SNAP CODE: **010104**
010204
010304
010404
010504
020104
020203
020303
030104

SOURCE ACTIVITY TITLE: **COMBUSTION IN ENERGY & TRANSFORMATION INDUSTRIES**
Gas Turbines

NOSE CODE: **101.04**

NFR CODE: **1 A 1 a**
1 A 1 b
1 A 1 c
1 A 2 a-f
1 A 4 a
1 A 4 b i
1 A 4 c i

1 ACTIVITIES INCLUDED

Gas turbine plant fall within the following CORINAIR SNAP and NFR classification codes:

SNAP		**NFR**
010104	Public power – gas turbines	1 A 1 a
010204	District heating plants – gas turbines	1 A 1 a
010304	Petroleum refining plants – gas turbines	1 A 1 b
010404	Solid fuel transformation plants – gas turbines	1 A 1 c
010504	Gas extraction/distribution – gas turbines	1 A 1 c
020104	Commercial and institutional plants – stationary gas turbines	1 A 4 a
020203	Residential plants – gas turbines	1 A 4 b i
020303	Plants in agriculture, forestry and aquaculture – stationary gas turbines	1 A 4 c i
030104	Combustion in industry – gas turbines	1 A 2 a-f

Emissions considered in this section are released by a controlled combustion process, taking into account primary reduction measures, such as furnace optimisation, the combustion chamber, and secondary reduction measures downstream of the combustion chamber.

2 CONTRIBUTION TO TOTAL EMISSIONS

This section covers emissions of SO_x, NO_x, CO, CO_2, NMVOC, CH_4, N_2O, NH_3 and heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, V). The contributions of emissions released by some categories of gas turbines to the total emissions in countries of the CORINAIR90 inventory are given as follows in Table 2.1:

Table 2.1 Contributions of emissions from combustion plants as point or area sources to total emissions of the CORINAIR90 inventory reported as point sources

		Contribution to total emissions [%]							
Source category	**SNAP90 code**	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Gas turbines	01 01 04 01 02 04 02 02 03 03 01 04	0	0.39	0.07	0.06	0.05	0.35	0.02	-

0 = emissions are reported, but the exact value is below the rounding limit of 0.1 per cent
\- = no emissions are reported

The most relevant pollutant emitted from gas turbines is nitrogen oxides (NO_x). Other relevant pollutants are carbon dioxide (CO_2), carbon monoxide (CO), and volatile organic compounds (non-methane VOC and methane (CH_4)) from older plant. Emissions of nitrous oxide (N_2O), sulphur oxides (SO_x), and ammonia (NH_3) are of less importance.

3 GENERAL

3.1 Description

A gas turbine is a type of internal combustion engine in which fuel is burnt with compressed air. Energy from the fuel combustion is recovered by a power turbine which drives a compressor turbine (which provides the compressed combustion air) and the external load.

Gas turbines are installed with a thermal capacity ranging from several hundred kW up to 500 MW. Gaseous fuels are mainly used, such as natural gas or the product of coal gasification (e.g. CCGT or IGCC installations) or other process gases. Also liquid fuels are used, such as light distillates (e.g. naphtha, kerosene or fuel oil) and in some cases other fuels (e.g. heavy fuel oil). Combustion temperatures of up to 1,300 °C in the combustion chambers may lead to considerable NO_x emissions.

3.2 Definitions

CCGT – Combined Cycle Gas Turbine Plants

IGCC – Integrated Coal Gasification Combined Cycle Gas Turbine Plants

SCR – Selective Catalytic Reduction

SNCR – Selective Non-Catalytic Reduction

3.3 Techniques

The load is typically an alternator or pipeline compressor in industrial use, or a fan or propeller in aircraft. Industrial gas turbines can have a single shaft (all components mounted on a single drive shaft) or may have two or three shafts. Aeroderivative industrial gas turbines have been developed from aircraft power units and tend to be lighter and more suitable for variable load than 'heavy' gas turbines.

Gas turbines used for gas transfer may operate frequently under part load conditions, where load control may be by shaft or generation output. However, gas turbines used for electricity generation are more often run under maximum load under combustor temperature control. Actual output under temperature control can be affected by ambient conditions (air temperature, pressure and humidity).

Open cycle, combined cycle and cogeneration plant

Open cycle gas turbines provide shaft power but are not fitted with heat recovery. Pipeline compressor engines and standby generators are generally open cycle systems. Although open cycle gas turbines for standby electricity generation are not uncommon, modern industrial gas turbines tend to be part of cogeneration plant, such as combined heat and power (CHP) plant, combined cycle gas turbine (CCGT) systems, or Integrated Coal Gasification Combined Cycle Gas Turbine (IGCC) Plants. In a CCGT plant, gas turbines are used to generate electricity and a heat recovery steam generator (boiler) is used to recover energy from the turbine exhaust gases. The steam produced is then used to generate more electricity using a steam turbine alternator set. For IGCC plants, the only emission-relevant unit is the gas turbine (combustion chamber); for CCGT, in addition to the gas turbine, any installed fossil fuelled boiler should also be taken into account.

A cogeneration plant also uses a gas turbine to generate electricity and can use the turbine exhaust gas for direct or indirect drying; or, more commonly, a waste heat boiler is employed for steam generation. In common with a CCGT plant the steam may be used to generate electricity, but in general the steam is required primarily for process use. Supplementary burners are commonly used in CHP plant to accommodate variable process steam demand.

3.4 Emissions

The most relevant pollutant emitted from gas turbines is nitrogen oxides (NO_x). Other relevant pollutants are sulphur oxides (SO_x), carbon dioxide (CO_2), and volatile organic compounds (non-methane VOC and methane (CH_4)) from older plant. Emissions of nitrous oxide (N_2O), carbon monoxide (CO) and ammonia (NH_3) are of less importance.

Emissions of POPs and heavy metals might be significant where heavy fuel oil is used.

3.5 Controls

Pollution control techniques for gas turbines have essentially targeted combustion efficiency and NO_x emissions. Various techniques have been employed for NO_x control, including the following:

- Steam injection;
- Water injection;
- low NO_x burner systems.

In addition, Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) systems have also been developed for NO_x control for larger gas turbines. Low NO_x burner systems are often termed dry control systems as they do not involve water or steam injection.

4 SIMPLER METHODOLOGY

The simpler methodology involves the calculation of emissions based on emission factors and activity data. The simpler methodology should only be used in cases where no measured data are available.

The annual emission is derived from an annual activity multiplied by an emission factor (Equation (1)):

$$\text{Annual emission} = \text{Annual activity} \times \text{Emission factor} \qquad (1)$$

The activity rate and the emission factor have to be determined on the same level of aggregation by using available data (e.g. fuel consumption).

Differences in design and operation of gas turbines, in fuels used and/or controls installed require different emission factors. The default emission factors in section 8 take into account these parameters.

If not stated otherwise, the emission factors presented in Section 8 refer to full load conditions. Start-up emissions can be considered separately but are small for gas turbines.

5 DETAILED METHODOLOGY

In principle, plant specific measurement data should be used, if available, for the determination of emissions from gas turbines.

6 RELEVANT ACTIVITY STATISTICS

For the activity rate, the energy input in [GJ] should be used, but in principle other relations are also applicable.

Activity data on the number and size of gas turbines and the amount of fuel burned should be available from statistical offices of individual countries or from statistical reports from Eurostat or OECD. A list of example statistical reports is given in section 18.

7 POINT SOURCE CRITERIA

According to CORINAIR90, combustion plants with:

- a thermal capacity ≥ 300 MW, or
- emissions of SO_2 or NO_x or NMVOC > 1,000 Mg/a[1]

should be considered as point sources. Within CORINAIR other combustion plants may also be considered as point sources on a voluntary basis.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

In the absence of better data, the following default emission factors may be used:

Simple Methodology

Tables 8.1 to 8.4 give default emission factors for the most significant pollutants from SNAP categories 010104, 010504 and 030104, where available, for plant running on natural gas with varying levels of NO_x control:

- Uncontrolled;
- steam injection;
- water injection;
- dry low-NO_x burner.

Table 8.5 gives a summary of emission factors by SNAP codes.

Table 8.6 gives a summary of emission factors measured on plant of varying age in Italy.

[1] For CO_2 a further optional criterion for point sources is the emission of > 300 Gg/a.

Table 8.1 Default Emission Factors for NO_x

NO_x Control	**NO_x emission factors, g GJ^{-1}**				
	Stewart 1998	**USEPA**		**EMEP/ CORINAIR**	**UK NAEI**
		Electricity	**Pipeline**		
Uncontrolled	104-312	189	146	160-480	-
				650 (aeroderivative)	
Steam injection	46-120	51.6	-	-	-
Water injection	115	60.2	-	-	-
Dry low NO_x burner	33-86	-	-	80	44

Notes :
1. NO_x is expressed as NO_2.
2. '-' denotes no data
3. USEPA emission factor data from AP-42 5th Ed including supplements A and B.
4. EMEP/CORINAIR emission factors from the Atmospheric Emission Inventory Guidebook and are data for point sources.
5. NAEI emission factors are for 1996 and represent gas-fired power stations.

Table 8.2 Default Emission Factors for CO

NO_x Control system	**CO emission factors, g GJ^{-1}**				
	Stewart 1998	**USEPA**		**EMEP/ CORINAIR**	**UK NAEI**
		Electricity	**Pipeline**		
Uncontrolled	<3-120	47.3	73.1	-	-
Steam injection	3-47	68.8	-	-	-
Water injection	20.8	120	-	-	-
Dry low NO_x burner	1.2-21	-	-	-	16

Notes :
1. '-' denotes no data.
2. USEPA emission factor data from AP-42 5th Ed including supplements A and B.
3. EMEP/CORINAIR emission factors from the Atmospheric Emission Inventory Guidebook and are data for point sources.
4. NAEI emission factors are for 1996 and represent gas-fired power stations.

Table 8.3 Default Emission Factors for VOCs

NO_x Control system	VOC emission factors, g GJ^{-1}				
	Stewart 1998	USEPA		EMEP/ CORINAIR	UK NAEI
		Electricity	Pipeline		
Uncontrolled	1.1-25	10.3	22.8	2.5-6.1 (CH_4) 2.5-5 (NMVOC)	-
Steam injection	1.3-6.3	-	-	"	-
Water injection	2.8	-	-	"	-
Dry. Low NO_x burner	0.6-2.6	-	-	"	6.0 (CH_4) 5.3 (NMVOC)

Notes:
1. '-' denotes no data.
2. VOC are expressed as methane.
3. USEPA emission factor data from AP-42 5th Ed including supplements A and B.
4. EMEP/CORINAIR emission factors from the Atmospheric Emission Inventory Guidebook and are for no specified type of gas turbine are data for point sources.
5. NAEI emission factors are for 1996 and represent gas-fired power stations.

Table 8.4 Default Emission Factors for N_2O

NO_x Control system	N_2O emission factors, g GJ^{-1}				
	Stewart 1998	USEPA		EMEP/ CORINAIR	UK NAEI
		Electricity	Pipeline		
Uncontrolled	2-6	-	-	-	-
Steam injection	3	1.29	-	-	-
Water injection	3	1.29	-	-	-
Dry. low NO_x burner	1-7	-	-	-	3.7

Notes:
1. '-' denotes no data.
2. USEPA emission factor data from AP-42 5th Ed including supplements A and B.
3. NAEI emission factors are for 1996 and represent gas-fired power stations.

Table 8.5 Summary of emission factors by SNAP codes (Stewart, 1998)

SNAP Code	Description	NO_x control	No of gas turbines in survey	Size of gas turbines MW	NO_x EFs g GJ^{-1}	CO EFs g GJ^{-1}	VOC EFs g GJ^{-1}	N_2O EFs g GJ^{-1}
010104	Public power, gas turbines	Low NO_x burner	4	150-215	33-86	1.2-21	0.6-2.6	1-7
		Steam injection	1	125	120	4.0	2.6	<9
		Uncontrolled	2	~25-125	198-250	6.6-51	1.1-4.2	<9
030104	Combustion in industry, gas turbines	Water injection	1	22	115	20.8	2.8	2
		Steam injection	2	4.8-40	46-91	3-47	1.3-6.3	2
		Uncontrolled	4	6.25-40	140-279	<3-14	1.6-3.0	<4-4
010504	Gas extraction / distribution, gas turbines	Uncontrolled	5	6.25-25	104-312	6-120	3.7-25	2-6

Notes :
1. NO_x is expressed as NO_2 .
2. VOC expressed as methane.
3. With the exception of the large CCGT gas turbines used for utility power generation, many of the gas turbines surveyed would be used in other industry sectors.

None of the pipeline compressor gas turbines, which were visited early in the measurement programme, were fitted with NO_x control systems.

Table 8.6 Summary of emission factors measured during the years 1997 and 1998, Italy (Caserini et al)

SNAP	Town	Unit number	Thermal Capacity (MW)	Fuel Cons. (GJ/year)	E.F.CO g/GJ	E.F.NOx g/GJ	Control system	Age of the plant (*)
010104	CASSANO D'ADDA	3	105	220,700	32	222	Steam injection	old
010204	SAN DONATO MILANESE	1	12	337,482	34	265	uncontrolled	old
010204	SAN DONATO MILANESE	2	12	247,068	34	263	uncontrolled	old
010104	TURBIGO	6	400	1,547,026	-	71	Dry low NOx	medium
010104	TURBIGO	7	400	2,336,386	-	77	Dry low NOx	medium
010104	TURBIGO	8	400	4,039,245	-	68	Dry low NOx	medium
010204	SAN DONATO MILANESE	3	15	392,070	5.9	157	Steam injection	medium
010204	SAN DONATO MILANESE	4	15	343,428	6.1	145	Steam injection	medium
010204	SESTO SAN GIOVANNI	1	120	3,409,998	16	39	Dry low NOx	new
010104	BOFFALORA SOPRA TICINO	1	205	1,766,430	5.7	20	Dry low NOx	new
010204	CREMONA	1	26	752,536	0.8	108	Steam injection	new

* old : 1970-1980; medium : 1980-1990; new: >1990

9 SPECIES PROFILES

Limited speciated data are available.

10 CURRENT UNCERTAINTY ESTIMATES

The emission factors in Section 8 have an uncertainty rating of B/C.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The emission factors are not necessarily representative of all gas turbine plant and could be improved if more data were available for plants in different countries.

For NM VOCs, these plants contribute a low proportion of total emissions and the generation of speciated data for this source should not be a priority.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

In general the following disaggregation steps for emissions released from residential combustion can be used:

- differentiation in spatial areas, e.g. administrative units (country, province, district, etc.), inhabited areas, settlement areas (divided in high and low density settlements);
- determination of regional emission factor per capita depending on the population density and the type of fuel used.

For emissions released from industrial combustion, spatial disaggregation takes into account the following steps:

- differentiation in spatial areas with regard to industrial areas;
- determination of emission factors related to the number of industrial employees.

13 TEMPORAL DISAGGREGATION CRITERIA

Temporal disaggregation of annual emissions released from combustion plants as point sources or industrial plant as area sources can be obtained from the temporal change of the production of power or the temporal change of the consumption, taking into account a split into:

- summer and winter time;
- working days and holidays;
- standstill times;
- times of partial load behaviour;
- number of start-ups / type of load design.

For non-industrial combustion (small consumer/residential combustion) temporal disaggregation should take into account:

- consumption of fuel;
- heating degree-days;
- summer and winter time (heating periods);
- working days and holidays;
- daily fluctuations of load.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

The combustion chapters of the 1st Edition of the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook should be referred to for more detail.

16 VERIFICATION PROCEDURES

For verification purposes, annual emissions can be compared to independently derived emission estimates. These independent emission estimates can be obtained by using relations between annual emissions and variables such as population equivalents, number of households, fossil fuel prices, etc.

Another possibility for verification is to make emission density comparisons of e.g. emissions per capita or emissions per GDP between countries with comparable economic structures.

17 REFERENCES

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