DIPARTIMENTO DI FISICA
DELL'UNIVERSITA' DI FERRARA

Spett.
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Ref.: production of total particulate matter from the ENEL power station and filtration of the Systemlife filtering station

The ARPA report "Atmospheric emissions from gas turbine power stations" written by the ARPA sections of Piacenza and Ferrara (annex 1) and which considers the emission values for some ENEL power stations in northern Italy was taken as the basis for the calculation.

The consumption of natural gas per unit of energy produced (kWh) amounts to 0.2 Nm3/kWh on average. Approximately 1 Nm3 of CH_4 is consumed to produce 5 kWh. In power stations, 1 Nm3 of natural gas is considered to produce approximately 30 Nm3 of fumes.

The maximum concentration envisaged for total particulate in emission fumes from stacks is approximately 0.6-0.7 mg/ Nm3 but measurements give peak values of 0.2 mg/Nm3 with average values of less than 0.1 mg/Nm3.

Considering these maximum concentrations, a production of 0.7mg/ Nm3 * 30 Nm3 is obtained which, **for 5 kWh, generates atmospheric emissions of 21 mg of total particulate matter**.

The Systemlife filtering station has a filtering efficiency of over 70%, for which reason, when turning on the machine for values in excess of 30 ug/Nm3, at least 21 ug/Nm3 of particulate matter is eliminated from the atmosphere (the legal limit is a 24-hour average of 40 ug/Nm3).

This value, multiplied by the 10,000 Nm3 filtered in an hour, **eliminates at least 210 mg of particulate matter** against a power consumption of 5 kWh.

It follows that at least 10 times more particulate matter is removed from the atmosphere than that introduced. Due to the above considerations, the filtering station generally reduces much more as it operates at particulate values which in practice reached and exceed 100 ug/Nm3, while emission values of power stations, considered for the purposes of the above calculation, have been considered greater than the values measured at the power stations themselves.

It should also be considered that the total particulate matter introduced by the power stations partly returns to the ground. This is estimated to amount to *approximately 1 ug/Nm3 in the meteorological conditions that are most unfavourable to dispersion* (final note of the attached report).

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ATMOSPHERIC EMISSIONS FROM GAS TURBINE POWER PLANTS

Drawn up by Arpa - Piacenza and Ferrara Department

Introduction

This document sets out to analyse the technical elements characterising atmospheric emissions from gas turbine power plants, especially as regards the more recent problems concerning particulate emissions.

Various factors must be considered when assessing particulate emissions from gas turbine power plants.

It is, in fact, indispensable to define both the characteristics of the fuel used and the systems for reducing nitrogen oxides.

Gas turbine power plants, in fact, can be fired by both diesel oil and natural gas; natural gas is used in Italy, while both fuels are used in the United States though preference is given to diesel oil.

It must also be considered that gaseous omissions differ according to the reduction systems used; the most popular ones are water-steam injection and dry reduction technologies.

The water-steam injection reduction system is surpassed by now, due both to its achievable reduction limits (100 mg/Nm^3 of NO_X) and to the need to make use of large amounts of water.

The systems used today are the dry technologies, especially burners with staged or premixed fuel introduction (Dry Low NO_X).

The first DLN1 systems, in fact, reach reduction limits of 50 mg/Nm^3 of NO_X, while the new DNL2 technology, which is beginning to be used in the United States and further improves the combustion system, reduces the nitrogen oxide emissions to 20 mg/Nm^3 .

In any case, these estimates, compared with higher potential power plants, such as those referred to in the above-mentioned article, reveal considerably lower annual mass flows of total particulate than those indicated in the article itself.

In particular, assuming particulate emissions to be 0.6 mg/Nm³ from a standard 800 Mwe plant with two sets of 400 Mw each, an overall fumes flow of 4,000,000 Nm³/h and a coefficient of use of 8,000 hours/year, one obtains 19 t/year of particulate emissions.

A useful comparison can be made with total particulate emissions from vehicular traffic.

A recent study performed in the city of Piacenza ,using the ISC3 model of the EPA, to estimate the contribution of various sources to atmospheric pollution estimates the quantity of particulate emissions by city traffic to stand at 73 t/year and attributes overriding responsibility for pollution levels from PM 10 measured by the air quality monitoring network to this source.

Moreover, again using the model study on the city of Piacenza, if one analyses emissions (fallout), which truly represent the environmental and health impact of a determined source, while traffic generates values of approximately 14 μg/m³ as an average daily value on a yearly basis (daily peaks are certainly higher) the fallout of emissions from a gas turbine power plant of 800 MWe, assuming an emission level of 0.6 mg/Nmc, can be estimated to stand at approximately 1 μg/m³ in the meteorological conditions most unfavourable dispersion.

In Italy, after the construction of some plants with water-steam injection systems, projects for dry reduction plants are now being submitted.

Particulate emissions

Theoretically speaking, natural gas combustion does not generate particulate and the use of natural gas or liquefied gas is considered as a means of limiting particulate emissions.

In conditions of incomplete combustion, natural gas can also generate particulate, but in an industrial plant where fuel usage is maximised, this is of scarce importance.

To assess particulate emissions experimentally and theoretically, the following measurements made on gas turbine power plants both by Arpa and by other certified laboratories are available.

Sarmato Consortium (arpa tests)

-Combined cycle co-generation plant with gas turbine

-Generating set	150 MW electrical
-power supply	natural gas
-stacks	1

DLN technology, based on a two-stage combustion chamber with premixing, was used to build the power plant.

Test results are summarised in the following table showing the main operating characteristics and the main pollutants

Electrical load (Mw)	145
Natural gas flow rate (Nm^3/h)	31,200
Fumes flow rate (Nm^3/h)	952,300
Total particulate matter (mg/Nm^3):	0.7
Nitrogen oxide emissions (mg/Nm^3)	58
Carbon monoxide emissions (mg/Nm^3)	3
Polycyclical Aromatic Hydrocarbons	< l.r.
Aldehydes	< l.r.

l.r. = measurement limit of instrument, equal to 0.1 µg

The following table shows the aldehydes and relative P.A.H.'s.

Aldehydes	**P.A.H.**
Formaldehyde	Fluoranthene
Acetaldehyde	Benzo(b)fluoranthene
Acrolein	Benzo(a)pyrene
Propionaldehyde	Indeno(1,2,3-c,d)pyrene
Crotonaldehyde	Benzo(g,h,i)perylene
Methacrolein	
Butyraldehyde	
Benzaldehyde	
Valeraldehyde	
p-tolualdehyde	
Hexaldehyde	

ENEL power plant at Castel San Giovanni (CESI tests)

-Combined cycle co-generation plant with gas turbine

-3 generating sets 380 MW electrical

-power supply natural gas

-stacks 3

-4th set currently being built

Dry combustor technology was used to build the power plant.

Test results are summarised in the following table showing the main operating characteristics and the main tested pollutants referred to dry fumes and 15% oxygen

Electrical load (Mw)	375
Natural gas flow rate (Nm^3/h)	70.000
Fumes flow rate (Nm^3/h)	1.900.000 *
Nitrogen oxide emissions (mg/Nm^3)	46 *
Carbon monoxide emissions (mg/Nm^3)	3 *
Total particulate matter (mg/Nm^3):	n.a.
Metals ($\mu g/Nm^3$)	
Arsenic	1.0
Beryllium	0.8
Cadmium	0.1
Cobalt	0.4
Chrome	0.4
Copper	3.7
Mercury	0.1
Manganese	51.8
Nickel	62.2
Lead	3.1
Palladium	0.2
Platinum	0.1
Rhodium	0.1
Antimony	0.1
Selenium	2.1
Tin	0.2
Tellurium	0.2
Thallium	0.1
Vanadium	4.3
Volatile Organic Substances (mg/Nm^3)	0.087
Polycyclical Aromatic Hydrocarbons ($\mu g/Nm^3$)	0.007

***average values inferred from continuous controls**

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The following table shows the concentrations of each tested Polycyclical Aromatic Hydrocarbon.

P.A.H. (ng/Nm^3)	
Naphthalene	0.04
2-methylnaphthalene	0.04
1-methylnaphthalene	0.04
2.6 dimethylnaphthalene	0.15
Acenaphthylene	0.26
Acenaphthene	0.18
2,3,5-trimethylnaphthalene	0.29
Fluorene	0.40
Phenanthrene	2.52
Anthracene	0.66
1-methylphenanthrene	1.06
Fluoranthene	3.17
Pyrene	2.04
Cyclopenta(c,d)pyrene	0.84
Benzo(a)anthracene	0.62
Chrysene	1.97
Benzo(j,b,k)fluoranthene	4.50
Benzo(e)pyrene	1.28
Benzo(a)pyrene	1.46
Terylene	1.35
Indeno(1,2,3-c,d)pyrene	1.64
Dibenzo(a,h)anthracene	1.31
Benzo(g,h,i)perylene	1.60
Dibenzo(a,l)pyrene	0.04
Dibenzo(a,e)pyrene	0.04
Dibenzo(a,i)pyrene	0.04
Dibenzo(a,h)pyrene	0.04

The CESI survey set out to determine organic and inorganic micropollutant emissions from set n° 1. Though total particulate matter was not determined, the measured values of metals, amounting to 0.13 mg/Nm^3, allow us to assume that concentrations of particulate matter are similar to those measured by Arpa.

Trino – Leri Cavour power plant (Not RER) (tests by ENEL lab. Piacenza)

-Combined cycle co-generation plant with gas turbine

-2 generating sets	380 MW electrical
-power supply	natural gas
-stacks	4

Dry combustor technology was used to build the power plant.

Test results are summarised in the following table showing the main operating characteristics and the main tested pollutants referred to dry fumes and 15% oxygen

Electrical load (Mw)	355
Fumes flow rate (Nm^3/h)	n.a.
Nitrogen oxide emissions (mg/Nm^3)	124
Carbon monoxide emissions (mg/Nm^3)	63
Total particulate matter (mg/Nm^3):	0,2*
Metals (µg/Nm^3)	
Arsenic	25,3
Beryllium	0,2

Cadmium	0,1
Cobalt	0,2
Chrome	5,9
Copper	5,7
Mercury	2,1
Manganese	1,5
Nickel	8,6
Lead	1,9
Palladium	0,1
Platinum	0,1
Rhodium	0,1
Antimony	0,1
Selenium	0,1
Tin	0,5
Tellurium	0,1
Thallium	0,2
Vanadium	24,4
Volatile Organic Substances (mg/Nm^3)	0,087
Polycyclical Aromatic Hydrocarbons (µg/Nm^3)	0,007

***maximum determined values, other values < 0.1 mg/Nm^3**

n.a. = non available

The ENEL laboratory survey set out to determine organic and inorganic micropollutant emissions from set n° 2.

Total particulate matter was determined to be 0.2 mg/Nm^3, consistently with measured heavy metals values of 0.07 mg/Nm^3.

Ferrara power plant (arpa tests)

-Combined cycle co-generation plant with gas turbine

-1 generating sets	150 MW electrical
-power supply	natural gas
-stacks	2

Dry combustor technology was used to build the power plant.

Test results are summarised in the following table showing the main operating characteristics and the main tested pollutants referred to dry fumes and 15% oxygen

Test on stack 1 of 16/10/2002

Electrical load (Mw)	75 *
Fumes flow rate (Nm^3/h)	466 500
Total particulate matter (mg/Nm^3):	< 0,6
Nitrogen oxide emissions (mg/Nm^3)	50,8
Carbon monoxide emissions (mg/Nm^3)	< 25

*** power attributed to a single stack**

Test on stack 2 of 22/05/2003

Electrical load (Mw)	75 *
Fumes flow rate (Nm^3/h)	512 000
Total particulate matter (mg/Nm^3):	< 0,6
Nitrogen oxide emissions (mg/Nm^3)	34
Carbon monoxide emissions (mg/Nm3)	< 25

*** power attributed to a single stack**

Conclusions.

The experimental data measured at a limited number of plants seems to exclude that appreciable particulate concentrations leave combined cycle gas turbine power plants; all the figures acquired up to today indicate concentration values of less than 1 mg/Nm^3.

Some considerations can be made concerning the recent article by N. Armaroli and C. Po, published in the magazine "Chimica e Ambiente" and reported on by the local press.

The figures indicated in the tables of the article, which indicate the most elevated particulate emission values, in particular PM10, in terms of tons per year, refer to gas turbine power plants fitted with a nitrogen oxide reduction device known as SCR (Selective catalytic reduction). This device introduces ammonium into the burned gas flow upstream from a catalyser system. As is known, ammonium produces a ammonium salts which give rise to solid granules, thus constituting airborne particulate matter. Among other things, it is known that ammonium is a precursor of the secondary particulate matter present in the atmosphere. Therefore the relevant reduction of NOx is obtained with an increase, less in absolute terms but anything but negligible, of particulate matter.

Today's turbine gas power plants, both authorised or subject to assessment in Emilia Romagna, have different characteristics. In particular, they do not use SCR to reduce NOx but dry reduction systems.

On the basis of the measurements used by ARPA to determine total particulate matter, one can deduce the annual mass flows of particulate matter for the power stations under study.

For the Sarmato power plant, in particular, comprising a 145 MW gas turbine section, a measured outlet fumes flow of 952,300 Nm^3/h and a measured concentration of 0.7 mg/Nm^3, the mass flow is 5.33 t/year, considering annual operation of 8,000 hours.

Similarly, for the Ferrara power plant, comprising two overall 150 MW gas turbine sections, a measured outlet fumes flow of 466,500 Nm^3/h and a measured concentration of less than 0.6 mg/Nm^3, prudently considered to be that value, the mass flow is 4.48 t/year, considering annual operation of 8,000 hours.