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# Project Summary

# Criteria Pollutant Emissions from Internal Combustion Engines in the Natural Gas Industry

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**This report contains emission data for oxides of nitrogen, carbon monoxide, methane, ethane, nonmethane hydrocarbons, and nonmethane-ethane hydrocarbons from stationary internal combustion (IC) engines and gas turbines used in the natural gas industry. The emission factors calculated from test results were from five test campaigns conducted as part of the Gas Research Institute's air toxics study, three of which were cofunded by the U.S. Environmental Protection Agency (EPA). Test results for individual engines tested are presented, along with full load engine family-specific factors, and the calculated emission factors are evaluated relative to the emission factors published in EPA report AP-42. Units tested included eleven 2-stroke engines and five 4-stroke engines, with and without controls, and two gas turbines. This data will enhance the current data base in AP-42 for stationary IC engines. It will not only enlarge the population of engine types covered, but will enhance the emission factor quality of several engine categories which have a limited data set.**

***This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Background

One function of the Air Pollution Prevention and Control Division (APPCD) of the U.S. Environmental Protection Agency's (EPA's) Office of Research and Development is improving current air pollutant emission inventory methodologies, especially for pollutants associated with tropospheric ozone formation. As part of the improvement of emission inventory methodologies, APPCD supports field emission measurement efforts. These data are used by EPA's Office of Air Quality Planning and Standards (OAQPS) to enhance their reference document "Compilation of Air Pollutant Emission Factors" (AP-42), which contains emission factors for oxides of nitrogen ($NO_x$), carbon monoxide (CO), methane ($CH_4$), ethane ($C_2H_6$), nonmethane hydrocarbon (NMHC), and nonmethane-ethane hydrocarbon (NMEHC) emissions from the large, stationary internal combustion (IC) reciprocating and turbine engines used in the natural gas industry. In AP-42, emission factors for some types of engines, especially those with air pollution controls, are based on an inadequate amount of emissions test data. To improve the understanding of emissions from these sources, additional testing is needed to enhance the emissions database, giving OAQPS the ability to revise AP-42.

Emissions characterization of IC engines in the natural gas industry is currently underway through a program sponsored by the Gas Research Institute (GRI), with the primary focus on determining the potential for air toxics emissions. Since information on $NO_x$, CO, $CH_4$, $C_2H_6$, NMHC, and NMEHC emissions is needed to completely characterize the IC engine emissions, EPA/APPCD provided cofunding to the GRI program to support gathering such data for enhancement of the emissions

database currently used in AP-42 for the development of emission factors. The work described in this document was conducted as part of this joint effort between GRI and EPA and involved:

- Field measurements of $NO_x$, CO, $CH_4$, $C_2H_6$, and total hydrocarbon (THC) emissions at three test sites (joint EPA/GRI effort);
- Incorporation of field data, collected by GRI at two earlier test sites, into the data set for evaluation; and
- Evaluation of all test data for use in enhancing the emissions database currently in AP-42.

## Results

Table 1 summarizes full load emission factors for $NO_x$, CO, $CH_4$, $C_2H_6$, THC, NMHC, and NMEHC expressed in grams per horsepower-hour and pounds per million British thermal units. The emission factors were averaged by engine family, and are presented for 2-stroke, lean-burn; 2-stroke, clean-burn; 4-stroke, lean-burn; 4-stroke, clean-burn; and 4-stroke, rich-burn engines; and gas turbines. Separate emission factors were calculated for engines using emission control equipment; e.g., nonselective catalytic reduction (NSCR) selective catalytic reduction (SCR), CO oxidation catalyst, or precombustion chamber (PCC). Only data from test periods during which the engines were operated within 90% of rated load and 95% of rated speed were used to calculate the average emission factors, except when the engine tested was the only one of a particular classification included in the test program, and the engine did not meet the minimum load and speed criteria during any of the test periods.

The $NO_x$, CO, and THC emission factors are based on continuous emissions monitoring system (CEMS) measurements while the $CH_4$ and $C_2H_6$ emission factors are based on gas chromatography (GC). Emission factors expressed as NMHC and NMEHC are calculated by subtracting the $CH_4$ and $CH_4/C_2H_6$ concentrations, respectively, from the THC concentrations. In some cases, the difference between the measured THC and $CH_4/C_2H_6$ concentrations was less than the analytical precision of the instruments. In these cases, NMHC/NMEHC emissions were not quantified.

Except for the 2-stroke, lean-burn engine family, the information presented in Table 1 is considered limited since the emission factors are based on tests conducted on only one to three engines/turbines. As expected, there are differences between the emission factors calculated in this study and those in AP-42. The differences between the data from this study and AP-42 can be attributed to the variability associated with the population of engines tested, and differences in the type of instrumentation used during the two studies.

## Conclusions

Based on examination of the test results from this study, the following conclusions are offered to enhance the emissions database currently in AP-42:

- Incorporate emissions data used to develop the emission factors for uncontrolled 2-stroke, lean-burn; 4-stroke, lean-burn; and 4-stroke, rich-burn engines; and gas turbines into the current AP-42 emissions database. Although the current factors are “A” quality, incorporation of these data will broaden the population of the engines covered.
- Incorporate the data used to develop the emission factors for 2-stroke, clean-burn engines into the current AP-42 emissions database. The current AP-42 factors are “C” quality. The additional data may upgrade the emission factor quality rating for this category.
- Use data for NSCR-controlled 4-stroke, rich-burn engine, PCC-controlled 4-stroke, lean-burn engine, and the 2-stroke, clean-burn engine with a CO oxidation catalyst to build and/or improve an emissions database for these categories.
- The current version of AP-42 has separate emission factors for “clean-burn” and “PCC” controlled engines. “Clean-burn” is a trade name used by one manufacturer to describe modifications to a lean-burn engine to lower emissions. A PCC is a primary component of the “clean-burn” modification to these engines. An engine equipped with PCC may also have all of the other clean-burn modifications, as did the one engine with PCC tested under this program. Consideration should be given to combining the emissions database for these control scenarios under a single generic description.

***Table 1.*** *Full Load Average Emission Factors*

| Engine Family | Emission Control | No. of Engines/ Runs[a] | Units | $NO_x$ | CO | $CH_4$ | $C_2H_4$ | THC | NMHC | NMEHC |
|---|---|---|---|---|---|---|---|---|---|---|
| 2-stroke; lean-burn | — | 7/16 | (g/hp-hr)[b] | 14 | 0.63 | 4.6 | 0.31 | 5.7 | 1.1 | 0.80 |
| | | | (lb/MMBtu) | 3.4 | 0.15 | 1.1 | 0.059 | 1.4 | 0.28 | 0.19 |
| 2-stroke; clean-burn | — | 1/3 | (g/hp-hr) | 0.48 | 1.4 | NA | 0.38[c] | 6.8 | —[c] | —[c] |
| | | | (lb/MMBtu) | 0.14 | 0.41 | NA | 0.11[c] | 2.0 | —[c] | —[c] |
| | CO | 1/1 | (g/hp-hr) | 0.54 | 0.11 | NA | NA | 6.3 | —[c] | —[c] |
| | catalyst | | (lb/MMBtu) | 0.17 | 0.030 | NA | NA | 1.9 | —[c] | —[c] |
| 4-stroke; lean-burn | — | 3/6 | (g/hp-hr) | 14 | 0.83 | 5.5 | 0.16 | 4.1 | —[c,d] | —[c,d] |
| | | | (lb/MMBtu) | 3.7 | 0.21 | 1.5 | 0.044 | 1.1 | —[c,d] | —[c,d] |
| | SCR | 1/2 | (g/hp-hr) | 5.0 | 0.43 | NA | 0.15 | 2.7 | —[c,d] | —[c,d] |
| | catalyst | | (lb/MMBtu) | 1.3 | 0.11 | NA | 0.036 | 0.69 | —[c,d] | —[c,d] |
| 4-stroke; clean-burn | PCC | 1/1 | (g/hp-hr) | 0.56 | 2.0 | NA | NA | 8.0 | —[c] | —[c] |
| | | | (lb/MMBtu) | 0.14 | 0.51 | NA | NA | 2.0 | —[c] | —[c] |
| 4-stroke; rich-burn | — | 1[e]/1 | (g/hp-hr) | 18 | 15 | NA | NA | 3.0 | —[c] | —[c] |
| | | | (lb/MMBtu) | 5.2 | 4.2 | NA | NA | 0.85 | —[c] | —[c] |
| | NSCR | 1[f]/2 | (g/hp-hr) | 0.050 | 0.26 | NA | NA | 1.7 | —[c] | —[c] |
| | catalyst | | (lb/MMBtu) | 0.015 | 0.075 | NA | NA | 0.49 | —[c] | —[c] |
| Gas turbine | — | 2/4 | (g/hp-hr) | 1.4 | 0.16[g] | ND | ND | ND | ND | ND |
| | | | (lb/MMBtu) | 0.31 | 0.038[g] | ND | ND | ND | ND | ND |

*NA = Not available. ND = Not detected. NSCR = nonselective catalytic reduction. SCR = selective catalytic reduction.*
*PCC = Pre-combustion chamber.*
*[a]For some pollutants, the number of engines/runs used in the average is less than the total number tested.*
*[b]There is uncertainty in the horsepower measurements made by the engine analyst for 4 of the 16 runs.*
*[c]GC hardware malfunction during Campaign 4 prevented collection of data for methane and/or ethane.*
*[d]Difference between recorded methane and THC measurements was less than the precision of either instrument.*
*[e]Based on one engine tested at 91% speed and below 90% load.*
*[f]Based on one engine tested at 90% speed.*
*[g]Test results below the detection limits were averaged as zero.*

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*The complete report consists of two volumes, entitled "Criteria Pollutant Emissions from Internal Combustion Engines in the Natural Gas Industry:"*
*"Volume I. Technical Report" (Order No. PB96-168265; Cost: $25.00)*
*"Volume II. Appendices A-I" (Order No. PB96-168273; Cost: $57.00)*
*The above reports will be available only from: (cost subject to change)*
*National Technical Information Service*
*5285 Port Royal Road*
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