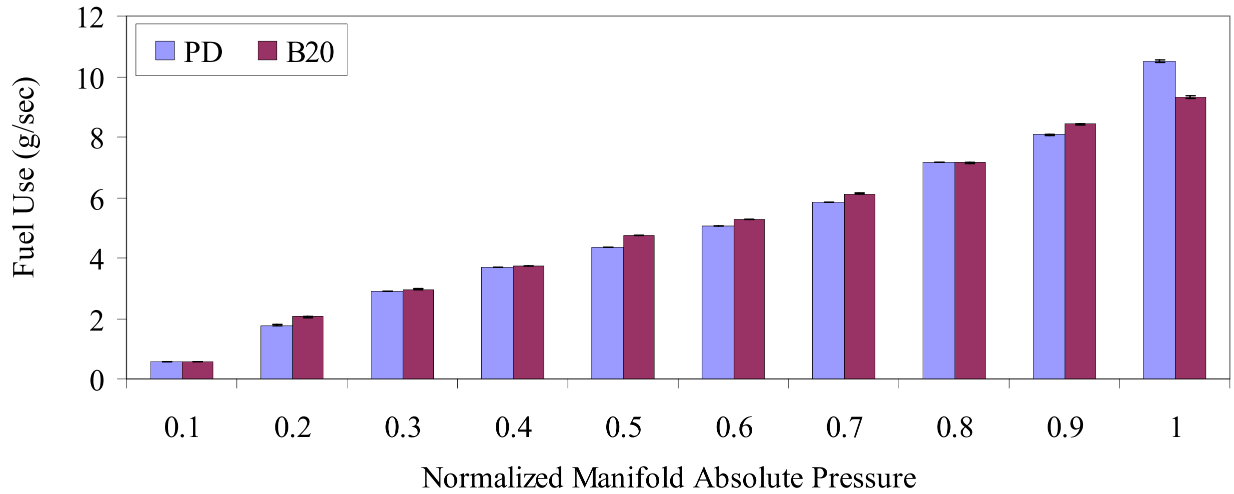
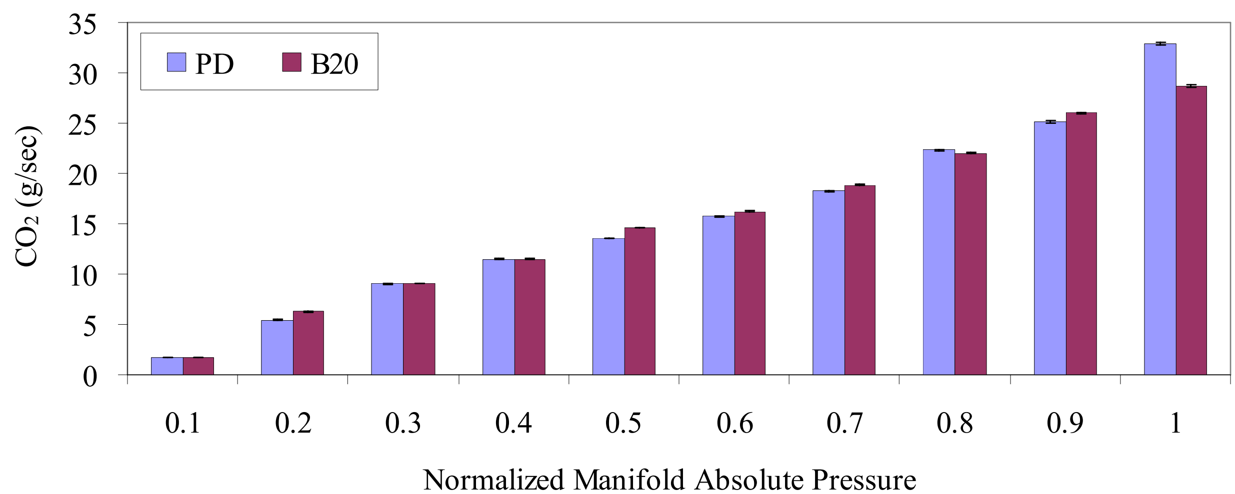


Figure F44. Continued

MOTOR GRADER 3

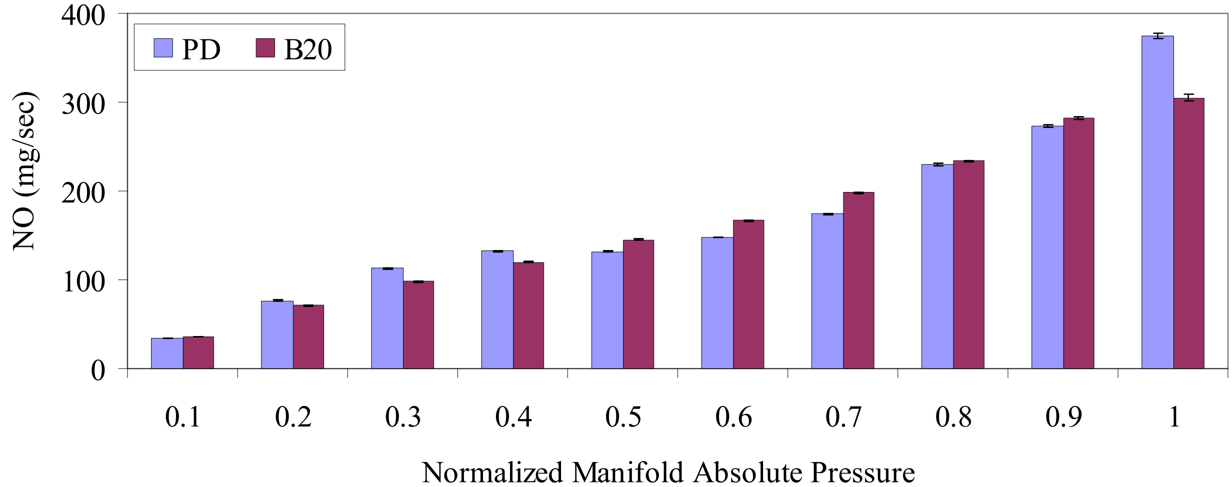


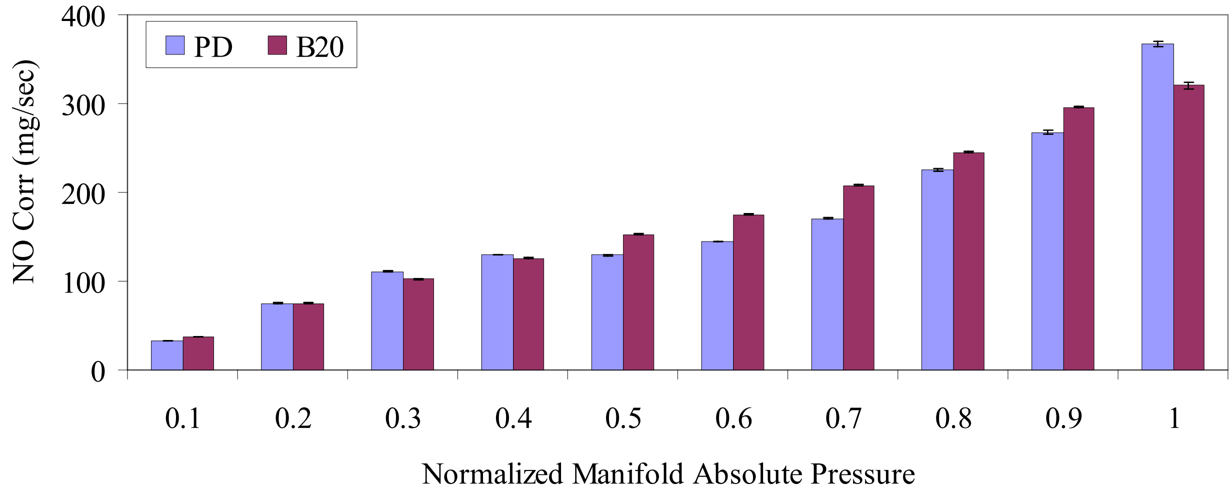


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 74 ^{o}F and the relative humidity was 54 %. For the B20 biodiesel test, the ambient temperature was 87 ^{o}F and the relative humidity was 63 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F45. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Motor Grader 3 (continued on next page)





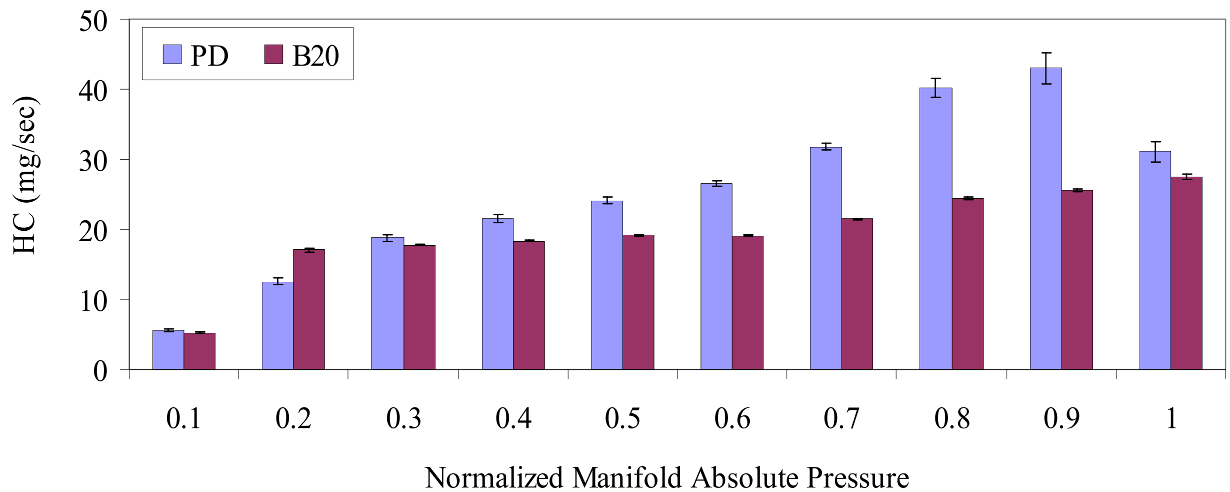
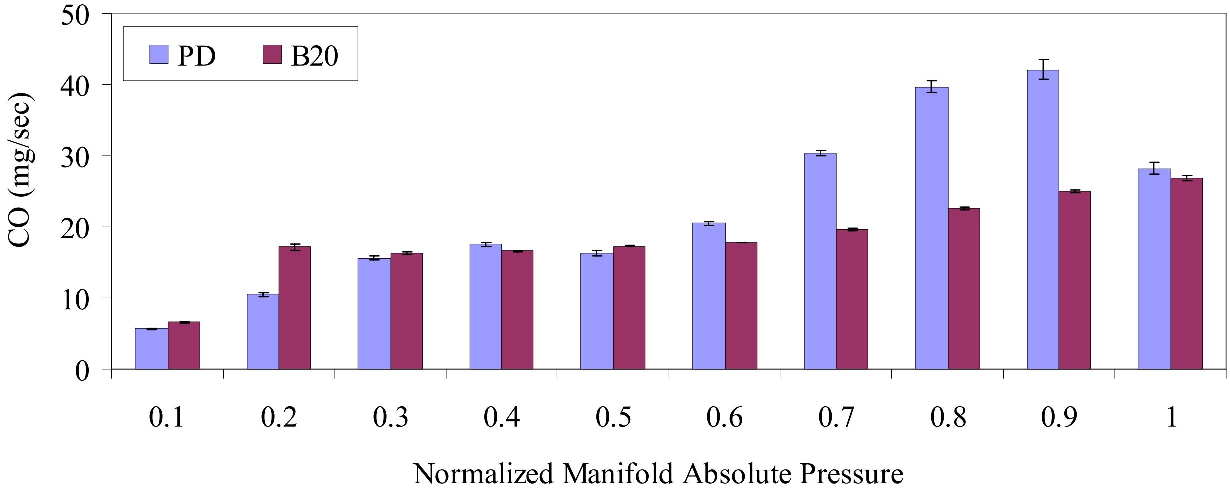


Figure F45. Continued



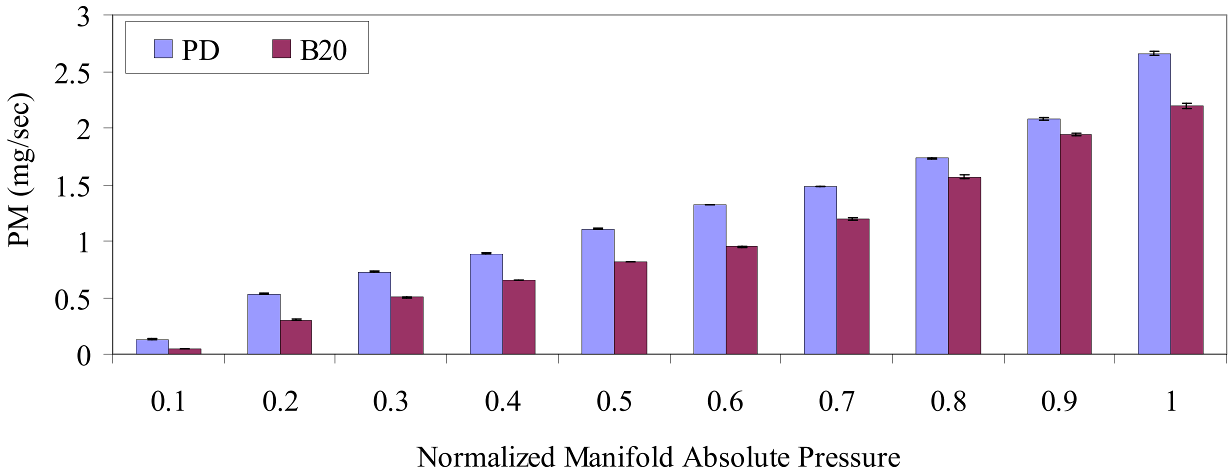
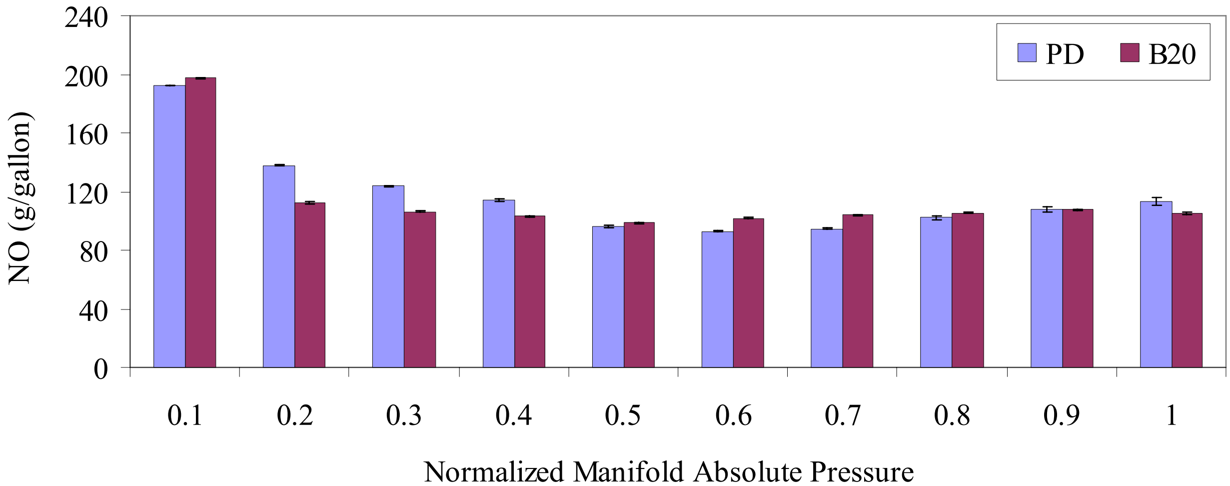
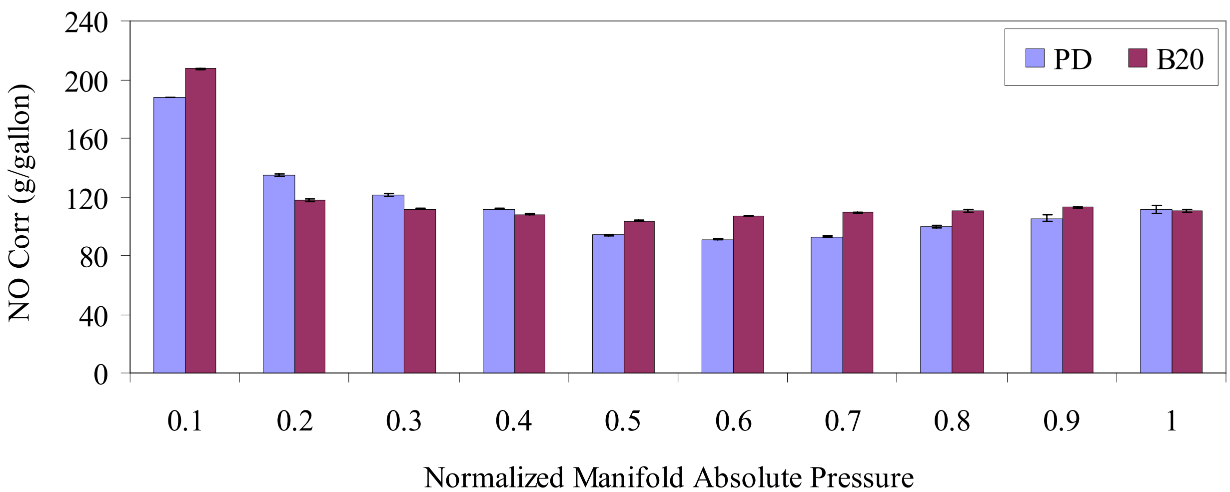


Figure F45. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 74 ^{o}F and the relative humidity was 54 %. For the B20 biodiesel test, the ambient temperature was 87 ^{o}F and the relative humidity was 63 %.

Values shown in the figure are the upper end of range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F46. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Motor Grader 3 (continued on next page)

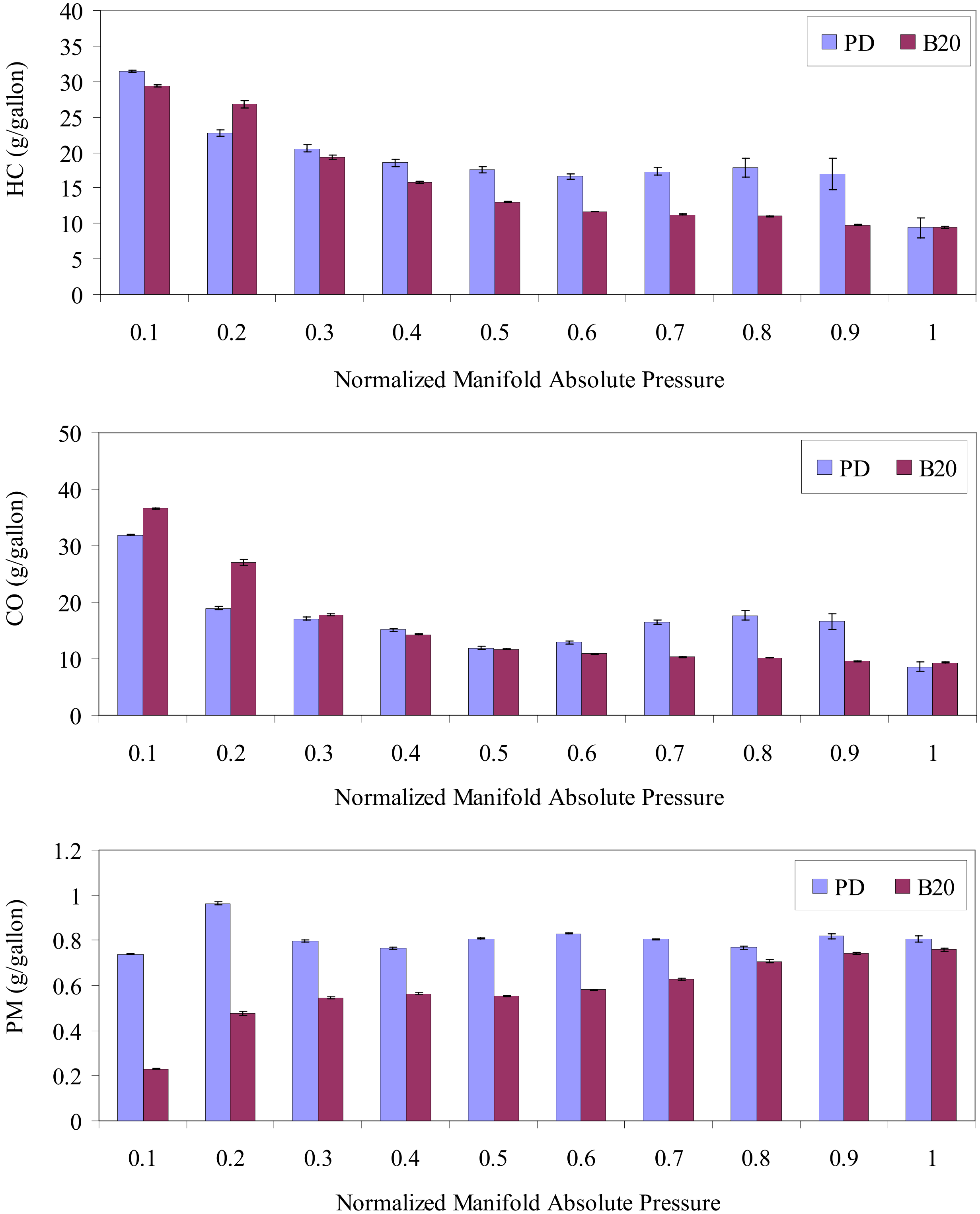
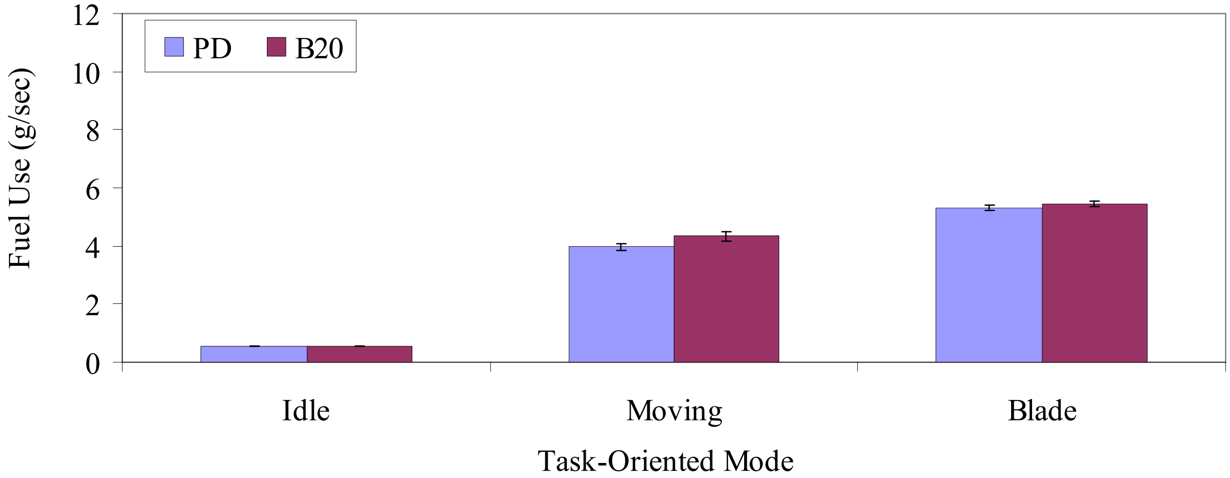
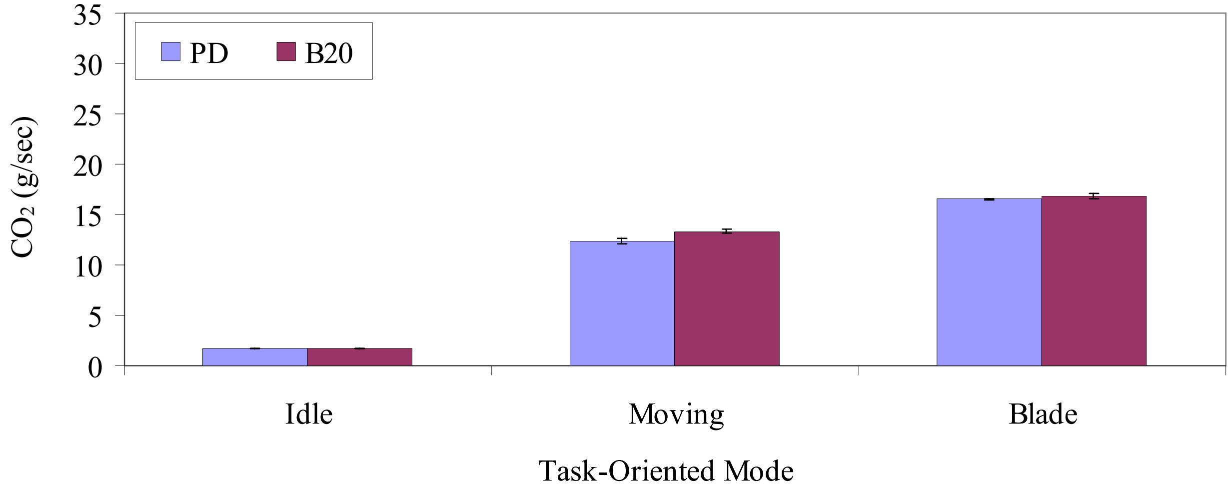


Figure F46. Continued

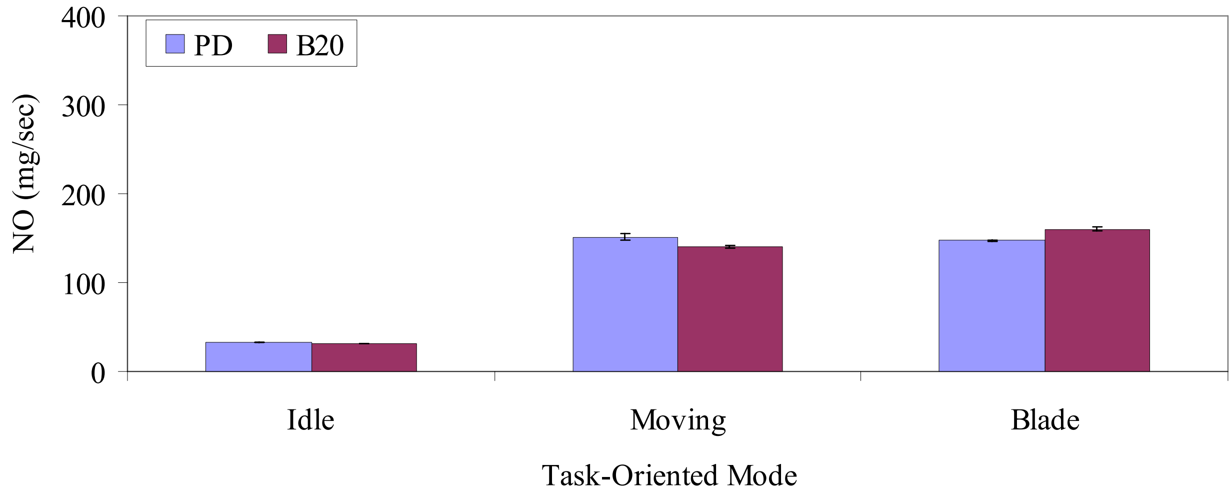


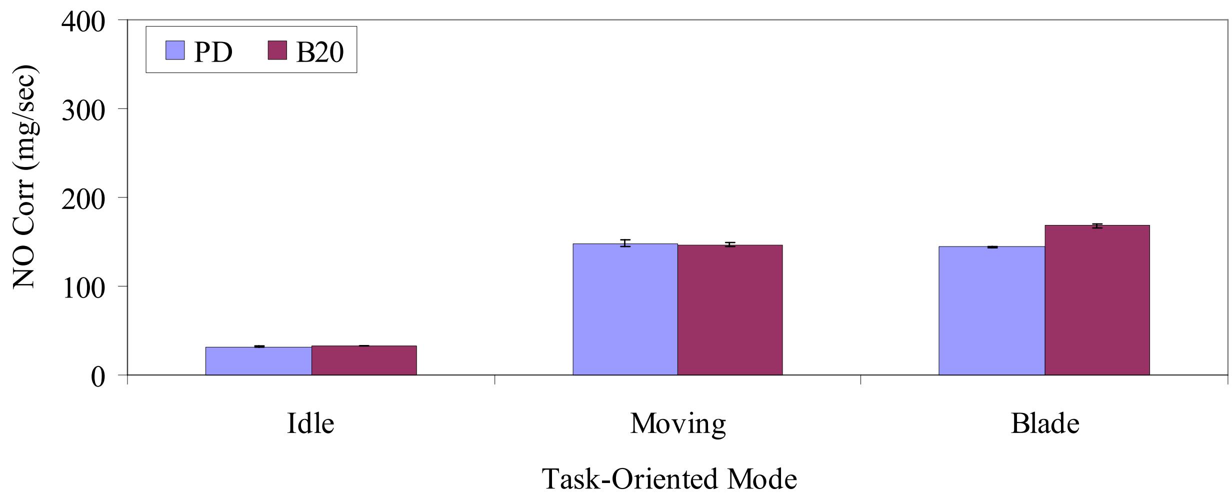


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 74 ^{o}F and the relative humidity was 54 %. For the B20 biodiesel test, the ambient temperature was 87 ^{o}F and the relative humidity was 63 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F47. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Motor Grader 3 (continued on next page)





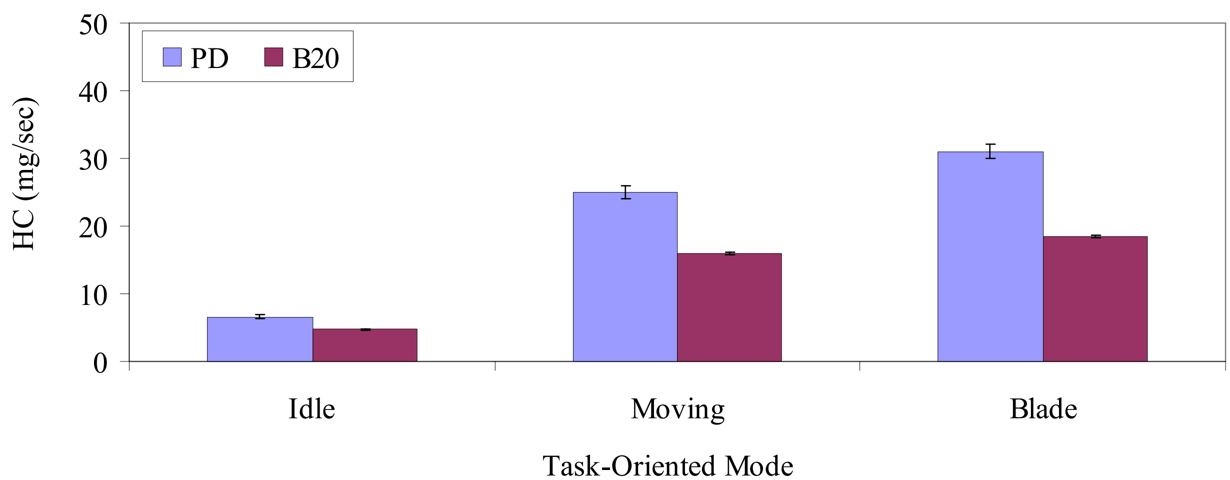


Figure F47. Continued

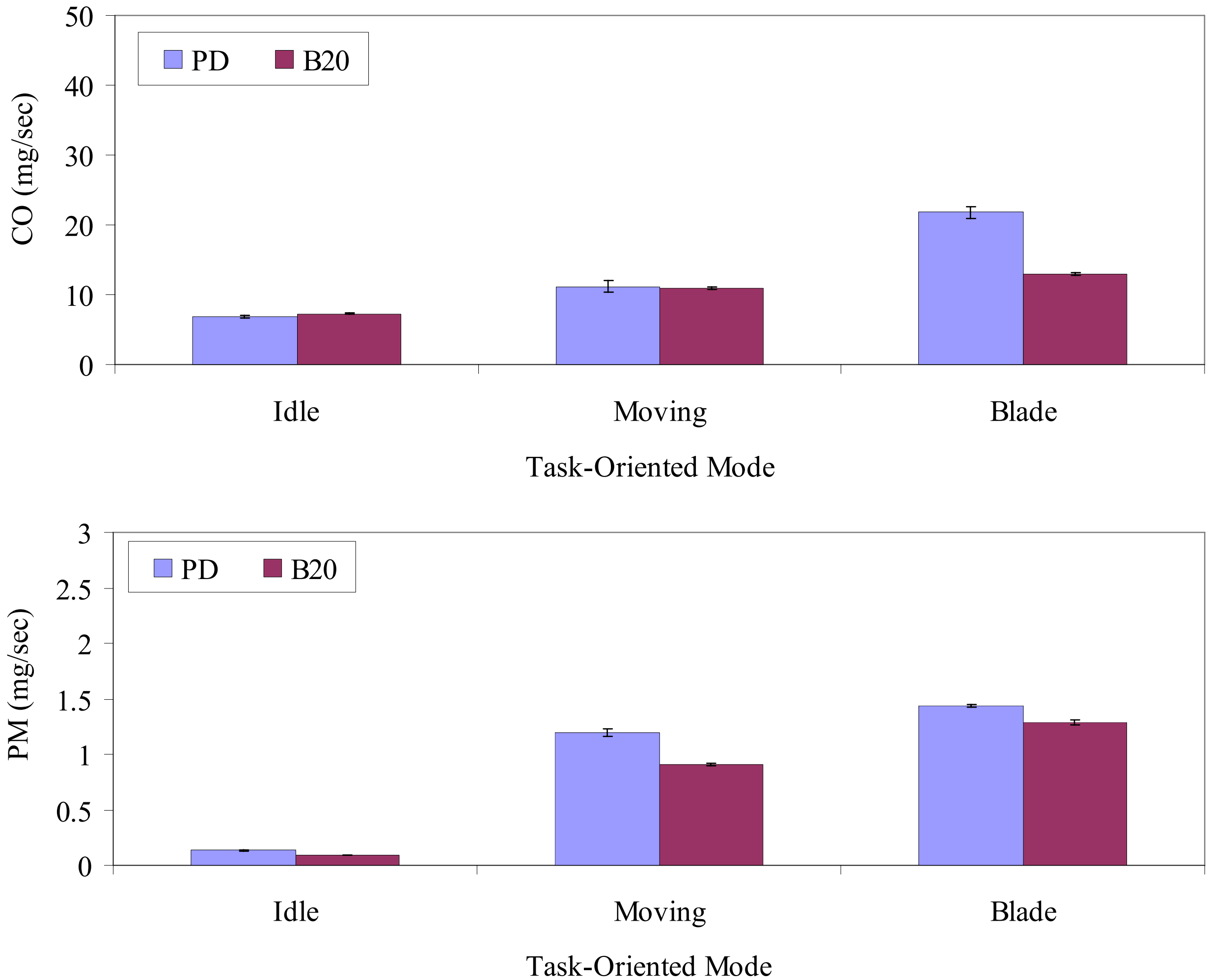
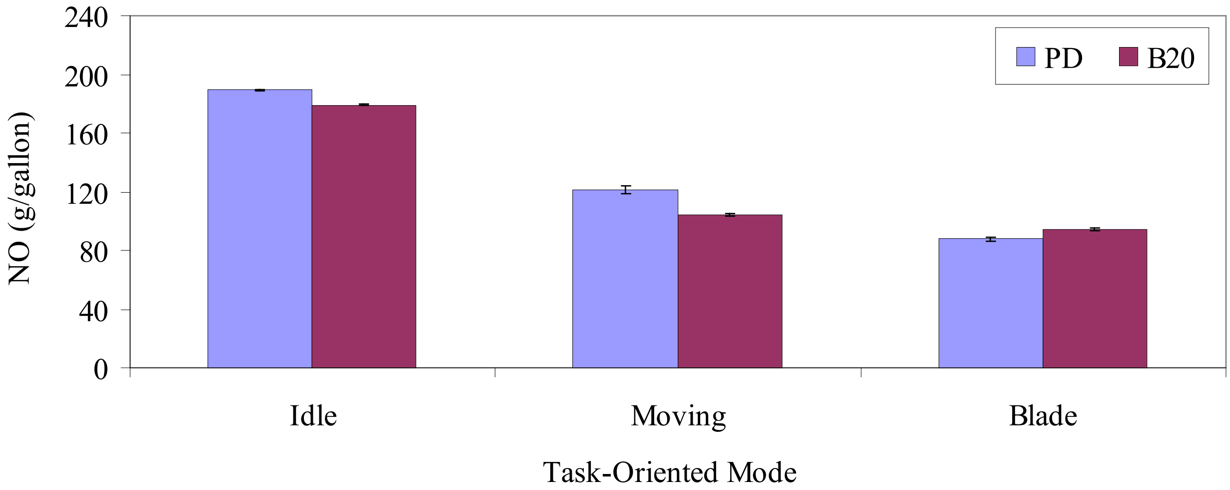
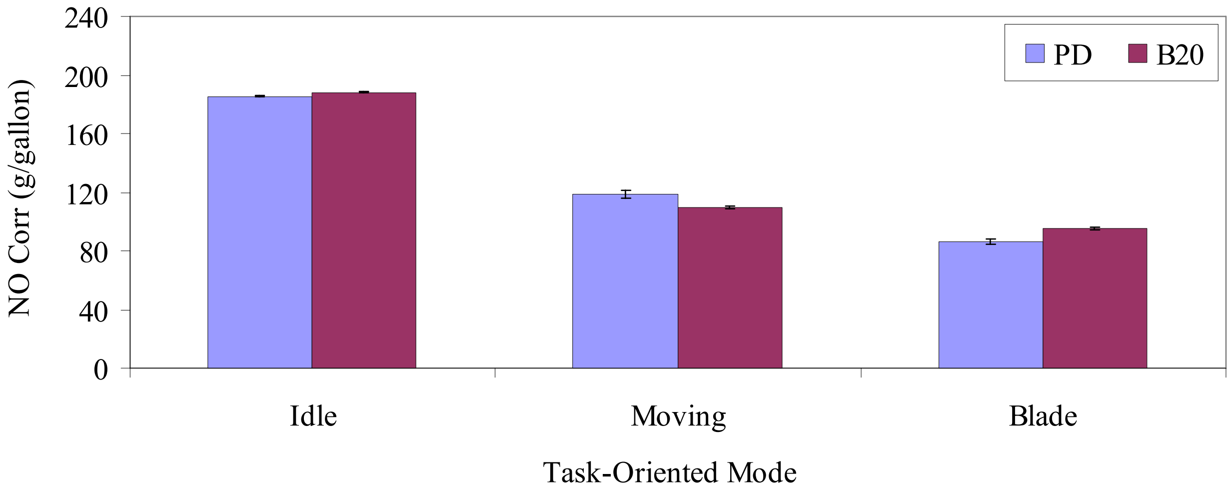


Figure F47. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 74 ^{o}F and the relative humidity was 54 %. For the B20 biodiesel test, the ambient temperature was 87 ^{o}F and the relative humidity was 63 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F48. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Motor Grader 3 (continued on next page)

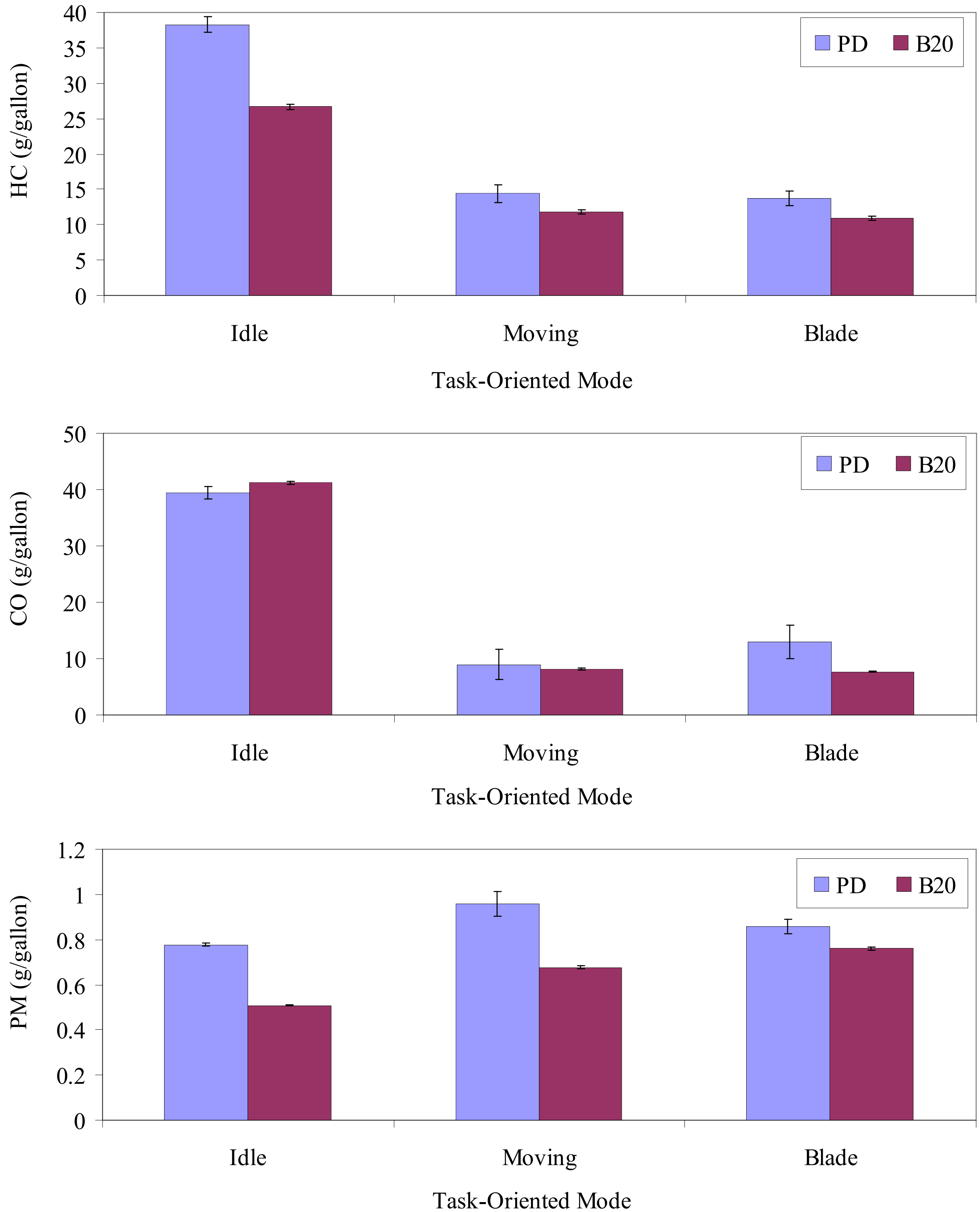
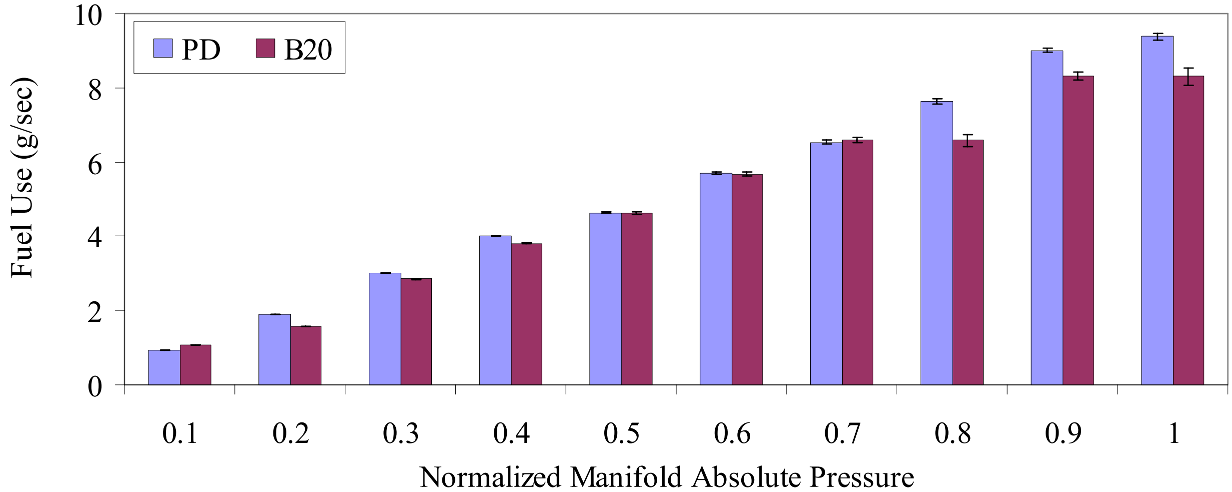
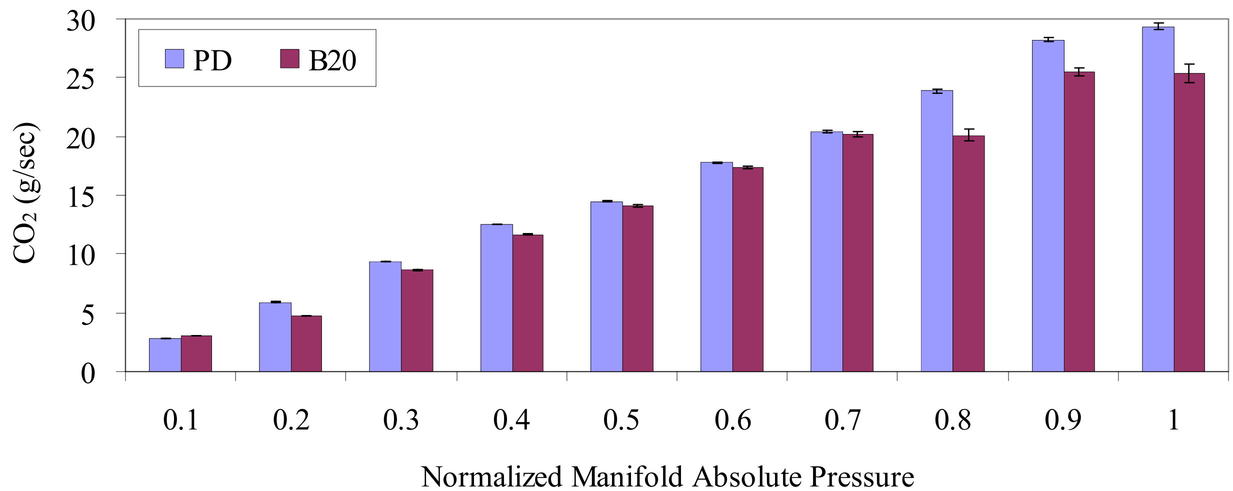


Figure F48. Continued

MOTOR GRADER 4





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 73 ^oF and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 45 ^oF and the relative humidity was 37 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F49. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Motor Grader 4 (continued on next page)

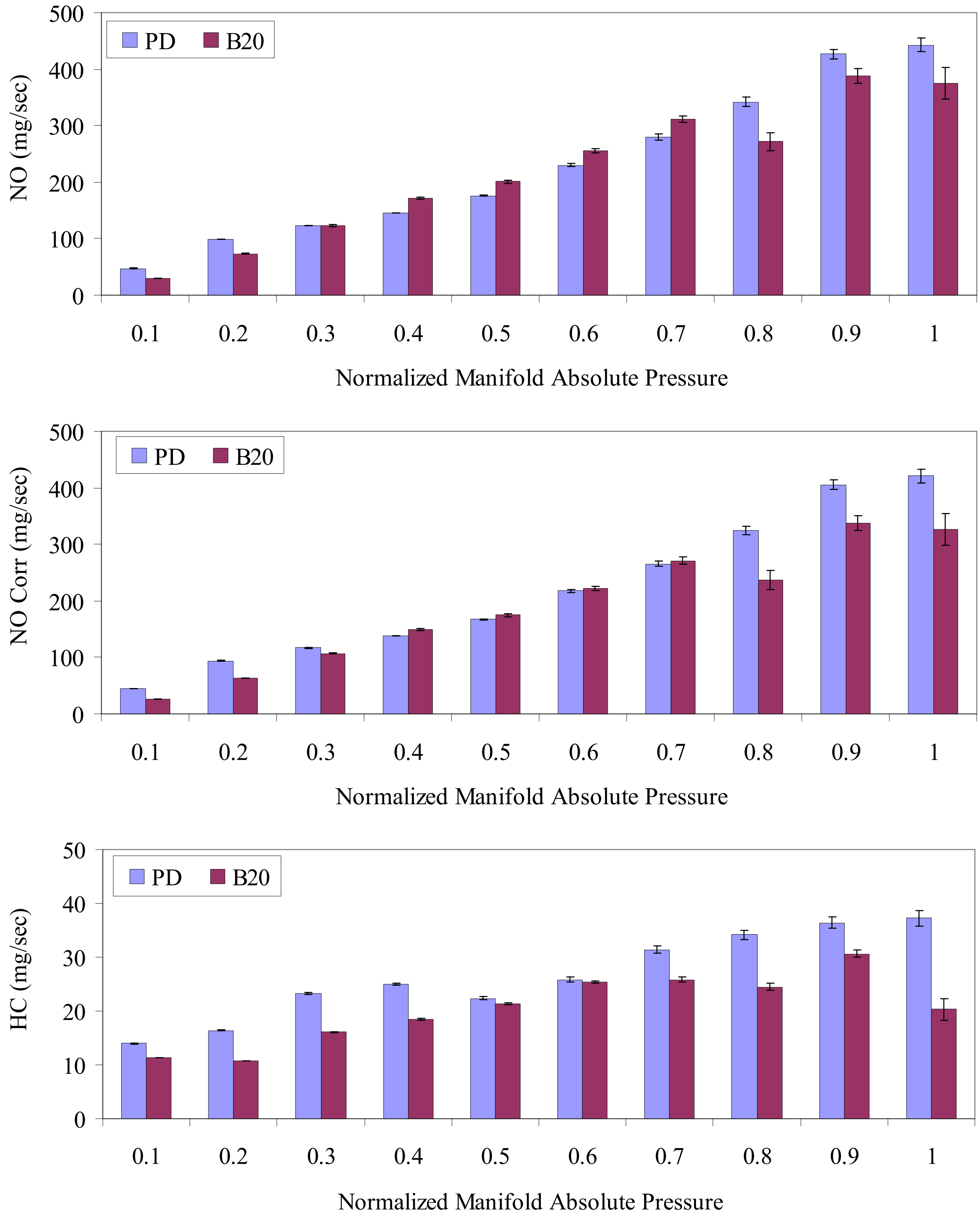
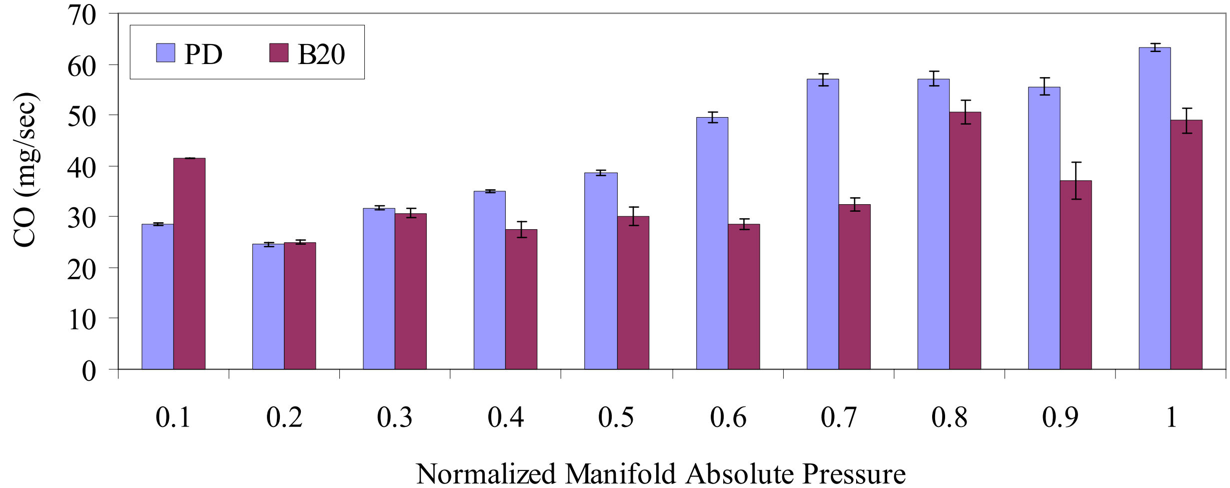


Figure F49. Continued



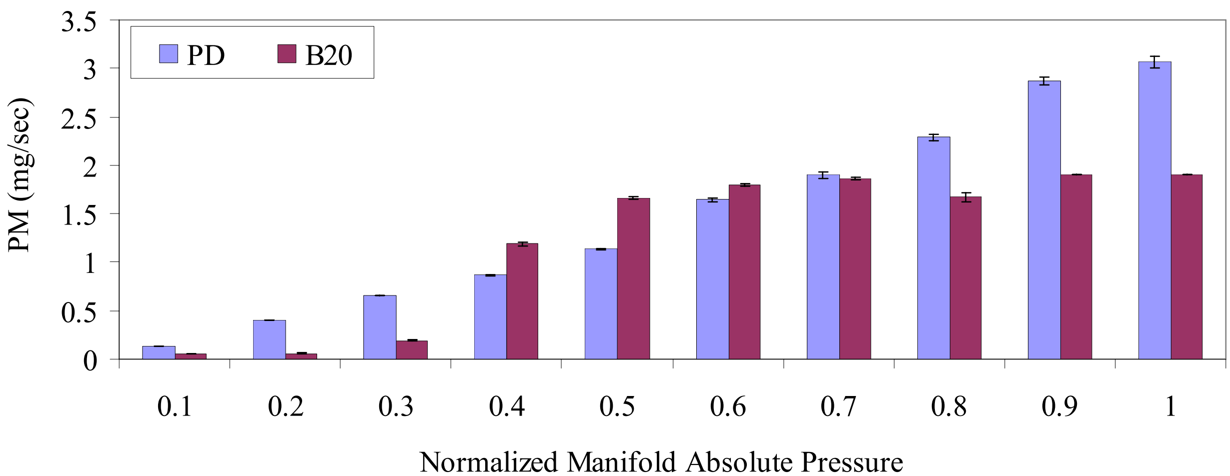
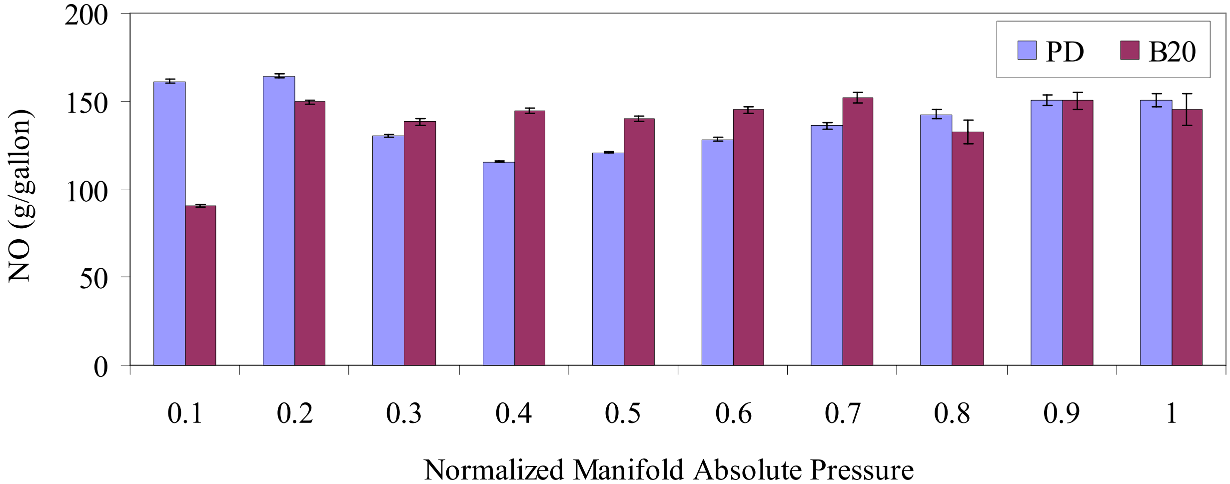
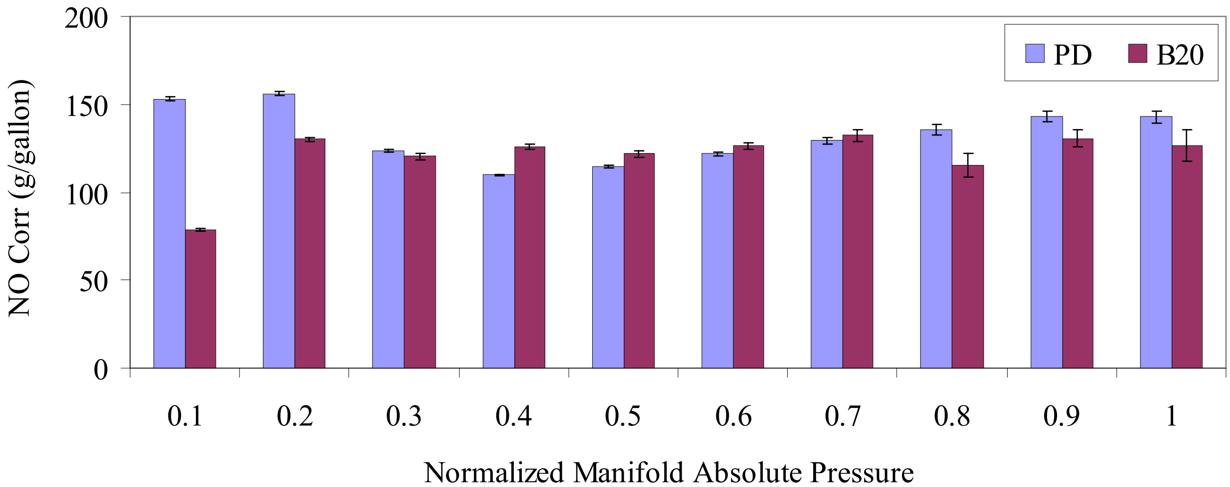


Figure F49. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 73 ^{o}F and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 45 ^{o}F and the relative humidity was 37 %.

Values shown in the figure are the upper end of the range: “0.1” = 0 ≤ Normalized MAP < 0.1; “0.2” = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F50. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Motor Grader 4 (continued on next page)

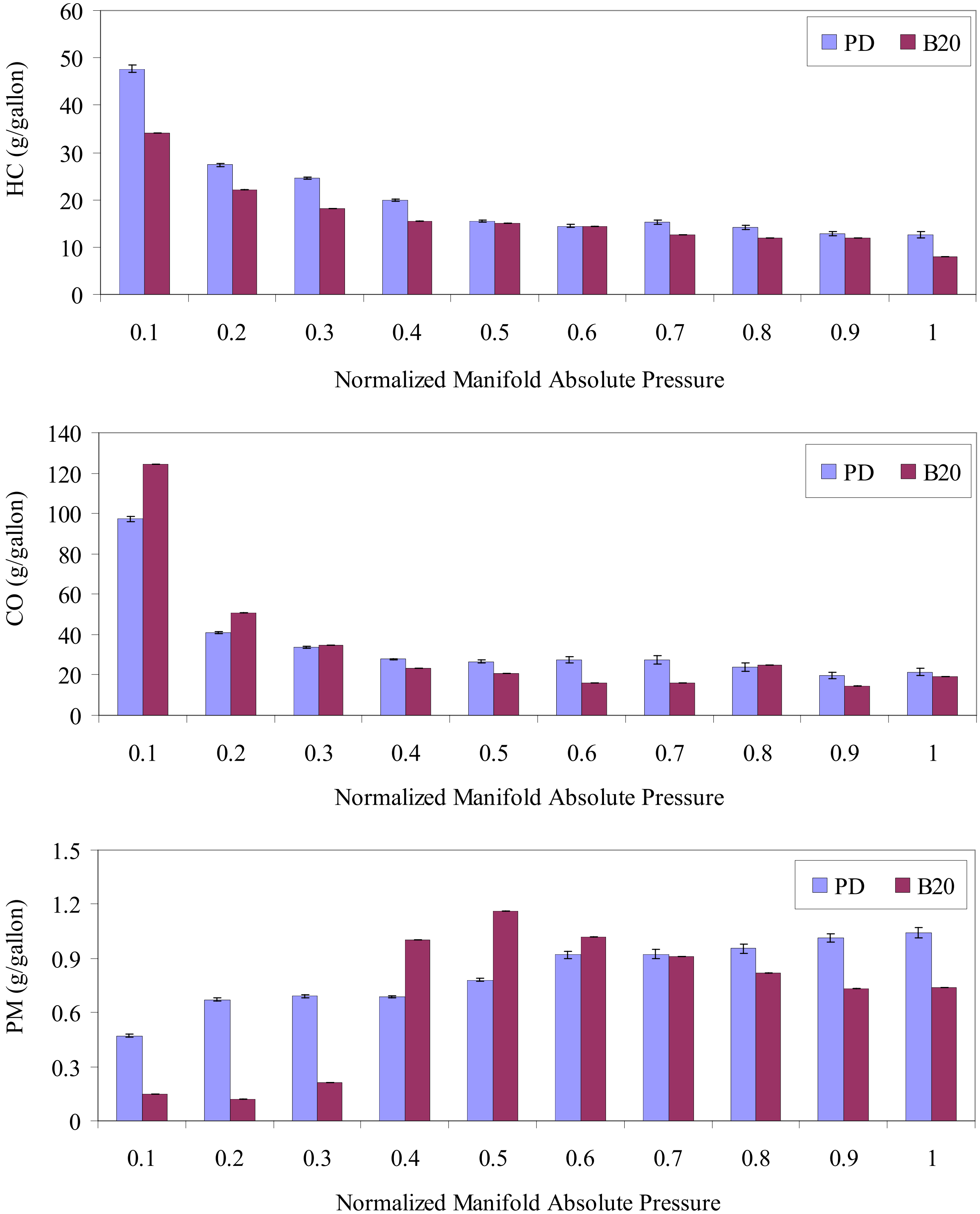
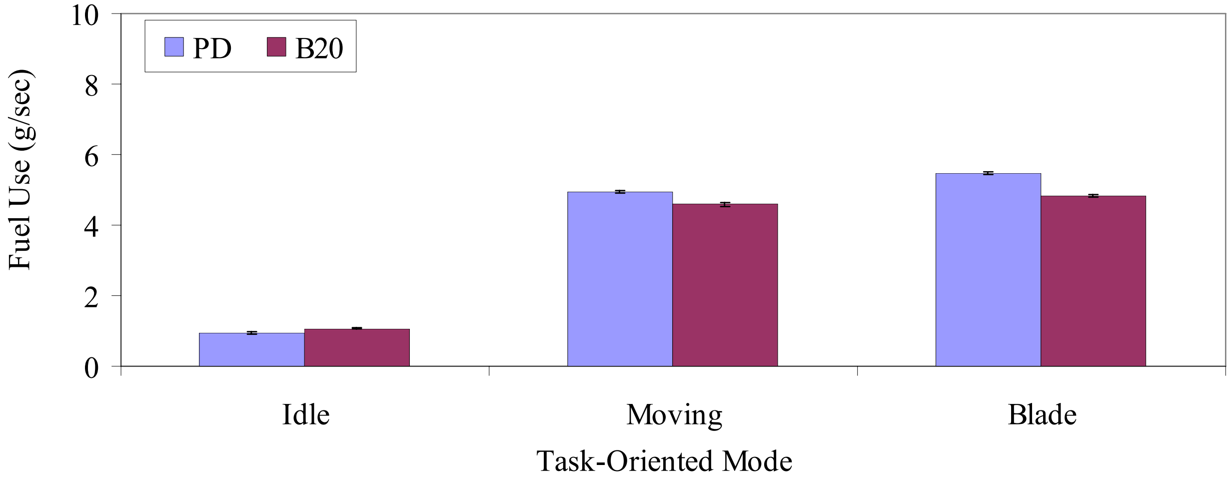
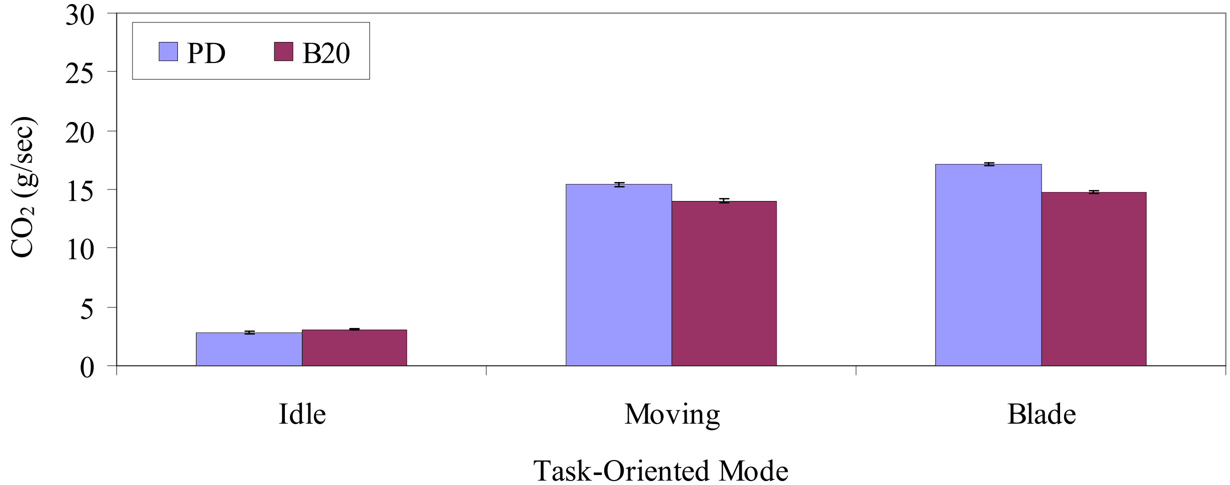


Figure F50. Continued

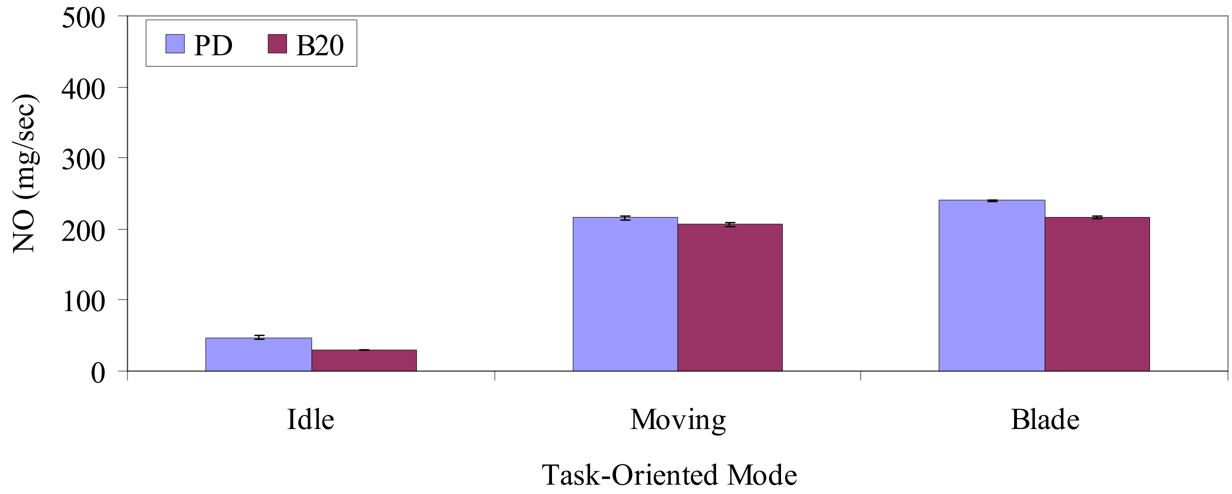


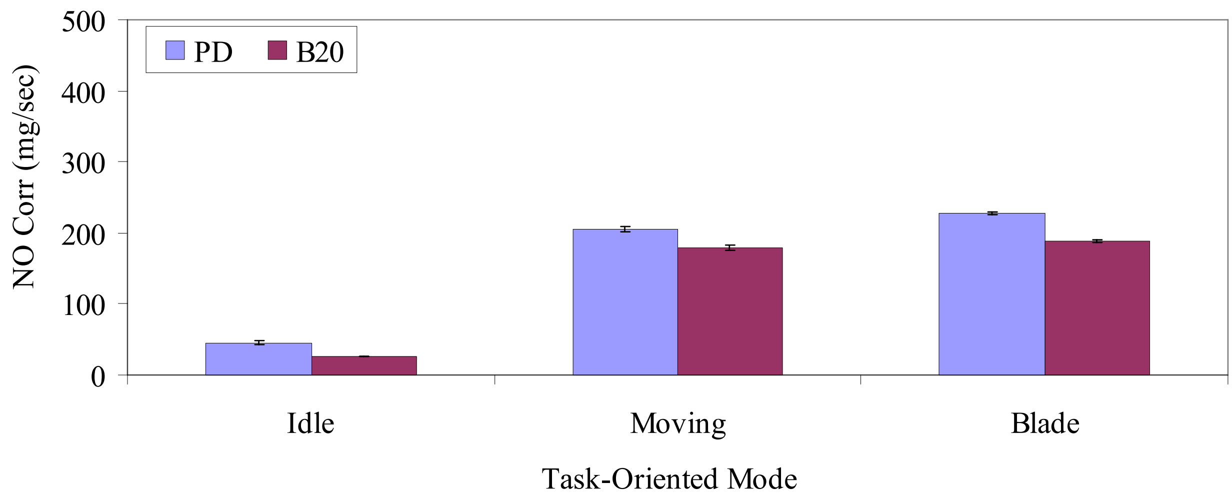


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 73 ^{o}F and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 45 ^{o}F and the relative humidity was 37 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F51. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Motor Grader 4 (continued on next page)





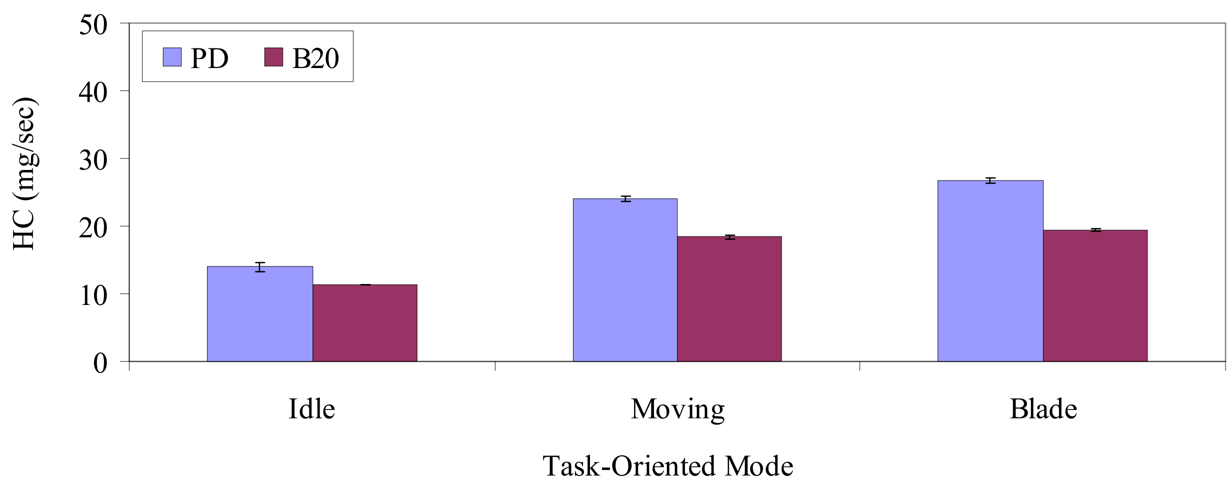


Figure F51. Continued

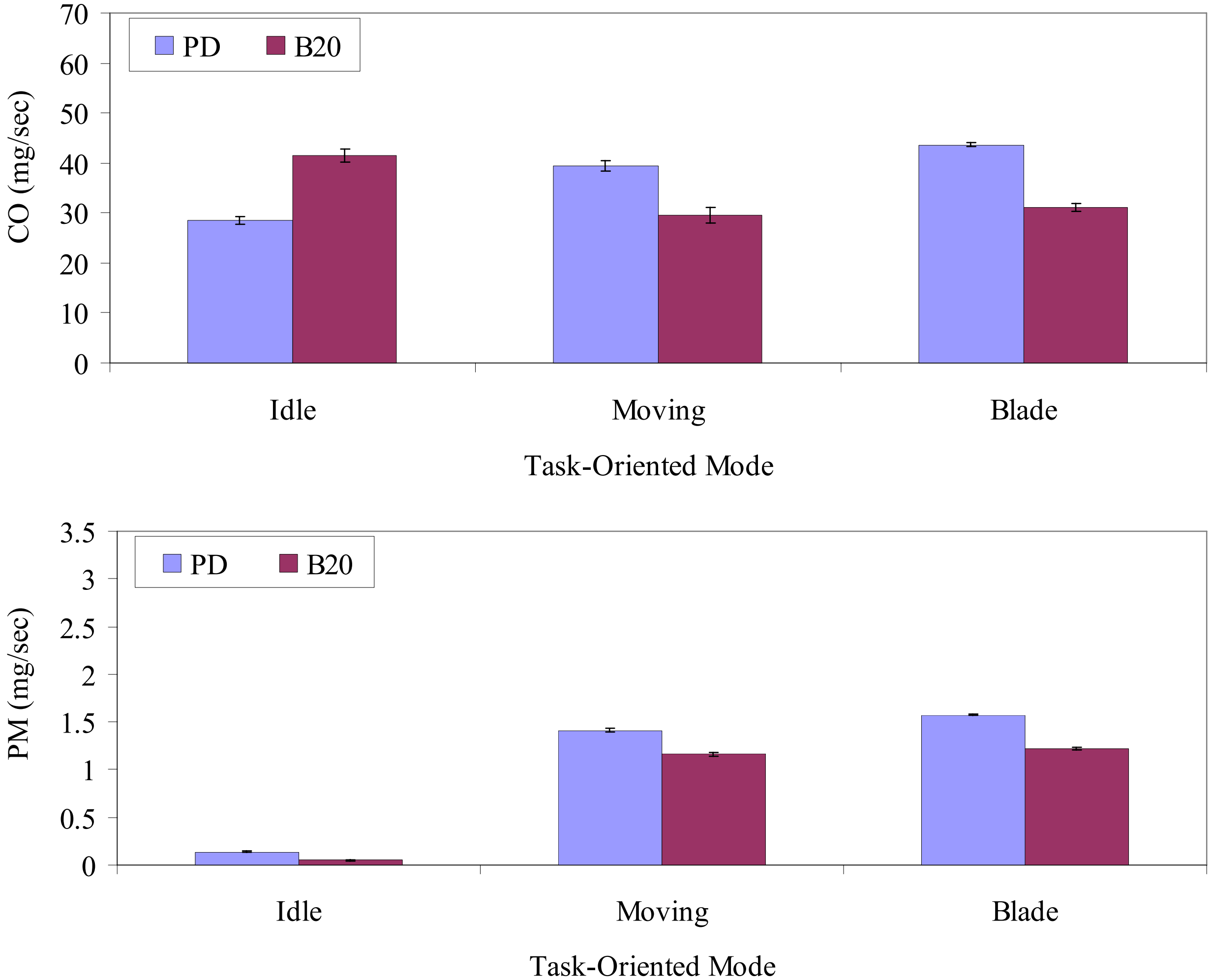
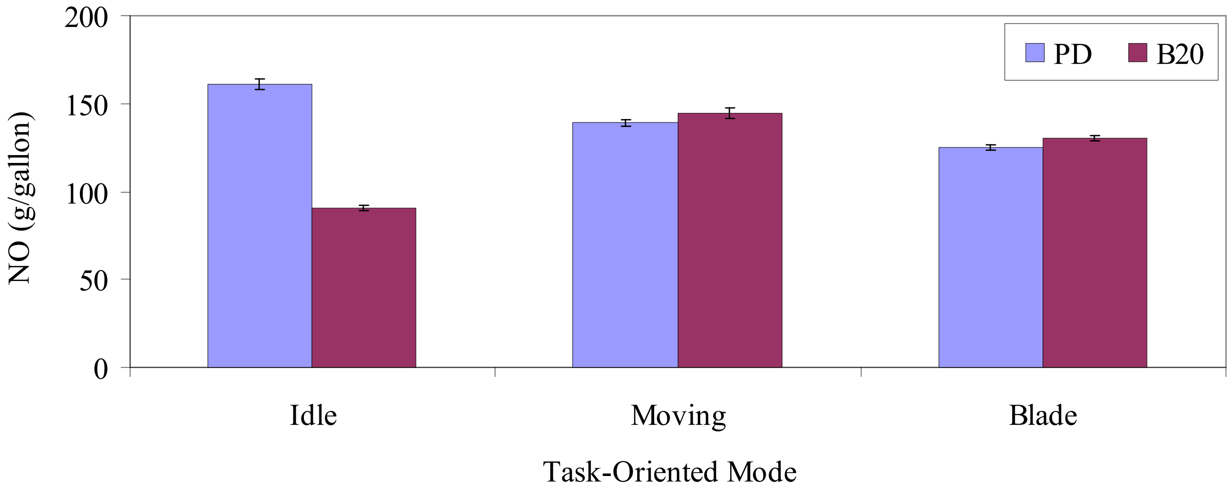
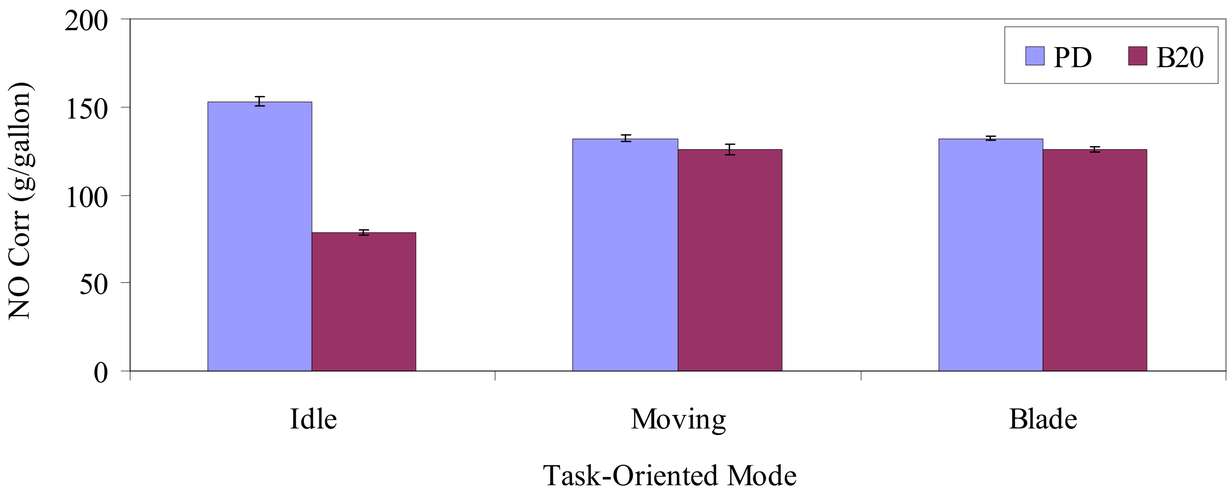


Figure F51. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 73 ^{o}F and the relative humidity was 44 %. For the B20 biodiesel test, the ambient temperature was 45 ^{o}F and the relative humidity was 37 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F52. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Motor Grader 4 (continued on next page)

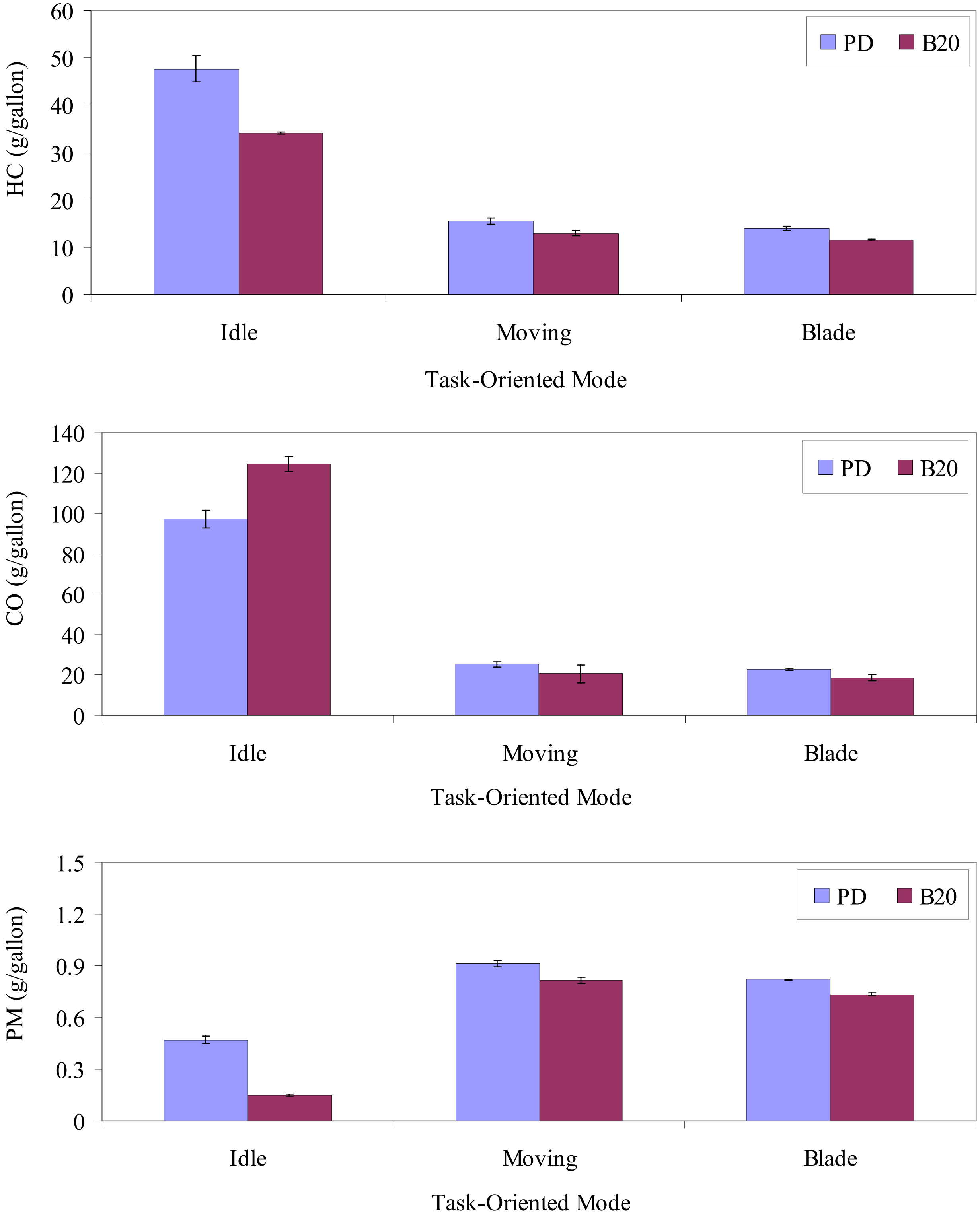
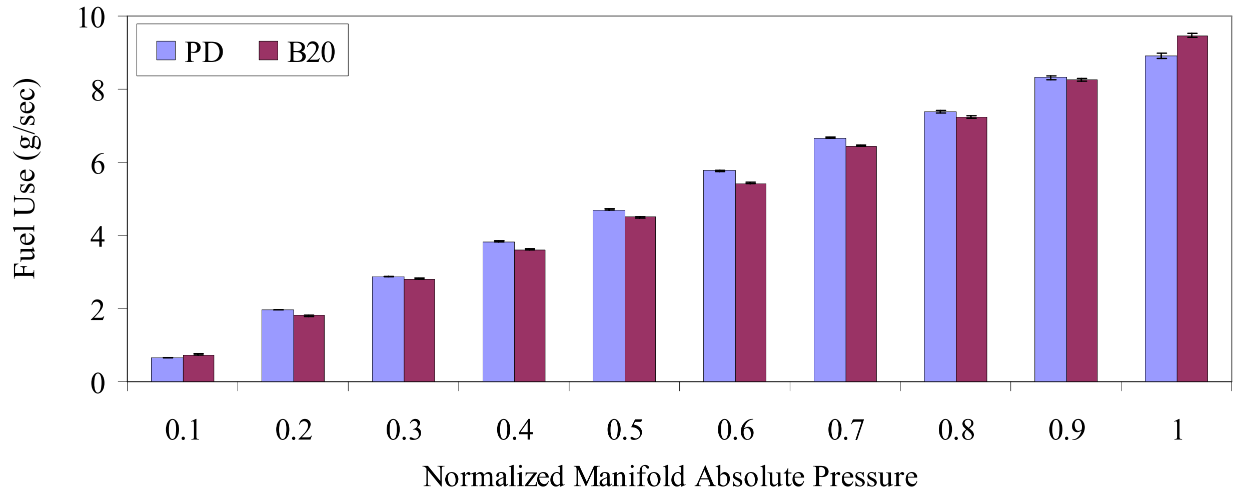
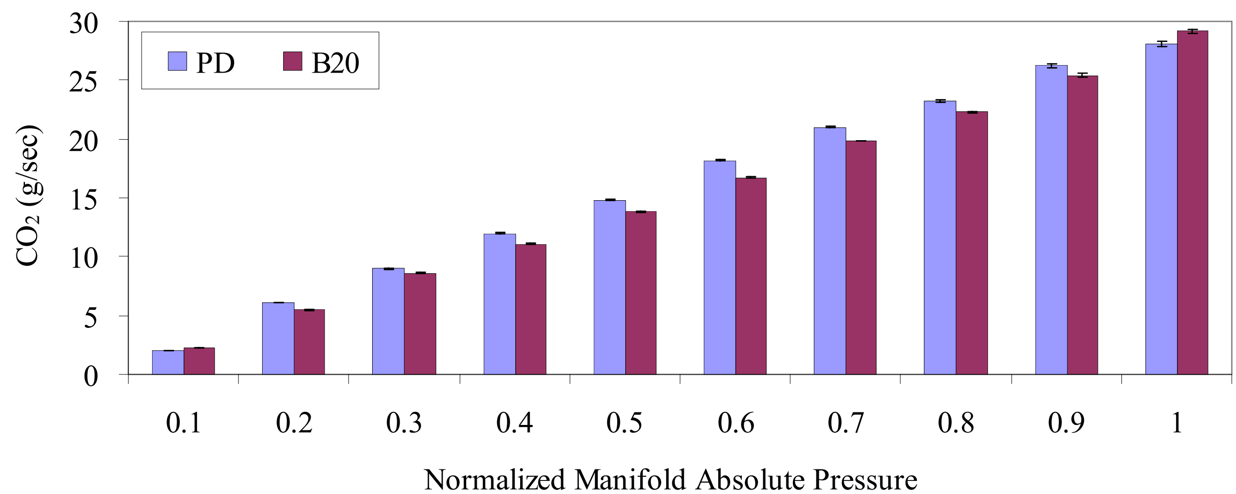


Figure F52. Continued

MOTOR GRADER 5





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 35 ^{o}F and the relative humidity was 39 %. For the B20 biodiesel test, the ambient temperature was 60 ^{o}F and the relative humidity was 72 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F53. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Motor Grader 5 (continued on next page)

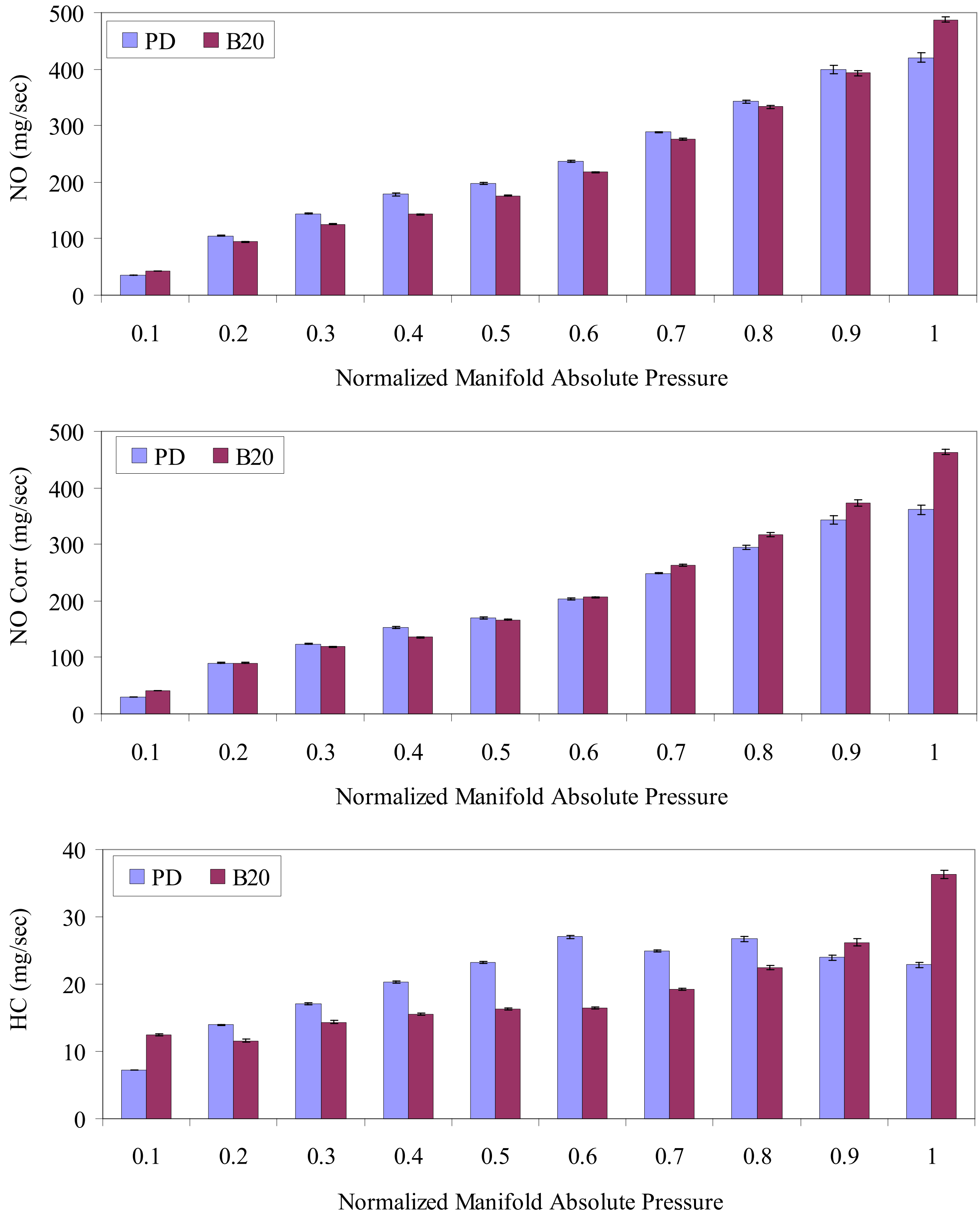
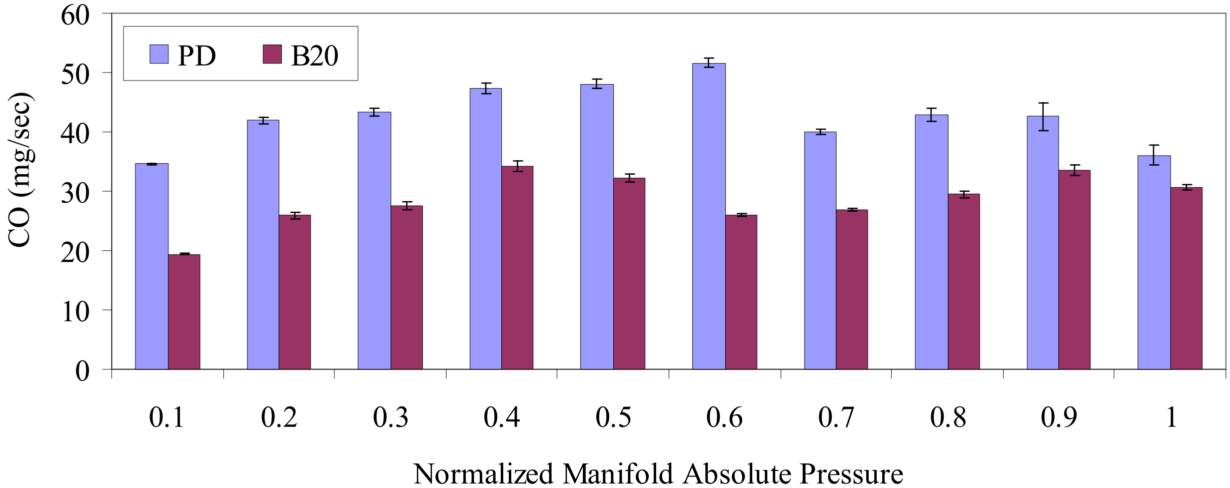


Figure F53. Continued



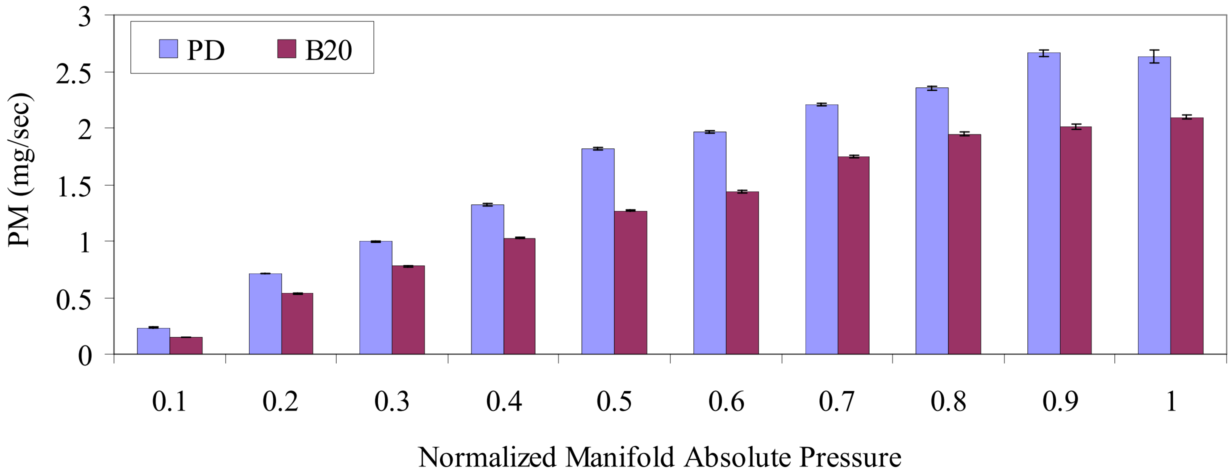
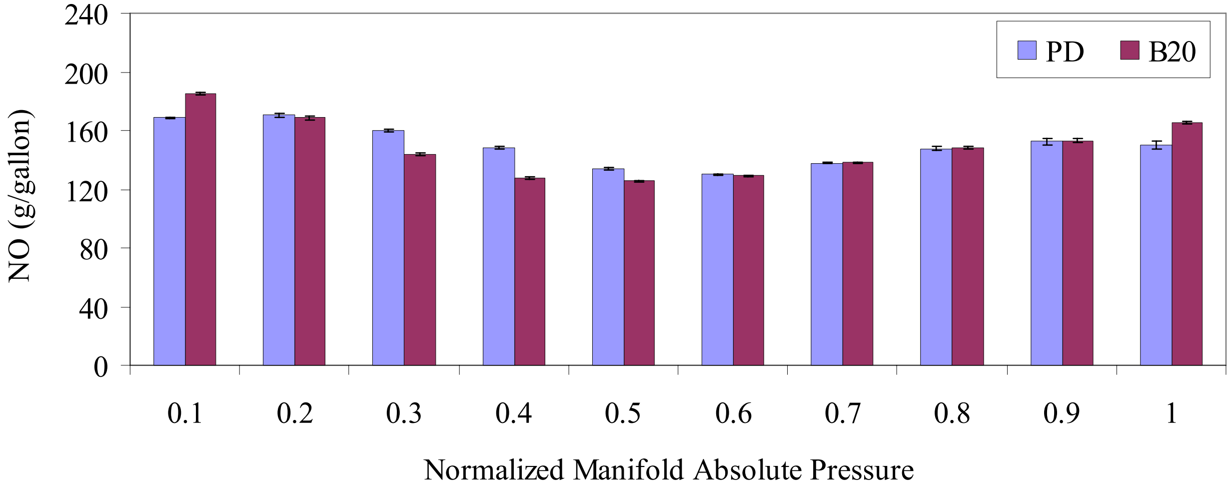
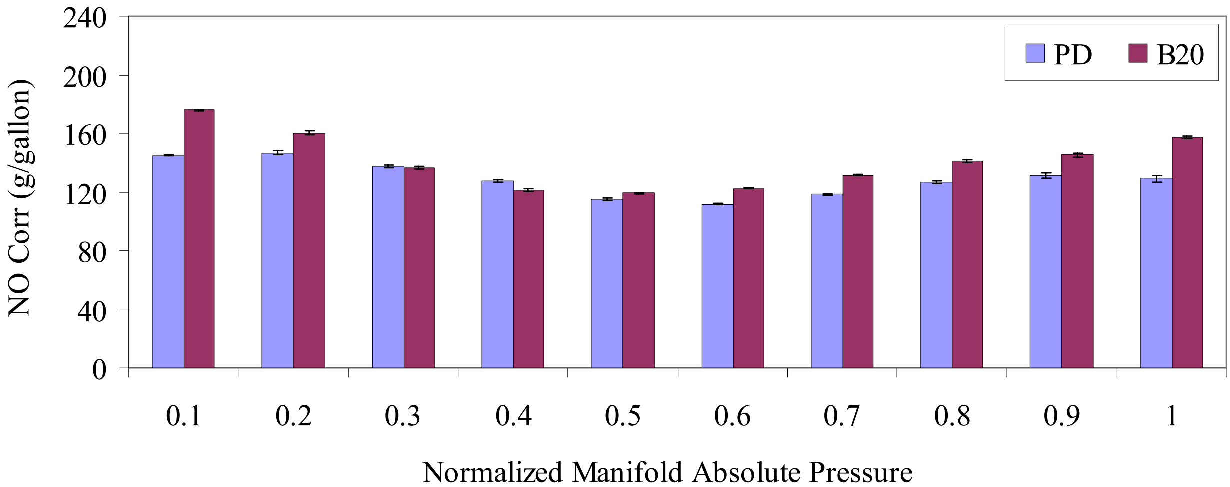


Figure F53. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 35 ^{o}F and the relative humidity was 39 %. For the B20 biodiesel test, the ambient temperature was 60 ^{o}F and the relative humidity was 72 %.

Values shown in the figure are the upper end of the range: “0.1” = 0 ≤ Normalized MAP < 0.1; “0.2” = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F54. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Motor Grader 5 (continued on next page)

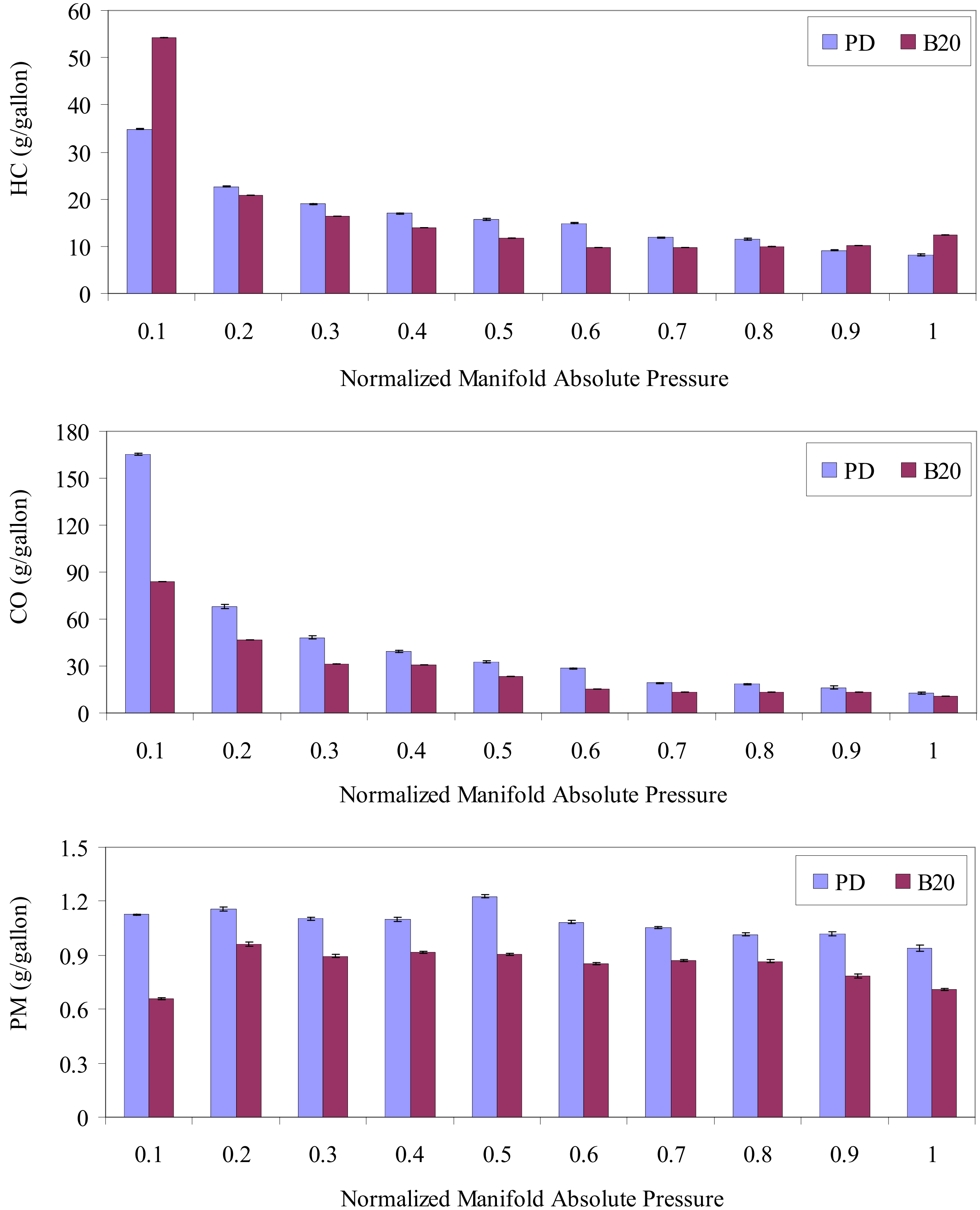
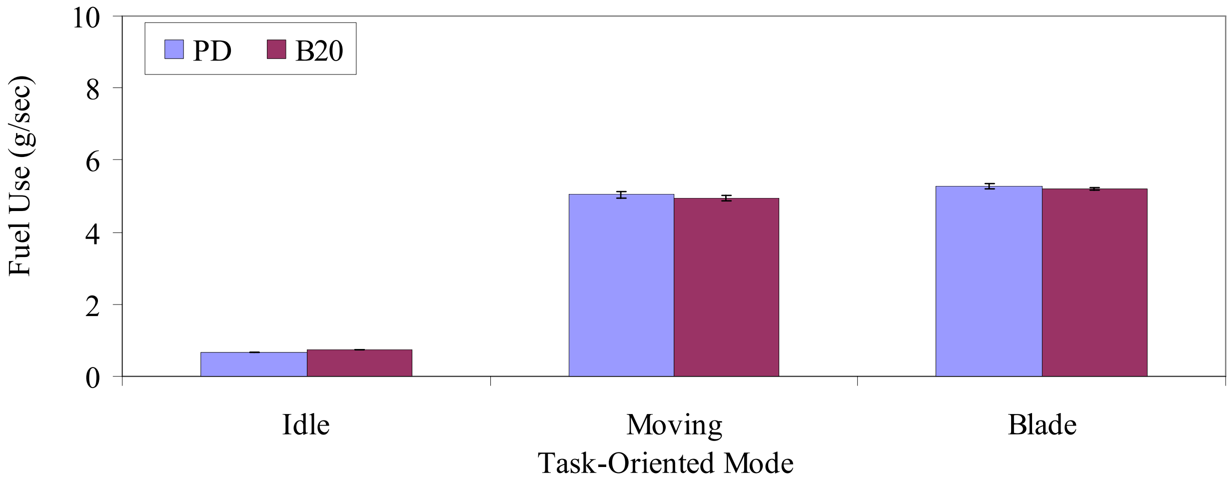
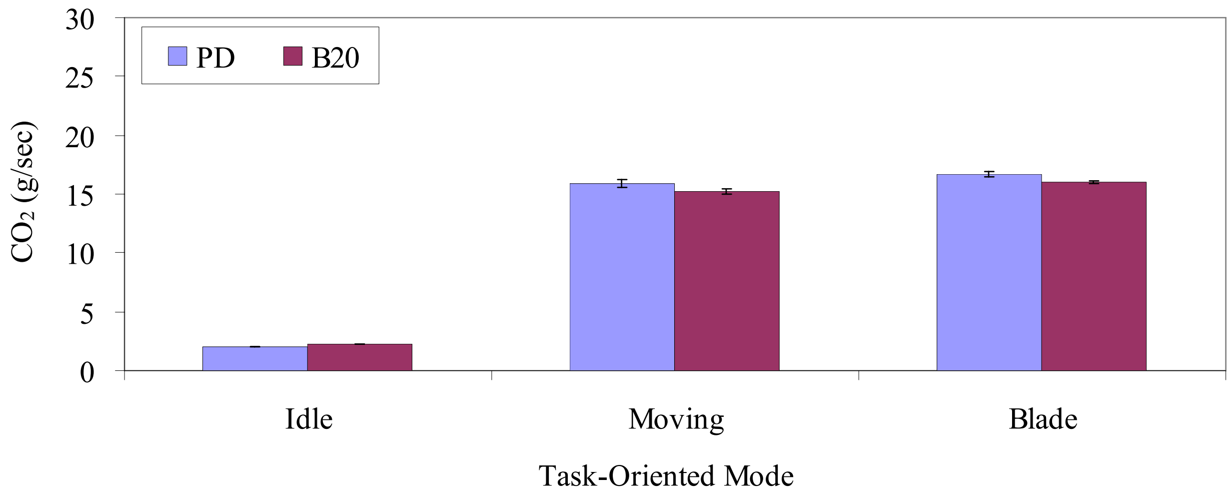


Figure F54. Continued

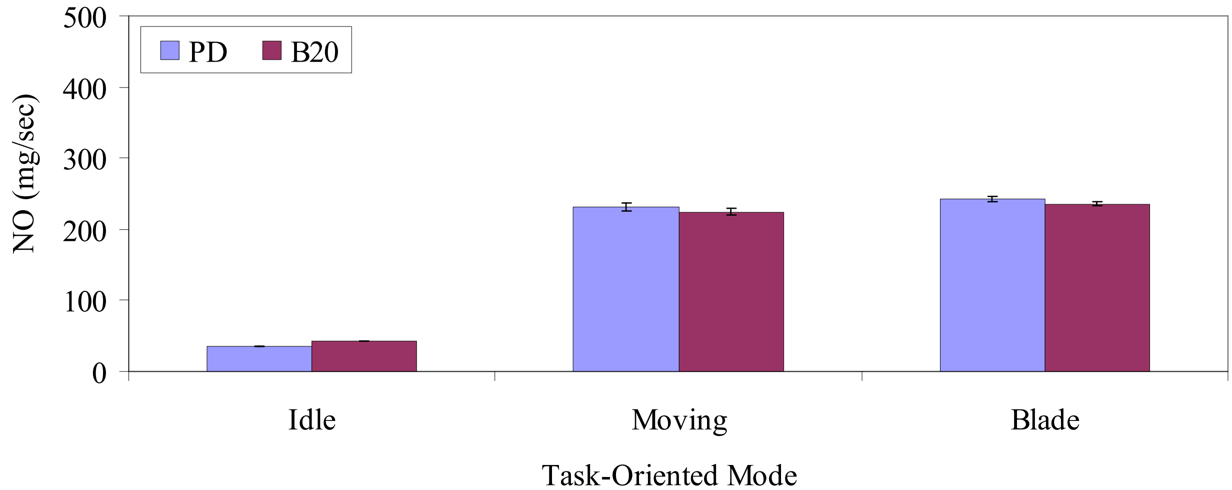


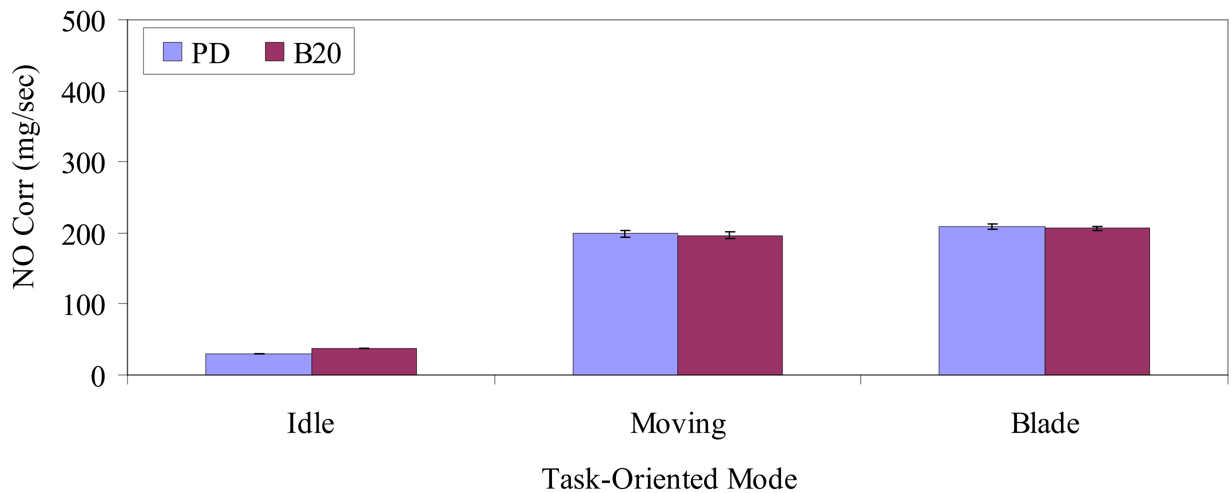


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 35 ^{o}F and the relative humidity was 39 %. For the B20 biodiesel test, the ambient temperature was 60 ^{o}F and the relative humidity was 72 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F55. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Motor Grader 5 (continued on next page)





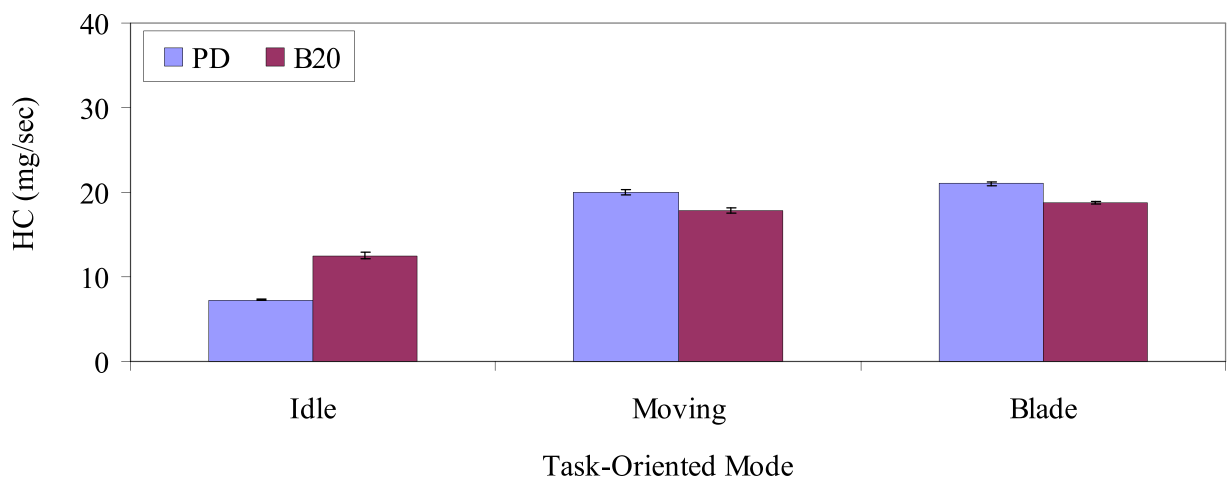


Figure F55. Continued

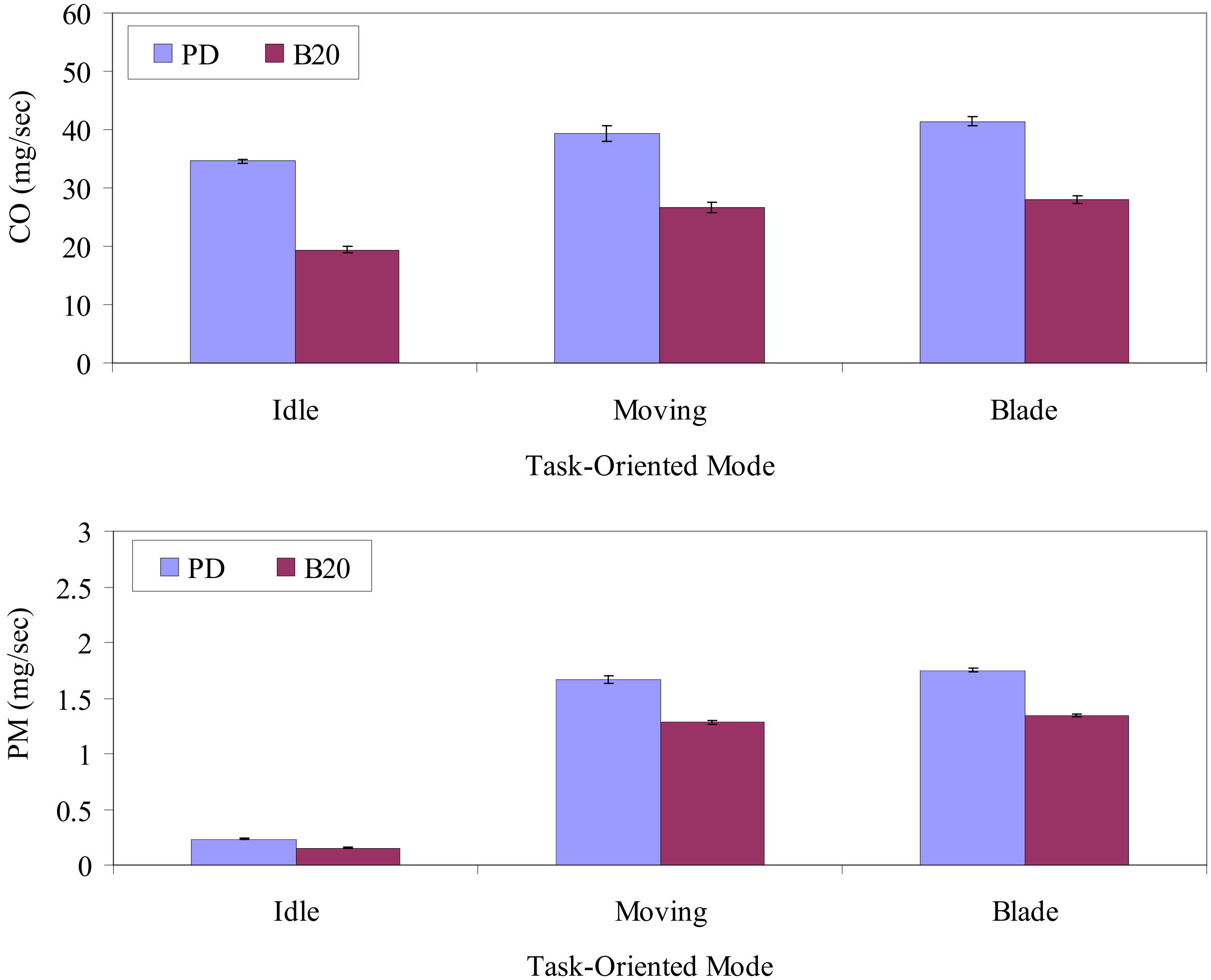
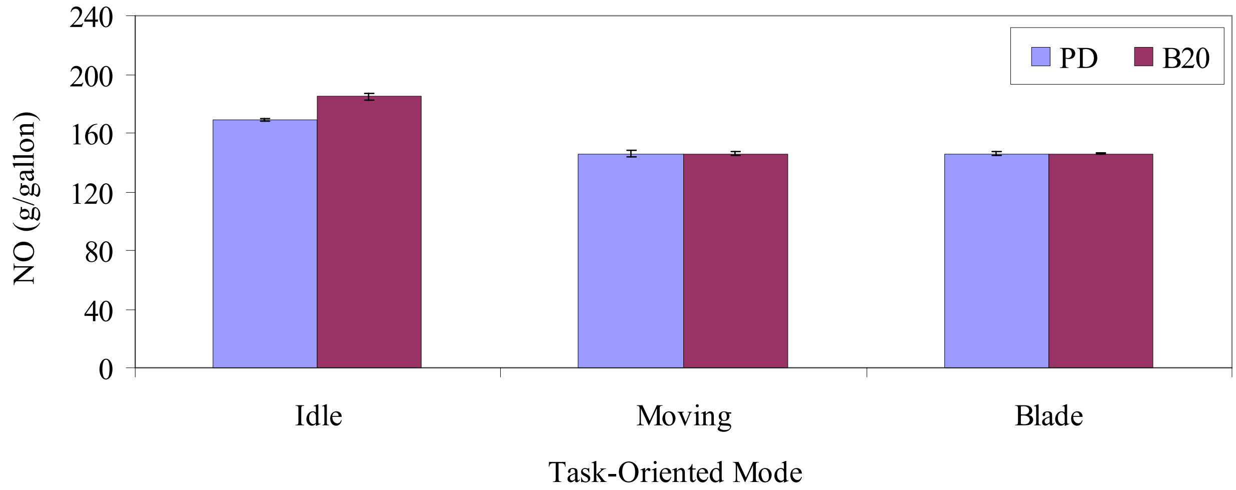
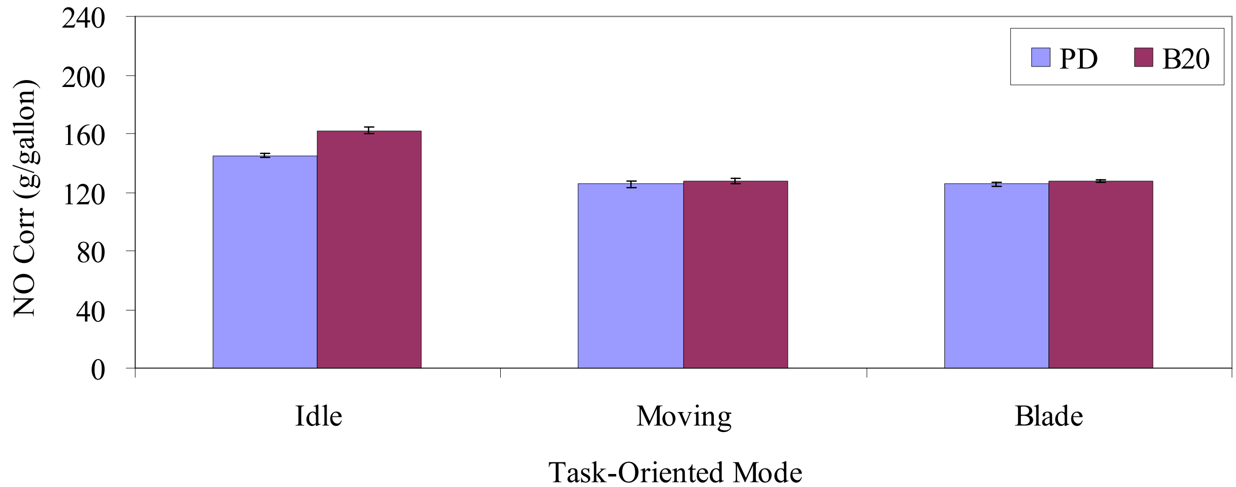


Figure F55. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 35 ^{o}F and the relative humidity was 39 %. For the B20 biodiesel test, the ambient temperature was 60 ^{o}F and the relative humidity was 72 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F56. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Motor Grader 5 (continued on next page)

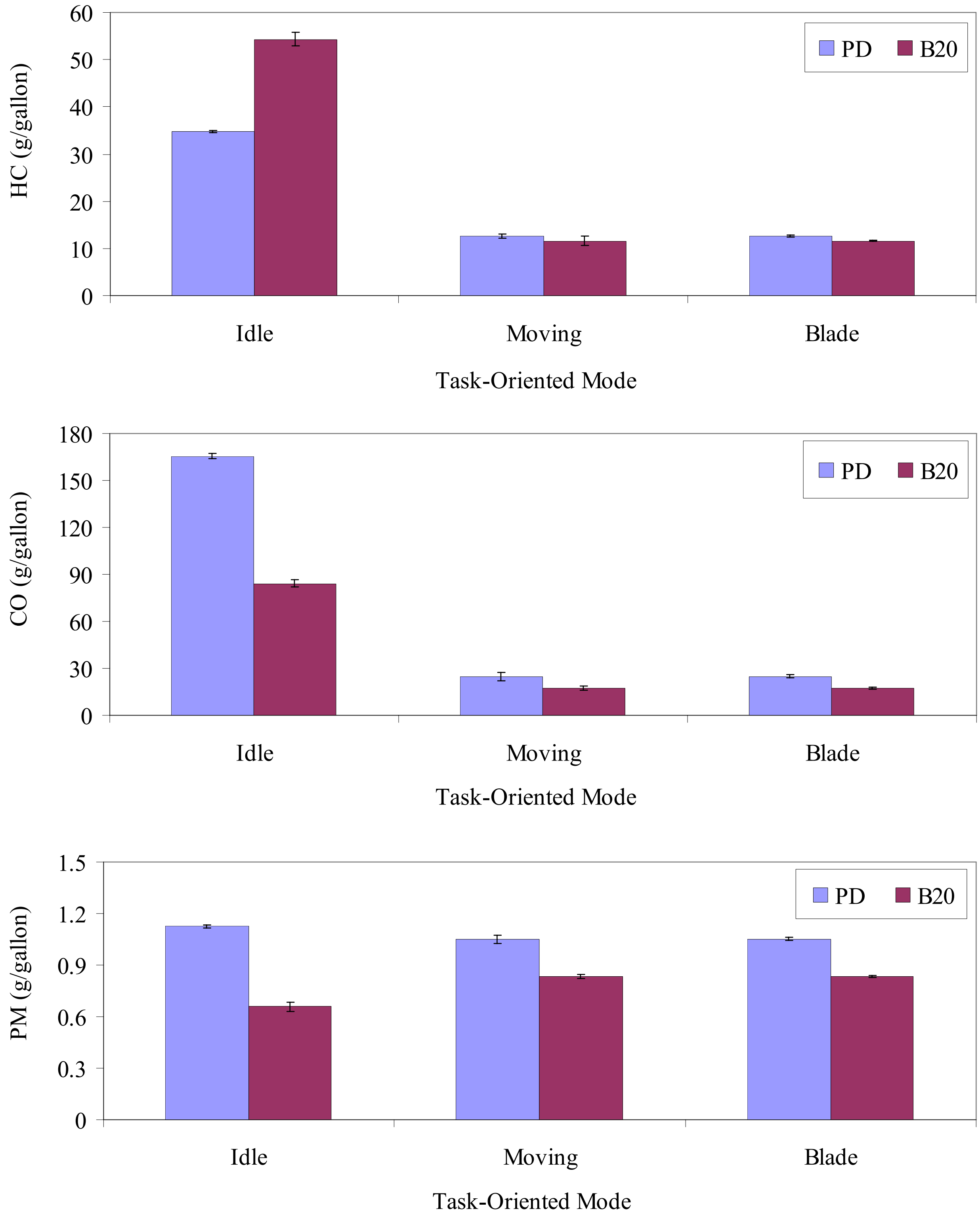
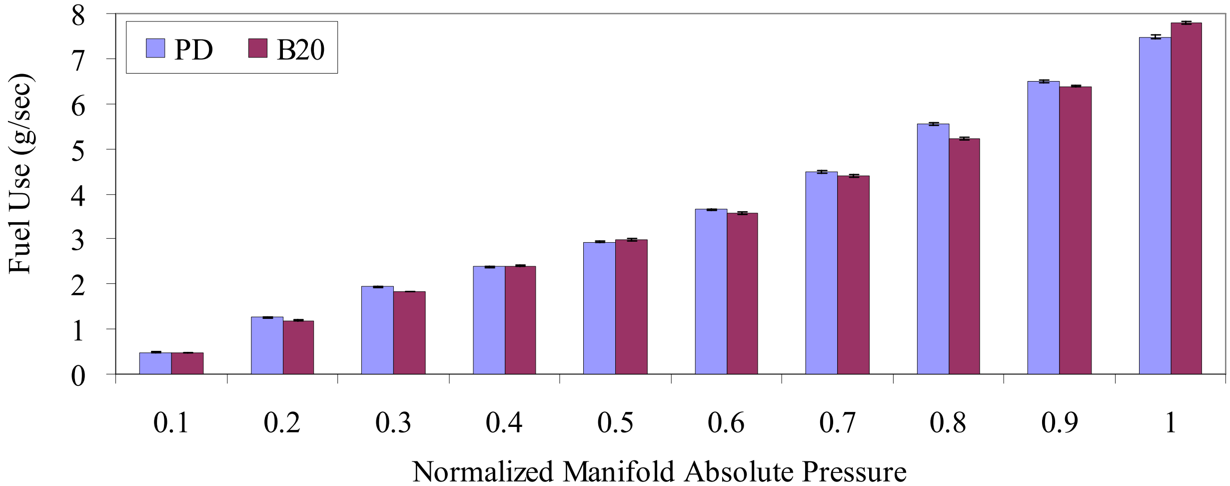
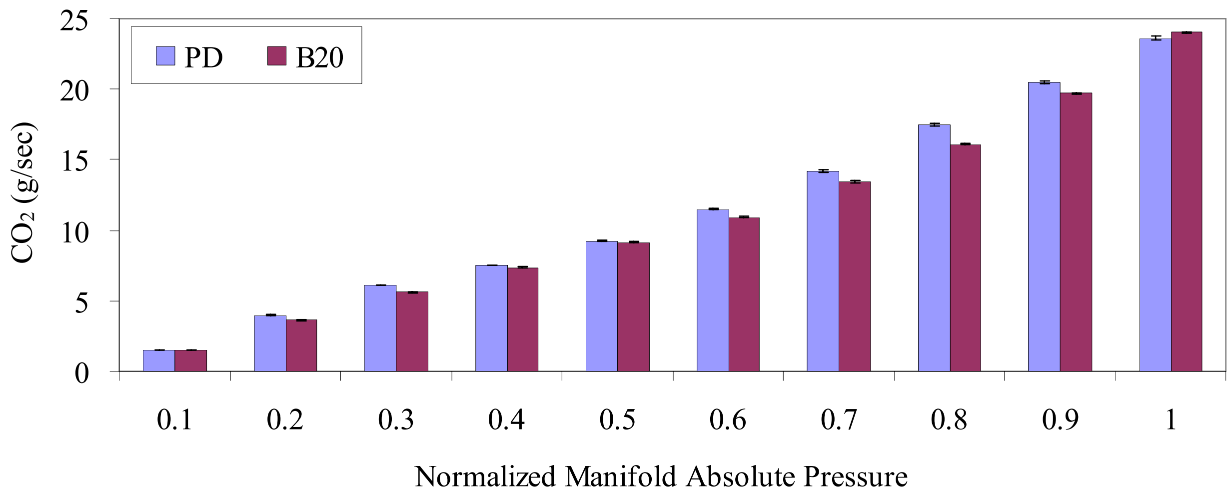


Figure F56. Continued

MOTOR GRADER 6





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 88 ^{o}F and the relative humidity was 56 %. For the B20 biodiesel test, the ambient temperature was 83 ^{o}F and the relative humidity was 42 %.

Values shown in the figure are the upper end of the range: “0.1” = 0 ≤ Normalized MAP < 0.1; “0.2” = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F57. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Engine-Based Modes for Motor Grader 6 (continued on next page)

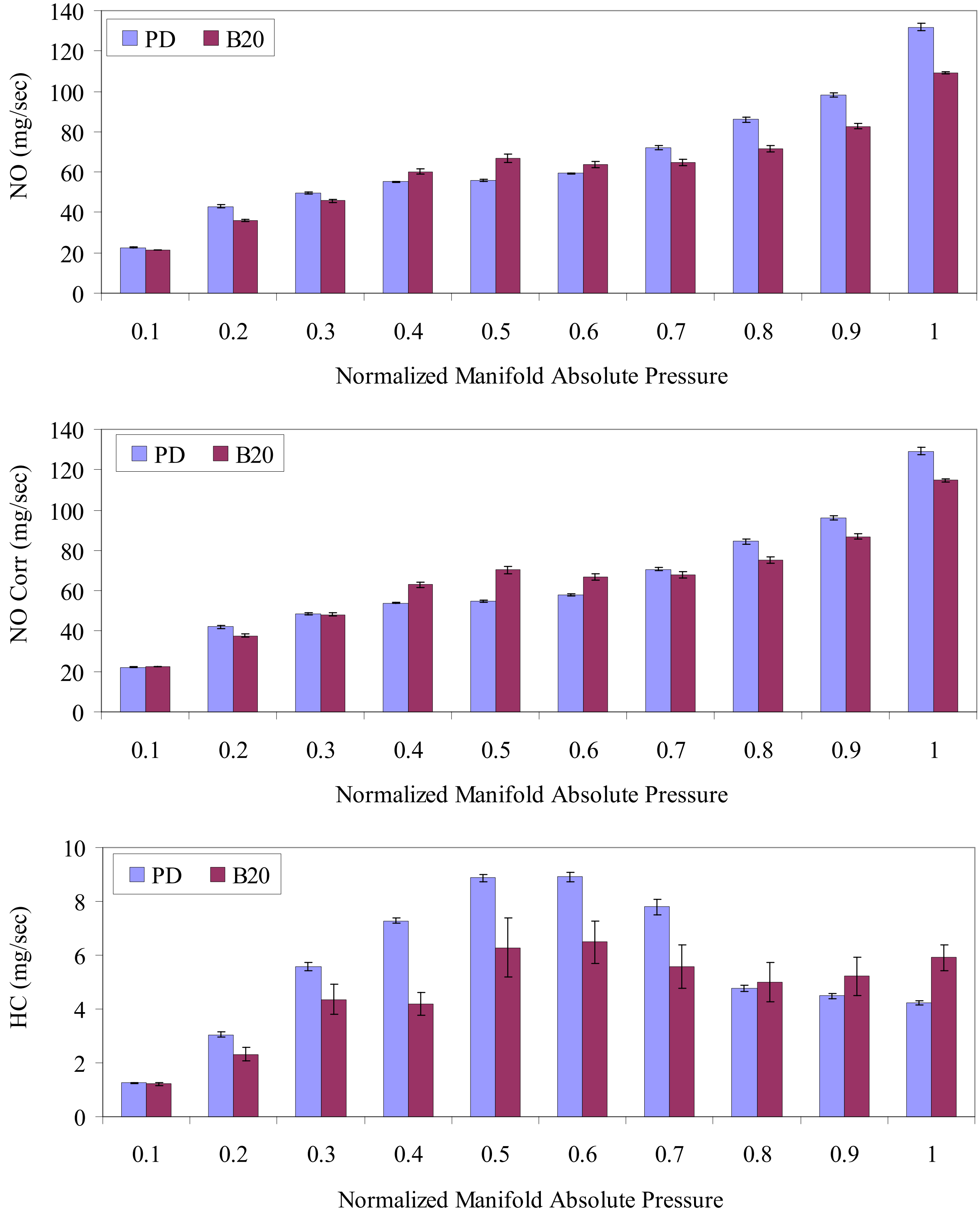
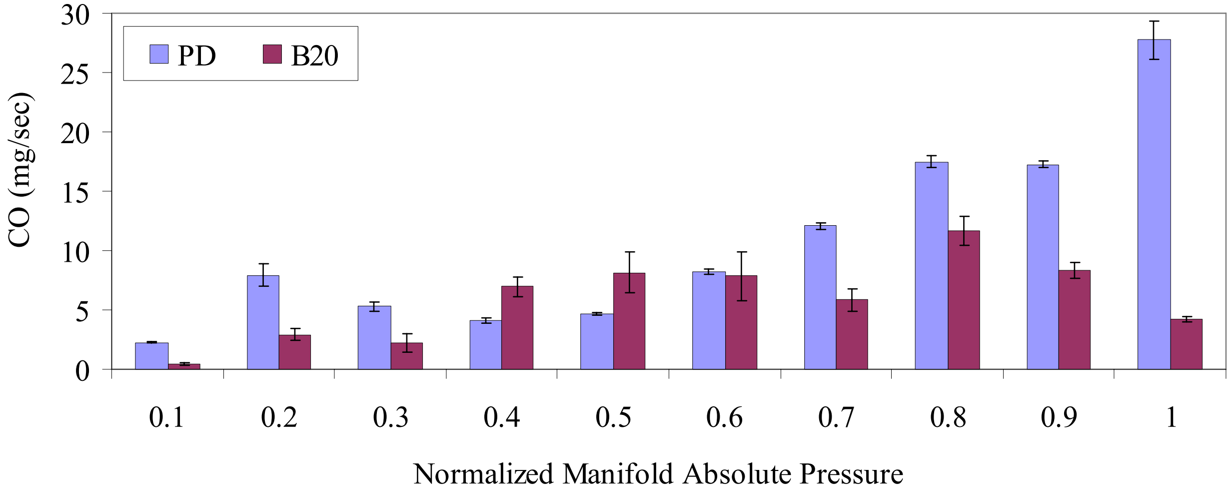


Figure F57. Continued



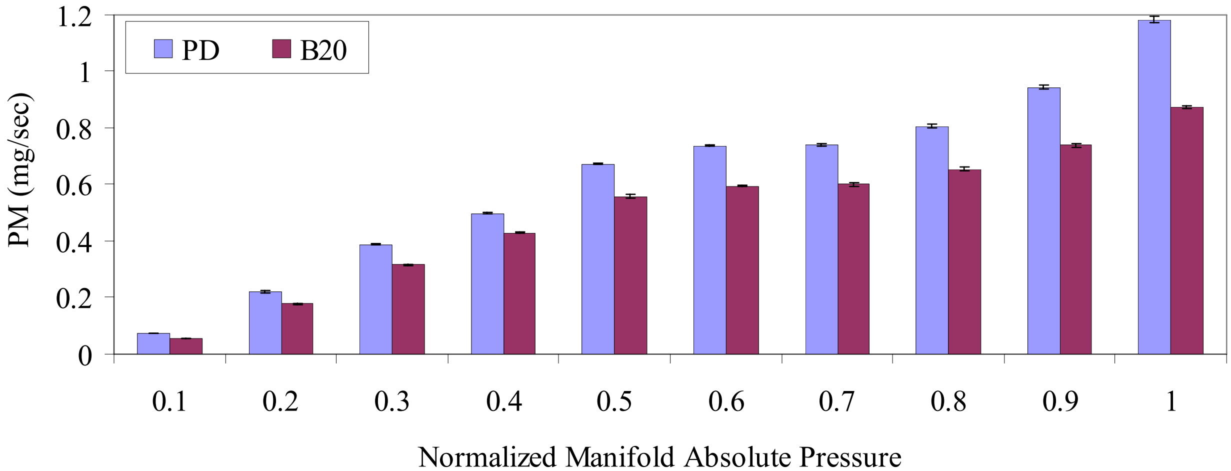
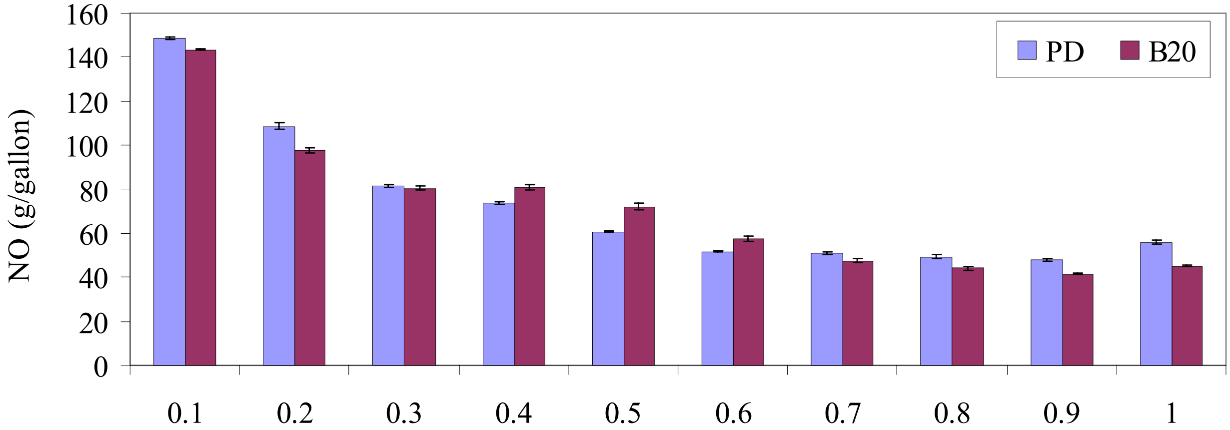
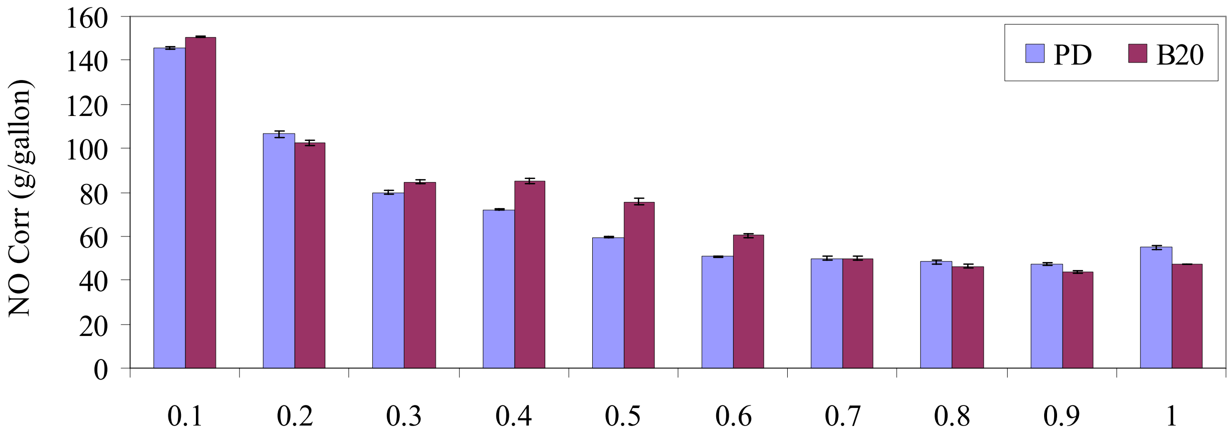


Figure F57. Continued



Normalized Manifold Absolute Pressure



Normalized Manifold Absolute Pressure

NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 86 ^oF and the relative humidity was 56 %. For the B20 biodiesel test, the ambient temperature was 83 ^oF and the relative humidity was 42 %.

Values shown in the figure are the upper end of the range: "0.1" = 0 ≤ Normalized MAP < 0.1; "0.2" = 0.1 ≤ Normalized MAP < 0.2, and so on.

Figure F58. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Engine-Based Modes for Motor Grader 6 (continued on next page)

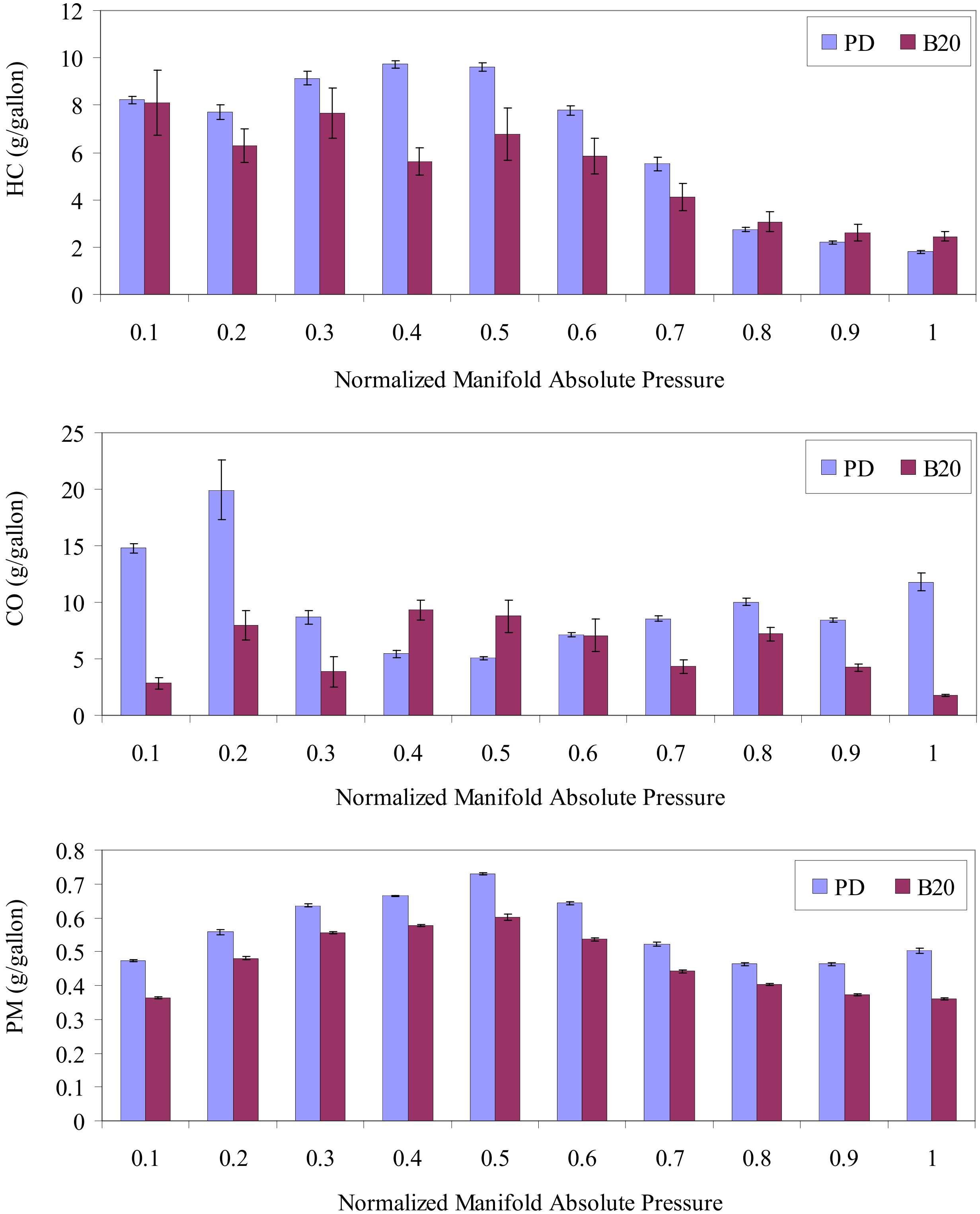
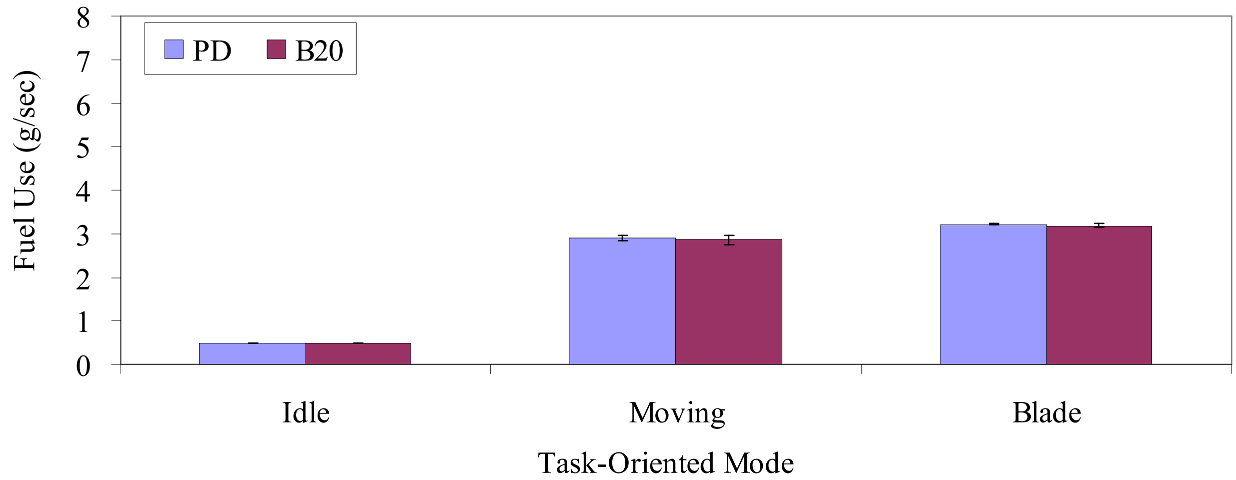
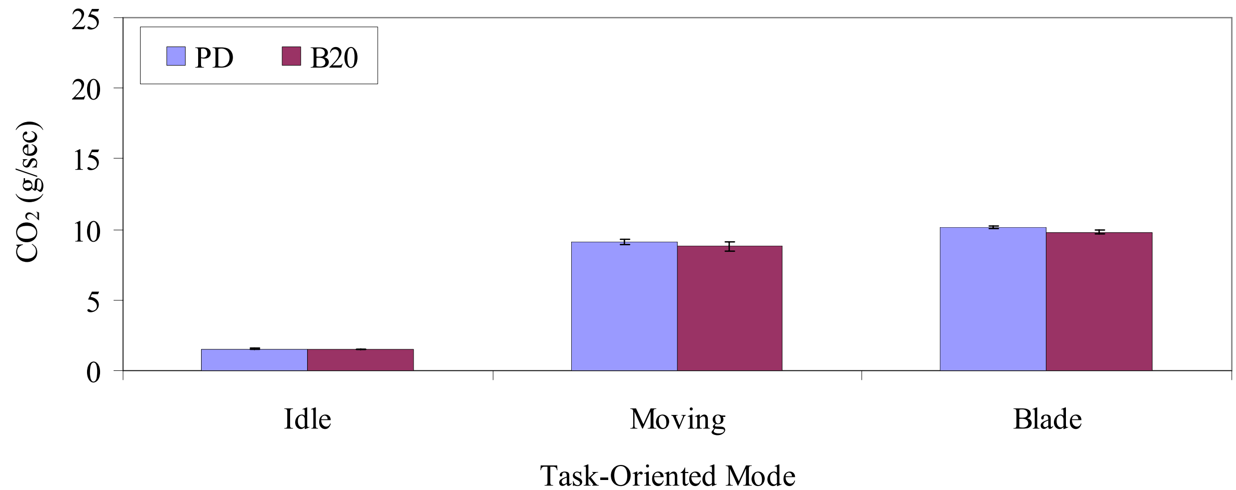


Figure F58. Continued

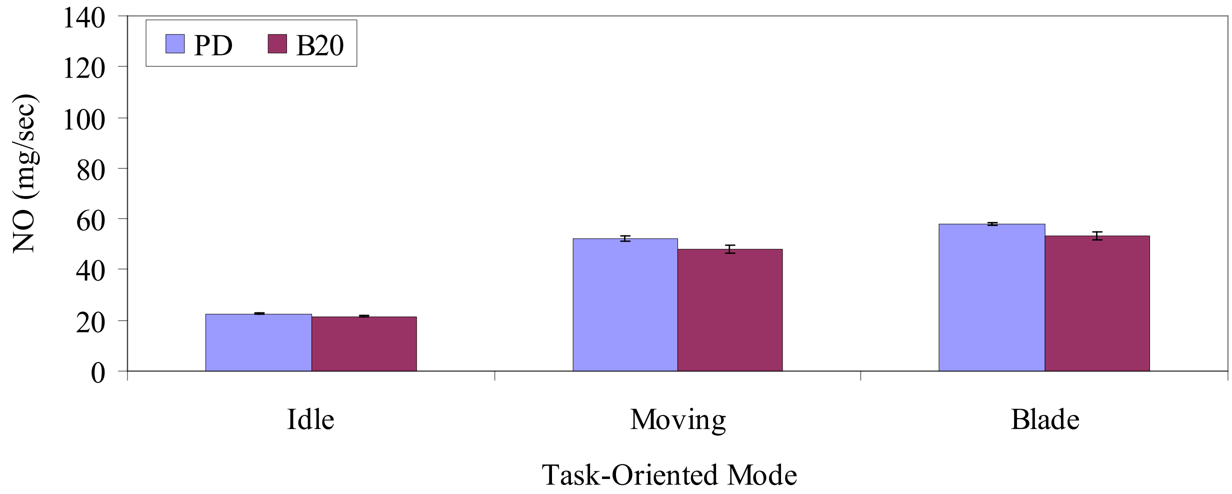


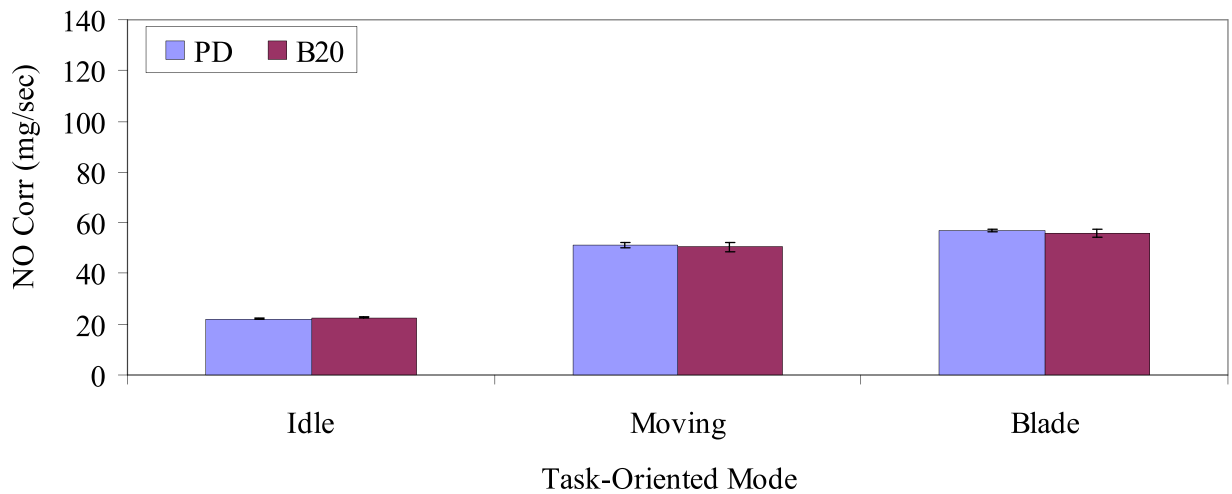


NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 86 ^{o}F and the relative humidity was 56 %. For the B20 biodiesel test, the ambient temperature was 83 ^{o}F and the relative humidity was 42 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F59. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Time Basis for Task-Oriented Based Modes for Motor Grader 6 (continued on next page)





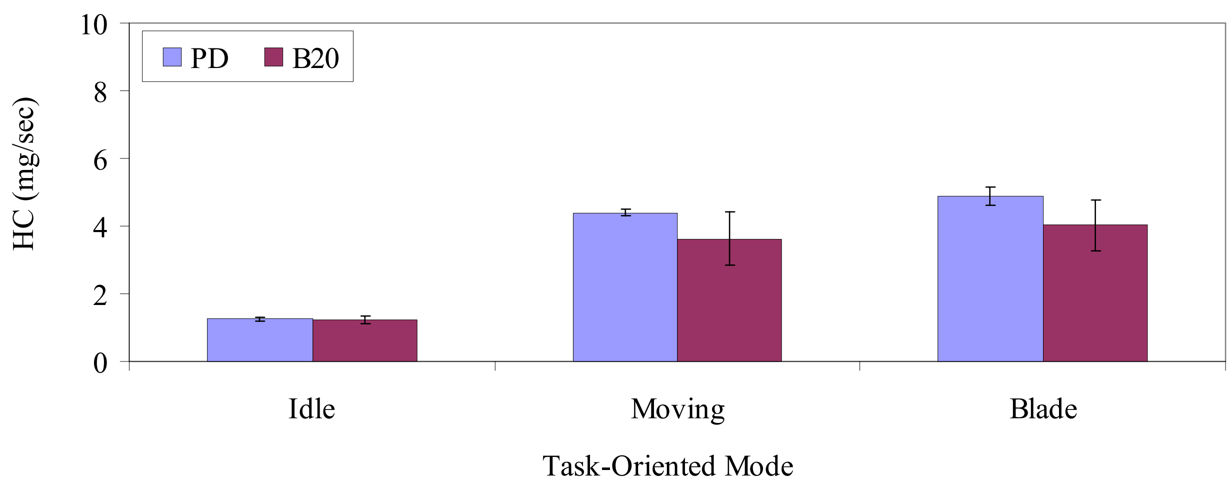


Figure F59. Continued

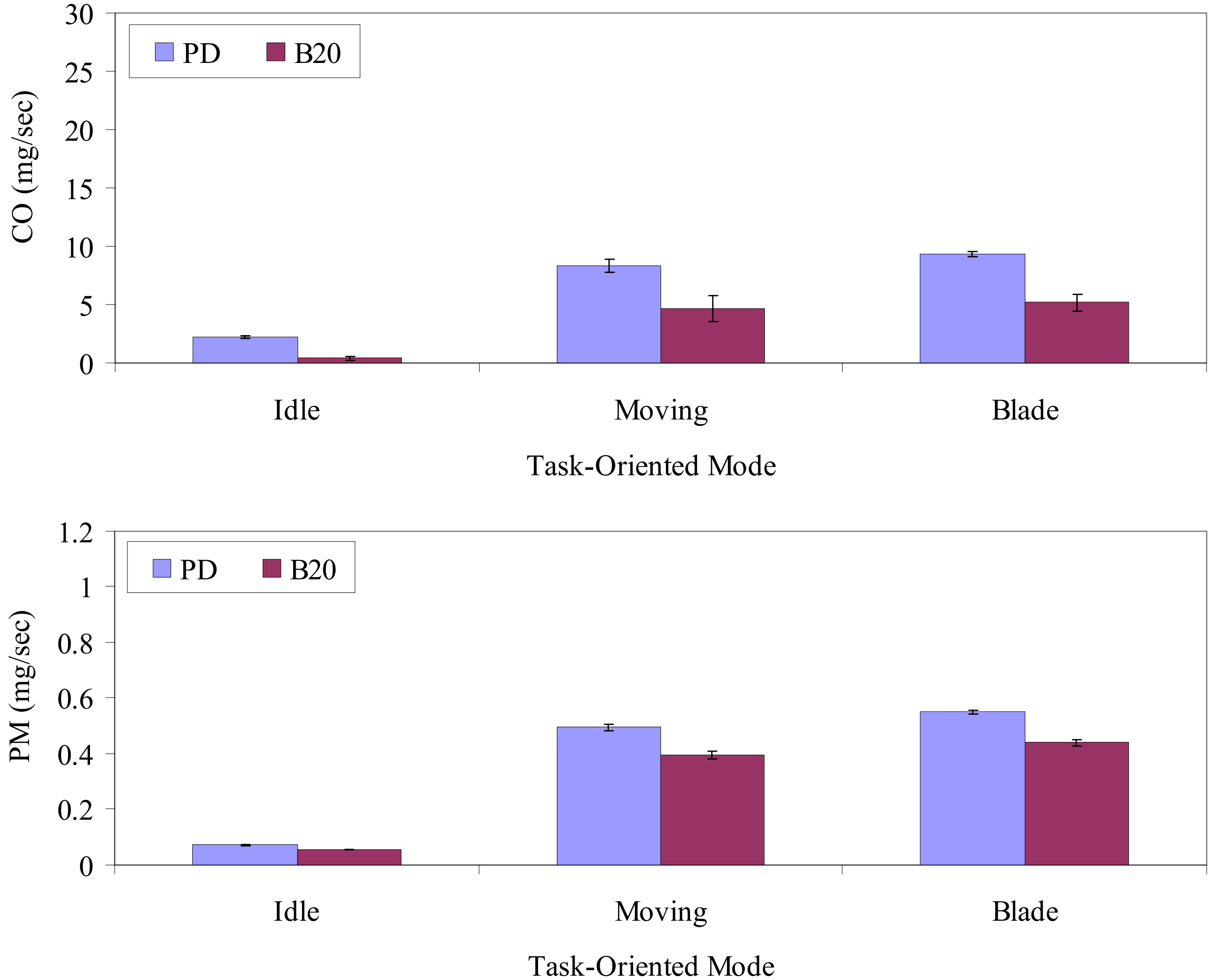
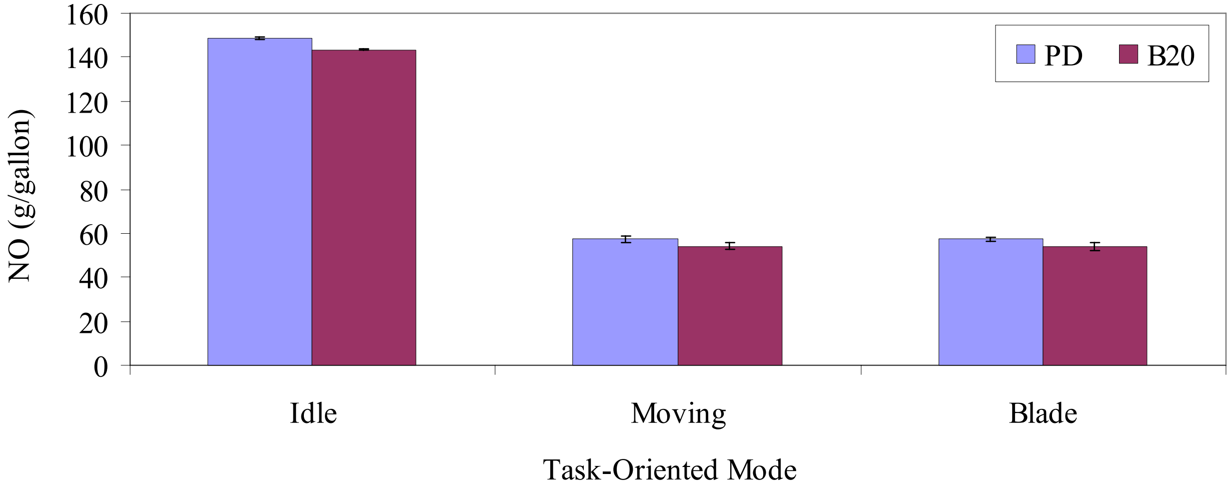
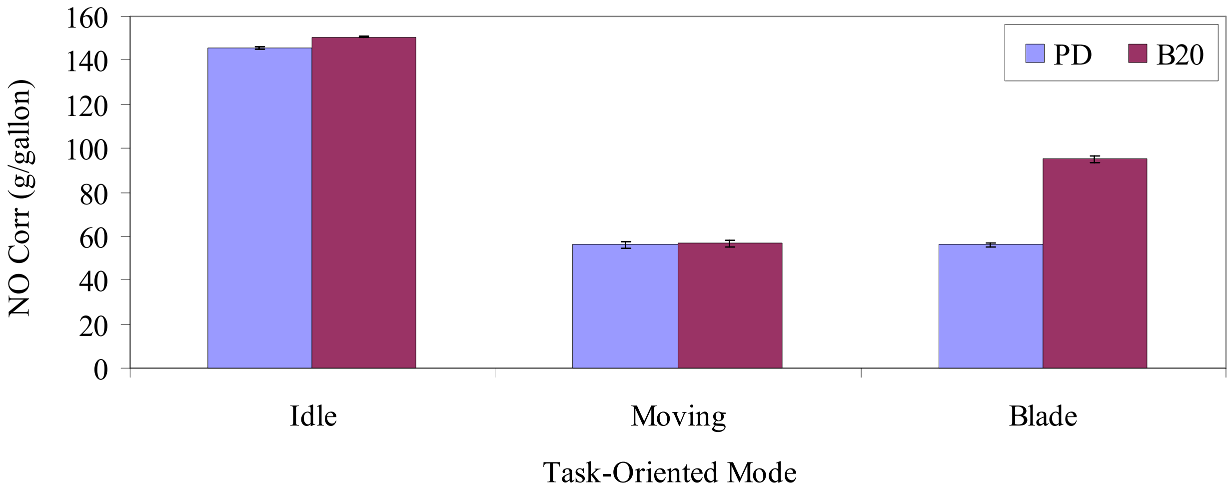


Figure F59. Continued





NO Corr: NO emissions are reported as equivalent NO_2 and are corrected based on ambient temperature and humidity. For the petroleum diesel test, the ambient temperature was 86 ^{o}F and the relative humidity was 56 %. For the B20 biodiesel test, the ambient temperature was 83 ^{o}F and the relative humidity was 42 %.

Task-oriented modes are: *idle*: engine on, but the vehicle is not working or moving; *moving*: movement of the motor grader when the blade is not in contact with the ground (forward or backward); *blade*: movement of the motor grader when the blade is in contact with the ground.

Figure F60. Comparison Between Petroleum Diesel and B20 Biodiesel of Average Fuel Use and Emission Rates of Each Pollutant on a Per Gallon of Fuel Consumed Basis for Task-Oriented Based Modes for Motor Grader 6 (continued on next page)

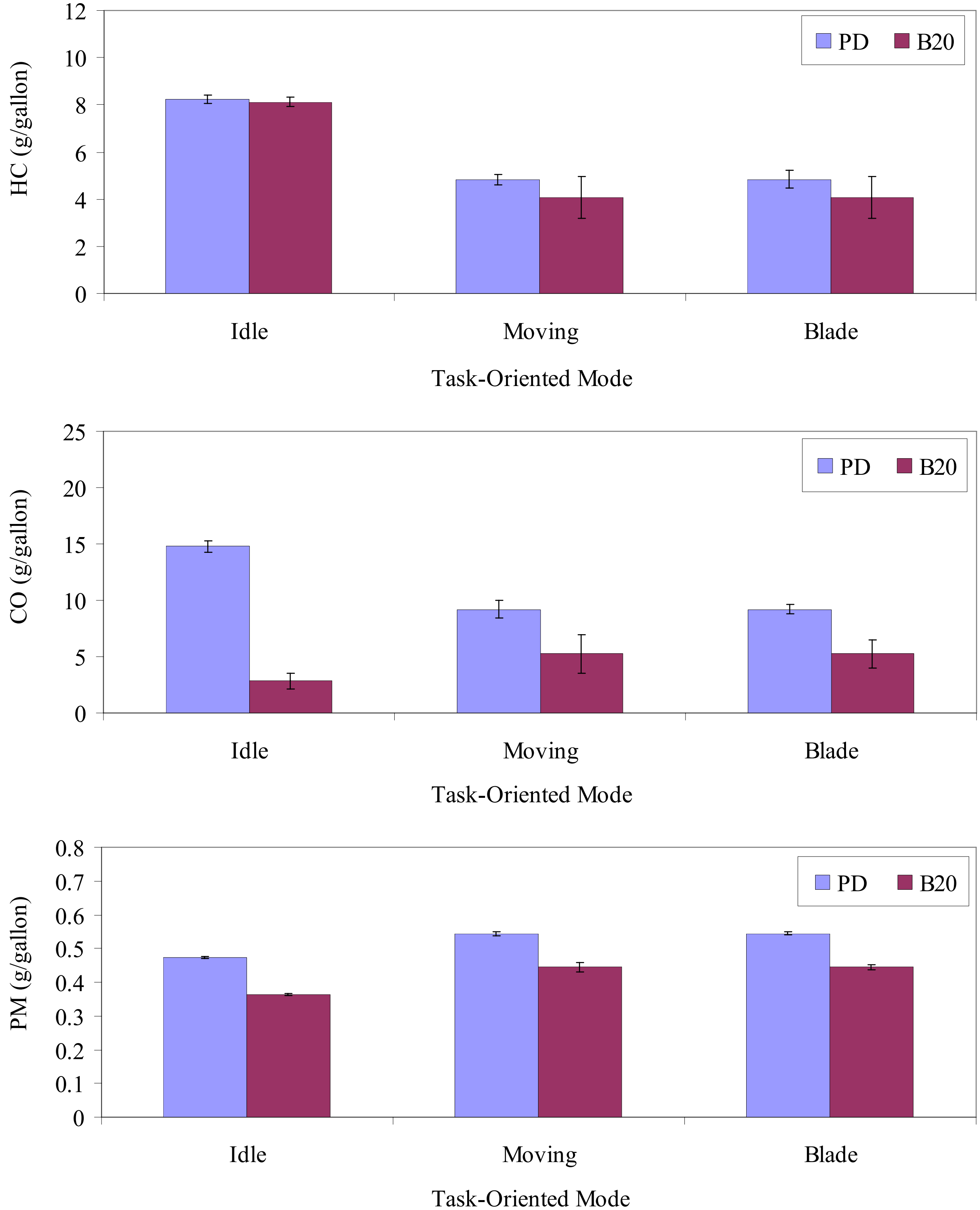


Figure F60. Continued

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EPA (2003). 40 CFR Chapter I Section 86.1342-90 "Humidity Correction Factor", U.S. Environmental Protection Agency, pp. 309, July 1st, 2003.

EPA (2004), 40 CFR Part II Section 85, 86, 89, 90, 91, 92, 94, 1039, 1048, 1051, 1065, and 1068 "Test Procedures for Testing Highway and Nonroad Engines and Omnibus Technical Amendments; Proposed Rule.", U.S. Environmental Protection Agency, Federal Register Vol. 69, No. 175, September 10th, 2004.

Norbeck, J.M., J.W. Miller, W.A. Welch, M. Smith, K. Johnson, and D. Pankratz (2001). "Develop On-Road System for Emissions Measurement from Heavy-Duty Trucks." *Final report, prepared by University of California at Riverside for South Coast Air Quality Management District Technology Advancement Office*.

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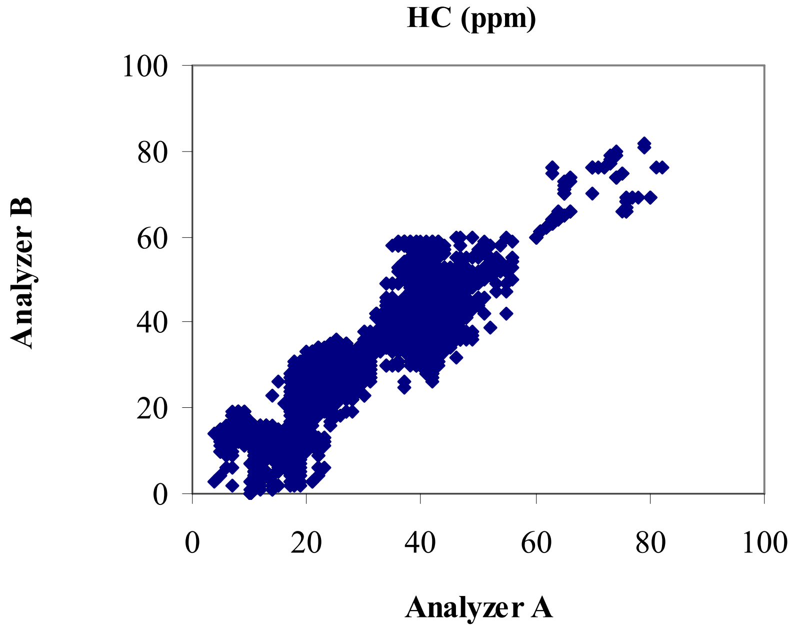
APPENDIX G. EVALUATION OF NON-DETECTED MEASUREMENTS OF HC AND CO EXHAUST GAS CONCENTRATIONS AND MODAL AVERAGE EMISSION RATES FOR ENGINE-BASED MODES

For diesel engines, nitric oxide (NO), oxygen (O_2), and carbon dioxide (CO_2) concentrations are above the detection limit of the gas analyzers in the PEMS. However, HC and CO concentrations from diesel engine can be below the detection limit of the gas analyzers in some cases. Thus, the robustness of comparisons of emission rates among modes or between fuels may be limited when a large proportion of data are below the detection limit. Based on previous work, mean values of a data set are often robust if the mean of the data is larger than the detection limit. In order to identify the uncertainty associated with modal emission rates, the detection limit of the PEMS need to be carefully determined.

The PEMS has two gas analyzers to measure the exhaust gas concentration of NO, HC, CO, O_2, and CO_2. In order to determine the detection limit for HC and CO, a scatter plot was used to compare the HC and CO concentration for both analyzers as shown in Figure G1. When the gas concentration is below the detection limit, the readings from two analyzers do not agree well typically.

To evaluate and select a detection limit, linear regression was applied to portions of the data. For example, if all concentrations above 20 ppm are removed, a linear regression to the remaining data has a very low coefficient of determination (R^2), indicating large random difference between the two gas analyzers. However, if a higher cut-off such as 40 ppm, is used, the scatter plot has a statistically significant association between the two gas analyzers. Based on Figure G1, the detection limits for HC and CO are approximately 20 ppm and 0.02 vol%, respectively. These detection limits are assumed to apply to all vehicles and both tests of each vehicle. If a mean modal emission rate in an MAP bin is below these detection limits, there is less confidence in the stability of the mean value. As shown in Table G2, there are 33 cases in which the mean modal concentration of either pollutant is below the detection limit for one or more of the 10 engine-based modes.

Tables G2 to G30 show the modal average concentrations of each pollutant for each of the engine-based modes. For cases in which the average modal concentration is below a detection limit, that cell is shaded. In this report, NO is reported as equivalent NO_2.



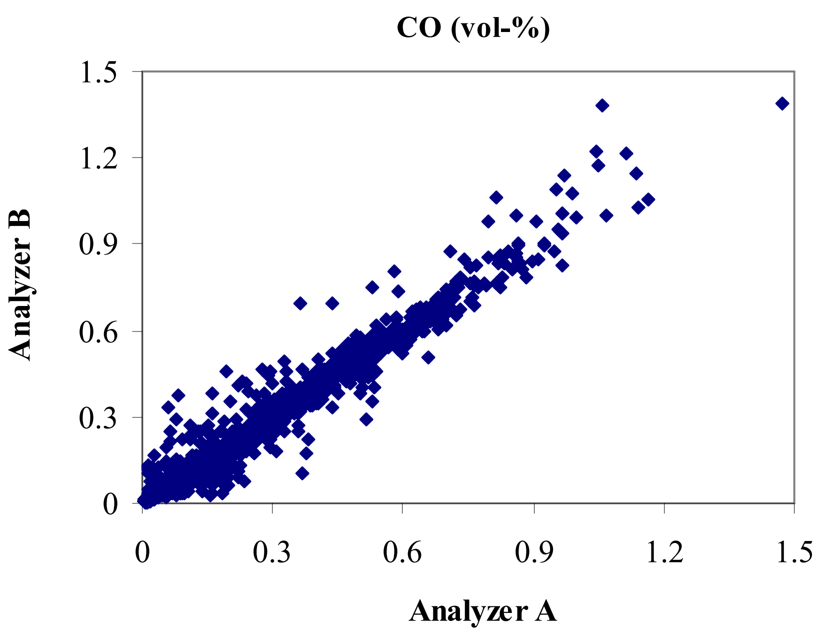


Figure G1. Comparison of Measured Exhaust Gas Concentrations for Analyzers A and B for HC and CO

Table G1. Frequency With Which Mean Exhaust Gas Concentration was Below Detection Limit for HC and CO Engine-Based Modal Emission Rates

Test Vehicle	Vehicle ID	Engine Type (Tier)	HC		CO	
			B20 Biodiesel	Petroleum Diesel	B20 Biodiesel	Petroleum Diesel
Backhoe	803-0242	0	O	O	X (1)	O
	803-0241	1	O	O	O	O
	808-0214	1	X (8)	X (8)	X (1)	O
	FDP22085	2	X (10)	X (8)	X (5)	X (10)
	FDP20882	2	X (10)	X (5)	X (10)	X (10)
Front-End Loader	010-0249	1	X (10)	O	X (9)	X (9)
	010-0301	1	X (10)	O	X (10)	X (10)
	010-5074	1	X (9)	O	X (10)	X (10)
	010-0388	2	X (10)	X (10)	X (7)	X (10)
Motor Grader	948-6647	0	O	O	O	O
	955-0277	0	O	O	O	O
	955-0515	1	O	O	O	O
	955-0516	1	O	O	O	O
	955-0606	2	X (8)	X (5)	X (7)	X (6)
	955-0633	3	X (10)	X (10)	X (10)	X (9)

O: The average modal concentrations are over detection limit

X: Number of engine-based modes for which the mean concentration was below the detection limit for a given tested vehicle

Table G2. Modal Average Concentrations for Each Pollutant for Backhoe 1 Fueled with B20 Biodiesel

BH1- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
95-102	0.1	342	12.8	0.003	1.46	18.5
103-110	0.2	442	18.2	0.005	2.69	16.3
111-118	0.3	442	14.7	0.005	3.21	15.8
119-126	0.4	452	14.5	0.006	3.65	15.4
127-134	0.5	358	15.9	0.006	3.44	15.8
135-142	0.6	318	18.1	0.006	3.41	15.8
143-150	0.7	312	16.8	0.006	3.68	15.5
151-158	0.8	311	18.8	0.007	3.87	15.3
159-166	0.9	403	18.6	0.007	4.79	14.5
167-179	1	503	17.9	0.007	5.43	13.4

Table G3. Modal Average Concentrations for Each Pollutant for Backhoe 1 Fueled with Petroleum Diesel

BH1- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
95-102	0.1	258	9.47	0.001	1.13	19.0
103-110	0.2	425	21.4	0.005	2.57	16.7
111-118	0.3	371	18.2	0.005	2.90	16.5
119-126	0.4	371	18.1	0.005	3.28	16.3
127-134	0.5	371	19.6	0.005	3.43	16.2
135-142	0.6	386	21.2	0.006	3.36	16.1
143-150	0.7	376	21.0	0.005	3.43	16.0
151-158	0.8	386	21.3	0.006	3.67	15.7
159-166	0.9	399	19.8	0.006	4.04	15.3
167-179	1	413	21.3	0.007	4.00	15.3

Table G4. Modal Average Concentrations for Each Pollutant for Backhoe 2 Fueled with B20 Biodiesel

BH2- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
94-97	0.1	104	45.3	0.017	2.13	18.5
98-102	0.2	431	42.9	0.030	4.70	14.5
103-107	0.3	523	36.2	0.040	5.41	13.3
108-112	0.4	673	47.1	0.092	6.29	11.8
113-117	0.5	859	47.4	0.222	7.86	9.80
118-122	0.6	1181	44.9	0.381	9.67	7.16
123-127	0.7	1228	44.1	0.288	9.81	6.98
128-132	0.8	1286	43.2	0.198	9.85	6.98
133-137	0.9	1347	41.2	0.162	9.97	6.91
138-141	1	1404	39.7	0.126	9.58	7.18

Table G5. Modal Average Concentrations for Each Pollutant for Backhoe 2 Fueled with Petroleum Diesel

BH2- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
94-97	0.1	94.4	59.1	0.024	2.33	17.4
98-102	0.2	420	46.7	0.032	4.76	14.3
103-107	0.3	520	39.2	0.041	5.54	13.1
108-112	0.4	659	54.2	0.090	6.30	11.8
113-117	0.5	856	56.7	0.221	7.91	9.65
118-122	0.6	1185	50.0	0.377	9.59	7.05
123-127	0.7	1229	48.9	0.288	9.79	6.88
128-132	0.8	1281	47.4	0.200	9.88	6.88
133-137	0.9	1325	43.0	0.160	9.95	6.89
138-141	1	1375	41.1	0.126	9.38	7.10

Shaded table cells indicate that the modal average is below the detection limit.

Table G6. Modal Average Concentrations for Each Pollutant for Backhoe 3 Fueled with B20 Biodiesel

BH3- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-101	0.1	93.0	25.0	0.019	2.10	17.8
102-107	0.2	609	27.1	0.021	4.77	13.8
108-113	0.3	699	27.3	0.031	5.61	13.0
114-119	0.4	678	25.7	0.050	6.20	12.7
120-125	0.5	677	32.7	0.070	6.75	12.6
126-131	0.6	658	50.6	0.047	6.56	11.7
132-137	0.7	677	66.5	0.034	6.56	11.4
138-143	0.8	705	79.9	0.034	6.78	11.3
144-149	0.9	759	69.1	0.038	7.06	11.1
150-155	1	825	71.6	0.046	9.04	8.93

Table G7. Modal Average Concentrations for Each Pollutant for Backhoe 3 Fueled with Petroleum Diesel

BH3- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-101	0.1	201	81.5	0.016	2.49	17.0
102-107	0.2	485	87.4	0.034	4.59	14.0
108-113	0.3	332	97.1	0.029	4.53	14.2
114-119	0.4	321	87.2	0.028	4.73	14.0
120-125	0.5	377	86.4	0.035	5.28	13.3
126-131	0.6	720	105	0.074	7.44	10.9
132-137	0.7	593	71.6	0.058	7.16	11.4
138-143	0.8	580	50.0	0.040	7.52	10.7
144-149	0.9	710	34.5	0.036	8.15	9.88
150-155	1	1025	31.6	0.046	9.05	8.69

Table G8. Modal Average Concentrations for Each Pollutant for Backhoe 4 Fueled with B20 Biodiesel

BH4- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
93-97	0.1	395	13.3	0.017	2.30	17.4
98-101	0.2	490	15.9	0.027	3.01	16.3
102-105	0.3	747	28.9	0.136	5.89	11.6
106-109	0.4	739	31.5	0.260	7.20	10.0
110-113	0.5	518	14.6	0.117	6.55	10.8
114-117	0.6	519	14.3	0.100	7.06	10.4
118-121	0.7	549	13.9	0.094	7.98	9.35
122-125	0.8	559	14.9	0.114	8.66	8.50
126-129	0.9	575	15.8	0.197	9.77	7.32
130-133	1	588	14.2	0.234	10.7	6.07

Table G9. Modal Average Concentrations for Each Pollutant for Backhoe 4 Fueled with Petroleum Diesel

BH4- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
93-97	0.1	505	25.6	0.030	2.72	16.9
98-101	0.2	714	20.4	0.027	4.03	14.9
102-105	0.3	675	18.2	0.036	5.28	13.3
106-109	0.4	648	18.3	0.042	5.82	12.9
110-113	0.5	697	18.3	0.071	6.86	12.1
114-117	0.6	837	17.7	0.247	8.53	10.7
118-121	0.7	859	17.1	0.357	9.46	9.34
122-125	0.8	834	14.9	0.520	9.74	9.03
126-129	0.9	734	15.2	0.752	9.14	9.94
130-133	1	750	13.3	0.684	11.3	6.16

Shaded table cells indicate that the modal average is below the detection limit.

Table G10. Modal Average Concentrations for Each Pollutant for Backhoe 5 Fueled with B20 Biodiesel

BH5- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
95-102	0.1	334	1.81	0.004	1.40	18.7
103-110	0.2	436	6.72	0.013	2.59	16.5
111-118	0.3	460	7.30	0.007	3.33	15.5
119-126	0.4	481	7.67	0.006	3.88	15.1
127-134	0.5	501	8.14	0.008	4.25	14.8
135-142	0.6	469	8.38	0.035	4.22	15.0
143-150	0.7	558	8.47	0.036	4.66	14.0
151-158	0.8	512	8.53	0.027	4.69	14.0
159-166	0.9	529	8.32	0.034	5.08	14.1
167-179	1	526	8.06	0.022	5.30	13.4

Table G11. Modal Average Concentrations for Each Pollutant for Backhoe 5 Fueled with Petroleum Diesel

BH5- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
95-102	0.1	267	13.2	0.005	1.27	18.8
103-110	0.2	447	15.1	0.008	3.11	16.2
111-118	0.3	425	18.5	0.009	3.27	16.1
119-126	0.4	397	22.0	0.010	3.23	16.2
127-134	0.5	403	22.3	0.011	3.32	16.1
135-142	0.6	473	14.0	0.009	3.65	15.9
143-150	0.7	485	16.2	0.009	3.44	16.1
151-158	0.8	472	14.4	0.010	3.76	15.7
159-166	0.9	476	14.5	0.010	3.67	15.8
167-179	1	459	16.9	0.011	3.80	15.7

Table G12. Modal Average Concentrations for Each Pollutant for Front-End Loader 1 Fueled with B20 Biodiesel

FL1- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
97-106	0.1	357	15.5	0.023	2.03	18.1
107-116	0.2	401	12.4	0.009	3.02	16.6
117-126	0.3	396	12.5	0.009	3.27	16.5
127-136	0.4	401	12.6	0.009	3.47	16.2
137-146	0.5	393	13.1	0.009	3.57	16.2
147-156	0.6	397	13.3	0.009	3.68	16.1
157-166	0.7	383	12.6	0.009	3.7	16.1
167-176	0.8	395	13.0	0.009	3.87	15.9
177-186	0.9	400	12.6	0.009	3.9	15.8
187-196	1	388	12.5	0.009	3.85	15.9

Table G13. Modal Average Concentrations for Each Pollutant for Front-End Loader 1 Fueled with Petroleum Diesel

FL1- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
97-106	0.1	385	46.1	0.024	2.16	17.6
107-116	0.2	491	41.6	0.013	3.49	15.3
117-126	0.3	605	41.5	0.011	4.64	13.8
127-136	0.4	580	41.1	0.011	4.98	13.5
137-146	0.5	596	41.3	0.01	5.34	13.3
147-156	0.6	595	40.7	0.01	5.53	13.1
157-166	0.7	595	40.6	0.01	5.77	12.9
167-176	0.8	578	40.9	0.011	5.92	12.8
177-186	0.9	580	40.9	0.01	6.14	12.5
187-196	1	592	42.9	0.01	6.32	12.2

Shaded table cells indicate that the modal average is below the detection limit.

Table G14. Modal Average Concentrations for Each Pollutant for Front-End Loader 2 Fueled with B20 Biodiesel

FL2- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
100-111	0.1	305	15.5	0.011	1.65	18.5
112-123	0.2	378	14.6	0.009	2.56	17.3
124-135	0.3	480	13.0	0.007	3.24	16.5
136-147	0.4	427	13.4	0.006	3.19	16.6
148-159	0.5	412	13.4	0.006	3.31	16.4
160-171	0.6	363	13.3	0.005	3.11	16.6
172-183	0.7	358	13.8	0.006	3.45	16.2
184-195	0.8	385	13.6	0.006	3.67	15.9
196-207	0.9	407	13.6	0.006	3.78	15.7
208-219	1	474	14.5	0.006	4.32	15.1

Table G15. Modal Average Concentrations for Each Pollutant for Front-End Loader 2 Fueled with Petroleum Diesel

FL2- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
100-111	0.1	420	40.8	0.01	2.36	17.3
112-123	0.2	484	39.9	0.008	3.44	15.8
124-135	0.3	557	41.0	0.007	4.04	15.0
136-147	0.4	578	38.4	0.007	4.45	14.4
148-159	0.5	593	40.5	0.007	4.67	14.1
160-171	0.6	600	38.5	0.006	5.01	13.7
172-183	0.7	590	39.4	0.006	5.12	13.5
184-195	0.8	590	42.1	0.006	5.35	13.2
196-207	0.9	589	37.1	0.007	5.51	12.9
208-219	1	585	38.5	0.007	5.68	12.7

Table G16. Modal Average Concentrations for Each Pollutant for Front-End Loader 3 Fueled with B20 Biodiesel

FL3- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
100-112	0.1	355	30.6	0.005	1.71	18.3
113-123	0.2	372	15.1	0.004	2.67	16.9
124-134	0.3	399	14.8	0.004	2.91	16.7
135-145	0.4	399	14.5	0.004	3.06	16.7
146-156	0.5	402	15.7	0.004	3.25	16.5
157-167	0.6	398	15.8	0.005	3.37	16.4
168-178	0.7	380	17.3	0.004	3.41	16.5
179-189	0.8	419	15.1	0.005	3.8	16.1
190-200	0.9	468	14.2	0.005	4.18	15.6
201-211	1	501	14.6	0.006	4.55	14.8

Table G17. Modal Average Concentrations for Each Pollutant for Front-End Loader 3 Fueled with Petroleum Diesel

FL3- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
100-112	0.1	338	34.3	0.015	2.34	17.2
113-123	0.2	543	29.5	0.011	4.09	14.7
124-134	0.3	527	31.3	0.011	4.59	14.0
135-145	0.4	524	32.8	0.011	4.86	13.5
146-156	0.5	522	29.1	0.011	5.1	13.4
157-167	0.6	536	29.0	0.012	5.59	13.0
168-178	0.7	576	28.6	0.011	5.54	12.7
179-189	0.8	612	28.9	0.011	6.15	12.0
190-200	0.9	655	28.7	0.011	6.68	11.4
201-211	1	678	28.5	0.01	6.56	11.3

Shaded table cells indicate that the modal average is below the detection limit.

Table G18. Modal Average Concentrations for Each Pollutant for Front-End Loader 4 Fueled with B20 Biodiesel

FL4- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
97-106	0.1	280	13.0	0.016	2.6	17.1
107-116	0.2	445	12.6	0.016	4.04	14.7
117-126	0.3	447	12.4	0.015	4.49	14.5
127-136	0.4	440	12.5	0.017	4.91	14.3
137-146	0.5	434	12.3	0.017	5.11	14.1
147-156	0.6	433	12.4	0.018	5.41	13.8
157-166	0.7	433	12.0	0.021	5.74	13.7
167-176	0.8	433	12.4	0.024	5.93	13.4
177-186	0.9	464	13.2	0.022	6.43	13.0
187-196	1	521	12.2	0.019	7.2	11.9

Table G19. Average Concentrations for Each Pollutant Based on Front-End Loader 4 Fueled with Petroleum Diesel

FL4- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
97-106	0.1	253	17.4	0.015	2.51	17.2
107-116	0.2	446	14.0	0.013	4.07	15.1
117-126	0.3	445	13.9	0.014	4.77	14.2
127-136	0.4	481	14.0	0.015	5.4	13.3
137-146	0.5	453	14.7	0.017	5.52	13.4
147-156	0.6	470	15.8	0.014	5.65	13.3
157-166	0.7	489	12.6	0.014	6.09	12.7
167-176	0.8	513	12.5	0.017	6.41	12.5
177-186	0.9	483	13.5	0.016	6.69	12.6
187-196	1	532	15.2	0.013	7.14	11.5

Table G20. Modal Average Concentrations for Each Pollutant for Motor Grader 1 Fueled with B20 Biodiesel

MG1- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
102-116	0.1	408	25.4	0.034	2.33	17.6
117-130	0.2	547	24.2	0.033	4.01	15.2
131-144	0.3	521	24.1	0.026	4.03	15.2
145-158	0.4	487	23.3	0.023	4.09	15.3
159-172	0.5	484	22.8	0.022	4.26	15.0
173-186	0.6	476	23.8	0.021	4.36	14.9
187-200	0.7	484	28.2	0.020	4.55	14.7
201-214	0.8	519	23.1	0.021	4.91	14.3
215-228	0.9	566	25.5	0.023	5.40	13.7
229-243	1	660	29.1	0.035	6.26	12.8

Table G21. Modal Average Concentrations for Each Pollutant for Motor Grader 1 Fueled with Petroleum Diesel

MG1- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
102-116	0.1	474	35.9	0.037	2.75	17.0
117-130	0.2	608	30.4	0.034	4.09	15.2
131-144	0.3	556	34.7	0.031	4.30	15.0
145-158	0.4	514	30.0	0.025	4.15	15.1
159-172	0.5	478	31.0	0.022	4.20	15.1
173-186	0.6	472	30.4	0.021	4.32	15.0
187-200	0.7	489	27.5	0.022	4.55	14.7
201-214	0.8	532	26.8	0.023	4.86	14.3
215-228	0.9	624	29.2	0.027	5.60	13.4
229-243	1	696	31.1	0.030	6.41	12.6

Shaded table cells indicate that the modal average is below the detection limit.

Table G22. Modal Average Concentrations for Each Pollutant for Motor Grader 2 Fueled with B20 Biodiesel

MG2- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
101-115	0.1	427	19.8	0.009	2.23	17.2
116-129	0.2	457	29.9	0.033	3.36	15.2
130-144	0.3	429	20.0	0.025	3.46	15.3
145-158	0.4	425	18.3	0.035	3.55	15.1
159-173	0.5	435	19.3	0.015	4.09	14.5
174-187	0.6	420	19.3	0.012	4.20	14.3
188-202	0.7	426	19.2	0.016	4.54	14.0
203-216	0.8	423	17.9	0.011	4.67	13.7
217-231	0.9	502	19.0	0.009	5.12	13.0
232-246	1	541	17.2	0.008	5.33	12.7

Table G23. Modal Average Concentrations for Each Pollutant for Motor Grader 2 Fueled with Petroleum Diesel

MG2- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
101-115	0.1	431	35.4	0.013	2.27	16.8
116-129	0.2	451	35.5	0.071	3.64	14.9
130-144	0.3	443	31.3	0.030	3.65	14.4
145-158	0.4	448	29.9	0.029	4.05	13.8
159-173	0.5	423	25.7	0.022	4.41	13.4
174-187	0.6	497	19.8	0.014	5.19	12.3
188-202	0.7	436	19.6	0.018	4.96	12.6
203-216	0.8	490	18.6	0.014	5.26	12.1
217-231	0.9	473	16.8	0.009	5.61	11.8
232-246	1	553	16.0	0.008	6.05	10.9

Table G24. Modal Average Concentrations for Each Pollutant for Motor Grader 3 Fueled with B20 Biodiesel

MG3- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-108	0.1	439	28.3	0.032	2.31	17.4
109-121	0.2	403	39.9	0.041	3.67	15.4
122-134	0.3	413	33.0	0.027	4.02	15.0
135-146	0.4	431	28.4	0.023	4.31	14.6
147-159	0.5	445	25.6	0.021	4.70	14.2
160-172	0.6	486	24.8	0.020	4.98	13.7
173-184	0.7	531	25.3	0.021	5.31	13.2
185-197	0.8	566	25.9	0.021	5.61	12.8
198-210	0.9	634	25.3	0.022	6.14	12.1
211-223	1	651	26.3	0.023	6.44	11.8

Table G25. Modal Average Concentrations for Each Pollutant for Motor Grader 3 Fueled with Petroleum Diesel

MG3- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-108	0.1	441	33.7	0.022	2.31	17.8
109-121	0.2	505	39.0	0.028	3.72	15.7
122-134	0.3	535	41.5	0.029	4.38	14.9
135-146	0.4	508	39.1	0.032	4.55	14.9
147-159	0.5	421	35.6	0.029	4.44	15.1
160-172	0.6	425	34.8	0.027	4.64	14.8
173-184	0.7	458	37.9	0.030	4.91	14.4
185-197	0.8	562	47.0	0.041	5.59	13.7
198-210	0.9	651	49.3	0.042	6.12	13.2
211-223	1	713	33.7	0.030	7.90	11.0

Shaded table cells indicate that the modal average is below the detection limit.

Table G26. Modal Average Concentrations for Each Pollutant for Motor Grader 4 Fueled with B20 Biodiesel

MG4- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-108	0.1	449	46.9	0.134	2.43	17.5
109-114	0.2	718	40.2	0.073	3.32	16.3
115-121	0.3	812	41.2	0.063	4.18	15.3
122-132	0.4	931	39.0	0.046	4.62	14.7
133-139	0.5	965	40.1	0.045	4.94	14.4
140-146	0.6	1093	42.4	0.039	5.45	13.8
147-158	0.7	1262	41.1	0.041	5.96	12.9
159-165	0.8	1124	40.7	0.073	6.25	13.6
166-172	0.9	1414	43.6	0.042	6.77	12.3
172-188	1	1467	30.8	0.065	7.35	12.1

Table G27. Modal Average Concentrations for Each Pollutant for Motor Grader 4 Fueled with Petroleum Diesel

MG4- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-108	0.1	544	69.2	0.099	2.39	17.3
109-114	0.2	858	55.6	0.060	3.68	15.8
115-121	0.3	728	55.1	0.054	3.98	15.4
122-132	0.4	709	50.4	0.050	4.41	14.9
133-139	0.5	819	43.4	0.055	4.91	14.4
140-146	0.6	1006	47.1	0.069	5.71	13.4
147-158	0.7	1193	55.3	0.076	6.43	12.5
159-165	0.8	1358	56.0	0.070	6.97	11.9
166-172	0.9	1559	54.5	0.060	7.55	11.2
172-188	1	1575	55.1	0.067	7.68	11.0

Table G28. Modal Average Concentrations for Each Pollutant for Motor Grader 5 Fueled with B20 Biodiesel

MG5- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-110	0.1	515	46.2	0.039	2.34	17.4
111-120	0.2	710	50.5	0.101	3.59	15.6
121-129	0.3	705	44.6	0.080	4.19	15.0
130-140	0.4	664	41.9	0.080	4.45	14.8
141-150	0.5	698	37.8	0.067	4.78	14.3
151-161	0.6	792	34.4	0.048	5.29	13.7
162-170	0.7	927	36.7	0.046	5.79	13.0
171-180	0.8	1098	38.6	0.049	6.38	12.2
181-190	0.9	1250	44.5	0.054	7.06	11.6
191-201	1	1382	56.1	0.043	7.23	11.0

Table G29. Modal Average Concentrations for Each Pollutant for Motor Grader 5 Fueled with Petroleum Diesel

MG5- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
96-110	0.1	515	54.9	0.126	2.73	17.7
111-120	0.2	804	57.2	0.148	4.54	15.8
121-129	0.3	886	53.9	0.119	5.28	15.1
130-140	0.4	888	50.8	0.101	5.67	14.6
141-150	0.5	793	48.9	0.085	5.59	14.6
151-161	0.6	814	49.6	0.081	6.02	14.2
162-170	0.7	906	48.7	0.057	6.33	13.8
171-180	0.8	1051	50.7	0.059	6.87	13.3
181-190	0.9	1191	45.1	0.058	7.60	12.7
191-201	1	1230	41.7	0.048	8.03	12.5

Shaded table cells indicate that the modal average is below the detection limit.

Table G30. Modal Average Concentrations for Each Pollutant for Motor Grader 6 Fueled with B20 Biodiesel

MG6- B20	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
97-116	0.1	289	12.3	0.005	2.02	17.6
117-135	0.2	226	10.4	0.006	2.30	17.2
136-154	0.3	190	12.8	0.008	2.37	17.1
155-174	0.4	184	10.6	0.007	2.63	16.7
175-193	0.5	186	14.0	0.011	2.85	16.4
194-212	0.6	172	12.5	0.009	2.99	16.0
213-232	0.7	155	9.81	0.007	3.29	15.8
233-251	0.8	156	8.03	0.007	3.59	15.3
252-270	0.9	167	7.85	0.006	4.03	14.8
271-290	1	205	8.38	0.005	4.63	14.0

Table G31. Modal Average Concentrations for Each Pollutant for Motor Grader 6 Fueled with Petroleum Diesel

MG6- PD	N_MAP	NO as Equivalent NO_2 (ppm)	HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)
97-116	0.1	296	9.82	0.011	1.99	17.9
117-135	0.2	279	12.6	0.012	2.56	17.1
136-154	0.3	201	13.4	0.011	2.46	17.3
155-174	0.4	188	15.6	0.009	2.59	17.1
175-193	0.5	168	16.8	0.033	2.81	16.8
194-212	0.6	161	15.3	0.010	3.15	16.3
213-232	0.7	181	11.9	0.013	3.58	15.6
233-251	0.8	197	9.97	0.015	4.02	15.1
252-270	0.9	205	9.23	0.013	4.33	14.7
271-290	1	267	8.73	0.021	4.77	14.1

Shaded table cells indicate that the modal average is below the detection limit.

APPENDIX H: SUPPLEMENTARY TABLES FOR EMISSIONS INVENTORY

LIST OF TABLES

The tables in this appendix show the intermediate data that was used to make the comparisons of emissions based on fuel type and engine tiers reported in Section 3.12 of this report. These tables show the average annual fuel use for petroleum diesel and B20 biodiesel, the emission factors for petroleum diesel and B20 biodiesel, and the resulting estimated average annual emissions for petroleum diesel and B20 biodiesel. This data is classified by engine tier for the backhoes, front-end loaders, and motor graders and results are provided for NO as equivalent NO_2, opacity, HC, and CO.

Table H1. Estimated Backhoe Average Annual Emissions Based on Current Fuel Use and Engine Tiers

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	B20	Petroleum	B20	Petroleum	B20	Petroleum	Total
Tier 0	16,094	63,286	108	105	1.9	7.3	9.2
Tier 1	17,756	75,435	94	104	1.8	8.6	10.5
Tier 2	3,566	22,736	97	99	0.4	2.5	2.9
TOTAL	37,416	161,457			4.1	18.4	22.6
Opacity							
Tier 0	16,094	63,286	1.16	1.2	0.021	0.084	0.104
Tier 1	17,756	75,435	1.06	1.31	0.021	0.109	0.130
Tier 2	3,566	22,736	0.54	0.71	0.002	0.018	0.020
TOTAL	37,416	161,457			0.043	0.210	0.254
HC							
Tier 0	16,094	63,286	13.9	15.4	0.2	1.1	1.3
Tier 1	17,756	75,435	8.5	10.1	0.2	0.8	1.0
Tier 2	3,566	22,736	5.8	10.4	0.0	0.3	0.3
TOTAL	37,416	161,457			0.4	2.2	2.6
CO							
Tier 0	16,094	63,286	72	88	1.3	6.1	7.4
Tier 1	17,756	75,435	38	44	0.7	3.7	4.4
Tier 2	3,566	22,736	10	13	0.0	0.3	0.4
TOTAL	37,416	161,457			2.1	10.1	12.2

Table H2. Estimated Backhoe Average Annual Emissions Using Petroleum Diesel Only

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	0	79,701	108	105	0	9.2	9.2
Tier 1	0	93,546	94	104	0	10.7	10.7
Tier 2	0	26,373	97	99	0	2.9	2.9
TOTAL	0	199,621			0	22.8	22.8
Opacity							
Tier 0	0	79,701	1.16	1.2	0	0.105	0.105
Tier 1	0	93,546	1.06	1.31	0	0.135	0.135
Tier 2	0	26,373	0.54	0.71	0	0.021	0.021
TOTAL	0	199,621			0	0.261	0.261
HC							
Tier 0	0	79,701	13.9	15.4	0	1.4	1.4
Tier 1	0	93,546	8.5	10.1	0	1.0	1.0
Tier 2	0	26,373	5.8	10.4	0	0.3	0.3
TOTAL	0	199,621			0	2.7	2.7
CO							
Tier 0	0	79,701	72	88	0	7.7	7.7
Tier 1	0	93,546	38	44	0	4.5	4.5
Tier 2	0	26,373	10	13	0	0.4	0.4
TOTAL	0	199,621			0	12.6	12.6

Table H3. Estimated Backhoe Average Annual Emissions Using B20 Only

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	78,113	0	108	105	9.3	0.0	9.3
Tier 1	91,683	0	94	104	9.5	0.0	9.5
Tier 2	25,847	0	97	99	2.8	0.0	2.8
TOTAL	195,643	0			21.5	0.0	21.5
Opacity							
Tier 0	78,113	0	1.16	1.2	0.100	0.000	0.100
Tier 1	91,683	0	1.06	1.31	0.107	0.000	0.107
Tier 2	25,847	0	0.54	0.71	0.015	0.000	0.015
TOTAL	195,643	0			0.222	0.000	0.222
HC							
Tier 0	78,113	0	13.9	15.4	1.2	0.0	1.2
Tier 1	91,683	0	8.5	10.1	0.9	0.0	0.9
Tier 2	25,847	0	5.8	10.4	0.2	0.0	0.2
TOTAL	195,643	0			2.2	0.0	2.2
CO							
Tier 0	78,113	0	72	88	6.2	0.0	6.2
Tier 1	91,683	0	38	44	3.8	0.0	3.8
Tier 2	25,847	0	10	13	0.3	0.0	0.3
TOTAL	195,643	0			10.3	0.0	10.3

Table H4. Estimated Front-End Loader Average Annual Emissions Based on Current Fuel Use and Engine Tiers

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0[1]	8,253	41,328	121	122	1.1	5.6	6.7
Tier 1	9,892	57,044	121	122	1.3	7.7	9.0
Tier 2	6,425	55,849	93	95	0.7	5.8	6.5
TOTAL	24,571	154,221			3.1	19.1	22.1
Opacity							
Tier 0[1]	8,253	41,328	0.61	0.81	0.006	0.037	0.042
Tier 1	9,892	57,044	0.61	0.81	0.007	0.051	0.058
Tier 2	6,425	55,849	0.57	0.63	0.004	0.039	0.043
TOTAL	24,571	154,221			0.016	0.127	0.143
HC							
Tier 0[1]	8,253	41,328	8.6	15.7	0.1	0.7	0.8
Tier 1	9,892	57,044	8.6	15.7	0.1	1.0	1.1
Tier 2	6,425	55,849	5	5.6	0.0	0.3	0.4
TOTAL	24,571	154,221			0.2	2.0	2.3
CO							
Tier 0[1]	8,253	41,328	10.9	14.9	0.1	0.7	0.8
Tier 1	9,892	57,044	10.9	14.9	0.1	0.9	1.1
Tier 2	6,425	55,849	9	11	0.1	0.7	0.7
TOTAL	24,571	154,221			0.3	2.3	2.6

[1] There were no Tier 0 front-end loaders tested during this study, therefore there are no emission factors for Tier 0 front-end loaders. Thus, Tier 1 emission factors were used for all Tier 0 front-end loaders.

Table H5. Estimated Front-End Loader Average Annual Emissions Using Petroleum Diesel Only

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	0	49,745	121	122	0	6.7	6.7
Tier 1	0	67,135	121	122	0	9.0	9.0
Tier 2	0	62,403	93	95	0	6.5	6.5
TOTAL	0	179,283			0	22.2	22.2
Opacity							
Tier 0	0	49,745	0.61	0.81	0	0.044	0.044
Tier 1	0	67,135	0.61	0.81	0	0.060	0.060
Tier 2	0	62,403	0.57	0.63	0	0.043	0.043
TOTAL	0	179,283			0	0.148	0.148
HC							
Tier 0	0	49,745	8.6	15.7	0	0.9	0.9
Tier 1	0	67,135	8.6	15.7	0	1.2	1.2
Tier 2	0	62,403	5.0	5.6	0	0.4	0.4
TOTAL	0	179,283			0	2.4	2.4
CO							
Tier 0	0	49,745	10.9	14.9	0	0.8	0.8
Tier 1	0	67,135	10.9	14.9	0	1.1	1.1
Tier 2	0	62,403	9.0	11.0	0	0.8	0.8
TOTAL	0	179,283			0	2.7	2.7

[1] There were no Tier 0 front-end loaders tested during this study, therefore there are no emission factors for Tier 0 front-end loaders. Thus, Tier 1 emission factors were used for all Tier 0 front-end loaders.

Table H6. Estimated Front-End Loader Average Annual Emissions Using B20 Only

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	48,754	0	121	122	6.5	0.0	6.5
Tier 1	65,796	0	121	122	8.8	0.0	8.8
Tier 2	61,158	0	93	95	6.3	0.0	6.3
TOTAL	175,707	0			21.5	0.0	21.5
Opacity							
Tier 0	48,754	0	0.61	0.81	0.033	0.000	0.033
Tier 1	65,796	0	0.61	0.81	0.044	0.000	0.044
Tier 2	61,158	0	0.57	0.63	0.038	0.000	0.038
TOTAL	175,707	0			0.115	0.000	0.115
HC							
Tier 0	48,754	0	8.6	15.7	0.5	0.0	0.5
Tier 1	65,796	0	8.6	15.7	0.6	0.0	0.6
Tier 2	61,158	0	5.0	5.6	0.3	0.0	0.3
TOTAL	175,707	0			1.4	0.0	1.4
CO							
Tier 0	48,754	0	10.9	14.9	0.6	0.0	0.6
Tier 1	65,796	0	10.9	14.9	0.8	0.0	0.8
Tier 2	61,158	0	9.0	11.0	0.6	0.0	0.6
TOTAL	175,707	0			2.0	0.0	2.0

[1] There were no Tier 0 front-end loaders tested during this study, therefore there are no emission factors for Tier 0 front-end loaders. Thus, Tier 1 emission factors were used for all Tier 0 front-end loaders.

Table H7. Estimated Motor Grader Average Annual Emissions Based on Current Fuel Use and Engine Tiers

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	B20	Petroleum	B20	Petroleum	B20	Petroleum	Total
Tier 0	26,583	132,680	131	134	3.8	19.6	23.4
Tier 1	85,803	388,014	108	109	10.2	46.6	56.8
Tier 2	6,524	138,883	102	98	0.7	15.0	15.7
TOTAL	118,910	659,577			14.8	81.1	95.9
Opacity							
Tier 0	26,583	132,680	0.81	0.96	0.024	0.140	0.164
Tier 1	85,803	388,014	0.68	0.84	0.064	0.359	0.423
Tier 2	6,524	138,883	0.5	0.63	0.004	0.096	0.100
TOTAL	118,910	659,577			0.092	0.596	0.687
HC							
Tier 0	26,583	132,680	14.6	16.6	0.4	2.4	2.9
Tier 1	85,803	388,014	12.8	16.4	1.2	7.0	8.2
Tier 2	6,524	138,883	8.7	11.8	0.1	1.8	1.9
TOTAL	118,910	659,577			1.7	11.2	12.9
CO							
Tier 0	26,583	132,680	25.6	33.1	0.7	4.8	5.6
Tier 1	85,803	388,014	13.6	14.6	1.3	6.2	7.5
Tier 2	6,524	138,883	10.8	11.9	0.1	1.8	1.9
TOTAL	118,910	659,577			2.1	12.9	15.0

Table H8. Estimated Motor Grader Average Annual Emissions Using Petroleum Diesel Only

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	0	159,794	131	134	0	23.6	23.6
Tier 1	0	475,533	108	109	0	57.1	57.1
Tier 2	0	145,538	102	98	0	15.7	15.7
TOTAL	0	780,865			0	96.4	96.4
Opacity							
Tier 0	0	159,794	0.81	0.96	0	0.169	0.169
Tier 1	0	475,533	0.68	0.84	0	0.440	0.440
Tier 2	0	145,538	0.5	0.63	0	0.101	0.101
TOTAL	0	780,865			0	0.710	0.710
HC							
Tier 0	0	159,794	14.6	16.6	0	2.9	2.9
Tier 1	0	475,533	12.8	16.4	0	8.6	8.6
Tier 2	0	145,538	8.7	11.8	0	1.9	1.9
TOTAL	0	780,865			0	13.4	13.4
CO							
Tier 0	0	159,794	25.6	33.1	0	5.8	5.8
Tier 1	0	475,533	13.6	14.6	0	7.6	7.6
Tier 2	0	145,538	10.8	11.9	0	1.9	1.9
TOTAL	0	780,865			0	15.4	15.4

Table H9. Estimated Motor Grader Average Annual Emissions Using B20 Only

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	156,609	0	131	134	22.6	0.0	22.6
Tier 1	466,057	0	108	109	55.4	0.0	55.4
Tier 2	142,630	0	102	98	16.0	0.0	16.0
TOTAL	765,296	0			94.1	0.0	94.1
Opacity							
Tier 0	156,609	0	0.81	0.96	0.140	0.000	0.140
Tier 1	466,057	0	0.68	0.84	0.349	0.000	0.349
Tier 2	142,630	0	0.5	0.63	0.079	0.000	0.079
TOTAL	765,296	0			0.567	0.000	0.567
HC							
Tier 0	156,609	0	14.6	16.6	2.5	0.0	2.5
Tier 1	466,057	0	12.8	16.4	6.6	0.0	6.6
Tier 2	142,630	0	8.7	11.8	1.4	0.0	1.4
TOTAL	765,296	0			10.5	0.0	10.5
CO							
Tier 0	156,609	0	25.6	33.1	4.4	0.0	4.4
Tier 1	466,057	0	13.6	14.6	7.0	0.0	7.0
Tier 2	142,630	0	10.8	11.9	1.7	0.0	1.7
TOTAL	765,296	0			13.1	0.0	13.1

Table H10. Estimated Backhoe Average Annual Emissions Based on Replacing All Tier 0 Engines with Tier 1 Engines (Based on Current Fuel Use)

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	16,094	63,286	94	104	1.7	7.2	8.9
Tier 1	17,756	75,435	94	104	1.8	8.6	10.5
Tier 2	3,566	22,736	97	99	0.4	2.5	2.9
TOTAL	37,416	161,457			3.9	18.4	22.3
Opacity							
Tier 0	16,094	63,286	1.06	1.31	0.019	0.091	0.110
Tier 1	17,756	75,435	1.06	1.31	0.021	0.109	0.130
Tier 2	3,566	22,736	0.54	0.71	0.002	0.018	0.020
TOTAL	37,416	161,457			0.042	0.218	0.260
HC							
Tier 0	16,094	63,286	8.5	10.1	0.2	0.7	0.9
Tier 1	17,756	75,435	8.5	10.1	0.2	0.8	1.0
Tier 2	3,566	22,736	5.8	10.4	0.0	0.3	0.3
TOTAL	37,416	161,457			0.3	1.8	2.1
CO							
Tier 0	16,094	63,286	38	44	0.7	3.1	3.7
Tier 1	17,756	75,435	38	44	0.7	3.7	4.4
Tier 2	3,566	22,736	10	13	0.0	0.3	0.4
TOTAL	37,416	161,457			1.5	7.0	8.5

Table H11. Estimated Backhoe Average Annual Emissions Based on Replacing All Tier 0 and Tier 1 Engines with Tier 2 Engines (Based on Current Fuel Use)

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	16,094	63,286	97	99	1.7	6.9	8.6
Tier 1	17,756	75,435	97	99	1.9	8.2	10.1
Tier 2	3,566	22,736	97	99	0.4	2.5	2.9
TOTAL	37,416	161,457			4.0	17.6	21.6
Opacity							
Tier 0	16,094	63,286	0.54	0.71	0.010	0.049	0.059
Tier 1	17,756	75,435	0.54	0.71	0.011	0.059	0.070
Tier 2	3,566	22,736	0.54	0.71	0.002	0.018	0.020
TOTAL	37,416	161,457			0.022	0.126	0.149
HC							
Tier 0	16,094	63,286	5.8	10.4	0.1	0.7	0.8
Tier 1	17,756	75,435	5.8	10.4	0.1	0.9	1.0
Tier 2	3,566	22,736	5.8	10.4	0.0	0.3	0.3
TOTAL	37,416	161,457			0.2	1.8	2.1
CO							
Tier 0	16,094	63,286	10	13	0.2	0.9	1.1
Tier 1	17,756	75,435	10	13	0.2	1.1	1.3
Tier 2	3,566	22,736	10	13	0.0	0.3	0.4
TOTAL	37,416	161,457			0.4	2.3	2.7

Table H12. Front-End Loader Average Annual Emissions Based on Replacing All Tier 0 Engines with Tier 1 Engines (Based on Current Fuel Use)

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0[1]	8,253	41,328	121	122	1.1	5.6	6.7
Tier 1	9,892	57,044	121	122	1.3	7.7	9.0
Tier 2	6,425	55,849	93	95	0.7	5.8	6.5
TOTAL	24,571	154,221			3.1	19.1	22.1
Opacity							
Tier 0[1]	8,253	41,328	0.61	0.81	0.006	0.037	0.042
Tier 1	9,892	57,044	0.61	0.81	0.007	0.051	0.058
Tier 2	6,425	55,849	0.57	0.63	0.004	0.039	0.043
TOTAL	24,571	154,221			0.016	0.127	0.143
HC							
Tier 0[1]	8,253	41,328	8.6	15.7	0.1	0.7	0.8
Tier 1	9,892	57,044	8.6	15.7	0.1	1.0	1.1
Tier 2	6,425	55,849	5	5.6	0.0	0.3	0.4
TOTAL	24,571	154,221			0.2	2.0	2.3
CO							
Tier 0[1]	8,253	41,328	10.9	14.9	0.1	0.7	0.8
Tier 1	9,892	57,044	10.9	14.9	0.1	0.9	1.1
Tier 2	6,425	55,849	9	11	0.1	0.7	0.7
TOTAL	24,571	154,221			0.3	2.3	2.6

[1] There were no Tier 0 front-end loaders tested during this study, therefore there are no emission factors for Tier 0 front-end loaders. Thus, Tier 1 emission factors were used for all Tier 0 front-end loaders.

Table H13. Front-End Loader Average Annual Emissions Based on Replacing All Tier 0 and Tier 1 Engines with Tier 2 Engines (Based on Current Fuel Use)

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	8,253	41,328	93	95	0.8	4.3	5.2
Tier 1	9,892	57,044	93	95	1.0	6.0	7.0
Tier 2	6,425	55,849	93	95	0.7	5.8	6.5
TOTAL	24,571	154,221			2.5	16.1	18.7
Opacity							
Tier 0	8,253	41,328	0.57	0.63	0.005	0.029	0.034
Tier 1	9,892	57,044	0.57	0.63	0.006	0.040	0.046
Tier 2	6,425	55,849	0.57	0.63	0.004	0.039	0.043
TOTAL	24,571	154,221			0.015	0.107	0.122
HC							
Tier 0	8,253	41,328	5.0	5.6	0.05	0.25	0.30
Tier 1	9,892	57,044	5.0	5.6	0.05	0.35	0.41
Tier 2	6,425	55,849	5.0	5.6	0.04	0.34	0.38
TOTAL	24,571	154,221			0.14	0.95	1.09
CO							
Tier 0	8,253	41,328	9.0	11.0	0.1	0.5	0.6
Tier 1	9,892	57,044	9.0	11.0	0.1	0.7	0.8
Tier 2	6,425	55,849	9.0	11.0	0.1	0.7	0.7
TOTAL	24,571	154,221			0.2	1.9	2.1

Table H14. Motor Grader Average Annual Emissions Based on Replacing All Tier 0 Engines with Tier 1 Engines (Based on Current Fuel Use)

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	26,583	132,680	108	109	3.2	15.9	19.1
Tier 1	85,803	388,014	108	109	10.2	46.6	56.8
Tier 2	6,524	138,883	102	98	0.7	15.0	15.7
TOTAL	118,910	659,577			14.1	77.5	91.6
Opacity							
Tier 0	26,583	132,680	0.68	0.84	0.020	0.123	0.143
Tier 1	85,803	388,014	0.68	0.84	0.064	0.359	0.423
Tier 2	6,524	138,883	0.5	0.63	0.004	0.096	0.100
TOTAL	118,910	659,577			0.088	0.578	0.666
HC							
Tier 0	26,583	132,680	12.8	16.4	0.4	2.4	2.8
Tier 1	85,803	388,014	12.8	16.4	1.2	7.0	8.2
Tier 2	6,524	138,883	8.7	11.8	0.1	1.8	1.9
TOTAL	118,910	659,577			1.6	11.2	12.9
CO							
Tier 0	26,583	132,680	13.6	14.6	0.4	2.1	2.5
Tier 1	85,803	388,014	13.6	14.6	1.3	6.2	7.5
Tier 2	6,524	138,883	10.8	11.9	0.1	1.8	1.9
TOTAL	118,910	659,577			1.8	10.2	12.0

Table H15. Motor Grader Average Annual Emissions Based on Replacing All Tier 0 and Tier 1 Engines with Tier 2 Engines (Based on Current Fuel Use)

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	26,583	132,680	102	98	3.0	14.3	17.3
Tier 1	85,803	388,014	102	98	9.6	41.9	51.5
Tier 2	6,524	138,883	102	98	0.7	15.0	15.7
TOTAL	118,910	659,577			13.4	71.2	84.5
Opacity							
Tier 0	26,583	132,680	0.5	0.63	0.015	0.092	0.107
Tier 1	85,803	388,014	0.5	0.63	0.047	0.269	0.316
Tier 2	6,524	138,883	0.5	0.63	0.004	0.096	0.100
TOTAL	118,910	659,577			0.065	0.458	0.523
HC							
Tier 0	26,583	132,680	8.7	11.8	0.3	1.7	2.0
Tier 1	85,803	388,014	8.7	11.8	0.8	5.0	5.9
Tier 2	6,524	138,883	8.7	11.8	0.1	1.8	1.9
TOTAL	118,910	659,577			1.1	8.6	9.7
CO							
Tier 0	26,583	132,680	10.8	11.9	0.3	1.7	2.1
Tier 1	85,803	388,014	10.8	11.9	1.0	5.1	6.1
Tier 2	6,524	138,883	10.8	11.9	0.1	1.8	1.9
TOTAL	118,910	659,577			1.4	8.6	10.1

Table H16. Motor Grader Average Annual Emissions Based on Replacing All Tier 0, Tier 1, and Tier 2 Engines with Tier 3 Engines

Engine Tier	Avg. Annual Fuel Use (gallons)		Emission Factor (g/gallon)		Avg. Annual Emissions (tons/year)		
NO as Equivalent NO_2	**B20**	**Petroleum**	**B20**	**Petroleum**	**B20**	**Petroleum**	**Total**
Tier 0	26,583	132,680	69	68	2.0	9.9	12.0
Tier 1	85,803	388,014	69	68	6.5	29.1	35.6
Tier 2	6,524	138,883	69	68	0.5	10.4	10.9
TOTAL	118,910	659,577			9.0	49.4	58.4
Opacity							
Tier 0	26,583	132,680	0.47	0.57	0.014	0.083	0.097
Tier 1	85,803	388,014	0.47	0.57	0.044	0.244	0.288
Tier 2	6,524	138,883	0.47	0.57	0.003	0.087	0.091
TOTAL	118,910	659,577			0.062	0.414	0.476
HC							
Tier 0	26,583	132,680	5.0	6.2	0.1	0.9	1.1
Tier 1	85,803	388,014	5.0	6.2	0.5	2.6	3.1
Tier 2	6,524	138,883	5.0	6.2	0.0	0.9	1.0
TOTAL	118,910	659,577			0.7	4.5	5.2
CO							
Tier 0	26,583	132,680	5.4	9.0	0.2	1.3	1.5
Tier 1	85,803	388,014	5.4	9.0	0.5	3.8	4.4
Tier 2	6,524	138,883	5.4	9.0	0.0	1.4	1.4
TOTAL	118,910	659,577			0.7	6.5	7.2