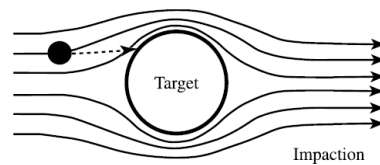
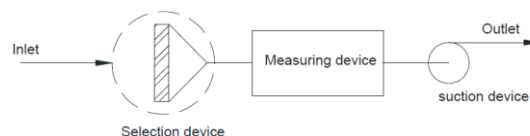


1. Define the following terms: stoichiometric air-to-fuel ratio, thermal inversion, smog, impaction, aerodynamic particle size, fuel desulfurization, primary air pollutants, terminal settling velocity, out-door air pollution, and sampling train

- a- Stoichiometric air-to-fuel ratio: is the amount of air just needed to burn completely one kilogram of fuel without any excess oxygen in the products
- b- Thermal inversion: is the existence of warmer air above cooler air, that prevents dissipation of pollutants.
- c- Smog is a secondary pollutant that combines smoke and fog resulting in visualization and haze problems and formed due to photochemical reactions.
- d- 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

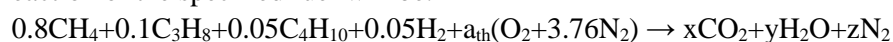


- e- Aerodynamic particle size: is defined as the diameter of a sphere of unit density ( $1 \text{ g/cm}^3$ ) which has the same terminal settling velocity in air as the particle under consideration.
- f- Fuel desulfurization process: is the removing of sulfur contents from fuel before it is burned. 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- Primary air pollutants: are the major regulated pollutants that emit directly from the pollution source; including nitrogen oxide, sulfur dioxide, carbon monoxide, volatile organic compounds, particulate matters, and heavy metals.
- h- 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.
- i- 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.
- j- Sampling train: is a system used to withdraw a sample of air and present it to the analysis system without significant change to the composition or characteristics of the sample.



2. For certain Natural Gas (NG) mixture that consists of 80 % CH<sub>4</sub>, 10 % C<sub>3</sub>H<sub>8</sub>, 5 % C<sub>4</sub>H<sub>10</sub>, and 5 % H<sub>2</sub> by volume is used to operate a boiler that emits an exhaust gaseous of the following dry volumetric composition 12.5 % CO<sub>2</sub>, 0.5% CO, 5 % O<sub>2</sub>. 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:



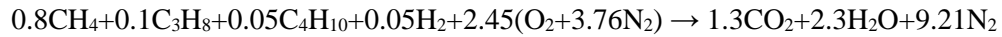
By performing elemental balance of carbon, hydrogen, and oxygen then:

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

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

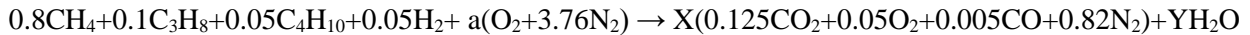
O:  $2a_{th}=2x+y$  or  $a=2.45$

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:



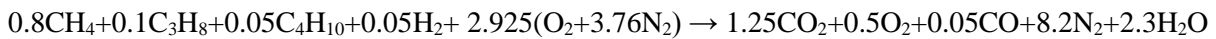
By performing elemental balance of carbon, hydrogen, and oxygen then:

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:



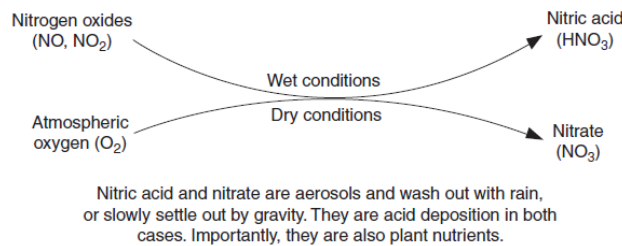
The equivalence ratio= $a_{th}/a=2.45/2.925=0.837$  or excess air is about 20%

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

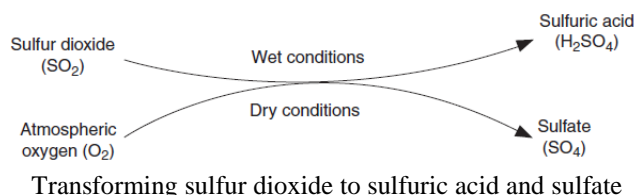
The water vapor partial pressure will be= $2.3/(1.8+8.2+2.3)*1.2=0.224$  bar

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

**1- Nitrogen oxides:** Atmospheric nitrogen, N<sub>2</sub> is chemically stable, but at high temperature during fuel combustion, there will be a reaction between N<sub>2</sub> and atmospheric oxygen, O<sub>2</sub> forming nitrogen oxides. Oxides of nitrogen include nitrous oxide (N<sub>2</sub>O), nitric oxide (NO), nitrogen dioxide (NO<sub>2</sub>), nitrogen trioxide (N<sub>2</sub>O<sub>3</sub>), and nitrogen pentoxide (N<sub>2</sub>O<sub>5</sub>) and all collectively referred as NO<sub>x</sub>. Of them there are primary of concern as air pollutants; NO and NO<sub>2</sub>. NO - a colorless gas is an active compound in photochemical reactions producing smog. NO<sub>2</sub> - 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 (HNO<sub>3</sub>) in atmosphere.

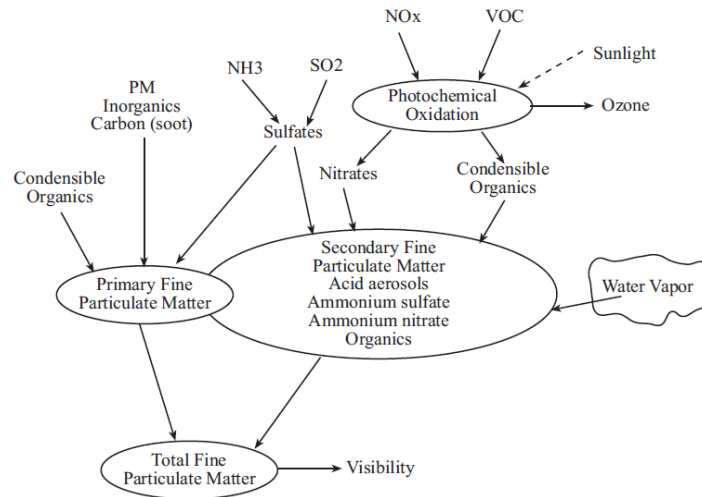


**2- Sulfur oxides:** Sulfur dioxide (SO<sub>2</sub>) is a corrosive acid gas, colorless with a sharp irritating odor. Other forms of sulfur emissions, including H<sub>2</sub>S, SO<sub>3</sub>, and sulfuric acid mist will be discussed. And, because some of the SO<sub>2</sub> control technologies are 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 SO<sub>2</sub> emissions, which is largely as a result of efforts to control SO<sub>2</sub> as a source of acid rain, is plotted in figure below.



**3- 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. State with details a comparison between
- a. different control devices for particulate matters with emphasize on the advantages and disadvantages for each device,
  - b. long-term and short-term air pollution control strategies,
  - c. atmospheric layers.

a)

1- Settling chamber. Advantages:

- Low capital cost
- Very low energy cost
- No moving parts
- Few maintenance requirements
- Low operating costs
- Excellent reliability
- Low pressure drop through device
- Device not subject to abrasion due to low gas velocity
- Provide incidental cooling of gas stream
- Dry collection and disposal

Disadvantages of Settling Chambers:

- Relatively low PM collection efficiencies
- Unable to handle sticky or tacky materials
- Large physical size
- Trays in multiple-tray settling chamber may warp

2- Venturi scrubber. Advantages:

- Capable of handling flammable and explosive dusts
- Can handle mists in process exhausts
- Relatively low maintenance
- Simple in design and easy to install
- Collection efficiency can be varied
- Provides cooling for hot gases
- Neutralizes corrosive gases and dusts

While their disadvantages include:

- Effluent liquid can create water pollution problems

- Waste product collected wet
- High potential for corrosion problems
- Requires protection against freezing
- Final exhaust gas requires reheating to avoid visible plume
- Collected PM may be contaminated, and not recyclable
- Disposal of waste sludge may be very expensive

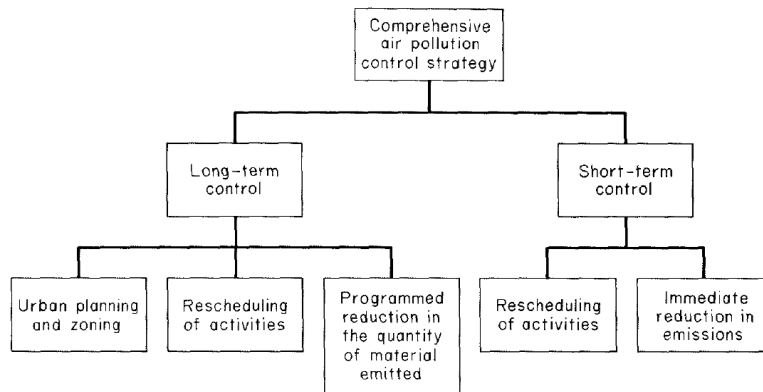
3- Cyclone. Advantages:

- Low capital cost
- No moving part
- Few maintenance requirements
- Low operating costs
- Relatively low-pressure drop
- Dry collection and disposal
- Relatively small space requirements

Disadvantages of Cyclones:

- Relatively low PM collection efficiencies
- Unable to handle sticky or tacky materials
- High efficiency units may experience high-pressure drops

b)



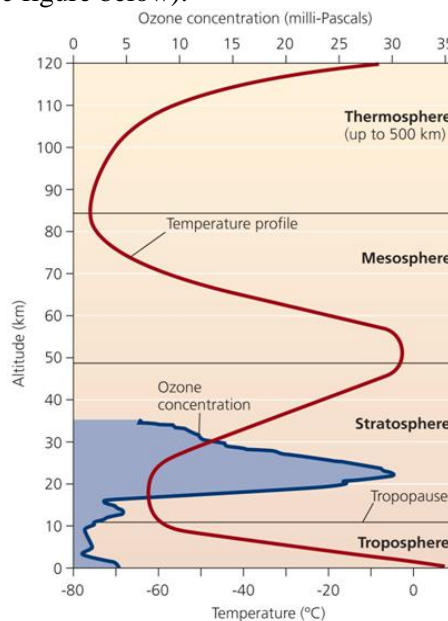
**Requirements for long-term planning**

- Air quality objective
- Airshed model (dynamic or static)
- Survey of control techniques and their costs
- Meteorological probabilities

**Requirements for real-time control**

- Air quality objective
- Dynamic model
- Rapid communications
- Strict enforcement of measures

C) Atmospheric layers. The atmosphere is layered in to four distinct zones of contrasting temperature due to differential absorption of solar energy. The four atmospheric layers are: Troposphere, stratosphere, mesosphere, and thermosphere (see figure below).



- **Troposphere** is the bottommost layer adjacent to earth's surface up to about 16 km where most weather events occur and containing over 80% of the total atmospheric air. Other characteristics of troposphere:
  - Air for breathing, weather and all live activities occur in this layer
  - Temperature declines with altitude
  - Contains water vapor, gases and dust
  - The residence time of particle in the troposphere is short due to rain, gravity, air movement
  - Mixing time is rapid due to wind or turbulence
  - Limiting mixing between troposphere and the layer above it
- **Stratosphere** extends from the tropopause up to about 50 km. Air temperature in this zone is stable or even increases with higher altitude. Although more dilute than the troposphere, the stratosphere has a very similar composition except two important components: water and ozone (less than one hundred of that in the troposphere). The characteristics of stratosphere
  - There is no water vapor nor dust
  - Drier and less dense, with little vertical mixing
  - Colder in its lower regions
  - Contains UV radiation-blocking ozone, 17-30 km above sea level
  - Amount of ozone vary depending on location and season; lowest above the equator and increase towards the poles, increased markedly between fall and spring
  - Mixing time is lower, so Pollution entering in this region tends to remain long time due to low mixing
- **Mesosphere** extends above the stratosphere (from 50 to 80 km), temperature diminishes again (up to -80°C) creating the mesosphere (middle) layer. Other characteristics of mesosphere:
  - Extremely low air pressure
  - Temperatures decrease with altitude
- **Thermosphere** is the top layer extending from altitude of 80 km up to 500 km containing highly ionized gases and very high temperature due to high solar and cosmic radiations, and characterized by:
  - Emit visible light
  - There is no sharp boundary that marks the end of the atmosphere
  - Pressure and density decreases gradually approaching the vacuum conditions of interstellar space
  - The composition gradually merges with that of interstellar space (mostly of H<sub>e</sub> and H<sub>2</sub>)

5. 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<sup>-3</sup>, and that the viscosity of air = 1.8 x 10<sup>-5</sup> N.s.m<sup>-2</sup> and density of air = 1.2 kg.m<sup>-3</sup>.

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  $3.9 \times 10^{-3} \text{ m s}^{-1}$ .

6. What are:

- a. The phases to specify the stack tests and the additional measurements needed for stack report include
- b. the major principles for pollutant selection/removing process,
- c. the main types of sampling processes

a) The phases to specify the stack tests include phases, the: (1) protocol review; (2) test observation, and (3) final report review. The additional measurements needed for stack report include:

1. fluctuations in velocity, temperature or pollutant concentration due to variation in the process
2. moisture content (particularly wet stack gases)
3. expected gas composition and likely interfering compounds
4. high vacuum, high pressure or high temperature gas streams
5. corrosive or very reactive compounds
6. calculation requirements of the Air Quality under defined standards
7. Reporting requirements of this manual.

b) There are a variety of approaches to removing/selecting specific gaseous pollutants from effluent streams, such as:

- 1- Absorption: molecules go into interior of substance
- 2- Adsorption: molecules stuck to surface.
- 3- Sorption: combination of adsorption and absorption
- 4- Condensation: cooling to remove low volatile components

c) 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*