United States Environmental Protection Agency

Air and Radiation

EPA420-P-02-003
August 2002
NR-013a

EPA

Refueling Emissions for Nonroad Engine Modeling

EPA420-P-02-003
August 2002

Refueling Emissions for Nonroad Engine Modeling

Report No. NR-013a

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

This technical report describes the methods and assumptions used in the draft NONROAD2002 emissions model to estimate refueling emissions from nonroad equipment. The discussion primarily focuses on refueling emissions for gasoline fueled equipment. Refueling emissions for diesel fueled equipment are discussed briefly at the end of this report. For ease of reference, the previous version of this technical report has been included as an appendix.

Background

Refueling emissions can be divided into two components: spillage and vapor displacement. Spillage emissions result when fuel is spilled during the refueling process. Some or all of the spilled fuel will subsequently vaporize, adding hydrocarbon compounds to the atmosphere. Vapor displacement emissions result when new liquid fuel being added to a fuel tank displaces fuel vapors already present in the tank. For example, if one gallon of gasoline is added to a fuel tank already containing some gasoline, one gallon of gasoline vapor will be displaced to the atmosphere by one gallon of liquid fuel.

Although spillage and vapor displacement both occur during a single refueling event, the draft NONROAD2002 model shows them as separate outputs. This is to provide additional flexibility in using NONROAD output for atmospheric modeling. Spillage emissions and vapor displacement emissions will typically have different chemical characteristics. Spillage emissions will be composed of all of the compounds found in gasoline, while vapor displacement emissions will be primarily composed of the lighter compounds that have vaporized in the gas tank (the heavier compounds will remain as liquids in the tank). Separating refueling emissions into the two components in the output allows atmospheric modelers to account for the effects of these differences on atmospheric chemistry.

For both spillage and vapor displacement, the model initially calculates an emission factor in terms of grams of emissions per gallon of fuel consumed. Fuel consumption is then used to calculate total emissions based on the g/gal emissions factors.

Refueling modes - Gasoline Pump vs. Portable Container

Many types of nonroad equipment are commonly refueled from a portable container rather than from a gasoline pump. Refueling nonroad equipment from a portable container results in different emissions for both spillage and vapor displacement compared to refueling from a gasoline pump. These differences are described in detail below. In addition, the use of portable containers also results in extra refueling events. Both spillage and displacement emissions will also occur when the container is filled from a gasoline pump. However, due to lack of data, we have not attempted to quantify this extra set of refueling emissions in the draft NONROAD2002 model. We welcome comments and data submissions that would help us quantify these refueling emissions in future versions of NONROAD.

Because the different refueling modes result in different emissions, we must make assumptions in NONROAD about which equipment will be refueled predominantly using a gasoline pump and which will be refueled predominantly from a portable container. Table 1 shows refueling mode assumptions that have been used in the past compared to the current version of NONROAD. The draft NONROAD2002 model allows the refueling mode to be based on horsepower or tank volume. For some types of gasoline-powered equipment, versions with larger horsepowers are fueled at the pump while versions with smaller horsepowers are fueled with a container. All equipment powered by diesel engines are assumed to be fueled at the pump

Table 1: Alternative Refueling Mode Assumptions.

Source	Portable container	Gasoline pump
NEVES	Lawn and garden (except chippers/stump grinders), recreational, light commercial, all other equipment with tank volumes less than 6 gallons.	Chippers/stump grinders, all other equipment with tank volumes greater than 6 gallons except lawn and garden, recreational, and light commercial equipment.
ARB Small Engine Model	All gasoline 2-stroke engines and all equipment less than 15 hp.	All gasoline 4-stroke engines greater than 15 hp
Draft 2002 NONROAD	- All lawn and garden equipment. - Smaller horsepower gasoline recreational, industrial, commercial, logging, recreational marine, and railway maintenance equipment.	- All gasoline construction equipment. - All gasoline agricultural equipment. - All gasoline aircraft ground support equipment. - Oil Field Equipment. - Larger horsepower gasoline recreational, industrial, commercial, logging, recreational marine, and railway maintenance equipment. - All diesels.

Spillage Emissions

EPA has received no significant new information on spillage emissions since the Nonroad Engine and Vehicle Emission Study (NEVES) was published in 1991. NEVES described two refueling factors; a value of 17 grams of fuel spilled per refueling event for equipment refueled from a portable container, and a value of 3.6 grams of fuel spilled per refueling event for equipment refueled from a gas pump. The first value was derived from an OPEI study and the second value was derived from MOBILE4 estimates for refueling of on-highway vehicles. NEVES gives the following reasons for the difference in these two values: (1) fuel containers are more difficult to use than gas pumps, and (2) fuel containers do not have automatic shutoff capability. Given the lack of new information, we have kept the NEVES values in draft NONROAD2002 using the following equations (all gasoline spilled is assumed to evaporate into the atmosphere):

For refueling from portable containers:

Spillage (g/gal.) = 17.0 ÷ tank volume

For refueling from gasoline pumps:

Spillage (g/gal.) = 3.6 ÷ tank volume

By using tank volumes in these equations, we assume that all refueling events are fill-ups of empty tanks. Given that some portion of refueling events are likely not fill-ups of empty tanks, this assumption will tend to underestimate spillage emissions. If we knew, on average, the percentage of the tank volume that was actually being filled, we could develop a better estimate of spillage emissions. However, we are not aware of any data on which to base an assumption. We welcome comments or data submissions on this issue.

Tank Volumes

Previous versions of the draft NONROAD Model used the method contained in the NEVES report [1]. For more information, please see the previous version of this technical report in the appendix.

For draft NONROAD2002, EPA expanded the regression approach used by NEVES for larger equipment to include all applications. The regression equation calculates proper tank volume for each horsepower bin using the appropriate ratio of tank size to horsepower (in gallons per horsepower) for each application. The resulting tank sizes have been included in the input data of NONROAD. Since actual tank size values are used in draft NONROAD2002 instead of the calculated values that could have resulted in unrealistically large fuel tank sizes in previous versions of the model, the 50 gallon cap on fuel tank size has been removed.

To revise recreational marine fuel tank sizes, EPA used data from an October 1999 database of specifications for new pleasure boats over 25 feet long from Ovation Digital Productions.[1] These data were then analyzed by looking only at the boats with gasoline engines

[1] CD-ROM's containing these data are available on the web at www.boatshow.com. In obtaining these data from Ovation, the US EPA has agreed that the data contained in the database are provided under license by Ovation digital Productions for internal use by the US Environmental Protection Agency, Office of Transportation and Air Quality, and that this EPA office will not resell or redistribute this data, including to other offices of the US government, without the consent of Ovation.

and separating outboards from sterndrive/inboards. Linear regression of these data yielded the following equations.

Sterndrive/Inboard

0 - 300 hp	$y = 0.3335x$	r-squared = 0.1996 (forced through 0,0)
over 300 hp	$y = 1.5871x - 354.1$	r-squared = 0.4206

Outboard

0 - 100 hp	$y = 0.4244x$	r-squared = 0.2473 (forced through 0,0)
over 100 hp	$y = 1.2218x - 74.45$	r-squared = 0.4246

where: y = fuel tank size (gallons)
x = engine horsepower

Vapor Displacement

For the draft NONROAD2002 model, we revised the methodology using the following formula from the Onboard Refueling Vapor Recovery Rule to calculate vapor displacement emissions:

$$\text{Displacement (g/gal)} = \text{EXP}(-1.2798 - 0.0049 \times (Td - Ta) + 0.0203 \times Td + 0.1315 \times RVP)$$

where Td = dispensed fuel temperature (degrees F)
Ta = ambient temperature (degrees F)
RVP = Reid Vapor Pressure (psi)

This formula relies on user-supplied input for temperature and RVP. The temperature of the equipment tank is assumed to be equal to the ambient temperature supplied by the user. The temperature of the dispensed fuel depends in part on the refueling mode. For equipment refueled by portable container, we assume that the temperature of the dispensed fuel equals the ambient temperature. For equipment refueled from a gasoline pump, NONROAD uses the following equation (derived from the relationship between equipment tank temperature and dispensed fuel temperature in the NEVES report) to calculate the temperature of dispensed fuel based on the ambient temperature:

$$\text{Dispensed Fuel Temperature } (^{o}F) = 62 + 0.6 \times (\text{ambient temperature} - 62)$$

Effect of Stage II Vapor Recovery Systems

Many ozone nonattainment areas are subject to Clean Air Act requirements for Stage II vapor recovery systems on gasoline pumps. These systems are designed to capture gasoline vapors displaced during refueling from a gasoline pump, preventing their release into the atmosphere. In general, the overall effectiveness of Stage II systems at controlling refueling emissions depends on a number of factors including the baseline efficiency of the system used, the amount of refueling done at stations exempt from Stage II requirements, and the frequency and stringency of enforcement programs. For nonroad equipment, the effectiveness of Stage II systems will also depend on the refueling mode (refueling from a portable container would not be affected by Stage II controls), the frequency at which nonroad equipment is refueled at exempt stations (some categories of nonroad equipment may be more likely to be refueled at private refueling depots exempt from Stage II requirements), and the efficacy of Stage II systems when refueling nonroad equipment (fuel tank filler openings on nonroad equipment may not be compatible with Stage II nozzles designed for refueling highway vehicles).

Given these uncertainties, we propose the following approach to account for Stage II controls in draft NONROAD2002. When the user specifies that Stage II controls are in place, they would also specify the effectiveness of the controls as a percent reduction in refueling emissions. That percent reduction would only be applied to vapor displacement emissions for equipment refueled from a gasoline pump.

Diesel Refueling Emissions

The draft 2002 NONROAD model assumes zero refueling emissions for diesel equipment. Because diesel fuel has a higher boiling point than gasoline, refueling emissions from diesel equipment tend to be much less significant than from gasoline equipment. As a result, very little refueling emissions data exist for diesel equipment. The NEVES report used a single emission factor of 0.041 g/gal for vapor displacement from diesel equipment under all conditions. However, this rate was based on a study conducted at fuel tank temperatures of approximately 80^o F. The actual rate at other temperatures was not identified. In addition, EPA has received no comments or information that supports the use of the NEVES value or suggests any alternatives.

References

1. "Nonroad Engine and Vehicle Emission Study", Appendix I, U.S. EPA Office of Air and Radiation, November, 1991.

2. "Offroad Equipment Refueling Emissions", Presentation by California Air Resources staff, Emissions Inventory Workshop, December 16, 1997.

Appendix

Refueling Emissions for Nonroad Engine Modeling

Report No. NR-013

August 20, 1998

Gary J. Dolce
Nonroad Engine Emissions Modeling Team
Assessment and Modeling Division
US EPA, Office of Mobile Sources

This technical report describes the methods and assumptions used in NONROAD to estimate refueling emissions from nonroad equipment. The discussion primarily focuses on refueling emissions for gasoline fueled equipment. Refueling emissions for diesel fueled equipment are discussed briefly at the end of this report.

Background

Refueling emissions can be divided into two components: spillage and vapor displacement. Spillage emissions result when fuel is spilled during the refueling process. Some or all of the spilled fuel will subsequently vaporize, adding hydrocarbon compounds to the atmosphere. Vapor displacement emissions result when new liquid fuel being added to a fuel tank displaces fuel vapors already present in the tank. For example, if one gallon of gasoline is added to a fuel tank already containing some gasoline, one gallon of gasoline vapor will be displaced to the atmosphere by one gallon of liquid fuel.

Although spillage and vapor displacement both occur during a single refueling event, the final version of NONROAD will show them as separate output. This is to provide additional flexibility in using NONROAD output for atmospheric modeling. Spillage emissions and vapor displacement emissions will typically have different chemical characteristics. Spillage emissions will be composed of all of the compounds found in gasoline, while vapor displacement emissions will be primarily composed of the lighter compounds that have vaporized in the gas tank (the heavier compounds will remain as liquids in the tank). Separating refueling emissions into the two components in the output allows atmospheric modelers to account for the effects of these differences on atmospheric chemistry.

For both spillage and vapor displacement, the model initially calculates an emission factor in terms of grams of emissions per gallon of fuel consumed. Fuel consumption is then used to calculate total emissions based on the g/gal emissions factors.

Refueling modes - Gasoline Pump vs. Portable Container

Many types of nonroad equipment are commonly refueled from a portable container rather than from a gasoline pump. Refueling nonroad equipment from a portable container results in different emissions for both spillage and vapor displacement compared to refueling from a gasoline pump. These differences are described in detail below. In addition, the use of portable containers also results in extra refueling events. Both spillage and displacement emissions will also occur when the container is filled from a gasoline pump. However, due to lack of data, we have not attempted to quantify this extra set of refueling emissions in this version of NONROAD. We welcome comments and data submissions that would help us quantify these refueling emissions in future versions of NONROAD.

Because the different refueling modes result in different emissions, we must make assumptions in NONROAD about which equipment will be refueled predominantly using a gasoline pump and which will be refueled predominantly from a portable container. Table 1 shows refueling mode assumptions that have been used in the past. Please note that the simplified method used in the draft version of NONROAD was in part necessitated by the fact that draft version of NONROAD was not designed to easily handle differences in refueling mode based on horsepower or tank volume cutoffs. The final version of NONROAD will allow the refueling mode to be based on more complicated criteria such as horsepower or tank volume. We could use the Nonroad Engine and Vehicle Emission Study (NEVES)[1] approach, the California Air Resources Board (ARB) small engine[2] approach, or some other approach. We invite comment on what to assume in the final version of NONROAD. We are also interested in any data submissions, such as survey results, that would be useful in separating equipment by refueling mode in future versions of NONROAD.

Table 1. Alternative refueling mode assumptions.

Source	Portable container	Gasoline pump
NEVES	Lawn and garden (except chippers/stump grinders), recreational, light commercial, all other equipment with tank volumes less than 6 gallons.	Chippers/stump grinders, all other equipment with tank volumes greater than 6 gallons except lawn and garden, recreational, and light commercial equipment.
ARB Small Engine Model	All gasoline 2-stroke engines and all equipment less than 15 hp	All gasoline 4-stroke engines greater than 15 hp
Draft NONROAD	All lawn and garden, recreational equipment, outboards and personal watercraft.	All others.

Spillage emissions

We have received no significant new information on spillage emissions since the Nonroad Engine and Vehicle Emission Study (NEVES) was published in 1991. NEVES described two refueling factors; a value of 17 grams of fuel spilled per refueling event for equipment refueled from a portable container, and a value of 3.6 grams of fuel spilled per refueling event for equipment refueled from a gas pump. The first value was derived from an OPEI study and the second value was derived from MOBILE4 estimates for refueling of on-highway vehicles. NEVES gives the following reasons for the difference in these two values: (1) fuel containers are more difficult to use than gas pumps, and (2) fuel containers do not have automatic shutoff capability. Given the lack of new information, we have incorporated the NEVES values into the draft version of NONROAD using the following equations (all gasoline spilled is assumed to evaporate into the atmosphere):

For refueling from portable containers:
Spillage (g/gal.) = 17.0 ÷ tank volume

For refueling from gasoline pumps:
Spillage (g/gal.) = 3.6 ÷ tank volume

By using tank volumes in these equations, we assume that all refueling events are fill-ups of empty tanks. Given that some portion of refueling events are likely not fill-ups of empty tanks, this assumption will tend to underestimate spillage emissions. If we knew, on average, the percentage of the tank volume that was actually being filled, we could develop a better estimate of spillage emissions. However, we are not aware of any data on which to base an assumption. We welcome comments or data submissions on this issue.

Tank Volumes

The NEVES report includes a lengthy discussion of gasoline fuel tank volumes. Fuel tank volumes in NEVES were primarily derived from manufacturer supplied information with adjustments made to deal with mismatches between the way manufacturers and EPA describe equipment categories. For a few equipment categories where manufacturer information was not available, tank volumes in NEVES were based on EPA judgement. For larger farm and construction engines, NEVES estimated tank volumes using a regression equation that related engine horsepower to tank volume. Based on this equation, NEVES used the average horsepower of each application to estimate an average tank volume.

While developing the draft version of NONROAD, we considered modifying and expanding the regression approach used by NEVES for larger equipment to include all applications and to have the model calculate the proper tank volume for each horsepower bin using the appropriate ratio of tank size to horsepower (in gallons per horsepower) for each application. We did a preliminary analysis of a small amount of available data and incorporated the resulting ratios in the draft version of NONROAD.

After further review of the data and methodology used in the draft NONROAD, we have concluded that this new approach needs a considerable amount of additional work before we can be certain that it improves on the NEVES methodology. Therefore, for the final version of NONROAD, we propose to go back to using the original NEVES methodology and data. We invite comment or data submissions that would help us to develop a better tank volume methodology.

Vapor Displacement

For the final version of NONROAD, we propose to adopt the methodology described in the NEVES report with some minor modifications. NEVES used the following formula to calculate vapor displacement emissions:

$$\text{Displacement (g/ gal)} = -5.909 - 0.0949 \times dt + 0.0884 \times T + 0.485 \times RVP$$

where: dt = Temperature of Equipment Tank - Temperature of Dispensed Fuel (°F)
T = Temperature of Dispensed Fuel (°F)
RVP = Reid Vapor Pressure

NEVES used this formula to create a simple lookup table of average summer and winter season emissions based on average temperatures and RVP values. The final version of NONROAD will incorporate this formula and rely on user supplied input for temperature and RVP. The temperature of the equipment tank is assumed to be equal to the ambient temperature supplied by the user. The temperature of the dispensed fuel depends in part on the refueling mode. For equipment refueled by portable container, we assume that the temperature of the dispensed fuel equals the ambient temperature. For equipment refueled from a gasoline pump, we will incorporate the following equation (derived from the relationship between equipment tank temperature and dispensed fuel temperature in the NEVES report) to calculate the temperature of dispensed fuel based on the ambient temperature:

$$\text{Dispensed Fuel Temperature (°F)} = 62 + 0.6 \times (\text{ambient temperature} - 62)$$

Effect of Stage II Vapor Recovery Systems

Many ozone nonattainment areas are subject to Clean Air Act requirements for Stage II vapor recovery systems on gasoline pumps. These systems are designed to capture gasoline vapors displaced during refueling from a gasoline pump, preventing their release into the atmosphere. In general, the overall effectiveness of Stage II systems at controlling refueling emissions depends on a number of factors including the baseline efficiency of the system used, the amount of refueling done at stations exempt from Stage II requirements, and the frequency and stringency of enforcement programs. For nonroad equipment, the effectiveness of Stage II systems will also depend on the refueling mode (refueling from a portable container would not be affected by Stage II controls), the frequency at which nonroad equipment is refueled at exempt stations (some categories of nonroad equipment may be more likely to be refueled at private refueling depots exempt from State II requirements), and the efficacy of Stage II systems when refueling nonroad equipment (fuel tank filler openings on nonroad equipment may not be compatible with Stage II nozzles designed for refueling highway vehicles).

Given these uncertainties, we propose the following approach to account for Stage II controls in the final version of NONROAD. When the user specifies that Stage II controls are in place, they would also specify the effectiveness of the controls as a percent reduction in refueling emissions. That percent reduction would only be applied to vapor displacement emissions for equipment refueled from a gasoline pump. EPA will develop guidance as to the appropriate effectiveness levels for Stage II controls for nonroad equipment.

Diesel Refueling Emissions

Because diesel fuel has a higher boiling point than gasoline, refueling emissions from diesel equipment tend to be much less significant than from gasoline equipment. As a result, very little effort has been spent studying diesel refueling emissions. NEVES did not include any spillage emissions for diesel equipment. NEVES used a single emission factor of 0.041 g/gal for vapor displacement from diesel equipment under all conditions. However, this rate was based on a study conducted at fuel tank temperatures of approximately 80 ^{o}F. The actual rate at other temperatures was not identified. We invite comment on whether to use the single emission rate used in NEVES for all diesel refueling emissions due to vapor displacement, or to assume no diesel refueling emissions until further information is available.

References

1. “Nonroad Engine and Vehicle Emission Study”, Appendix I, U.S. EPA Office of Air and Radiation, November, 1991.

2. “Offroad Equipment Refueling Emissions”, Presentation by California Air Resources staff, Emissions Inventory Workshop, December 16, 1997.