

Air Quality: Criteria Pollutants & Regulations

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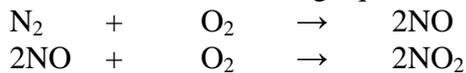
Criteria Pollutants

Nitrogen Dioxide

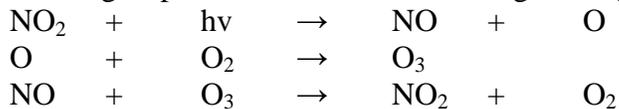
Nitrogen dioxide (NO₂) is a reddish-brown, nonflammable, toxic gas that is characterized by its pungent and irritating odour (Stocker, 1976; MOE, 2010d). Along with being a criteria pollutant, nitrogen dioxide also is key in the production of ground level ozone (MOE, 2010d). All combustion creates nitrogen oxides, collectively referred to as NO_x, either in the form of nitrogen monoxide (NO) or nitrogen dioxide (Stocker, 1976; MOE, 2010d). The following chart, adapted from the Ontario Ministry of the Environment (2010d), outlines the major sources of nitrogen oxide emissions:

Sector	Percent
Smelters/Primary Metals	2%
Cement and Concrete	5%
Miscellaneous	6%
Utilities	8%
Other Industrial Processes	11%
Road Vehicles	28%
Other Transportation	40%

The creation of nitrogen dioxide as a result of combustion occurs through a series of two simple chemical reactions: nitrogen gas and oxygen in the air react in the high temperature to form nitrogen monoxide which is then oxidized to form nitrogen dioxide (Stoker, 1976). This can be demonstrated with the following equations:



Once in the atmosphere, nitrogen monoxide and nitrogen dioxide become involved in a cycle known as the nitrogen dioxide photolytic cycle, a series of photochemical reactions that result in a decrease in nitrogen monoxide and an increase in nitrogen dioxide (Stoker, 1976). It is outlined in the following steps, in which $h\nu$ stands for light energy:



In this series of reactions, there are hydrocarbons from the same combustion source as the nitrogen oxides that compete with the atomic oxygen (O) and ozone (O₃) reactants (Stoker, 1976). This makes the cycle unbalanced as nitrogen monoxide is converted to nitrogen dioxide much faster than the dissociation of nitrogen dioxide can occur (Stoker, 1976). Furthermore, the competing hydrocarbons also cause a buildup of oxidants, which are important components of photochemical smog (Stoker, 1976).

Nitrogen dioxide pollution is a concern due to several different reasons. Nitrogen dioxide has the ability to deeply penetrate lung tissue, leading to tissue damage, lung irritation and breathing issues, especially for those who suffer from asthma and bronchitis (Krupa, 1997; MOE, 2010d).

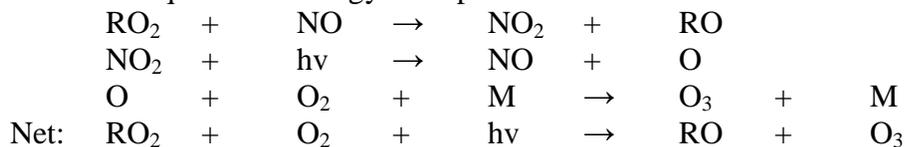
It can also result in a resistance to respiratory infection in those with no prior respiratory issues (MOE, 2010d). These adverse effects generally are not visible until several hours after exposure (Krupa, 1997). Environmentally, nitrogen dioxide is a concern because it can react with water vapour to form nitric acid (HNO₃), a major component of acid rain and contributor to lake acidification, and it also damages trees and crops (Vallero, 2008; MOE, 2010d). Aside from human and environmental issues, nitrogen dioxide also has the capacity to corrode metals, fade fabrics, and degrade rubber (MOE, 2010d).

Ozone

Ozone (O₃) is a colourless, odourless gas that is a major component of smog (MOE, 2010c). Ozone is not directly emitted into the atmosphere, it is the product of photochemical reactions between nitrogen oxides and volatile organic compounds (VOCs) (MOE, 2010c). The following chart, adapted from the Ontario Ministry of the Environment (2010c), outlines the major sources of volatile organic compound emissions:

Sector	Percent
Miscellaneous	3%
Residential	8%
Road Vehicles	14%
Other Industrial Processes	14%
General Solvent Use	18%
Printing/Surface Coating	19%
Other Transportation	24%

As noted in the nitrogen dioxide photolytic cycle, atomic oxygen and oxygen gas react to form ozone. Elevated ozone levels occur as a result of these reactions that convert nitrogen monoxide to nitrogen dioxide, especially in the presence of competing hydrocarbons (Stoker, 1976; Godish, 2004). Volatile organic compounds include both hydrocarbons and non-hydrocarbons and when oxidized, they form peroxy radicals (RO₂) (Godish, 2004; Vallero, 2008). These peroxy radicals then react with nitrogen oxides to form ozone in the following steps, where M is any third body molecule required for energy absorption:



Ozone pollution is mainly a concern due to human health issues (Krupa, 1997). Exposure to polluted environments over time results in measurable changes in lung function such as increased respiratory rate, increased pulmonary resistance, and decreased volume of air intake (Krupa, 1997). More visible reactions include chest tightness, coughing, wheezing, shortness of breath, headache, and nausea (Krupa, 1997; MOE, 2010c). Those with respiratory and heart problems have been found to be more at risk for these symptoms and ozone pollution has been connected to increased hospital admissions and premature death (MOE, 2010c).

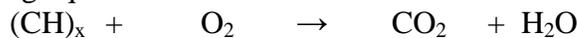
Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless, tasteless, but poisonous gas that is one of the most abundant air pollutants found in the lower atmosphere (Stoker, 1976; MOE, 2010a). While both natural and anthropogenic sources contribute to atmospheric carbon monoxide levels, anthropogenic sources account for more than 10x more carbon monoxide than natural sources (Stoker, 1976). The following chart, adapted from the Ontario Ministry of the Environment (2010a), outlines the major sources of anthropogenic carbon monoxide emissions:

Sector	Percent
Smelter/Primary Metals	3%
Other Industrial Processes	5%
Residential/Miscellaneous	7%
Other Transportation	40%
Road Vehicles	45%

Carbon monoxide is primarily produced as a result of incomplete combustion, however, there are three different processes that form carbon monoxide (Stoker, 1976).

Process 1 is the creation of carbon monoxide as a result of incomplete combustion of carbon or carbon-containing compounds (Stoker, 1976). Complete combustion is modelled by the following equation:



However, most thermal processes do not achieve complete combustion due to a lack of oxygen (Vallero, 2008). In a scenario with limited oxygen, the above equation changes with carbon dioxide replaced by carbon and carbon monoxide, shown in the following equation:



Process 2 is the creation of carbon monoxide as a result of a high-temperature reaction that occurs between carbon dioxide and carbon-containing materials (Stoker, 1976). This reaction mostly occurs in industrial devices, such as blast furnaces, where the carbon monoxide is used by industry as a reducing agent, but some of the gas escapes and becomes a pollutant (Stoker, 1976). This reaction is:



Process 3 is the creation of carbon monoxide as a result of dissociation of carbon dioxide at high temperatures (Stoker, 1976). Carbon dioxide and carbon monoxide exist in a high temperature equilibrium with the production of carbon monoxide favoured at higher temperatures (Stoker, 1976). This equilibrium can be demonstrated by:



The poisonous nature of carbon monoxide makes it a major health risk to humans. It has the capacity to enter the bloodstream where it tightly binds with hemoglobin, reducing oxygen delivery to tissues and organs (Krupa, 1997; MOE, 2010a). Exposure to high levels of carbon monoxide can result in impaired vision, headache, fatigue, and dizziness (Krupa, 1997; MOE,

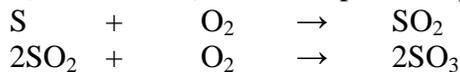
2010a). In extreme cases and high concentrations, commonly in house fires, carbon monoxide can lead to asphyxiation as a result of oxygen deprivation (Krupa, 1997).

Sulphur Dioxide

Sulphur dioxide (SO₂) is a colourless, nonflammable gas with a pungent odour akin to that of burnt matches (Stoker, 1976; MOE, 2010e). It is emitted almost exclusively from anthropogenic sources through combustion, however, it is also a by-product of volcanic activity and the oxidization of hydrogen sulphide (H₂S) given off by decomposition of organic matter (Stoker, 1976). The following chart, adapted from the Ontario Ministry of the Environment (2010e), outlines the major sources of anthropogenic sulphur dioxide emissions:

Sector	Percent
Miscellaneous	3%
Transportation	4%
Cement and Concrete	6%
Other Processes	9%
Downstream Petroleum Industry	9%
Utilities	19%
Smelters	50%

The combustion of sulphur-containing materials, predominantly in smelters, produce both sulphur dioxide and sulphur trioxide (SO₃), but due to the instability of sulphur trioxide at high temperatures, the relative amounts of these products is not dependent on oxygen availability (Stoker, 1976). Over time, the sulphur dioxide produced becomes oxidized to form sulphur trioxide (Stoker, 1976). These steps are:



It is important to note that sulphur trioxide has a high affinity for atmospheric water vapour and as such, its lifetime in the atmosphere is a matter of seconds (Godish, 2004). When sulphur trioxide reacts with water vapour, sulphuric acid (H₂SO₄), a major component of acid rain, is formed (Godish, 2004; Vallero, 2008). This simple reaction is shown by:



The sulphuric acid has the capacity to react with other substances in the atmosphere, such as ammonia, to form sulphate salts which are components of particulate matter (Stoker, 1976; MOE, 2010e).

There are some health effects that result from sulphur dioxide exposure, such difficulty breathing and cardiovascular disease with individuals with compromised respiratory and cardiovascular systems (Krupa, 1997; MOE, 2010e). However, very little inhaled sulphur dioxide reaches the lung tissue and bloodstream since it is removed by the mouth and nose as a result of its solubility in water (Krupa, 1997). Concerns regarding sulphur dioxide pollution arise mostly due to the impacts of subsequent sulphuric acid on the environment in the form of lake acidification and damage to trees and soils (MOE, 2010e).

Fine Particulates

Particulate matter is made up of small, solid particles and liquids including smoke, mist, dust, and pollen, that are present in the atmosphere (Stoker, 1976; MOE, 2010b). These particles vary in size and composition and in terms of air quality, the focus is on particles smaller than 2.5 microns in diameter, also known as fine particulate matter (PM_{2.5}) (MOE, 2010b). PM_{2.5} consists mostly of sulphate and nitrate particles that are formed as a result of chemical reactions in the atmosphere after combustion (MOE, 2010b). These particles can also be emitted directly into the atmosphere (Godish, 2004). The following chart, adapted from the Ontario Ministry of the Environment (2010b), outlines the major sources of anthropogenic fine particulate emissions:

Sector	Percent
Pulp and Paper	3%
Miscellaneous	6%
Smelters/Primary Metals	12%
Other Industrial Processes	21%
Transportation	24%
Residential	34%

Since particulate matter is classified based on particle size, chemical composition is highly variable and is an important indicator of the particle's source (Vallero, 2008). There are, however, some generalizations that can be made with particle size (Godish, 2004). For instance, PM_{2.5} is mostly comprised of sulphate compounds in the form of ammonium sulphate ((NH₄)₂SO₄), ammonium acid sulphate (NH₄HSO₄), sulphuric acid (H₂SO₄), and calcium sulphate (CaSO₄) (Godish, 2004).

Fine particulates are of a particular concern because they are known as respirable particles, meaning they are able to travel much further into the respiratory system (MOE, 2010b). Exposure to fine particulates can result in difficulty breathing, asthma, and other respiratory issues (Krupa, 1997). Those most at risk include people with pre-existing lung disease, smokers, children and the elderly (MOE, 2010b). In severe cases, prolonged exposure to fine particulate matter can result in premature death (MOE, 2010b).

Regulations

Air pollution can be controlled by air quality standards of which there are two types: primary and secondary standards (Vallero, 2008). Primary standards are set to protect human health with a certain margin of safety while not necessarily preventing other adverse effects of air pollution (Seinfeld, 1986; Vallero, 2008). Secondary standards, on the other hand, go a step further by specifying levels at which adverse effects can be avoided (Seinfeld, 1986). Overall, air quality standards are levels that air pollutant concentrations should be below in order to avoid adverse effects on humans as well as the environment (Seinfeld, 1986).

In Canada, the Canadian Clean Air Act gives the provincial Ministers of the Environment the ability to set air quality standards (Vallero, 2008). Together, the Canadian Council of Ministers of the Environment (CCME) has set national ambient air quality standards with three different

ranges: tolerable, acceptable, and desirable (Vallero, 2008; CCME, 2014). The tolerable range indicates a necessary and immediate reduction; the acceptable range indicates satisfactory protection against adverse effects; and the desirable range indicates a long-term goal for air quality (Vallero, 2008). The following tables, adapted from the CCME (2014), outline the current guidelines for the 5 major air contaminants:

Nitrogen Dioxide

Unit	Objective	1 hour	24 hour	1 year
$\mu\text{g}/\text{m}^3$	Desirable			60
	Acceptable	400	200	100
	Tolerable	1000	300	

Ozone

Unit	Objective	1 hour	24 hour	1 year
$\mu\text{g}/\text{m}^3$	Desirable	100	30	
	Acceptable	160	50	30
	Tolerable	300		

Carbon Monoxide

Unit	Objective	1 hour	24 hour
mg/m^3	Desirable	15	6
	Acceptable	35	15
	Tolerable		20

Sulphur Dioxide

Unit	Objective	1 hour	24 hour	1 year
$\mu\text{g}/\text{m}^3$	Desirable	450	150	30
	Acceptable	900	300	60
	Tolerable		800	

Fine Particulates

Unit	Objective	1 hour	24 hour	1 year
$\mu\text{g}/\text{m}^3$	Reference Level			15

As shown by the series of tables, there is no consistent measurement interval across the five pollutants. As such, and in order to have easy to work with data, the Your Environment website has converted these standards through interpolation and extrapolation to produce standards for monthly concentrations.

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