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Basic Evaporative and Crankcase Emission Rates for Nonroad Engine Modeling

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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Report No. NR-012b

revised April 2004

Assessment and Standards Division
EPA, Office of Transportation and Air Quality

Purpose

This report documents the basic evaporative emission assumptions and calculations currently used in EPA's draft NONROAD2004 emissions model. This includes diurnal and hot soak evaporative emissions as well as crankcase emissions, running losses, and resting losses. An appendix also has been included with this report that contains the previous version of this technical report. Separate reports from the EPA Nonroad Engine Emissions Modeling Team address refueling emissions and adjustments of basic evaporative emissions for different ambient temperatures and fuel volatilities. These technical reports are provided to allow better understanding of the appropriate uses and limitations of the modeling results, and to allow informed comment on the modeling methodology. Comments are encouraged concerning other possible modeling approaches and any newer test data that may be available.

Introduction

Based on the limited testing that has been done, non-exhaust emissions account for a substantial portion of the hydrocarbon (HC) emissions from nonroad equipment. With expected future controls on exhaust emissions, these non-exhaust HC emissions will become an even more important component of the total HC emissions. For certain engine types, the non-exhaust component could become comparable to the exhaust component. The bulk of these non-exhaust emissions come from diurnal losses, covered in this report, and refueling losses, covered in a separate report. The information presented on diurnal and hot soak emissions only applies to gasoline-fueled engines. Diesel engines are assumed to have no significant evaporative emissions due to the very low volatility of diesel fuel compared to gasoline.

Diurnal Emissions

Diurnal evaporative emissions are generated within the fuel tank by daily ambient temperature changes while the engine is not in use. As the tank warms up during the day, the gasoline vapor in the tank expands and is forced out of the tank cap or any other vents in the fuel system. The more days a fuel tank sits with the same fuel in it, the lower the fuel volatility gets as the more volatile fractions of the gasoline evaporate.

Diurnal: Values used in NONROAD

The draft NONROAD2004 model uses 1.0 gram per day per tank gallon for all equipment powered by spark-ignition gasoline engines. For an explanation of the values used in previous versions of the model, please see the appendix at the end of this report. The 1.0 gram per day per gallon value is based on small engine diurnal emissions test data from the California ARB [2] and an EPA analysis using the Wade-Reddy equation [3,4], which is also used in the MOBILE6 model. This analysis showed that a 1.0 gram per day per tank gallon value at 9.0 psi is more defensible than the 3.0 gram per day per tank gallon value that was used in previous versions of NONROAD.

The calculation of diurnal emissions involves fuel tank size, since the emission factor is expressed per fuel tank gallon. It should be noted that changes were made concerning fuel tank sizes in the draft NONROAD2002 model. These changes include replacing the calculated tank sizes based on 0.5 gallon per horsepower with actual values based on regressions of industry data, as well as removing the 50 gallon cap on fuel tank size. For more information on fuel tank size, please consult the report, "Refueling Emissions for Nonroad Engine Modeling" (NR-013a).

Hot Soak Emissions

Hot soak emissions are the gasoline vapors generated immediately following shutdown of an engine due to vaporization of the fuel remaining in the carburetor float bowl as it is warmed by the residual heat of the engine.

Hot Soak: Source of values used in NONROAD

The draft NONROAD2004 model does not include any estimates of hot soak evaporative emissions. There are two reasons for this. First, the limited data that are available indicate that hot soak emissions are minimal relative to the other types of hydrocarbon emissions -- on the order of 1% of total HC emissions from gasoline-fueled nonroad engines. Second, the available hot soak data for nonroad engines is limited to rather inconclusive data from just 8 engines in a narrow power range (see appendix), and values available from highway engines are not considered representative of nonroad engines due to the different size, design, packaging, and fuel metering systems involved.

Thus, until more data become available, the EPA plans to follow the same approach used in NEVES as well as in the EPA Phase I small engine regulatory model and in the CARB OFFROAD model -- namely to not include hot soak emission factors in the model. However, the model code is written to allow for the addition of a hot soak emission data file if such estimates become available.

Crankcase Emissions

Crankcase emissions are those emissions that escape from the combustion chamber past the piston rings into the crankcase of four-stroke spark-ignition engines. Crankcase emissions from 2-stroke engines do not exist due to the free flow of gases from the crankcase to the combustion chamber in these engines. EPA Phase I regulations require closed crankcases for all 1997 and later spark-ignition engines under 19 kilowatts (25 hp), so these are assumed to have zero crankcase emissions.[5] Also, all 4-stroke engines used in marine vessels are assumed to have closed crankcases, including inboard, sterndrive, and 4-stroke outboards. All other gasoline 4-stroke equipment are assumed to have open crankcases, except lawn and garden equipment produced prior to 1997. The draft NONROAD2004 model uses the estimate that 21 percent of pre-1997 lawn and garden equipment have open crankcases. In addition, the model assumes that all compression ignition diesel engines have crankcase emissions.

Regarding crankcase emissions from chippers/stump grinders, previous versions of this technical report stated: "All pre-1997 chippers/stump grinders are assumed to have open crankcases." However, it should be noted that prior versions of the draft NONROAD model did not conform to the technical report, using the 21% estimate applied to pre-1997 lawn and garden equipment mentioned above. EPA corrected the draft NONROAD2002 model to assume that all pre-1997 chippers/stump grinders have open crankcases.

It should be noted that the final Nonroad Diesel Engine Tier 4 Rule assumes zero crankcase emissions for Tier 4 nonroad engines, and this is reflected in draft NONROAD2004.

Crankcase Emissions: Sources of Values Used in NONROAD

Due to lack of any other sources of crankcase emission data, the draft NONROAD2004 model uses the crankcase emission factors from NEVES for all engines produced without closed crankcases. NEVES uses data from on-highway engines to estimate nonroad crankcase emission rates. Using the NEVES data, NONROAD assumes the crankcase HC emission factor is equal to 33% of the exhaust HC emission factor for 4-stroke engines with open crankcases. For diesel engines with open crankcases, NONROAD assumes the HC emission factor is equal to 2.0% of the exhaust HC emission factor. These percentages are applied to the final calculated exhaust emission factors, so the resulting crankcase emission factors include the same percentage deterioration as used for exhaust HC.

Although NEVES also provides diesel crankcase emission factors for CO (0.2% of exhaust CO) and NOx (0.05% of exhaust NOx), there is no provision within NONROAD for modeling these since they are so small. Comments are welcome regarding the need for inclusion of CO and NOx crankcase emissions either within the model or as a manual addition to the exhaust estimates produced by the model.

Running and Resting Losses

Because of a lack of data, the draft NONROAD2004 model does not calculate running and resting loss emissions. However, these emissions are generally expected to be minor compared to diurnal and refueling emissions.

References

[1] Nonroad Engine and Vehicle Emission Study with Appendixes, US Environmental Protection Agency, Office of Mobile Sources, EPA-21A-2001, November 1991.

[2] "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model," draft report by Energy and Environmental Analysis, Inc., for California Air Resources Board, August 1995.

[3] D. T. Wade, "Factors Influencing Vehicle Evaporative Emissions," SAE Paper 670126, 1967, Docket A-2000-01, Document II-A-59.

[4] Wade et. al., "Mathematical Expressions Relating Evaporative Emissions from Motor Vehicles without Evaporative Loss-Control Devices to Gasoline Volatility," SAE Paper 720700, 1972, Docket A-2000-01, Document II-A-58.

[5] Federal Register: July 3, 1995 (Volume 60, Number 127), Page 34581-34657, "Control of Air Pollution; Emission Standards for New Nonroad Spark-ignition Engines At or Below 19 Kilowatts," and Code of Federal Regulations 40 CFR 90.109 "Requirement of certification--closed crankcase."

Appendix

Previous Documentation of Evaporative Emissions for the Draft NONROAD Emissions Model

Basic Evaporative Emission Rates for Nonroad Engine Modeling

Report No. NR-012
February 13, 1998

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Purpose

This report documents the basic evaporative emission assumptions and calculations planned for use in the beta release of the U.S. Environmental Protection Agency (EPA) emission inventory model. This includes diurnal and hot soak evaporative emissions as well as crankcase emissions, running losses and resting losses. Separate reports from the EPA Nonroad Engine Emissions Modeling Team address refueling emissions and adjustments of basic evaporative emissions for different ambient temperatures and fuel volatilities. These technical reports are provided to allow better understanding of the appropriate uses and limitations of the modeling results, and to allow informed comment on the modeling methodology. Comments are encouraged concerning other possible modeling approaches and any newer test data that may be available.

Introduction

Based on the limited testing that has been done, non-exhaust emissions account for a substantial portion of the hydrocarbon (HC) emissions from nonroad equipment. With expected future controls on exhaust emissions these non-exhaust HC emissions will become an even more important component of the total HC emissions; for certain engine types the non-exhaust component could become comparable to the exhaust component. The bulk of these non-exhaust emissions come from diurnal losses, covered in this report, and refueling losses, covered in a separate report. The information presented on diurnal and hot soak emissions only applies to gasoline-fueled engines; diesel engines are assumed to have no significant evaporative emissions due to the very low volatility of diesel fuel compared to gasoline.

Diurnal Emissions

Diurnal evaporative emissions are the evaporative emissions from the fuel tank while the engine is not in use generated by the daily ambient temperature changes. As the tank warms up during the day, the gasoline vapor in the tank expands and is forced out of the tank cap or any other vents in the fuel system. The more days a fuel tank sits with the same fuel in it, the lower the fuel volatility gets as the more volatile fractions of the gasoline evaporate.

Diurnal: Source of values used in NONROAD

The methodology used to estimate diurnal emissions in NONROAD is based primarily on the EPA Nonroad Engine and Vehicle Emissions Study (NEVES) [1] with modifications for smaller engines from the California Air Resources Board (ARB) OFFROAD model.[4] The NEVES methodology assumes diurnal emissions of 3.0 grams per gallon of fuel tank capacity per day (g/gal/day). The NEVES estimate is based on a rough average of estimates determined in 1973 by Southwest Research Institute (SwRI) [2,3] for fuel tanks protected from direct sunlight (2 g/gal/day) and those more exposed to the sun (4 g/gal/day). Table 1 summarizes the results of the SwRI analysis.

It should be noted that these estimates were not based on any actual tests of nonroad equipment. The 2.0 g/gal/day estimate was based on test results and modeling of highway vehicles using 9.0 psi RVP gasoline and an average fuel tank fill level of 40%. The 4.0 g/gal/day estimate was based on measurements of evaporative losses from shaded and unshaded large (300 gal) storage tanks that indicated up to four times as much evaporation could occur from an unshaded tank relative to a shaded one. Since mobile source equipment tanks may be partially shaded, SwRI assumed that the more exposed tanks would emit roughly twice as much as the fully protected tanks -- 4.0 g/gal/day versus 2.0 g/gal/day. For equipment types with a mixture of shaded and unshaded tank configurations SwRI assumed diurnal losses of 3.0 g/gal/day.

Table 1 **Diurnal Estimates from 1973 SwRI Study**	
Equipment Type	Diurnal Loss (grams/gallon/day)
Farm: tractors	4.0
Farm: other HD equipment	3.0
Construction: wheel tractors, motor graders	4.0
Construction: all other	3.0
Industrial: All	3.0
Small Utility: All	2.0

For engines less than or equal to 25 hp (19kw) NONROAD modifies the NEVES method to incorporate the method used in the California Air Resources Board (ARB) OFFROAD model.[4] Although OFFROAD uses the same NEVES 3.0 g/gal/day estimate for engines greater than 25 hp, engines under 25 hp are assigned a diurnal loss rate of 1.0 g/gal/day. This rate for small engines is based on testing of ten pieces of equipment by Southwest Research Institute (SwRI) and the Outdoor Power Equipment Institute (OPEI). These tests were similar to the standard vehicle diurnal test using a one hour heat build from 60F - 84F.

Diurnal: Other possible methods and data

The EPA small gasoline engine emission regulatory model uses a diurnal emissions modeling approach based on equipment type rather than fuel tank size. This approach is based on tests of 30 fuel tanks typical of those used on various types of small non-handheld gasoline equipment. These tests were extended diurnal tests lasting seven days with daily temperature swings of 72F - 96F and 50% full tanks, instead of the 60F - 84F tests with 40% full tanks used in other studies. Since these tests showed no correlation between diurnal losses and fuel tank size, the gram/day results were grouped by equipment type and then averaged within each group. The diurnal loss estimates being used in the EPA small engine regulatory model are summarized in Table 2. The EPA NEEMT will consider switching to this method following beta release of NONROAD, depending on comments and any additional data that we receive. Such a change would require modifications to the core model source code which can not be done before release of the beta version.

Table 2 Diurnal Estimates in EPA Small Engine Regulatory Model	
Equipment Type	**Diurnal Loss (g/day)**
Walk-Behind Mowers	4.0
Trimmers/Edgers	0.54
Chainsaws	0.32
Leaf Blowers	0.61
Generator Sets	3.4
Tillers	1.8
Snow Blowers	2.8
Commercial Turf Equipment	5.5
Rear Engine Mowers	3.3
Lawn/Garden Tractors	3.7
Pumps	3.5
All Others	2.4

Hot Soak Emissions

Hot soak emissions are the gasoline vapors generated immediately following shutdown of an engine due to vaporization of the fuel remaining in the carburetor float bowl as it is warmed by the residual heat of the engine.

Hot Soak: Source of values used in NONROAD

The beta release of NONROAD does not include any estimates of hot soak evaporative emissions. There are two reasons for this. First, the limited data that are available indicate that hot soak emissions are minimal relative to the other types of hydrocarbon emissions -- on the order of 1% of total HC emissions from gasoline-fueled nonroad engines. Second, as described in the following section on other methods and data, the available hot soak data for nonroad engines is limited to rather inconclusive data from just 8 engines in a narrow power range, and values available from highway engines are not considered representative of nonroad engines due to the different size, design, packaging, and fuel metering systems involved.

Thus, until more data become available, the Nonroad Engine Emissions Modeling Team (NEEMT) plans to follow the same approach used in NEVES as well as in the EPA Phase I small engine regulatory model and in the CARB OFFROAD model -- namely to not include hot soak emission factors in the model. However, the model code is written to allow for the addition of a hot soak emission data file if such estimates become available.

Hot Soak: Other possible methods and data

One possible source of hot soak emission factors is the 1995 report documenting input factors for the CARB OFFROAD model. [4] That report lists hot soak test data collected by SwRI and the Outdoor Power Equipment Institute for eight 4-stroke engines ranging from 4 hp to 22 hp. The data from the eight engines were combined into the following categories:

2.05 g/gal per shutdown for lawn/garden equipment except for riding mowers/tractors,
1.12 g/gal per shutdown for riding mowers & tractors, and
0.39 g/gal per shutdown for utility equipment.

It should be noted that since the data are so limited, these emission factors have not been incorporated into the CARB model, although placeholders are available in the model whenever adequate data become available.

Furthermore, an analysis of these same hot soak test data by Air Improvement Resource, Inc (AIR) for the Engine Manufacturers Association found that the small sample size and wide variability within each equipment type argued against any significant correlation between hot soak emissions and tank size.[5] The AIR analysis of these test data concludes by recommending use of 0.6 grams per engine shutdown for Class 1 engines and 2.0 grams per shutdown for Class 2 engines. Comments are welcome on whether such an approach should be used, and if so, what numbers to use for engine shutdowns per day for residential and for commercial applications on weekdays and on weekends.

Crankcase Emissions

Due to lack of any other sources of crankcase emission data, the beta release of NONROAD uses the crankcase emission factors from NEVES for all engines produced without closed crankcases. Crankcase emissions from 2-stroke engines do not exist due to the free flow of gases from the crankcase to the combustion chamber in these engines, and EPA Phase I regulations require closed crankcases for all 1997 and later spark-ignition engines under 19 kw (25 hp), so those are assumed to have zero crankcase emissions.[6] Also, all 4-stroke engines used in marine vessels are assumed to have closed crankcases, including inboard, sterndrive, and 4-stroke outboards. All other gasoline 4-stroke equipment are assumed to have open crankcases, except lawn and garden equipment produced prior to 1997 (other than chippers/grinders) for which only 21% are assumed to have open crankcases. All pre-1997 chippers and stump grinders are assumed to have open crankcases.

Due to the scarcity of nonroad engine crankcase emission test data, NEVES uses data from on-highway engines to estimate nonroad crankcase emission rates. Using the NEVES data, the NONROAD model assumes the crankcase HC emission factor is equal to 33% of the exhaust HC emission factor for 4-stroke engines with open crankcases. For diesel engines with open crankcases, NONROAD assumes the HC emission factor is equal to 2.0% of the exhaust HC emission factor. These percentages are applied to the final calculated exhaust emission factors, so the resulting crankcase emission factors include the same percentage deterioration as used for exhaust HC.

Although NEVES also provides diesel crankcase emission factors for CO (0.2% of exhaust CO) and NOx (0.05% of exhaust NOx), there is no provision within NONROAD for modeling these since they are so small. Comments are welcome regarding the need for inclusion of CO and NOx crankcase emissions either within the model or as a manual addition to the exhaust estimates produced by the model.

References

[1] Nonroad Engine and Vehicle Emission Study with Appendixes, US Environmental Protection Agency, Office of Mobile Sources, EPA-21A-2001, November 1991.

[2] "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Charles T. Hare and Karl J. Springer, Final Report, Part 4 Small Air-Cooled Spark Ignition Utility Engines, May 1973.

[3] "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Charles T. Hare and Karl J. Springer, Final Report, Part 5 Heavy-Duty Farm, Construction, and Industrial Engines, October 1973.

[4] "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model," draft report by Energy and Environmental Analysis, Inc., for California Air Resources Board, August 1995.

[5] "EMA's Comments on the OFFROAD Inputs Report," letter and attachment from Michael Block, Engine Manufacturers Association, to Mark Carlock, California Air Resources Board, July 7, 1997.

[6] Federal Register: July 3, 1995 (Volume 60, Number 127), Page 34581-34657, "Control of Air Pollution; Emission Standards for New Nonroad Spark-ignition Engines At or Below 19 Kilowatts," and Code of Federal Regulations 40 CFR 90.109 "Requirement of certification--closed crankcase."