Question ① 《5 marks》

State with details a comparison between

A- main factors affecting between smog formation at London on 1952 and that at Loss Anglos on 1943,

B- long-term and short-term air pollution control strategies,

C- physisorption and chemisorption.

Question ② 《10marks》

What are:

A- the different forms and compositions of NOx, SOx, and PM pollutants?

B- the devices used to control particulate emissions?

C- the exhaust gases treatment methods to control NOx emissions?

D- the major principles for pollutant selection/removing process,

E- the main plume behaviors

Question ③ 《5 marks》

Derive the relation used to compute terminal settling velocity. Hence calculate the settling velocity for dust particles of 10 μm and 60 μm diameter in air at 21°C and 100 kPa. Assume that the particles are spherical and of density 1280 kg.m-3, and that the viscosity of air = 1.8 x 10^{-5} N.s.m^{-2} and density of air = 1.2 kg.m-3.

Question ④ 《5 marks》

For Natural Gas (NG) mixture consisting 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) Equivalence ratio, (ii) the water vapor partial pressure in the exhaust gaseous at 1.2 bar, and (iii) the dry mass analysis of the exhaust gaseous. .

Question ⑤ 《5 marks》

Define the following terms: Sampling train, Flue gas desulfurization, Thermal inversion, Aerodynamic particle size, Impaction, Theoretical amount of air, Terminal settling velocity, Out-door air pollution, Smoke, and Fumigation

Best Wishes for all,
Dr. Ali Attia

Benha University	**Department: Mechanical Eng.**
Benha Faculty of Engineering	**Program: General**
Date: 29/5/2017	**Time: 120 min**
Semester: External	**Subject: Environment and Pollution**
Examiner: Dr. Ali Attia	**Code: M502**
Total Points: 30	**No. of Pages: 6**

Final Exam Model Answer

Question ① 《*5 marks*》

State with details a comparison between

A- main factors affecting between smog formation at London on 1952 and that at Loss Anglos on 1943,

B- long-term and short-term air pollution control strategies,

C- physisorption and chemisorption.

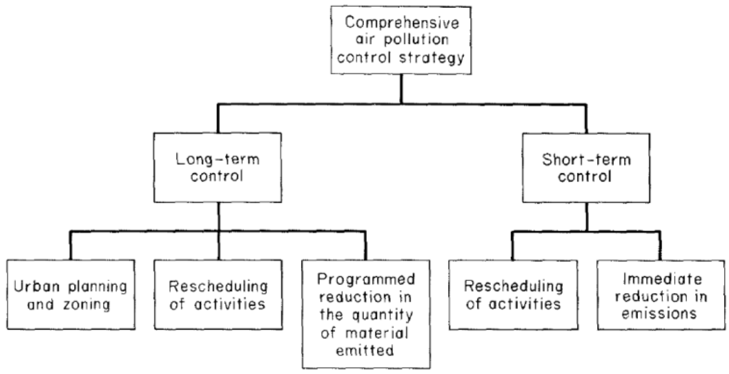
Answer

a. main factors affecting smog formation at London - 1952 and that at Loss Anglos - 1943

1- **London type smog** (1952) comes from coal smoke combining with the water vapor and liquid water in cool, humid or foggy air. In this case burning of many coal resources in stagnant humid air lead to the formation of acidic rains ($SO_2+H_2O \rightarrow H_2SO_4$)

2- **Loss- anglos** and other urbans over the world (1943 and verified 1951) comes from auto exhaust pollutants (CO, NO_x, and ROG- reactive organic gas from unburned gasoline), primarily (we will see later that there is a significant "stationary" source). Emissions of NO_x, ROG into sunny atmosphere will lead to formation of O_3 and NO_2 due to photochemical reactions

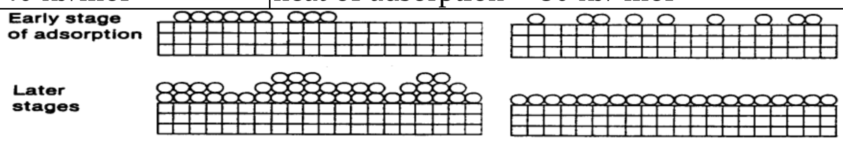
b. long-term and short-term air pollution control strategies



Requirements for long-term planning	**Requirements for real-time control**
Air quality objective	Air quality objective
Airshed model (dynamic or static)	Dynamic model
Survey of control techniques and their costs	Rapid communications
Meteorological probabilities	Strict enforcement of measures

c. Physisorption and chemisorption

Physisorption	**chemisorption**
Van der Waals forces between molecules	Chemical bond (stronger than Van der Waals bonds)
multilayer adsorption	monolayer
predominates at low temperatures	chemical adsorption decreases at low temperatures
occurs rapidly	activation energy involved
reversible	irreversible
heat of adsorption < 40 kJ/mol	heat of adsorption > 80 kJ/ mol



Question ② (10marks)

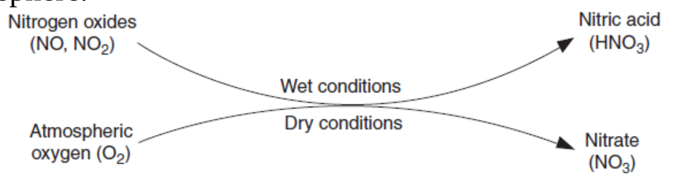
What are:

- A- the different forms and compositions of NOx, SOx, and PM pollutants?
- B- the devices used to control particulate emissions?
- C- the exhaust gases treatment methods to control NOx emissions?
- D- the major principles for pollutant selection/removing process,
- E- the main plume behaviors

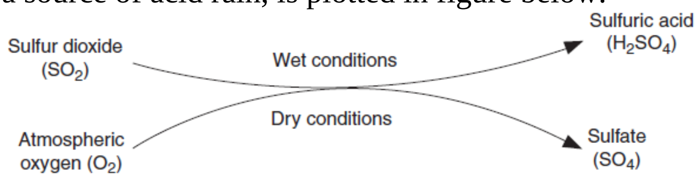
Answer

a- the different forms and compositions of NO_x, SO_x, and PM pollutants:

a. Nitrogen oxides: Oxides of nitrogen include nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO2), nitrogen trioxide (N_2O_3), and nitrogen pentoxide (N_2O_5) and all collectively referred as NO_x. Of them there are primary of concern as air pollutants; NO and NO_2. NO - a colorless gas is an active compound in photochemical reactions producing smog. NO_2 - 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_3) in atmosphere.



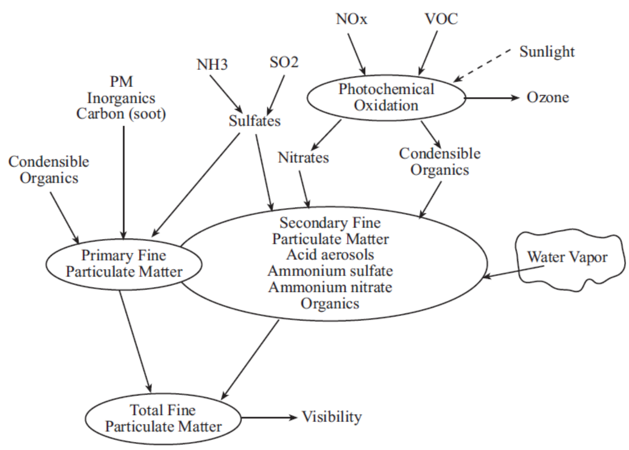
b. Sulfur oxides: Sulfur dioxide (SO_2) is a corrosive acid gas, colorless with a sharp irritating odor. Other forms of sulfur emissions, including H_2S, SO_3, and sulfuric acid mist will be discussed. The declining trend in SO_2 emissions, which is largely as a result of efforts to control SO_2 as a 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 metals);
2) Organic carbon;
3) Elemental carbon;
4) Sulfate;
5) Nitrate; and
6) Ammonium.



Fine particulate formation pathways

b- the devices used 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- the exhaust gases treatment methods to control NOx emissions

This technique provides a chemically reducing (i.e., reversal of oxidization) substance to remove oxygen from nitrogen oxides. Examples include:

1- Selective Catalytic Reduction (SCR), which uses ammonia,

2- Selective Non-Catalytic Reduction (SNCR) that use ammonia (NH_3) or urea (H_2NCONH_2) 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

3- Low-Temperature Oxidation with Absorption: NO_x can be removed at low-temperature by its oxidation to highly soluble N_2O_5 that can be absorbed in a wet absorption tower.

4- Catalytic Absorption: This system utilizes a single catalyst for removal of both NO_x and CO. First, NO, CO, and hydrocarbons are oxidized to NO_2 and CO_2. Then NO_2 is absorbed in a coating of potassium carbonate on the catalyst.

d) 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

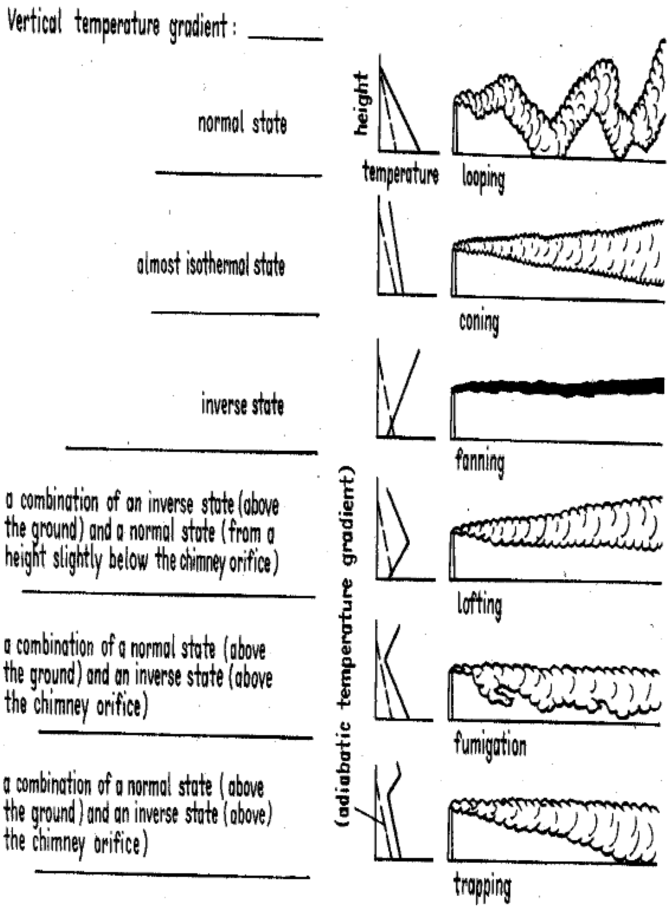
2- Adsorption: molecules stuck to surface.

3- Sorption: combination of adsorption and absorption

4- Condensation: cooling to remove low volatile components

E) The behavior of a plume depends on the degree of instability of the atmosphere and the prevailing wind turbulence, it may be:

1. Looping: occurs under super adiabatic conditions with light to moderate wind speeds on a hot summer after noon when large scale thermal eddies are present.
2. Conning: occurs under cloudy skies during day and night when the atmosphere is essentially neutral.
3. Fanning: occurs when the plume is dispersed in the presence of very light winds as a result of strong atmospheric inversions.
4. Fumigation: here a stable layer of air lies a short distance above the release point of the plume and the unstable air layer below the plume causes the pollutant to mix downwind toward the ground.
5. Lofting : The condition for lofting plume are the inverse of fumigation.
6. Trapping: occurs when the plume effluent is caught between two inversion layers.



<u>Question ③ (5 marks)</u>

Derive the relation used to compute terminal settling velocity. Hence calculate the settling velocity for dust particles of 10 µm and 60 µm diameter in air at 21°C and 100 kPa. Assume that the particles are spherical and of density 1280 kg.m-3, and that the viscosity of air = 1.8 x 10^{-5} 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:

$F_D = 3\pi\mu d_p V_p$, for 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

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

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

If $(\rho_p >> \rho)$ then $V_{sT} \approx \dfrac{\rho_p d_p^2 g}{18\mu}$

where:

V_P = particle velocity (m/s), ρ_P = particle density (kg/m^3)
ρ = fluid density (kg/m^3), d = particle diameter (m),
g = gravitational acceleration (9.81 m/s^2), μ= fluid viscosity (kg/m·s)

For 60 µm particle:
V_{sT} = $(60 \times 10^{-6})^2 \times 9.81 \times (1280 - 1.2)/(18 \times 1.8 \times 10^{-5}) = 0.14$ m s^{-1}
For 10 µm particles since V_{sT} will be 3.9×10^{-3} m s^{-1}.

Question ④ (5 marks)

For Natural Gas (NG) mixture consisting 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) Equivalence ratio, (ii) the water vapor partial pressure in the exhaust gaseous at 1.2 bar, and (iii) the dry mass analysis of the exhaust gaseous.   .

Answer

The theoretical reaction of the specified fuel will be:

$$0.8CH_4+0.1C_3H_8+0.05C_4H_{10}+0.05H_2+a_{th}(O_2+3.76N_2) \rightarrow xCO_2+yH_2O+zN_2$$

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

$$0.8CH_4+0.1C_3H_8+0.05C_4H_{10}+0.05H_2+2.45(O_2+3.76N_2) \rightarrow 1.3CO_2+2.3H_2O+9.21N_2$$

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:

$$0.8CH_4+0.1C_3H_8+0.05C_4H_{10}+0.05H_2+ a(O_2+3.76N_2) \rightarrow$$
$$X(0.125CO_2+0.05O_2+0.005CO+0.82N_2)+YH_2O$$

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:

$$0.8CH_4+0.1C_3H_8+0.05C_4H_{10}+0.05H_2+ 2.925(O_2+3.76N_2) \rightarrow$$
$$1.25CO_2+0.5O_2+0.05CO+8.2N_2+2.3H_2O$$

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_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

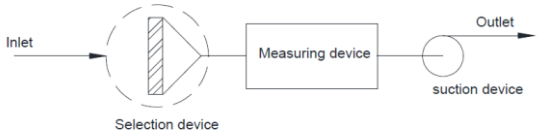
*The water vapor partial pressure will be=2.3/(1.8+8.2+2.3)*1.2=0.224 bar*

Question ⑤ (5 marks)

Define the following terms: Sampling train, Flue gas desulfurization, Thermal inversion, Aerodynamic particle size, Impaction, Theoretical amount of air, Terminal settling velocity, Out-door air pollution, Smoke, and Fumigation.

Answer

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.

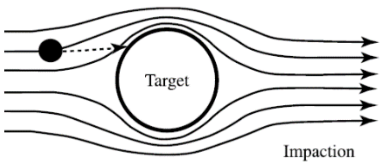


Desulfurization process: is the removing of sulfur contents either from fuel or from flue gases, it may be done physically (if the sulfur exist as elemental compound) or chemically (when sulfur exists within organic-bond)

Thermal inversion: is the existence of warmer air above cooler air, that prevents dissipation of pollutants, pollutants collect, no wind.

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.

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



Theoretical amount of air: is the minimum quantity of air needed for complete combustion without excess oxygen in the products.

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.

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.

Smoke: aerosols consist of particles in the solid and sometimes also liquid-phase and the associated gases that result from combustion.

Fumigation: is the sudden return of pollutants emitted into atmosphere back to the earth

Best Wishes for all,
Dr. Ali Attia