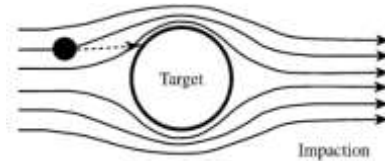




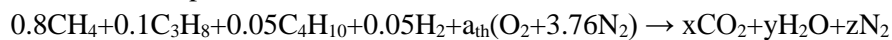
Model Answer

1. Define the following terms: smog, polluted air, equivalence ratio, sampling train, atmospheric inversion, aerodynamic diameter, troposphere, and impaction. (5)
- a- Smog: type of air pollution that contains two groups of pollutants; Smoke and fog referring to smoky fog as that detected in London (1952) and Los Angeles (1943).
 - b- Polluted air: is a clean or natural air that contains any foreign toxic substance that have a harmful effect directly or indirectly on the human, animals and plants health.
 - c- Equivalence ratio: is the ratio of the actual fuel-to-air ratio relative to the theoretical fuel-to-air ratio.
 - d- 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.
 - e- Atmospheric inversion (thermal inversion): temperature inversion, warmer air above cooler air, prevents dissipation of pollutants, pollutants collect, no wind.
 - f- Aerodynamic diameter is particle size 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
 - g- Troposphere: The first and lowest of the atmospheric layers is called the “troposphere”.
 - h- 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



2. For certain Natural Gas (NG) mixture that consists of 80 % CH₄, 10 % C₃H₈, 5 % C₄H₁₀, and 5 % H₂ by volume is used to operate a boiler that emits an exhaust gaseous of the following dry volumetric composition 12.5 % CO₂, 0.5% CO, 5 % O₂. 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. (10)

The theoretical reaction of the specified fuel will be:



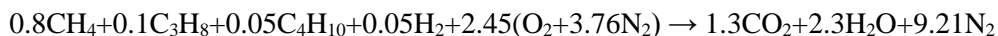
By performing elemental balance of carbon, hydrogen, and oxygen then:

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

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

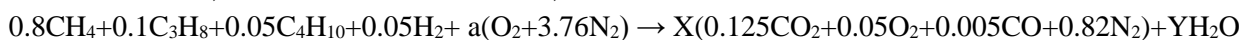
O: $2a_{\text{th}} = 2x + y$ or $a = 2.45$

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:



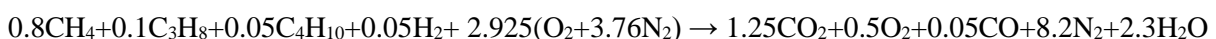
By performing elemental balance of carbon, hydrogen, and oxygen then:

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 $m_i=y_iM_i$	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

3. What are:

(5)

- a. the major sources of pollution in Cairo,
- b. the main approaches for pollution control.
- c. the main types of sampling stations
- d. the major types of fuel desulfurization processes
- e. the main components of particulate matters

a. the major sources of pollution in Cairo

- 1- Traffics transport devices
- 2- Agricultural waste burning.
- 3- Unregistered lead and copper smelters.
- 4- Land pollution.
- 5- Lead.
- 6- Water pollution .
- 7- The dangerously high levels of mercury in the city's water system has global health officials concerned over related health risks

b. Air pollution can be controlled by performing different approaches, such as

1. Regulations on auto industry
2. Fines to enforce bans; Incentives for reduction
3. Switch from high sulfur coal to low sulfur coal
4. Switch to oil, gas, wind, solar, nuclear power
5. "Scrubbers" on smoke stacks to remove sulfur after use

c. the main types of sampling stations include:

- 1- **Peak stations:** are located in areas where the maximum ground level concentration (GLC) is likely to be measured.
- 2- **Neighborhood stations:** are generally located in an area representative of uniform land use such as **residential**, industrial or commercial. These stations are used to assess compliance with air quality standards and to measure trends over time.
- 3- **Background stations:** are sited to assess air quality in areas without substantial sources and may be useful in providing background levels and measuring levels resulting from transport of pollution.

d. Fuel desulfurization which includes two major processes:

- 1- Physical coal cleaning can reduce the ash and sulfur content of coal and hence the potential SO₂ emissions which result from coal combustion. Physical coal cleaning depends on the differences in density of both coal and the impurities. Coal is crushed, washed, and then separated by settling processes using cyclones, air classifiers or magnetic separators.
- 2- Chemical coal cleaning methods that reduce the organic-bound sulfur include two technologies: (1) microwave desulfurization and (2) hydrothermal desulfurization. In microwave desulfurization, coal is crushed, then heated for 30 to 60 Sec by exposure to microwaves. Mineral sulfur selectively absorbs this radiation forming hydrogen sulfide gas (H₂S). The H₂S is usually reduced to elemental sulfur by the Claus process. Another microwave process adds calcium hydroxide [Ca(OH)₂] to crushed coal. The organic sulfur converts to calcium sulfite (CaSO₃) when exposed to this radiation.

- e. 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.

4. State with details a comparison between

(5)

- a. terminal and curvilinear settling velocities
- b. damage and control costs,
- c. NO_x mechanisms of formations
- d. Secondary and primary particulates (aerosols).
- e. physisorption and chemisorption.

a. terminal and curvilinear settling velocities

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

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

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

If $(\rho_p \gg \rho)$ then $V_{st} \approx \frac{\rho_p d_p^2 g}{18\mu}$

where:

V_p = particle velocity (m/s),

ρ_p = particle density (kg/m³)

ρ = fluid density (kg/m³)

d = particle diameter (m),

g = gravitational acceleration (9.81 m/s²)

μ = fluid viscosity (kg/m·s)

In case of curvature path or when a particulate-laden gas stream is made to flow in a circular manner within a cylinder, as shown below. Inertial force that is applied in a spinning gas stream is often termed centrifugal force. The movement of particles due to inertial force in a spinning gas stream is estimated using the same procedure described for terminal settling velocity due to gravitational force. Accordingly the particle will be in rest when the centrifugal force balances the drag force:

$$F_C = F_D \text{ where } F_C = m_p V_t^2 / R = \pi d_p^3 \rho_p V_t^2 / 6R \text{ and } F_D = 3\pi\mu d_p V_p$$

$$\text{thus } V_p = \frac{(\rho_p - \rho)d_p^2 V_t^2}{18\mu R}$$

where

FC = centrifugal force

m_p = mass of the particle

V_t = tangential velocity of the gas

R = radial position of the particle

d_p = physical particle diameter

ρ_p = particle density

V_p = radial particle velocity

μ = gas viscosity

b. damage and control costs determines the total cost of air pollution control costs:

1. **Damage costs:** the costs to the public of living in polluted air, for example, tangible (real) losses such as crop damage and deteriorated materials and intangible losses such as reduced visibility and eye and nasal irritation
2. **Control costs:** the costs acquired by emitters (and the public) in order to reduce emissions, for example, direct costs such as the price of equipment that must be purchased and indirect costs

such as induced unemployment as a result of plant shutdown or relocation

c. NO_x mechanisms of formations


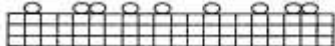
- 1- **Thermal NO_x**: This mechanism was first proposed by Zeldovich and involves the combination of oxygen and nitrogen radicals in the following manner. It's noted that, the reaction rate is a strong function of temperature. Gases reside in the flame zone of a burner for a very short time, less than 0.5 s. The time required to produce 500 ppm NO at 2000°C is only about 0.1 s, but at 1750°C the required time is 1.0 s. Once the gases leave the flame zone, reaction rates are reduced by orders of magnitude, so NO formation stops quickly, with very slow rate of reversible reactions, thus “freezing” the NO_x concentration.
- 2- **Prompt NO_x**: Are the NO_x concentrations pre-flame of hydrocarbon combustion demonstrating less temperature dependence than those due to Zeldovich mechanism discussed above for thermal NO_x. Near the flame zone, radicals such as O and OH enhance the rate of NO_x formation. Hence, some NO_x will form despite aggressive controls on flame temperature and oxygen concentration.
- 3- **Fuel NO_x**: NO_x formed due to reaction of nitrogen contents in fuels, e.g., ammonia or organically bound nitrogen in hydrocarbon compounds with oxygen regardless of the flame temperature or excess oxygen concentration in the combustion air. For coal-fired burners, fuel-NO_x typically falls in the range of 50 to 70% of the total NO_x emissions. Carbon–nitrogen bonds are broken more easily than diatomic nitrogen bonds, so fuel-NO_x formation rates can be higher than thermal-NO_x. The combustion techniques to reduce NO_x may be not effective for fuels that have high nitrogen content.

d. Secondary and primary particulates (aerosols)

Primary particles are emitted in several size ranges, the most common being less than 1 μm in aerodynamic diameter from gas fired combustion sources and larger than 1 μm in aerodynamic diameter from dust sources. Particles larger than 10 μm in aerodynamic diameter usually deposit to surface within a few hours after being emitted and do not have a large effect on light scattering, unless high winds and turbulence re-suspend the particles.

Some of the gaseous species, by a series of chemical transformations, are converted into particles, forming **secondary aerosols**. Sulfates and nitrates are the most common secondary particles, though a fraction of organic carbon can also be formed via atmospheric reactions involving volatile organic compounds (VOC). Atmospheric gases can also become suspended particles by absorption, solution, or condensation. Several of these mechanisms may operate in series in the process of secondary particle formation. Chemical transformation and equilibrium processes for inorganic secondary aerosols are complicated, depending on many meteorological and chemical variables, and are not completely understood.

e. Physisorption and chemisorption

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