PARTICULATE MATTER, PM10 AND PM2.5:

WHAT IS IT, HOW IS IT REGULATED, HOW IS IT MEASURED, AND WHAT IS GE'S POSITION ON PM EMISSIONS FROM GAS TURBINES?

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Forward

The purpose of this document is to provide a brief introduction to particulate matter, what it is, what it is made of and how it is measured. It is intended for GE sales and engineering to provide a background and basic understanding of the issues associated with particulate matter and its emissions from fossil-fuel power plants. More detailed information can be found at the citations listed in the footnotes.

The intent is to present brief, easily understood explanations and examples, which may be used for clarification of discussion points which may arise during communication with GE Customers and Partners.

1.0 WHAT IS PARTICULATE MATTER?

The US EPA defines particulate matter (PM) as "a mixture of solid particles and liquid droplets found in the air."[i] PM can be in sizes or colors large or dark enough to be observed or it can be so small that an electron microscope is required to distinguish it. PM can be divided into size categories: PM10 emissions are defined as PM emissions that are less than ten (10) microns in diameter; PM2.5 are PM emissions that are less than 2.5 microns in diameter. PM10 and PM2.5 emissions, as defined by US EPA, include filterable and condensable emissions. PM2.5 may also be referred to as fine particulate matter. In the EU and the remainder of the world, PM requirements typically only include filterable emissions.

Smaller PM, like PM10 and PM2.5, is a concern because this size particulate can penetrate more deeply into the lungs, and has been linked to adverse health effects in people. Ambient PM2.5 (the PM measured in the ambient air) derives from combustion activities such as motor vehicles, fossil-fueled power plants, wood burning, and certain industrial processes. The portion of ambient PM10 between 2.5 and 10 micrometers, referred to as "coarse," can have non-combustion origins, such as crushing or grinding operations, and dust from paved or unpaved roads.[ii] The following table summarizes the PM size categories.

PM Size Designation	Definition	Typical Source
PM	All solid particles and liquid droplets including PM10 and PM2.5	Various
PM 10	PM less than 10 microns in diameter, including PM2.5	Crushing and grinding operations, dust from road paving
PM 2.5	PM less than 2.5 microns in diameter	Motor vehicles, fossil-fuel power plants, wood-burning

Filterable emissions are emissions that exit the stack in either solid or liquid state, and may also be referred to as "front-half" emissions or non-condensable emissions. It is the solid portion that is captured in the front-half of the sampling apparatus, typically on a filter.

Condensable emissions may also be referred to as "back-half" emissions, due to the standard method of measurement that captures the PM in the back half of the sampling train.

Condensable PM is the portion of PM emissions that exit the stack in gaseous form and condense upon mixing with cooler ambient air to form particulate matter. These emissions are most likely from liquid hydrocarbons and sulfates in the fuel.

2.0 REGULATORY DRIVERS

2.1 United States

There is currently no Federal performance standard on PM emissions from gas turbines. PM emission standards contained in the regulations of states apply to PM in general, not specifically to PM10 or PM2.5. In addition, the states' PM emission standards are not specific to stationary combustion turbines. Rather, they tend to be applicable to fuel combustion equipment in general, e.g., boilers, indirect heat exchangers, combustion turbines, etc. In some states or districts the PM standards are specifically identified as not applicable to combustion turbines.[iii]

Observed permit limits are generally established on a case-by-case basis, depending on a variety of factors, such as total plant emissions, expected source emission levels and fuel types to be burned. These and other factors determine whether a particular project triggers New Source Review (NSR) requirements. An area's attainment or nonattainment status will determine what requirements are applied; areas where the ambient PM2.5 concentrations are above the National Ambient Air Quality Standard are designated as nonattainment areas. Attainment areas require application of Best Available Control Technology (BACT) under the Prevention of Significant Deterioration (PSD) regulations; nonattainment areas must meet Lowest Achievable Emission Rate (LAER) levels under companion regulations, as well as obtain emission offsets.

In nonattainment areas, states must develop state implementation plans (SIPs) to achieve compliance with ambient PM standards. The deadline for states to submit their PM2.5 compliance SIPs to the US EPA is April 2012, and they achieve compliance within another two years (by April 2014). These SIPs may involve tighter requirements on power plant emissions and the need to obtain emission offsets for any PM2.5 that will be emitted by the new installation. Emission reduction credit (ERC) programs vary widely among the states; the highest costs are found in California and can add significant costs to the customer for their projects. Efforts of states to come into attainment may result in stricter regulations for PM2.5 emissions from power plants in the coming years.

Even if major NSR is not triggered, a number of states also require the application of BACT to establish stringent emission limits as part of the preconstruction permitting process. For most major gas turbine projects air emissions modeling is performed to ensure the source impact will be below the allowed ambient air concentration of PM. Many times the emission levels required to achieve the allowed ambient concentration are more stringent than other requirements and become the dominant limit for the emission source.

2.2 European Union

The main environmental emissions regulation for the European Union (EU) is the Large Combustion Plant Directive (LCPD). There are PM limits in the document, but the LCPD contains language specifically exempting gas turbines from these limits. However, each country can impose more stringent limits should they choose, and guidance for this is provided as part of the Integrated Pollution Protection and Control (IPPC) Directive and the Best Available Techniques (BAT) References Documents (BREF Notes). Unlike the US, the EU currently only regulates filterable PM emission from sources. This filterable only requirement is implied by the test methods specified for compliance testing, which only measure filterable PM.

Problems have been encountered with misapplication of the LCPD, using the PM limit for gas-fired sources even though the directive wording exempts gas turbines from the PM limits. Some countries are ignoring this exemption and applying the gas-fired limit to GTs.

A PM2.5 air quality standard has been recently introduced throughout the EU. As a result of increased scrutiny on PM2.5 emissions, this pollutant was also added to the list of pollutants in the 2006 review for the National Emission Ceiling Directive. PM2.5 will therefore likely be included in the Directive after 2010. The primary immediate consequence of the new PM2.5 air quality standard is that, during the permitting process, PM2.5 will have to be assessed for air quality impacts, similar to other pollutants with air quality standards. However, there is no indication at present that gas turbines are seen as a significant source of PM2.5. Regulation on emissions of PM2.5 is focused more on road transport and the formation of secondary particulate matter from large combustion sources as a consequence of SO_2 and NOx emissions.[iv]

2.3 Other Countries Around the World

World Bank (International Finance Corporation (IFC)) requirements may be applied in countries where there are no PM limits, especially in cases where external funding requires meeting these limits. There are no limits for combustion turbines firing natural gas, as the emissions are already assumed to be sufficiently low; there are suggested limits for combustion turbines firing other fuels.[v] As with the EU, the World Bank and the majority of countries outside of Europe only consider filterable emissions.

Canada is currently implementing a similar process as the SIPs in the United States. Each province is writing an implementation plan to meet the Canada Wide Standards for PM and PM2.5, so regulations for PM emissions from gas turbines may follow.

3.0 PM FROM GAS TURBINES

In general, gas turbines fired on natural gas do not produce significant amounts of PM. The reported emissions from gas turbines are dependant on the measurement techniques used, and may come from a variety of sources that are independent of the combustion process. Filterable PM from combustion turbines may derive from airborne PM that passes through the gas turbine inlet air filters, particulate matter (inert solids) in the fuel gas supply, airborne construction debris, metallic rust or oxidation products, or mineral and organic impurities in the water used for water injection.

Condensable PM may consist of sulfates, especially if there is a selective catalytic reduction (SCR) system, and unburned fuel hydrocarbons, which agglomerate to form particles. Formation of ammonium sulfates from the SCR system in a combined cycle application will also accelerate the corrosion of the heat recovery steam generator (HRSG) tubes downstream from the catalyst, which can contribute to the PM loading.

Very limited size-speciation data exists on PM emissions from gas turbines. As such, it is not possible to make a definitive estimate of the percentage of total PM turbine emissions that are PM10 and PM2.5. It would be expected that the majority of emissions fall under the PM2.5 size designation and a slightly higher percent fall under the PM10 designation.

4.0 PM Testing

Methods used for filterable and condensable PM can have significant error and associated artifacts that cause the measured value to have a positive bias. The traditional methods in common use today were developed many years ago for use on high-emission sources, such as coal-fired power plants. Improvements have been made, but these methods are not adequate to measure to the levels of PM emitted from gas turbines. Test methods for PM10 and PM2.5 typically require the measurement of filterable and condensable PM, with specific requirements generally listed in the source's air permit.

4.1 Filterable PM

US EPA Method 5B has been GE's traditional preferred method for measurement of filterable PM. This method uses a heated filter that is placed out of the stack to collect PM, which is then weighed to determine the concentration of PM in the emissions. However, this method does not separate PM by size, so is not a true measure of PM10 or PM2.5.

The EU method, EN 13284-1, is similar to EPA Method 5B, however there is an option to place the filter in the stack as an alternative to an external, heated filter. As with the US EPA method, the EU method does not separate PM by size; there is no promulgated EU method that specifically measures PM10 or PM2.5.

In order to measure size-segregated PM10 and PM2.5, a method must be chosen that separates out this smaller PM from the total PM emitted by a source. U.S. EPA Method 201A uses a cyclone that is placed in front of the filter. All of these components are located inside the stack, so the PM that is sampled is collected at the temperature of the stack. A proposed revision to Method 201A is in process now that would include the addition of a PM2.5 cyclone between the PM10 cyclone and the filter to allow this method to be used for the measurement of PM2.5 and PM10 during the same test series.

Due to the small amounts of PM emitted by gas turbines, the recommended sample times must be extended in order to collect a quantifiable amount of PM. A typical test run may last approximately 6 hours. After the samples are collected, the cyclones and sampling components upstream of the filter are rinsed with acetone to collect the deposited PM in the different size fractions. These rinses are sent with the filter to an analytical lab where they are weighed to determine the total amount of PM.

4.2 Condensable PM

PM10 and PM2.5 limits generally include condensable PM. U.S. EPA Method 202 is the only promulgated method for measurement of condensable PM in the U.S., and is used in conjunction with a front-half method, such as Method 201A. A series of water-filled, glass impingers are connected downstream of the filter and placed in an ice bath. The hot stack gas passes through these impingers, and any PM that was not solid at stack conditions is condensed out in the water. The contents are recovered and sent to a laboratory for gravimetric analysis.

The water in the impingers of Method 202 is known to create a positive bias due to formation of pseudoparticulate from oxidation of SO_2 in the impinger water over the course of sampling. This bias can be significant when compared to the low levels expected from GTs. A proposed revision to Method 202 that looks to reduce this bias is currently in a regulatory comment period right now. The revised method removes water from the impingers, and uses a condenser upstream of the impingers and a filter downstream to aid in the collection of any condensable PM. Other additional requirements aim to minimize the variability that has historically been encountered with this method.

4.3 Dilution Sampling

One alternative to the traditional EPA methods is dilution sampling, which mixes the stack gas with clean, ambient air in order to better replicate the processes taking place as the emissions exit the stack. As the gases mix, the sample is cooled allowing the condensable PM to form. The composite sample is collected on a filter that is then sent for gravimetric analysis. This method has been used for many years for testing of mobile sources, but has only recently been developed for use on stationary sources such as GTs. U.S. EPA has a conditional test method (CTM-039) and there is an ASTM method under development, but very little data has been collected, so there is still some uncertainty as to the reliability of the method for use on GTs.

5.0 GE POSITION

GE believes that the natural gas combustion process itself generates limited PM, PM10 and PM2.5 emissions, and that the majority of reported levels in the gathered data are due to non-combustion factors, and test method error. PM10 and PM2.5 emissions from oil-fired turbines are dependent on the amount of ash, sulfur and impurities in the fuel. PM emissions from natural-gas combustion are difficult to demonstrate due to the extremely low quantities being emitted. Improved sampling methods are necessary to provide more accurate and precise measurements of the PM emissions from low-level sources, like GTs.

Until test methods for PM 2.5 are promulgated, GE will offer guarantees based on current testing methods and existing data collected for PM and PM10 emissions from natural gas combustion. GE will reevaluate this position once actual test data is available.

Due to the limited amount of size-speciated PM emissions data from gas turbines, GE is forced to assume that PM2.5 and PM10 levels are equal to the current values used for total PM when providing both emission estimate and guarantees. As the body of scientific knowledge and testing methodology improve it is hoped that a better estimate of PM10 and PM2.5 from gas turbines will be obtained.

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[i] Particulate Matter, Basic Information http://www.epa.gov/air/particlepollution/basic.html
[ii] Fine Particle ($PM_{2.5}$) Designations , Frequent Questions- http://www.epa.gov/pmdesignations/faq.htm#0
[iii] "Summary of Current Air Quality Issues in Europe" and "Summary of Selected US States and Districts Regulatory and Emission Reduction Credit (ERC) Issues Associated with Particulate Matter (PM) Emissions from Utility Size Combustion Turbines," ERM, February 2009. (GE internal reports)
[iv] Ibid.
[v] "Environmental, Health, and Safety Guidelines for Thermal Power Plants," International Finance Corporation, World Bank Group, December 19, 2008