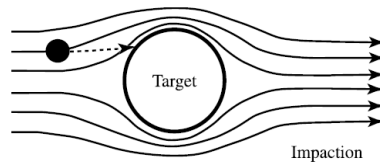


1. Define the following terms: thermal inversion, aerodynamic particle size, impaction, theoretical amount of air, terminal settling velocity, fuel desulfurization, out-door air pollution, and fumigation

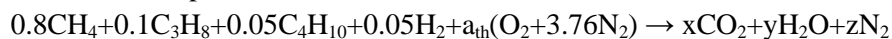
- a- Thermal inversion: is the existence of warmer air above cooler air, that prevents dissipation of pollutants.
- b- Aerodynamic particle size: is defined as the diameter of a sphere of unit density (1 g/cm^3) which has the same terminal settling velocity in air as the particle under consideration.
- c- Impaction: is a flow-particle interaction mechanism in which large particles moving toward the target have mass, and so momentum that tends to cause particle motion in a straight line toward the target. As the gas streamlines bends around the target, the particle will leave (is separated) from carried streamline



- d- Theoretical amount of air: is the minimum quantity of air needed for complete combustion without excess oxygen in the products.
- e- Terminal settling velocity: is the flow velocity at which the particle weight force is balance by the flow drag force, so for flow velocity beyond this value the particle will settle while for higher values particle will be carried by the flow.
- f- Fuel desulfurization process: is the removing of sulfur contents from fuel before it is burned. Coal contains sulfur in two forms; (a) mineral sulfur in the form of inorganic pyrite: mineral sulfur can be removed by physical coal cleaning, and (b) organic sulfur which is chemically bound to the coal: organic sulfur requires chemical cleaning. either from fuel or from flue gases, it may be done physically (if the sulfur exist as elemental compound) or chemically (when sulfur exists within organic-bond).
- g- Outdoor air pollution: Pollutions from outdoor services and environmental mixings, such as: transportation-automobiles, industries-refineries, atomic energy plant-nuclear, and community activities-cleaning of streets.
- h- Fumigation: is the sudden return of pollutants emitted into atmosphere back to the earth.

2. For certain Natural Gas (NG) mixture that consists of 80 % CH_4 , 10 % C_3H_8 , 5 % C_4H_{10} , and 5 % H_2 by volume is used to operate a boiler that emits an exhaust gaseous of the following dry volumetric composition 12.5 % CO_2 , 0.5% CO , 5 % O_2 . Determine the mass analysis of this mixture. Determine the following: (i) stoichiometric air-to-fuel ration, (ii) Equivalence ratio, (iii) the water vapor partial pressure in the exhaust gaseous at 1.2 bar, and (iv) the dry mass analysis of the exhaust gaseous

The theoretical reaction of the specified fuel will be:



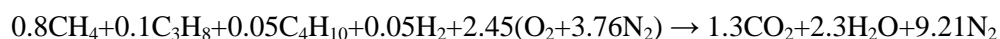
By performing elemental balance of carbon, hydrogen, and oxygen then:

C: $0.8 + 0.3 + 0.2 = x$, or $x = 1.3$

H: $3.2 + 0.8 + 0.5 + 0.1 = 2y$ or $y = 2.3$

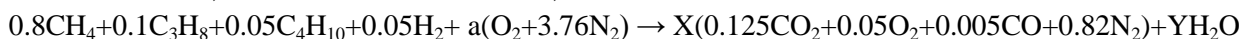
O: $2a_{\text{th}} = 2x + y$ or $a = 2.45$

N: then $z = 9.21$



The theoretical air-to-fuel ratio = $2.45 * 4.76 * 28.84 / (0.8 * 16 + 0.1 * 44 + 0.05 * 58 + 0.05 * 2) = 336.3 / 20.2 = 16.65$

For actual reaction, let one mole of fuel is burnt, then:



By performing elemental balance of carbon, hydrogen, and oxygen then:

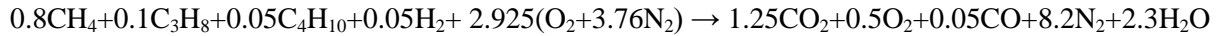
C: $1.3 = X(0.125 + 0.005)$, or $X = 1.3 / 0.13 = 10$

H: $4.6 = 2Y$ or $Y = 2.3$



O: $2a = X(0.25 + 0.1 + 0.005) + Y$ or $a = 2.925$

Then the actual reaction will be:



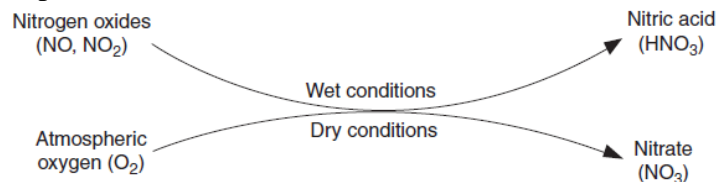
The equivalence ratio $= a_{\text{th}}/a = 2.45/2.925 = 0.837$ or excess air is about 20%

Element i	Number of moles n_i	Molecular weight M_i [kg/kmole]	Mass of i $m_i = y_i M_i$	Mass fraction $M_{fi} = m_i / m_m$
CO ₂	1.25	44	55	0.182
CO	0.05	28	1.4	0.005
O ₂	0.5	32	16	0.053
N ₂	8.2	28	229.6	0.76
mixture	12.8		302	1

The water vapor partial pressure will be $= 2.3 / (1.8 + 8.2 + 2.3) * 1.2 = 0.224$ bar

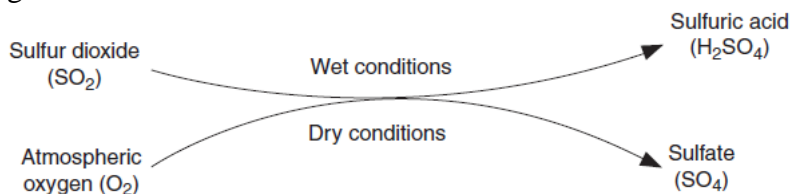
3. What are the forms and composition of the following pollutants (with schematic representation about their formation pathways and transformation into atmosphere):
- Nitrogen oxides
 - Sulfur oxides
 - Particulate matters

a. Nitrogen oxides: Atmospheric nitrogen, N₂ is chemically stable, but at high temperature during fuel combustion, there will be a reaction between N₂ and atmospheric oxygen, O₂ forming nitrogen oxides. Oxides of nitrogen include nitrous oxide (N₂O), nitric oxide (NO), nitrogen dioxide (NO₂), nitrogen trioxide (N₂O₃), and nitrogen pentoxide (N₂O₅) and all collectively referred as NO_x. Of them there are primary of concern as air pollutants; NO and NO₂. NO - a colorless gas is an active compound in photochemical reactions producing smog. NO₂ - reddish brown gas gives color to smog, contributes to opacity in flue gas plumes from stacks, and is major contribution for acidic rain as a precursor to nitric acid (HNO₃) in atmosphere.



Nitric acid and nitrate are aerosols and wash out with rain, or slowly settle out by gravity. They are acid deposition in both cases. Importantly, they are also plant nutrients.

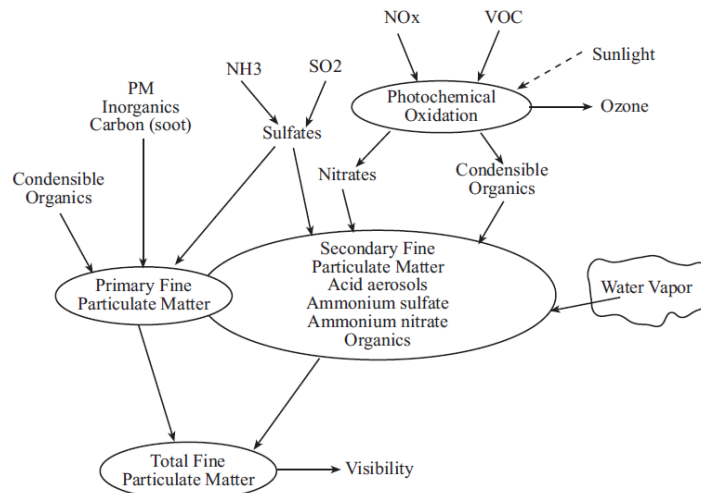
b. Sulfur oxides: Sulfur dioxide (SO₂) is a corrosive acid gas, colorless with a sharp irritating odor. Other forms of sulfur emissions, including H₂S, SO₃, and sulfuric acid mist will be discussed. And, because some of the SO₂ control technologies are directly applicable to HCl control, there will be brief discussion of HCl emissions as well. By far the largest source of sulfur emissions is from burning coal to generate electricity. The declining trend in SO₂ emissions, which is largely as a result of efforts to control SO₂ as a source of acid rain, is plotted in figure below.



Transforming sulfur dioxide to sulfuric acid and sulfate

c. **Particulate Matters:** There are six major components account for nearly all of the PM10 mass in most urban areas:

- 1) Geological material (oxides of aluminum, silicon, calcium, titanium, and iron);
- 2) Organic carbon (consisting of hundreds of compounds);
- 3) Elemental carbon;
- 4) Sulfate;
- 5) Nitrate; and
- 6) Ammonium.



Fine particulate formation pathways

4. Deduce a relation to compute the settling velocity, hence calculate the settling velocity of dust particles of (a) 60 μm and (b) 10 μm diameter in air at 21°C and 100 kPa pressure. Assume that the particles are spherical of density 1280 kg.m^{-3} , and that the viscosity of air = $1.8 \times 10^{-5} \text{ N.s.m}^{-2}$ and density of air = 1.2 kg.m^{-3} .

Answer:

For a spherical particle under Stokes's law, which is generally valid for the aerosol in the ambient atmosphere, the drag force is:

$$F_D = 3\pi\mu d_p V_p, \text{ for } \text{Re} < 1$$

This relation is based on the following assumptions:

- rigid spherical particle
- Stokes's law or inertial force is much smaller than viscous force
- continuum fluid
- free flow with neglected wall effects
- the density of air is constant or low Mach number flow
- steady state flow

At terminal settling velocity, the drag force is equal to the gravitational force

$$3\pi\mu d_p V_p = \frac{(\rho_p - \rho)\pi d_p^3 g}{6} \text{ and } V_p = V_{sT}, \text{ thus}$$

$$V_{sT} = \frac{(\rho_p - \rho)d_p^2 g}{18\mu}$$

Thus for 60 μm particle: $V_{sT} = (60 \times 10^{-6})^2 \times 9.81 \times (1280 - 1.2) / (18 \times 1.8 \times 10^{-5}) = 0.14 \text{ m s}^{-1}$

While for 10 μm particles since V_{sT} will be $3.9 \times 10^{-3} \text{ m s}^{-1}$.

5. What are:

- a. the main strategies of air pollution control,
- b. the major principles for particulate removing,
- c. the after-treatment techniques to reduce NO_x emissions,
- d. the main types of sampling processes

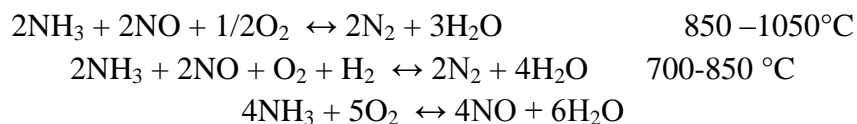
a) generally there are two strategies to control air pollution; namely long and short-term strategies. Long-term control strategies involve an authorized set of measures to be adopted over a long period (many years). For long-term control, a typical objective might be to reduce to a specified value the expected number of days per year that the maximum hourly average concentration of a certain pollutant exceeds a given value. Short-term control involves shutdown and slowdown procedures suitable for short time testing (from hours to several days) under impending adverse meteorological conditions. An example of a short-term strategy is the emergency procedures for fuel substitution by coal-burning power plants when SO₂ concentrations reach certain levels. The goal of short-term control is ordinarily to keep the maximum concentration of a certain pollutant below a given value on that particular day. In figure below, requirements and the elements of a comprehensive regional air pollution control strategy, including both long- and short-term measures are illustrated.

b) The principles used in many practical devices to control particulate emissions include:

1. Electrostatic Precipitation (particle obstruction)
2. Fabric Filters (particle obstruction)
3. Venturi Scrubbers (particle obstruction and gravity forces)
4. Cyclones (enhancement of centrifugal forces)
5. Settling Chambers (enhancement of gravity forces)

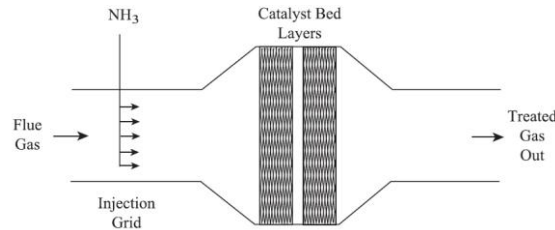
c) Exhaust gases treatment techniques provide a chemically reducing (i.e., reversal of oxidization) substance to remove oxygen from nitrogen oxides. Examples include Selective Catalytic Reduction (SCR), which uses ammonia, Selective Non-Catalytic Reduction (SNCR) that use ammonia (NH₃) or urea (H₂NCONH₂) to reduce NO_x to nitrogen and water, and Fuel Reburning. Non-thermal plasma, an emerging technology, when used with a reducing agent, chemically reduces NO_x; these methods are briefly described below.

a. Selective Noncatalytic Reduction (SNCR): The overall reactions using ammonia as the reagent are:



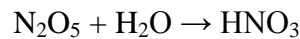
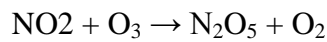
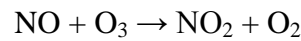
In a typical application, SNCR produces about 30 to 50% NO_x reduction. For larger reduction levels SNCR system is replaced by SCR system. But the capital costs of SNCR may be lower than an SCR system

b. Selective Catalytic Reduction (SCR): An SCR system consists primarily of an ammonia injection grid and a reactor that contains the catalyst be; as simplified in figure below with the following system of reactions leading to reduction of NO_x in an SCR system:



SCR systems are capable of reducing NO_x up to 90%. In the common power-generation application of gas-fired turbines, less than 5 ppm NO_x at 15% O₂ can be achieved.

- c. **Low-Temperature Oxidation with Absorption:** NO_x can be removed at low-temperature by its oxidation to highly soluble N₂O₅ that can be absorbed in a wet absorption tower. Ozone is used as the oxidizing agent for the reactions:



This technique able to remove up to 99% of NO_x, in some facilities may be there an acidic absorber for SO₂ control, so only the ozone generation and injection systems will be added. A possible disadvantage for some facilities would be additional nitrate in the wastewater discharge, since NO_x is removed in the form of nitric acid.

- d. **Catalytic Absorption:** This system utilizes a single catalyst for removal of both NO_x and CO. First, NO, CO, and hydrocarbons are oxidized to NO₂ and CO₂. Then NO₂ is absorbed in a coating of potassium carbonate on the catalyst. The process can operate effectively at temperatures ranging from 150 to 350°C. Significant advantages of this process include the simultaneous removal of CO, hydrocarbons, and NO_x to very low levels, and the lack of ammonia storage and emissions. Less than 2 ppm NO_x has been demonstrated when used in conjunction with other NO_x control technologies.

d) Main types of sampling processes include:

Passive and active sampling. Passive sampling is used to get an indication of pollution levels over a period of a few weeks to months. Sampling of this type is taken near the source of pollutions as roads and power generation sites to detect levels of nitrogen dioxide and benzene. This method is used to get an idea of average pollution levels. Passive sampling does not use a physical pump for air collection. Instead a “whole air” sample may be collected in a specially designed and prepared canister or inert sampling bag for later analysis. The sample collector is mounted in the area to be tested, allowing the normal air flow to move through the tube. At the end of the sample period, caps are placed on the ends of the tube and the unit is taken for lab analysis. **Active sampling** is the same as passive sampling, except this method uses a pumping mechanism. The air is physically pushed through a filter, or chemical solution, to obtain the sample for later testing in the lab. Air flows over the filter at a specific rate (volume) for a set amount of time. Using this method allows the lab to calculate the amount of pollutant in the air. Switching sample catchers in the unit enables the tester to test for specific pollutants in the given area, and can be done on a daily basis.

Sample can be classified according to continuity as **batch or continuous sampling**.

Another classification of sampling depends on the location; **outdoor sampling or indoor sampling**.

Best wishes, Ali M.A. Attia