BAY AREA AIR QUALITY MANAGEMENT DISTRICT

BAAQMD

Toxic Air Contaminant (TAC) Emission Factor Guidelines

Appendix A

Default TAC Emission Factors for Specific Source Categories

August 2020

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Appendix A

Default TAC Emission Factors for Specific Source Categories

A-0. Introduction

This document is intended to be an accompaniment to the Air District's Toxic Air Contaminant (TAC) Emission Factor Guidelines. The TAC Emission Factor Guidelines document explains the procedures the Air District will follow when determining TAC emission factors for individual sources. The Air District has applied these procedures to common source categories to develop sets of default TAC emission factors for specific source categories.

The default TAC emission factors in this document are suitable for use when no other site-specific emission factor data is available. A site-specific factor for an individual TAC that is determined in accordance with the Air District's TAC Emission Factor Guidelines shall replace a default TAC emission factor for that pollutant. However, the other default TAC emission factors remain in effect for that source category.

The default TAC emission factor data presented here is appropriate for use in developing emission inventories, calculating prioritization scores, assessing TAC-based emission inventory fees, calculating emissions for new source review projects,

assessing permit exemptions, determining the applicability of health risk assessment requirements, and conducting health risk assessments.

Additional source categories will be added to this Appendix as the default TAC emission factors for the individual source categories are developed. It is the Air District's intention to incorporate this updated TAC emission factor data into the applicable Air District Permit Handbook Chapter for the source category. Meanwhile, if there is a discrepancy between the TAC emission factors cited in a Permit Handbook Chapter and the TAC emission factors cited in this document, the Air District will use the set of data that has been most recently approved by the Air District.

A-1. Boilers

A boiler is an enclosed vessel that provides a means for combustion and transfers heat to water or other liquid until it has become hot and steam or vapor is generated. The hot water or steam under pressure is then used for transferring the heat to a process. Boilers are generally classified by the maximum rated combustion capacity as: commercial (< 10 MMBTU/hr), small industrial (10 – 100 MMBTU/hr), large industrial (100 – 250 MMBTU/hr), or utility boilers, generally rated above 250 MMBTU/hr.

The primary emissions from boilers are combustion products: nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM), and sulfur dioxide (SO_2). Toxic air contaminants (TACs) are also emitted from boilers, primarily due to incomplete combustion of the fuel. The emission rates of organic TACs, such as formaldehyde, polycyclic aromatic hydrocarbons (PAHs), and benzene, are influenced by operating load and combustion conditions (time, temperature, and turbulence). Under normal high operating load conditions, organic TAC emissions are low due to the high combustion temperatures, but organic TAC emissions will increase at low operating load conditions when combustion temperatures are lower. Particulate TAC emissions may result from contaminants in the fuel, tubes, or other construction materials.

Default TAC emission factors for boilers are discussed below based on the type of fuel burned in the boiler.

A-1.1 Boilers – Natural Gas Fired

The default TAC emission factors presented in this section apply to boilers fired on natural gas, propane, or liquid petroleum gas (LPG). These factors may also be used for any general external combustion sources (such as furnaces, heaters, and ovens) that are fired on natural gas, propane, or LPG, until default TAC emission factors are available for these specific source categories.

These default natural gas emission factors may also be considered during the development emission factors of biogas, landfill gas, digester gas, or other waste-gas fired boilers. However, each of these other gaseous fuels have a unique set of contaminants and heat content that are dependent on the source of the gas and that will result in unique residual and secondary TAC emission profiles due to combustion of these gaseous fuels. Site-specific analyses of waste gas and biogas fuels and other measurements should be used to develop a site-specific set of TAC emission factors that will apply to waste gas or biogas fired boilers in addition to and in place of the default TAC emission factors presented below.

The default TAC emission factors presented below apply to all boiler sizes and combustion design types. These factors are based on boilers with no add-on emission controls. Default emission factors for boilers fired on natural gas were developed based on CARB's California Air Toxic Emission Factors (CATEF) database[1], EPA's AP-42 Compilation of Air Emission Factors, fifth edition, Chapter 1.4 Natural Gas Combustion[2], and Ventura County Air Pollution Control District's toxic emission factors for natural gas fired external combustion equipment.[3]

In general, the Air District gives preference to CATEF factors over AP-42 data, and the Air District uses the highest available mean CATEF factor. If a compound was not detected based on data in the CATEF database or AP-42, the Air District's emission factor was based on one-half of the minimum detection limit identified for that compound.

Ventura County Air Pollution Control District (VCAPCD) stated that their TAC emission factors for external combustion equipment were based on boiler source tests (dated May 1990 through April 1994). If a TAC emission factor was available for both Ventura County APCD and AP-42 Chapter 1.4, the Air District typically chose the VCAPCD emission

1 CARB's California Air Toxic Emission Factor (CATEF) database: https://www.arb.ca.gov/ei/catef/catef.htm

2 EPA's AP-42 Compilation of Air Emission Factors, fifth edition, Chapter 1.4 Natural Gas Combustion: https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf

3 Ventura County Air Pollution Control District's toxic emission factors for natural gas fired external combustion equipment: http://www.vcapcd.org/pubs/Engineering/AirToxics/combem.pdf

factor as the Air District default factor, because the VCAPCD factors were similar to but higher than the AP-42 Chapter 1.4 factors. One exception was hexane. Since the AP-42 Chapter 1.4 hexane emission factor seemed inordinately high (33% of the total VOC factor), the Air District chose the maximum hexane emission factor from the VCAPCD data (6.18E-6 lbm/MMBTU) instead of the AP-42 Chapter 1.4 hexane factor (1.76E-3 lbm/MM BTU). For naphthalene, the Air District chose the higher AP-42 Chapter 1.4 factor. For PAHs, the Air District derived the equivalent factor for benzo(a)pyrene based on the individual TAC PAH species cited in AP-42 Chapter 1.4, because the Ventura County APCD may have included non-TAC PAH species. The Air District also included the VCAPCD emission factors for acrolein, ethylbenzene, propylene, and xylene, which are not listed elsewhere.

The CATEF database only identified three TACs for natural gas fired boilers: acetaldehyde, benzene, and formaldehyde. For acetaldehyde and benzene, the CATEF data was based on reported detection limits. The Air District choose to use the higher VCAPCD emission factors for acetaldehyde and benzene as the default emission factor instead of CATEF detection limit data. For formaldehyde, the emission factor from CATEF, AP-42, and VCAPCD data were all based on detected emission levels. CATEF data is generally preferred and was also the highest factor. Therefore, the Air District chose the CATEF emission factor for the default formaldehyde emission factor.

All default emission factors for inorganic TACs were based on the AP-42 Chapter 1.4 data.

Boilers are commonly equipped with add-on emission controls including selective catalytic reduction (SCR) systems. SCR systems use ammonia to reduce NOx emissions. Ammonia is an important secondary TAC emission for boilers equipped with SCR systems. A source-specific ammonia emission factor should be determined for any boiler controlled by SCR.

Oxidation catalysts are often used on utility and large industrial boilers to reduce carbon monoxide emissions. Oxidation catalysts will typically achieve emission reductions for organic TACs as well. A source and pollutant specific emission control efficiency should be developed and applied to the uncontrolled organic TAC emission factors listed below for any boiler equipped with an oxidation catalyst. If no site-specific emission control efficiency data is available, a default emission control efficiency of 50% by weight may be applied to organic TAC emission factors other than naphthalene and PAHs. Oxidation catalyst control efficiency is uncertain for these high molecular weight compounds.

The default TAC emission factors for boilers fired on natural gas are presented in the following table. All factors are based on boilers with no add-on emission control devices.

TABLE A-1.1 BOILERS - NATURAL GAS FUEL, NO ADD-ON EMISSION CONTROL

Toxic Air Contaminant (TAC)	CAS #	DEFAULT EMISSION FACTORS LBM/MMBTU	Comments[1, 2, 3, 4]
ACETALDEHYDE	75-07-0	4.22E-06	Ventura County APCD, Natural Gas Fired External Combustion Equipment
ACROLEIN	107-02-8	2.65E-06	Ventura County APCD, Natural Gas Fired External Combustion Equipment
ARSENIC	7440-38-2	1.96E-07	AP-42 CHAPTER 1.4, Table 1.4-4
BENZENE	71-43-2	7.84E-06	Ventura County APCD, Natural Gas Fired External Combustion Equipment
BERYLLIUM	7440-41-7	5.88E-09	AP-42 CHAPTER 1.4, Table 1.4-4; ND [3]
CADMIUM	7440-43-9	1.08E-06	AP-42 CHAPTER 1.4, Table 1.4-4
COPPER	7440-50-8	8.33E-07	AP-42 CHAPTER 1.4, Table 1.4-4
ETHYLBENZENE	100-41-4	9.31E-06	Ventura County APCD, Natural Gas Fired External Combustion Equipment
FORMALDEHYDE	50-00-0	2.17E-04	CATEF FACTOR - Boiler, Natural Gas
n-HEXANE	110-54-3	6.18E-06	Ventura County APCD, Natural Gas Fired External Combustion Equipment
LEAD	7439-92-1	4.90E-07	AP-42 CHAPTER 1.4, Table 1.4-4
MANGANESE	7439-96-5	3.73E-07	AP-42 CHAPTER 1.4, Table 1.4-4
MERCURY	7439-97-6	2.55E-07	AP-42 CHAPTER 1.4, Table 1.4-4
NAPHTHALENE	91-20-3	5.98E-07	AP-42 CHAPTER 1.4, Table 1.4-3
NICKEL	7440-02-0	2.06E-06	AP-42 CHAPTER 1.4, Table 1.4-4
PAH (as benzo(a)pyrene-equiv.)	1150/1151	6.60E-09	AP-42 CHAPTER 1.4, Table 1.4-3; ND [3]
PROPYLENE	115-07-1	7.17E-04	Ventura County APCD, Natural Gas Fired External Combustion Equipment
SELENIUM	7782-49-2	1.18E-08	AP-42 CHAPTER 1.4, Table 1.4-4; ND [3]
TOLUENE	108-88-3	3.59E-05	Ventura County APCD, Natural Gas Fired External Combustion Equipment
VANADIUM	7440-62-2	2.25E-06	AP-42 CHAPTER 1.4, Table 1.4-4
XYLENES	1330-20-7	2.67E-05	Ventura County APCD, Natural Gas Fired External Combustion Equipment

1 Conversions from lbs/MMscf to lbs/MMBTU used a natural gas heat of 1020 BTU/scf per AP-42.

2 Ventura County APCD data was reportedly derived from AP-42 data. It includes newer data than AP-42 Chapter 1.4 and data for compounds not listed in AP-42 Chapter 1.4. If data was available for both Ventura County APCD and AP-42 Chapter 1.4, the Ventura County APCD data was preferred, except for naphthalene and PAHs. For naphthalene, the Air District chose the higher AP-42 Chapter 1.4 factor. For PAHs, the Air District derived the equivalent factor for benzo(a)pyrene based on the individual TAC PAH species cited in AP-42 Chapter 1.4, because the Ventura County APCD may have included non-TAC PAH species.

3 The cited reference indicated that this compound was not detected (ND). The Air District emission factor is equal to ½ of the reported detection limit-based emission factor. For CATEF, ND emission factors are based ½ of the minimum detection limit.

4 Definitions:

BTU: British Thermal Unit
LBM: pounds
MM: million
ND: not detected
NP: value not provided
SCF: standard cubic fees

A-2. Gas Turbines

Gas turbines are internal combustion engines that operate with rotary power. A gas turbine is comprised of three parts: compressor, combustor and power turbine. Air is drawn in through the compressor and compressed up to 30 times ambient pressure and then the air is directed to the combustor area where the fuel is then added (natural gas or other gaseous fuel[4]) and the fuel is ignited and burned. Energy from the hot exhaust gases, which expand in the power turbine, are recovered in the form of shaft power.

The primary emissions from gas turbines are combustion products: nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM), and sulfur dioxide (SO_2). Toxic air contaminants (TACs) are also emitted from gas turbines, primarily due to incomplete combustion of the gaseous fuel. The emission rates of organic TACs, such as formaldehyde, polycyclic aromatic hydrocarbons (PAHs), and benzene, are influenced by operating load and combustion conditions (time, temperature, and turbulence). Under normal high operating load conditions, organic TAC emissions are low due to the high combustion temperatures, but organic TAC emissions will increase at low operating load conditions when combustion temperatures are lower. Particulate TAC emissions may result from contaminants in the fuel or air or due to corrosion or degradation of turbine blades, coatings, and housing materials, especially in sea-coast regions such as the Bay Area. The key particulate TACs of concern are nickel, cadmium, and hexavalent chromium, which may be present in the stainless-steel used to make the turbine blades or in protective coatings applied to the blades.

Default TAC emission factors for gas turbines are discussed below based on the type of fuel burned in the turbine.

A-2.1 Gas Turbines – Natural Gas Fired

The default TAC emission factors in this section apply to uncontrolled gas turbines fired on natural gas or similar gaseous fuels. Default emission factors for gas turbines fired on refinery fuel gas, waste gases, biogases, and other gaseous fuels will be identified in separate sections. These default factors may also be used for natural gas fired turbines equipped with add-on controls by including the additional emission factors and abatement factors discussed below.

[4] Emissions from turbines fired on liquid fuels will be discussed in a separate sections of this Appendix that will be added later.

Default emission factors for gas turbines were developed for uncontrolled units fired on natural gas or similar fuels. The Air District evaluated data from Ventura County Air Pollution Control District's report on natural gas fired external combustion equipment[3], EPA's AP-42 Compilation of Air Emission Factors, fifth edition, Chapter 3.1 Stationary Gas Turbines[5] and CARB's California Air Toxic Emission Factors (CATEF) database[6]. Data was evaluated for both uncontrolled and controlled gas turbines fired on natural gas and similar fuels to develop the most comprehensive list possible of default emission factors. Source test data on Bay Area sites was given the highest preference for development of a default factor. The highest available mean CATEF factor was used, and CATEF factors were given preference over AP-42 if both references had data for the same pollutant. If a compound was not detected based on data in a source test, CATEF database, or AP-42, the District's emission factor was based on one-half of the minimum detection limit identified for that compound.

Gas Turbines are commonly equipped with add-on emission controls including selective catalytic reduction (SCR) systems and oxidation catalysts. SCR systems use ammonia to reduce NOx emissions. Ammonia is an important secondary TAC emission for gas turbines equipped with SCR systems. Any turbines equipped with SCR should include an ammonia emission factor developed based on site-specific information such as ammonia slip limits or ammonia measurements.

For gas turbines equipped with oxidation catalysts, the uncontrolled TAC emission factors may be combined with an appropriate abatement factor to determine the emission factor for the controlled gas turbine. Whenever possible, site-specific information should be used to develop the appropriate oxidation catalyst abatement factor for individual TAC constituents. If no site-specific emission control efficiency data is available, a default emission control efficiency of 50% by weight (an abatement factor of 0.5) may be applied to organic TAC emission factors other than naphthalene and PAHs. Oxidation catalyst control efficiency is uncertain for these high molecular weight compounds.

The default TAC Emission Factors for uncontrolled gas turbines fired on natural gas are summarized in the following table.

5 https://www3.epa.gov/ttn/chief/ap42/ch03/final/c03s01.pdf

6 https://www.arb.ca.gov/ei/catef/catef.htm

TABLE A-2.1 GAS TURBINES - NATURAL GAS FIRED - NO ADD-ON EMISSION CONTROLS

Pollutant- TAC	CAS #	DEFAULT EMISSION FACTORS LBM/MMBTU	Comments [1, 2, 3, 4, 5]
ACETALDEHYDE	75-07-0	1.34E-04	CATEF FACTOR - NATURAL GAS
ACROLEIN	107-02-8	1.85E-05	CATEF FACTOR - NATURAL GAS
ARSENIC	7440-38-2	2.21E-08	BAAQMD Source Test # 20105; ND [2, 3]
BENZENE	71-43-2	8.91E-05	CATEF FACTOR - NATURAL GAS
BERYLLIUM	7440-41-7	4.81E-08	BAAQMD Source Test # 20105; ND [2, 3]
1,3-BUTADIENE	106-99-0	6.07E-08	CATEF FACTOR - NATURAL GAS; ND [3]
CADMIUM	7440-43-9	1.88E-07	BAAQMD Source Test # 20105 [2]
CHROMIUM 6+	18540-29-9	1.84E-08	BAAQMD Source Test # 20121 [2]
COPPER	7440-50-8	1.76E-06	BAAQMD Source Test # 20105 [2]
ETHYL BENZENE	100-41-4	1.76E-05	CATEF FACTOR - NATURAL GAS [5]
FORMALDEHYDE	50-00-0	6.74E-03	CATEF FACTOR - NATURAL GAS
n-HEXANE	110-54-3	2.54E-04	CATEF FACTOR - NATURAL GAS
LEAD	7439-92-1	5.27E-07	BAAQMD Source Test # 20105 [2]
MANGANESE	7439-96-5	1.47E-06	BAAQMD Source Test # 20105 [2]
MERCURY	7439-97-6	1.47E-06	BAAQMD Source Test # 20105 [2]
NAPHTHALENE	91-20-3	1.63E-06	CATEF FACTOR- NATURAL GAS
NICKEL	7440-02-0	1.88E-07	BAAQMD Source Test # 20105 [2]
PAH (AS B(a)P-EQUIV)	1150/1151	2.12E-08	CATEF FACTOR - NATURAL GAS [5]
PROPYLENE (PROPENE)	115-07-1	7.56E-04	CATEF FACTOR - NATURAL GAS
PROPYLENE OXIDE	75-56-9	1.95E-05	CATEF FACTOR - NATURAL GAS; ND [3]
SELENIUM	7782-49-2	3.72E-07	BAAQMD Source Test # 20105 [2]
TOLUENE	108-88-3	6.96E-05	CATEF FACTOR - NATURAL GAS [5]
XYLENES (mixed isomers)	1330-20-7	2.56E-05	CATEF FACTOR - NATURAL GAS [5]

1 Conversions from lbs/MMscf to lbs/MMBTU used a natural gas heat of 1020 BTU/scf per AP-42.

2 BAAQMD Source Tests # 20105 and # 201212 were conduct on December 10-12, 2019 on a gas turbine and heat recovery steam generator operating at a combined heat input rate of 1994 MM BTU/hour, fired on natural gas, and equipped with SCR and Oxidation Catalyst controls. These add-on controls are not expected to impact the particulate TAC emission rates. Therefore, these source tests are considered to be representative of both controlled and uncontrolled natural gas fired gas turbines.

3 The cited reference indicated that this compound was not detected (ND). The Air District emission factor is equal to ½ of the reported detection limit-based emission factor. For CATEF, ND emission factors are based ½ of the minimum detection limit.

4 Definitions:

BTU: British Thermal Unit
LBM: pounds
MM: million
ND: not detected
NP: value not provided
SCF: standard cubic fees

5 Although the emission factor from AP-42 Chapter 3.1-3 was higher than the CATEF emission factor for that pollutant, the Air District chose the CATEF factor as the default. In accordance with Air District TAC Emission Factor Guidelines, CATEF data is preferred to AP-42 data.

A-2.2 Gas Turbines – Biogas Fuels and Waste Gas Fuels

This section will apply to gas turbines fired on biogas fuels, such as landfill gas or digester gas, and to similar waste gas fuels. The TAC emission factors for natural gas fired gas turbines may be used as a starting point or a partial list of TAC factors that may be applicable to gas turbines fired on biogas or waste gas fuels. However, biogas and waste gas fuels have additional contaminants that will result in unique residual and secondary TAC emission profiles due to combustion of these fuels. In addition, heat content and other fuel characteristics may be sufficiently different from natural gas to warrant development of site-specific TAC emission factors for biogas or waste gas fired turbines. Default TAC factors for gas turbines fired on biogas fuels with known characteristics will be presented below, when they are developed.

Additional source category sections will be added to Appendix A as they are developed.