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PM2.5 EMISSIONS ESTIMATES FOR NATURAL GAS-FIRED GAS TURBINES AND OTHER NATURAL GAS COMBUSTION SOURCES

Glenn C. England*†, Jasmine Urisk**

***Ramboll Environ, Irvine, California. USA (†gengland@ramboll.com)**
****Canadian Energy Partnership for Environmental Innovation, Ontario, Canada (jtu@sentex.net)***

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ABSTRACT

The utilization of natural gas for industrial and power generation applications is increasing in response to increased supplies of natural gas and environmental considerations including air pollution and climate change. Air pollutant emissions from natural gas-fired gas turbines, reciprocating engines and other gas-fired combustion sources are very low, yet such facilities face increasing scrutiny of emissions that contribute to ambient PM2.5 especially in areas that are not meeting ambient air quality standards. Widely-used filterable and condensable particulate mass emission factors significantly overstate emissions from gas-fired sources due to liquid-phase measurement artifacts and sensitivity limitations associated with the underlying hot filter/cooled impinger test methods.

New PM2.5 emission factors for gas-fired internal combustion engines and external combustion boilers and process heaters were developed based on recent and historical tests using an emerging dilution sampling methodology that provides more accurate results than traditional hot filter/cooled impinger methods. The methodology provides greater sensitivity and avoids measurement artifacts that are inherent in traditional hot filter/cooled impinger methods. This results in significantly lower PM2.5 emission factors compared with other published emission factors. The modified method was used to determine PM2.5 mass and species concentrations and heat input-based emission factors.

Compared with estimates based on widely-used emission factors, the new PM2.5 emission factors and species profiles result in significantly lower air quality and health risk impacts related to natural gas-fired gas turbine engines and other natural gas-fired sources. This is especially significant, for example, when estimating PM2.5 annual emissions relative to the 0.3 tonnes per year facility PM2.5 reporting threshold for the Canada National Pollutant Release Inventory or the 10 tons per year PM2.5 major source significant emission rate threshold under U.S. New Source Review rules. A new test method embodying the test protocol is being prepared for publication.

Introduction

The utilization of natural gas for industrial and power generation applications is increasing in response to increased supplies of natural gas and environmental considerations including air pollution and climate change. Although air pollutant emissions from natural gas-fired turbines, reciprocating engines, boilers and other combustion sources are very low, facilities face increasing scrutiny of emissions that contribute to ambient air quality and human health effects. Emissions that contribute to particles with aerodynamic diameter of 2.5 micrometers and smaller (PM2.5) in the ambient air are of special interest, especially in areas not meeting PM2.5 ambient air quality standards.

Emission factors provide a means of relating pollutant releases to the atmosphere based on an activity associated with the release of that pollutant. PM2.5 emissions estimates for natural gas combustion based on widely cited filterable and condensable particulate matter emission factors published in U.S. Environmental Protection Agency's (U.S. EPA's) Compilation of Air Pollutant Emission Factors (AP-42) [1], are thought to significantly overstate emissions from gas-fired sources due to sensitivity limitations [2] and measurement artifacts [3] associated with the underlying hot filter/cooled impinger test methods such as U.S. EPA Methods 201A and 202. Thus, there is a need for improved PM2.5 emission factors for gaseous fuels (including natural gas) combustion.

Background

PM2.5 emission factors and species profiles were previously reported [4,5] based on tests conducted in the United States (U.S.) from 1998 to 2003 during an industry-government collaboration, led by GE Energy and Environmental Research Corporation (GE EER). The tests used a research dilution sampling methodology with ambient air sample collection and analysis methods for tests on six different gas-fired sources, including two heavy duty gas turbine-combined cycle units and one aeroderivative gas turbine cogeneration unit. The U.S. EPA subsequently developed new PM2.5 and PM10 emission factors for natural gas combustion based on the GE EER test results that have been used in its National Emission Inventory (NEI) program starting in 2004. The American Petroleum Institute sponsored tests of three natural gas-fired reciprocating engines using the same research dilution sampling methodology.[6] In 2008, a modification of U.S. EPA's Conditional Test Method 039 [7] (CTM 39) was developed and evaluated in tests on a natural gas-fired combined cycle power generation unit.[8] In 2014, lessons from the 2008 tests and other improvements were applied to modified CTM 39 tests of six different refinery gas-fired boilers and process heaters.[9] In 2015, the Canadian Energy Partnership for Environmental Innovation (CEPEI), Petroleum Technology Alliance Canada and the British Columbia Oil and Gas Research and Innovation Society co-sponsored a test program applying modified CTM 39 to two natural gas-fired engines in natural gas pipeline compressor applications in Canada.

A key finding from the 2008 modified CTM 39 tests is that replicate recovery rinse samples and sample train field blanks were not significantly different – net weights were statistically the same even with application of highly evolved best practices for minimizing potential contamination and imprecision. The study concluded that further evaluation was needed especially regarding the recovery rinse procedures and 47-mm filter holders used in those tests. The updated 47-mm filter holders used in the recent pipeline engine tests performed well and method performance was consistent with expectations. These tests continue to show that the net weights of replicate sample recovery rinses and the net weights of replicate sample train field blanks are not significantly different at very low particulate matter concentrations, setting a lower limit for which the rinse procedures are useful.

Sources of PM10 Emissions from Gas-Fired Combustion Sources

PM10 emissions from indirect (external) combustion of gaseous fuels in industrial systems may originate from sources such as:

- Combustion and post-combustion conversion of sulphur (& chlorine) to acid aerosols & salts (e.g., ammonium and transition element salts);
- Incomplete fuel combustion (carbon conversion to soot, high-molecular weight organics);
- Vaporization and condensation of volatile elements contained in the fuel, inlet air and emission control reagents;
- Transmission of non-volatile elements contained in the fuel, inlet air and emission control reagents;
- Particle agglomeration and breakup;
- Corrosion/erosion of system components; and
- Entrainment of debris remaining from system construction and maintenance activities.

For example (Figure 1a), a gas-fired gas turbine cogeneration system may have duct burners and emission control catalysts (SCR, with reagent ammonia injection) and/or oxidation catalyst) in the heat recovery steam generator (HRSG). The gas turbine may use water injection into the compressor for power augmentation.

The input streams entering the system - fuel, air, ammonia reagent, turbine water, etc. – contain trace impurities that are potential sources of PM10 emissions. Although combustion in modern gas turbines is very well controlled to achieve complete combustion, all combustion processes exhibit slight departures from ideal conditions that can lead to manufacture of trace amounts of unburned fuel as soot or semivolatile hydrocarbons. Particles in the ambient air remaining after the inlet air filters participate in the combustion chemistry and approach equilibrium with other constituents. Trace amounts of sulphur in the fuel are partially converted acid aerosols, which can be further increased by SO_2 oxidation on emission control catalysts. Some of the manufactured acid aerosols are condensed and captured within the cold end of the HRSG as ammonium sulphate/bisulphate tube deposits.

Although the quantities of compounds transferred through and manufactured in the system are very small, so are the measured concentrations of PM10 in the exhaust. Using typical specifications for impurities in the various input streams and assigning simple mass transfer functions to estimate their fates, one study used Monte Carlo simulations to illustrate their relative potential impact on PM emissions (Figure 1b) [10]. The illustration shows that one might reasonably expect very low concentrations of various chemical species contributing to PM10 emissions.

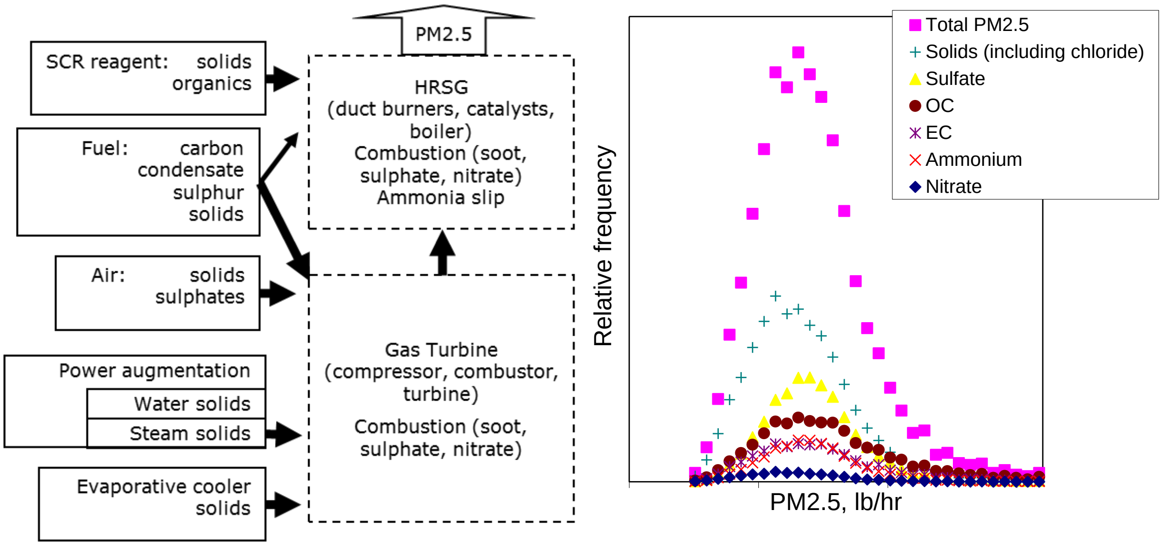

Figure 1. (a, left) Potential input stream sources of and (b, right) their estimated relative contributions to PM10 emissions from a natural gas-fired combustion system [10].

Measurements

An emerging dilution sampling protocol was used to measure PM2.5 emissions for development of PM2.5 emission factors and species profiles. The protocol combines a modification of CTM 39 with proven ambient air sample collection and analysis methods. The sampler (Figure 2) dilutes the hot exhaust gas sample with conditioned ambient air and then collects filterable PM2.5 and condensable PM together on the same filter without distinguishing between them.

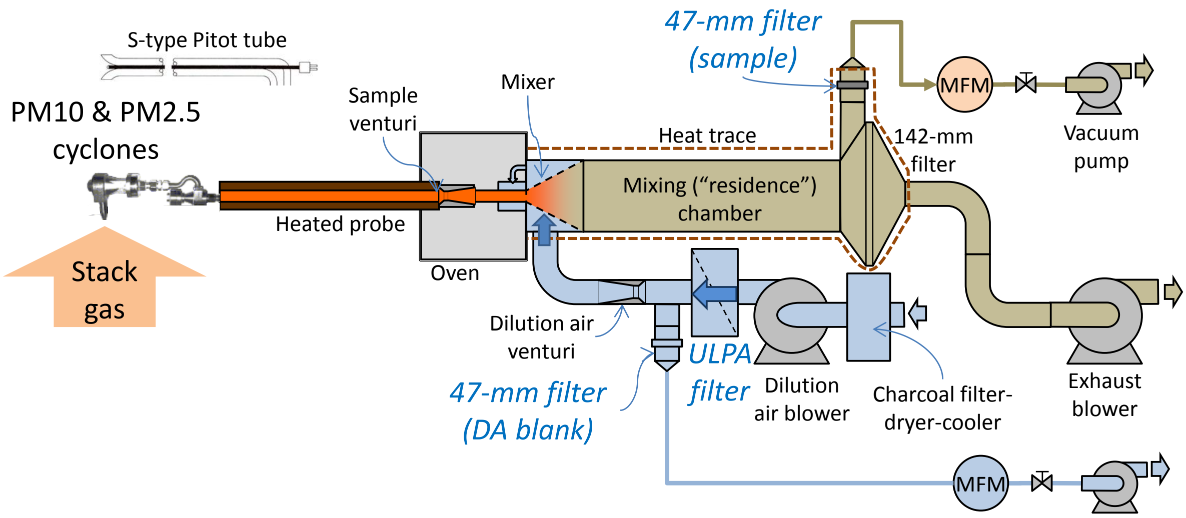

Figure 2. Modified CTM 39 sampling train (normal configuration).

Key CTM 39 modifications for the CEPEI test program included:

- Addition of ambient air sample collection and analysis methods [11]:
  - Collection of particulate mass on 47-mm Teflon® membrane filters (TMFs) from a portion of the diluted stack gas sample;

- Conditioning the TMFs at 20 °C and 40% relative humidity before weighing, to avoid analytical imprecision due to hygroscopicity of collected particulate matter. This is the same protocol used for ambient air PM2.5 measurements, so it provides for direct comparability of stack and ambient air measurements;
- Weighing TMFs on an analytical balance with 1 microgram sensitivity (100 times more sensitive than analytical balances specified for traditional hot filter/cooled impinger methods);
- Analysis of the TMFs after weighing for chemical elements (by x-ray fluorescence);
- Simultaneous collection of particulate matter on pre-fired 47-mm quartz fiber filters and subsequent analysis for organic and elemental carbon (by thermal-optical reflectance/transmittance) and water-soluble ions (by ion chromatography);

- Substitution of electropolished surface finish rather than Teflon coating for the internal surfaces of the sampling apparatus in contact with the sample, to eliminate potential buildup of particle deposits on the surfaces due to electrostatic charge;
- Improvements to dilution air conditioning including substituting an ultra-low penetration air (ULPA) filter in place of the high-efficiency particulate arrest (HEPA) filter, addition of a charcoal filter to remove volatile organic compounds and provision for collection of dilution air blanks on 47-mm filters;
- Elimination of the in-stack cyclones and addition of an external heated PM2.5 cyclone between the sample probe exit and sample venturi inlet. This modification was made because the threaded cyclones used in these tests would be damaged if exposed to the high exhaust temperatures (>425 °C) at both CEPEI test sites;
- Elimination of solvent rinses (to recover PM from the internal surfaces of the sampling apparatus) when testing gas-fired sources. This change was made because rinse samples have been shown to be not significantly different from replicate sample train field blanks and a significant mass of particles from gas combustion is not expected to deposit on surfaces since the particles are much smaller than 1 micrometer [1,9].
- Because of the high exhaust temperatures of the engines, the threaded in-stack PM2.5 cyclone was relocated between the probe and sample venturi, inside a heated enclosure.

This protocol provides much greater sensitivity than, and avoids measurement artifacts associated with, traditional stationary source test methods using hot filters/cooled impingers. It also replicates aerosol formation that occurs in a source's exhaust gas stream as it mixes and cools in the atmosphere near the stack. It is very similar to well-proven and internationally accepted dilution sampling test methods used for determining particulate matter emissions from non-road and mobile source engines [12,13]. This method enables measurements of PM2.5 at the very low concentrations characteristic of gas-fired sources with much greater accuracy and precision than traditional hot filter/cooled impinger test methods are capable of.

The cost of tests using modified CTM 39 methodology is currently greater than traditional methods because of higher equipment costs and setup time, test personnel training and development of organizational best practices. The sampling equipment is significantly different from traditional method sampling equipment, and thus there is a significant learning curve for testers who are unfamiliar with it. Training and development costs should decrease with experience over time. These higher costs may be partially offset in specific applications by reduced test duration afforded by the methodology's greater sensitivity.

Engine Test Results

A 27.5 megawatt (MW) gas turbine engine with lean premix combustors and no emission control catalysts and a 2.3 MW reciprocating engine with precombustion chambers, air-fuel controller and no emission control catalysts were tested. The engines were operated on "pipeline" natural gas fuel at approximately constant power output, with an engine load of 80% of rated capacity or higher. The natural gas total sulphur species content was approximately 0.00015 kilograms per gigajoule (kg/GJ). Sample was drawn through the apparatus during three four-hour test runs for each unit.

Although emissions from both engines are very low in absolute terms, the average measured PM2.5 mass emission rate is much higher for the reciprocating engine (Table 1) than for the gas turbine engine (Table 2). This is attributed to lubricating oil blow-by, quenching of combustion gases in the combustion chamber crevices and unsteady-state combustion characteristics of reciprocating engines compared with steady-state combustion in gas turbines.

Thirty-one elements and ions were analyzed but were not detected in the samples from any test runs on the reciprocating engine. Twenty species that were detected in at least one reciprocating engine test run account for 99.69% of total reconstructed mass (Table 1). 94% of total mass is accounted for by organic carbon (OC), followed by 4.5 percent of total mass from the sum of sulphur (S), elemental carbon (EC) and calcium (Ca). Nitrate ion accounted for 0.33%. On the gas turbine engine, thirty-six elements and ions were not detected in any test runs. Twenty detected species account for 98.9% of reconstructed mass (Table 2). OC accounts for 80% of total reconstructed mass, followed by sodium (Na), EC and magnesium (Mg).

PM2.5 Emission Factors

PM2.5 emission factors were calculated for gas turbines (including gas turbines, combined cycle and cogeneration units) and four-stroke reciprocating engines using data from all of the available test results (Tables 3 and 4). The two data sets fit normal distributions; therefore, no data transformations were considered necessary in calculating emission factor statistics. One combined cycle unit was tested at full load with duct burners on and reduced load with duct burners off – these were treated as separate sources for emission factor development to incorporate the emission factor variability that may be represented by units with and without duct burners. Because test results were available for only a single source, no emission factor for two-stroke reciprocating engines is recommended.

Table 1. CEPEI reciprocating engine test results – modified CTM 39 test method (species detected in at least one test run, as fraction of reconstructed mass).

Average PM2.5 mass (kg/GJ):		0.00150	
Species	**Mass Fraction**	**Species**	**Mass Fraction**
OC	0.94	Eu	0.00064
S	0.018	Na^+	0.00050
EC	0.017	Ba	0.00031
Ca	0.011	Fe	0.00028
NO_3^-	0.0033	Ti	0.00024
Zn	0.0015	W	0.00021
Cl	0.0014	Ce	0.00022
Si	0.0013	K	0.00021
P	0.0012	Cs	0.00018
Al	0.00060	La	0.00012

Note! Apply this species profile only to PM2.5 mass determined by dilution methods. Other test methods may give different speciation results. Do not apply to PM2.5 mass determined by hot filter/cooled impinger methods.

Table 2. CEPEI gas turbine engine test results – modified CTM 39 test method (species detected in at least one test run, as fraction of reconstructed mass).

Average PM2.5 mass (kg/GJ):		0.000236	
Species	**Mass Fraction**	**Species**	**Mass Fraction**
OC	0.80	NO_3^-	0.0018
Na	0.089	W	0.0012
EC	0.042	Br	0.0015
Mg	0.023	Cs	0.00049
P	0.0076	Cl	0.00050
Sm	0.0053	K	0.00054
Eu	0.0046	Cd	0.00045
Si	0.0041	Ba	0.00041
Tb	0.0033	Sb	0.00033
Ce	0.0023	Sn	0.00028

Note! Apply this species profile only to PM2.5 mass determined by dilution methods. Other test methods may give different speciation results. Do not apply to PM2.5 mass determined by hot filter/cooled impinger methods.

Table 3. PM2.5 emission factor data set for natural gas-fired reciprocating engines (dilution sampling test methods).

Source	Engine type	Fuel	Controls	Test Date	PM2.5 kg/GJ
Two-stroke engines:					
API	Two-stroke lean burn, 2.0 MW	Natural gas	PCC	2004	0.00859
No emission factor recommended					
Four-stroke engines:					
API	Four-stroke rich burn, 1.2 MW	Natural gas	NSCR	2004	0.000774
API	Four-stroke lean burn, 1.2 MW	Natural gas	None	2004	0.00216
CEPEI	Four-stroke lean burn, 2.3 MW	Natural gas	PCC, A/F	2015	0.00156
99% confidence upper prediction limit (default emission factor)					0.00710
Average±95% uncertainty					0.00150±116%
95% confidence upper bound					0.00226

Table 4. PM2.5 emission factor data set for gas-fired gas turbines (dilution sampling test methods).

Facility ID	Unit ID	Fuel	Controls	Test Date	kg/GJ
Bravo	GTCC/C (2xDB on + 1x DB off), 159 MW	Natural gas	LPC+CO Cat+SCR	2001	0.000108
Echo	GTCC/C (High load, DB on), 170 MW	Natural gas	LPC+CO Cat+SCR	2003	0.0000451
Echo	GTCC/C (Reduced load DB off), 170 MW	Natural gas	LPC+CO Cat+SCR	2003	0.0000688
Golf	GT-Cogen (DB on), 48 MW	Refinery gas	WI+CO Cat+SCR	2003	0.000126
NGCC	NGCC (no DB), 170 MW	Natural gas	LPC+SCR	2008	0.0000215
CEPEI	Gas turbine, 27.5 MW	Natural gas	LPC	2015	0.000236
99% confidence upper prediction limit (default emission factor)					0.000380
Average±95% uncertainty					0.000101±80%
95% confidence upper bound					0.000148

Note, there are clearly differences in design, fuels, emission controls and operating characteristics among the sources included in each data set. These differences certainly can be expected to contribute to the variability of PM2.5 emissions observed among them. It would not be unusual to subcategorize sources according to size, combustion system design, emission control equipment and/or fuel types, providing different emission factors for each subcategory. However, the numbers of sources in each data set are too few (in several cases only a single source) to distinguish between these differences with statistical confidence. It is not considered good practice to publish emission factors based on tests of a single source among a population of like sources. Therefore, data were aggregated to increase the number of sources in each category, which lowered the statistical uncertainty associated with the aggregate emission factors compared with the uncertainties for smaller subgroups of sources. It is likely that the PM2.5 emission factor for any individual unit and the average aggregate emission factor will be different and may depend on the specific configuration of the individual unit. As more data become available in the future, it may be appropriate to revisit potential subcategorization of emission factors for different unit configurations.

The average, 95% confidence upper bound and 99% upper prediction limit (99% UPL) are included in Tables 3 and 4. The 95% confidence upper bound and 99% UPL values incorporate factors that account for variability of average PM2.5 emissions among the sources included in the data sets. The most appropriate value will depend on the end user's objectives. An average emission factor may be appropriate to use for estimating the average emissions from a population of similar sources (e.g., for emission inventory or regional air quality modelling purposes). However, the average should not be used as an emission standard because some of the sources will have higher emissions than the population average at some or all times because of variations in design, fuels and other factors affecting emissions. Thus, the "best" expression of an emission factor will depend on a particular end user's application.

To allow for different potential end user objectives, it is appropriate to include an allowance for variability among the data in any default emission factors intended for multiple end uses. CEPEI's default emission factors therefore are based on the 99% UPL. The 99% UPL is the value for which there is 99% confidence that 95% of future test averages will fall below that value, based on the tests included in the data sets. The UPL estimates the upper bound of future test averages, and encompasses the source-to-source variability within the data set. The UPL derives from widely accepted and commonly used statistical principles. The UPL is used in a wide variety of industries and professions, including by U.S. EPA for establishing source emission limits under certain regulations.

Discussion

The average CEPEI PM2.5 emission factors are lower than the average AP-42 emission factors for total PM (sum of filterable and condensable PM) (Table 5). The differences are much more pronounced for gas turbines than for reciprocating engines. The average CEPEI PM2.5 emission factor for gas turbines is 28 times lower and the default CEPEI emission factor (99% UPL) is 7.5 times lower than the average AP-42 emission factor. The CEPEI and AP-42 data sets for gas turbines are the same size, each with tests of five different units (one source in the CEPEI data set was tested at two loads which are treated as separate tests, as previously noted).

Table 5. Comparison of CEPEI and AP-42 PM10/PM2.5 emission factors for gas-fired gas turbine and four-stroke reciprocating engines.

		kg/GJ		
	Parameter	Gas turbines/NGCC/ Cogen	Four-stroke reciprocating engines	External Combustion (boilers, process heaters)
CEPEI	default 99% UPL	0.000380 [a]	0.00710	0.000637
	average±95% uncertainty	0.000101±80% [a]	0.00150±116%	0.000100±69%
	# of tests (units)	6 (5) [a]	3	12
AP-42	average±95% uncertainty	0.00285±85%	0.00673±446% [b]	0.00353±119%
	# of tests (units)	5	5 filterable PM 2 condensable PM	21 filterable PM 4 condensable PM

[a] Includes gas turbines, combined cycle and cogeneration units with and without duct burners, with and without emission control catalysts, and firing natural gas and/or refinery gas.

[b] For purposes of comparison with the CEPEI emission factor, the AP-42 filterable and condensable PM data for two four-stroke lean burn engines and three four-stroke rich burn engines were combined to calculate the statistics for four-stroke rich burn and lean burn engines. Condensable PM accounts for 63% of the total AP-42 PM emission factor. Note, the AP-42 data set does not include any condensable PM measurements for four-stroke rich burn engines. The condensable PM emission factor given in AP-42 is based on tests for two four-stroke lean burn engines.

The average CEPEI PM2.5 emission factor for reciprocating engines is approximately 15 times higher than the average CEPEI PM2.5 emission factors for gas turbines, but is only 4.4 times lower than the combined (rich burn and lean burn engines – see note in Table 5) AP-42 emission factor for four-stroke engines. That the difference between CEPEI and AP-42 emission factors for reciprocating engines is smaller than it is for other source types is likely due to higher actual PM2.5 emissions resulting from unsteady-state combustion, exhaust quenching and lubrication oil transport characteristics of reciprocating engines, which leads to higher PM emissions compared with combustion in gas turbines and external combustion equipment (e.g. boilers). Both the CEPEI and AP-42 data sets for reciprocating engines are very small – only two lean burn engines and three rich burn engines in the AP-42 data sets and three four-stroke engines in the CEPEI data set. Further, there are only two tests in the AP-42 data set for condensable PM, which comprises 51 to 99% of the AP-42 total PM emission factors for rich burn and lean burn engines, respectively.

The data sets used for developing these emission factors are considered small for commercial use, e.g., for establishing commercial emissions guarantees. At the present time, engine manufacturers may be reluctant to offer commercial PM2.5 emissions performance guarantees based on these methods until a sufficient body of test results is available to understand commercial risk. Until that time, facilities that choose to use these emission factors as emission limits for permitting new engines may be faced with accepting the potential risk that future tests may yield higher results.

U.S. EPA published new draft guidelines for emission factor development in 2013 [14]. The guidelines include a new formulaic approach for determining emission factor quality based on test report scores, the number of tests and size of the overall population of similar units. Emission factors are qualified as “poorly representative”, “moderately representative” or “highly representative.” Test report scores from 0 to 100 are based on separate reviews conducted by the tester and a regulatory agency representative, following a scorecard template which encompasses criteria for documentation completeness, measurement execution and other factors. However, the new approach addresses neither the emission factor uncertainty nor the representativeness of the tested source configuration with respect to the overall population, nor other factors at the time of the test that may influence emissions.

The emission factor quality rating scheme in EPA’s new guidelines can convey a somewhat different impression of emission factor quality compared with the more subjective AP-42 “A” through “E” emission factor rating scheme. For example, the current AP-42 condensable PM emission factor for gas turbines is based on single tests of just five near-identical units conducted in the 1990s. AP-42 assigns it a “C” rating, which means “Average. Factor is developed from A-, B-, and/or C-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A rating, the source category population is sufficiently specific to minimize variability.” Under the new rating approach, the condensable PM emission factor would be rated “moderately representative” if the five reports scored an average of 78 points or higher (this would be relatively easy to achieve by the new scoring method).

Assuming that the test reports used for CEPEI’s emission factors would receive at least moderately high scores after regulatory agency review and following EPA’s quality rating approach, the reciprocating engine emission factor would be rated as “poorly representative” and the gas turbine emission factor would be rated as “moderately representative”. The small data sets, diversity of fuels, designs and emission controls among the units included in the data sets compared with the broader population and the large relative uncertainties in the average emission factors indicate the need for caution when applying them to any individual unit. Nevertheless, the CEPEI emission factor statistical uncertainties (in kg/J) are substantially lower compared with those calculated for the AP-42 combined filterable and condensable PM emission factors. Considering also the improvements in test methodology, we would judge the CEPEI emission factors to be significantly more accurate than the AP-42 emission factors.

As an application example, the impact of the new PM2.5 emission factor on PM2.5 emissions estimates for natural gas-fired gas turbine engines is potentially substantial in the context of air quality permitting for major sources under the U.S. New Source Review (NSR) rules. For example, a typical 170 MW gas turbine operating at full load for 8760 hours per year would have an average annual heat input of approximately 13.6 million MMBtu/year. The average annual PM2.5 emissions would be approximately 45 tons per year using the AP-42 emission factor for filterable plus condensable particulate matter. This is well above the 10 tons per year major source significant emission rate threshold for PM2.5 emissions under NSR that would trigger further analysis and mitigation under prevention of significant deterioration (PSD) rules. This can be a significant barrier to licensing of new power plants, for example, especially in PM2.5 non-attainment areas where PM2.5 mitigation measures (offsets, regulatory agency fees) have limited availability and/or are very costly. The estimated average annual PM2.5 emissions would decrease to 6.0 tons per year using the CEPEI default (99% UPL) PM2.5 emission factor for gas turbines, and 1.6 tons per year using the CEPEI average PM2.5 emission factor, potentially avoiding the need for further analysis and mitigation measures.

The CEPEI data sets include results from a variety of sources with different gaseous fuels (natural gas and refinery gas) and differences in design and emissions control configuration. The maintenance condition of sources at the time of testing and many other site-specific and environmental factors also can affect source performance and emissions. Fuel sulphur is a key source of PM emissions from combustion of gaseous fuels. [6,15] Fuel sulphur content of natural gas and refinery gas fuels varies depending on origin and gas processing before use. Thus, emissions from any individual source at any particular point in time may be different from an estimate derived from emission factors. Such influences should be taken into consideration when applying the CEPEI PM2.5 emission factors for evaluating emissions from any particular individual or group of sources.

Findings

The new CEPEI PM2.5 emission factors provide improved emission factors for large gas-fired engines that are much lower than emission factors previously published in AP-42. All fully documented test results currently available to the authors were used to develop the CEPEI emission factors. The CEPEI PM2.5 emission factors may provide some relief from barriers to licensing and permitting gas-fired sources, especially in PM2.5 non-attainment areas, subject to acceptance of the emission factors and underlying modified CTM 39 methodology by regulatory agencies.

The dilution sampling techniques used to develop these emission factors are considered more accurate for gas-fired combustion system applications than traditional stationary source test methods for PM emissions using hot filter/cooled impinger techniques. The test protocol applied in these tests recently has been accepted in at least one instance for use in regulatory emissions performance tests. Stationary source dilution sampling test methods are available that can be modified to the test protocol used in these tests [7,16] and suitable test equipment is commercially available. Interest in using these methods is growing among facilities, combustion equipment manufacturers and regulators.

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