Model Answer for final exam

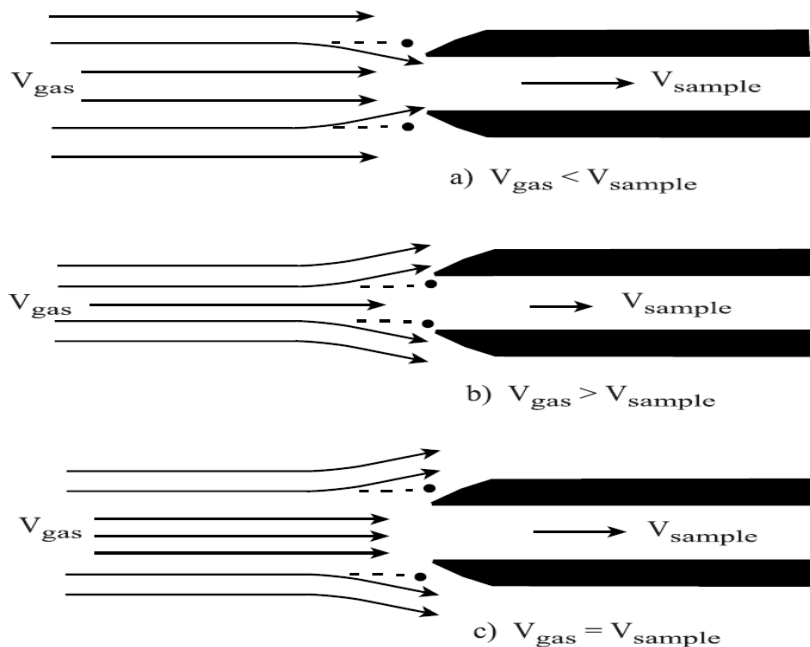**Prepared by**

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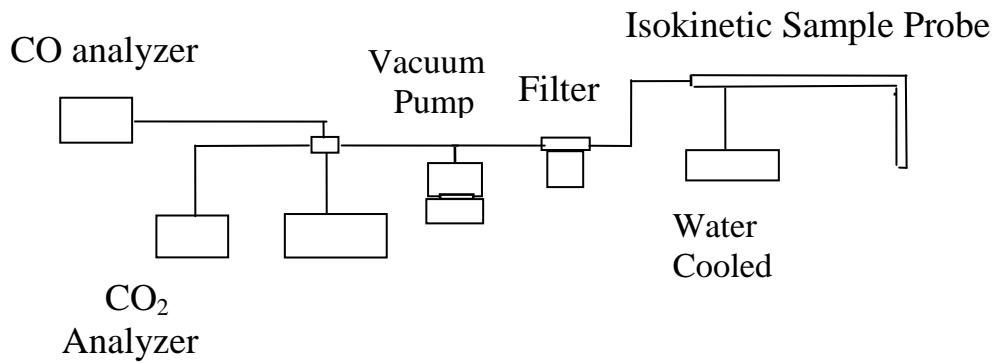
Answer The Following Questions

First Question

1. With the help of sketch explains how it can measured exhaust gas species correctly and state the different recommendations during measuring process.

Answer

Extracting a particulate sample from a moving gas stream using a probe in a duct requires that the sample be taken at the same velocity as the gas flow, i.e., iso-kinetically. If the velocity of the sample is higher than that of the gas flow, then excess gas moving toward the probe will divert toward the probe and be collected with the sample. Meanwhile, particles with sufficient momentum will tend to continue traveling in a straight line, leaving the gas flow streamlines and will not be carried into the sampling probe, as illustrated in blow figure. This produces a sample that, after measuring the collected gas volume and weighing the collected particulate filter, has an erroneously low particulate concentration. Similarly, if the sample velocity is too low, excess gas is diverted away from the probe while particles are carried into the probe, as illustrated in blow Figure, resulting in an erroneously high particulate concentration. The correct isokinetic sample flow rate is determined by conducting a velocity traverse prior to collecting a particulate sample. During the particulate sample, the collected gas volume is measured with a gas meter. After the sample is taken and as data is being evaluated, the sample velocity as a percentage of gas velocity is determined and reported as a quality check on the particulate sample.

Reason for isokinetic sampling probe

CO analyzer   Vacuum   Filter   Isokinetic Sample Probe
                  Pump

CO$_2$
Analyzer   Water
                                            Cooled

2. Explains the different operating parameters affecting formation of :-
   i-   Unburned hydrocarbon and carbon monoxide.
   ii- NO$_X$

   The different operating parameters affecting formation of UHC and NO$_X$ are:
   - a- Fuel type and phase
   - b- Equivalences ratio
   - c- Inlet temperature
   - d- Reynolds number
   - e- Flame temperature
   - f- O$_2$ concentration
   - g- Residence time
   - h- Mixing process

   iii- Smoke
   The different operating parameters affecting formation of smoke are:
   - a- Fuel type.
   - b- Droplet size
   - c- Local air/fuel ratio.
   - d- Burner Design
   - e- Turbulence

3. Explain the following methods for emissions control (The aim, applications, species of control, advantage and disadvantage)
   I-   Exhaust Gas Recirculation.   II- Variable geometry Combustion.
   III- Catalytic Combustors.
           (Review Lectures)

4- Methane CH_4 is burned with atmospheric air. The mole analysis of the products on the dry base is as follows:

10% CO_2, 2.37% O_2, 0.53% CO, and 87.1% N_2 Calculate:

1   The air-fuel ratio
1-   The percentage of theoretical air
2-   The actual combustion equation.

Solution

We write combustion equation for 100 komle of dry product.

A CH_4+b O_2+ f N_2 $\longrightarrow$ 1CO_2 + 2.37 O_2 +0.52 CO+87.1 N_2+dH_2O
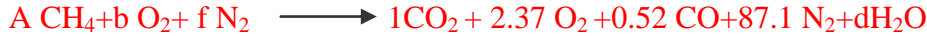
The balance of each of the elements will enable w to solve for all the unknown coefficients:

Nitrogen balance f=87.1, Where all nitrogen comes from air

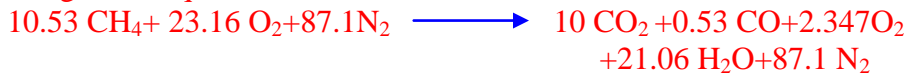$$\frac{f}{b}=3.76\longrightarrow b=\frac{87.1}{3.76}=23.16$$

Carbon balance   A=10+0.53+1.53
Hydrogen balance   d=2a=21.06
Oxygen balance: all the unknown coefficients have been solved, and therefore the oxygen balance provides a check on the accuracy, thus b can also be determined by an oxygen balance

$$b=10.00+\frac{0.53}{2}+2.37+\frac{21.06}{2}=23.16$$
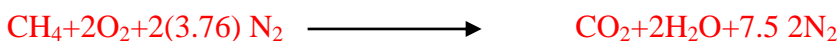
∴ The general equation for combustion of CH_4

10.53 CH_4+ 23.16 O_2+87.1N_2 $\longrightarrow$ 10 CO_2 +0.53 CO+2.347O_2
                                                      +21.06 H_2O+87.1 N_2

Dividing by 10.53

∴CH_4+2.2 O_2+8.27N_2 $\longrightarrow$ 0.95CO_2+0.05CO+2 H_2O + 0.2250$2N_2$

∴A/F on mole basis is (2.2+8.27)/1=10.47 kmol air/kmol fuel

$$(A/f)\,\text{on mass basis}=\frac{10.47\times 28.97}{16}=18.97 \quad \text{kg air/kg fuel}$$

Theoretical (A/F) ratio is calculated from

CH_4+2O_2+2(3.76) N_2 $\longrightarrow$ CO_2+2H_2O+7.5 2N_2

$$(A/F)_{\text{theoretical}}=\frac{(2+7.52)\times 28.97}{16}=17.23 \quad \text{Kg air/Kg fuel}$$

The percentage theoretical air is

$$\text{The percentage theoretical air is } \frac{18.79}{17.23} = 110\%$$

$$\varphi = (1/18.97)\Big/(\frac{1}{17.23}) = 0.9082$$

Second Question

1. Explains the different operating parameters affecting SO_X formations. Explains the different methods for removing sulfur oxides. State why sulfur oxides consider as one of the major emissions species. State the different between soot and smoke.

Answer

A point of concern for flue gas desulfurization (FGD) and selective catalytic reduction (SCR) systems is the emission of sulfuric acid/sulfur trioxide (SO_3) aerosols that could result in increased opacity at the stack as a direct result of firing high-sulfur fuels that naturally generate more SO_3 than do low-sulfur coals. SO_3 is formed during the coal combustion process and converted to gaseous (H2SO4) by homogeneous condensation, leading to a submicron acid fume that is very difficult to capture in a dry electrostatic precipitator (ESP). Also, the condensed acid can combine with the fly ash in the duct and scale the duct wall, potentially resulting in problems.

The results showed that, decreased SO_3 emissions at lower flue gas temperatures, typically in the range of 121 to 138°C. It was concluded that the SO3 selectively condenses on the available fly ash and is then neutralized by the inherent alkalinity of the fly ash.

Used humidification technique to reduce SO_3 emissions even at relatively high concentrations of SO_3 using a low-sulfur Maryland eastern bituminous coal. It has an existing flue gas humidification system, as show in Fig. (1) with adjustable water injection rates of 0 to 45.4 L/min. Three locations were selected for sampling: the air heater inlet, the ESP inlet, and the stack. At each sample point, the particulate mass loading and gas-phase SO_3 were measured. By injecting additional SO_3 gas into the duct upstream of the air heater, the SO_3 concentration in the flue gas at the injection location was varied from 10 to 50 ppmv.

The resulting vapor-phase SO_3 concentrations and the total removal efficiency are plotted in Figure (2) as a function of sampling location and different SO_3 injection levels. As expected, the stack vapor-phase SO_3 emissions increased as the injection level increased. The stack vapor-phase SO_3 emissions were 8.1 and 13.2 ppmv for the SO_3

injection levels of 30 and 50 ppmv, respectively. In general, the data showed an inverse correlation between the collection efficiency and initial SO_3 vapor concentration, which is in agreement with the theoretical analysis.

The fly ash collected from 5 filters at the three sampling locations was analyzed for sulfates (all sulfate concentrations were converted to SO_3 concentrations). With increasing SO_3 injection rates from 0 to 50 ppmv, the sulfate concentration on the fly ash collected at the air heater increased from 1780 ppmv for the baseline condition up to 6180 ppmv when 50 ppmv was injected. These results indicate that the SO_3 vapor was transferred to the particulate phase during condensation. It appears that most of the depleted SO_3 vapor is condensed in the air heater. The sulfate was clearly enriched on the fine fly ash emitted at the stack as a result of condensation of SO_3 vapor on fly ash particles and the formation of sulfuric acid mist. The higher sulfate concentration on the fine fly ash at the stack when 50 ppmv SO_3 was injected compared to the 10-ppmv injection test indicated that more fine sulfate aerosols were formed in the ESP at the higher SO_3 concentration. Not surprisingly, the total sulfur concentrations in the fly ash were approximately the same as the sulfate form.

Tests were then conducted using flue gas humidification. Humidification of the flue gas enhances SO_3 condensation by decreasing flue gas temperature. Once the SO_3 has condensed, the ESP removes it from the flue gas. In addition, ESP performance is generally enhanced because of reduced flue gas temperature and the presence of SO_3. By reducing the temperature and adding SO3, the ash resistivity is reduced. SO_3 samples were collected and analyzed at different humidification and SO3 injection levels at the air heater inlet, ESP inlet, and stack. The results show the benefit of using humidification. The overall SO_3 removal was >90% at a humidification level of 45.4 L/min for all SO_3 concentrations tested.
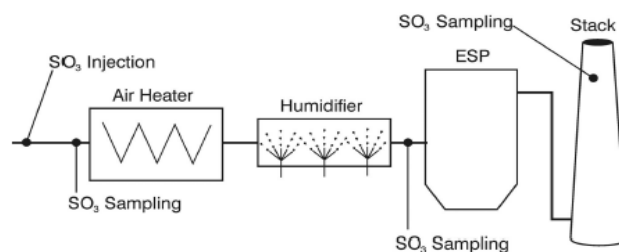
Schematic showing the sampling

By injecting water into the flue gas to reduce the temperature, the condensation of SO_3 vapor on fly ash was enhanced. Combining the improved ESP performance due to reduced

fly ash resistivity (higher sulfate concentration on fly ash) and the lower flue gas temperature, the overall SO_3 collection efficiency was substantially increased with flue gas humidification. The SO_3 collection efficiencies for the SO_3 injection tests are plotted as a function of flue gas temperature at the stack in Figure (2).
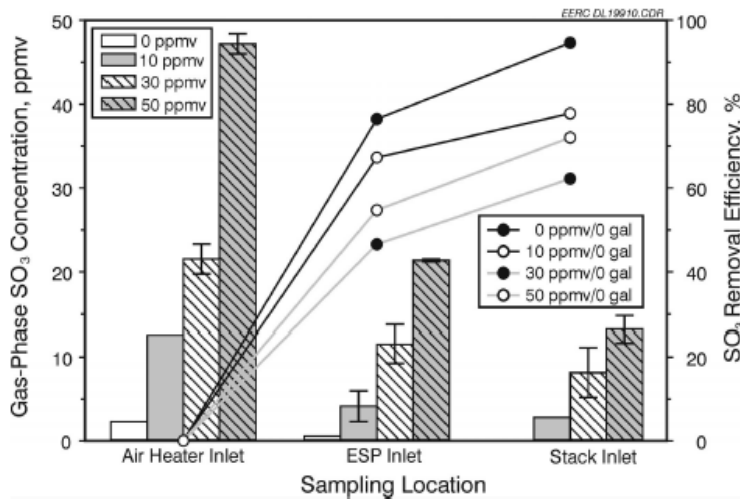

Figure (2) SO_3 concentration and removal efficiency with no humidification

It should be noted that variation in coal and plant operation result not only in changes in flue gas temperature but also in fly ash properties dust loading. These changes, in turn affect the SO_3 vapor condensation across the system. Thereafter, the SO_3 removal efficiency also varied, even at the same stack temperature. However, given these variations and those in the SO_3 injection rates, the results appear to be relatively linear, as shown by the regression line in Figure (3).

The flue gas temperature at the stack varied from 265° to 344°F (129 to 173°C), depending on the water injection rate. The lower flue gas temperature obtained at the higher water injection rate consistently resulted in improved SO_3 collection efficiency, regardless of SO_3 flue gas concentration. The SO_3 collection efficiency was the highest, >92%, at the lowest flue gas temperature.
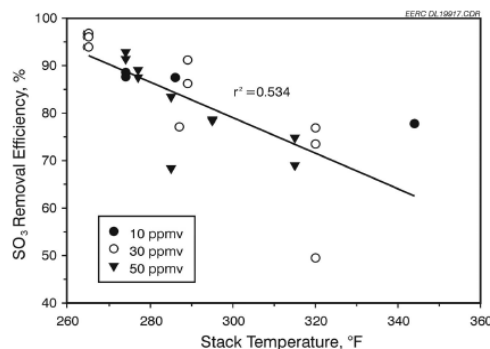

Figure (3) Overall SO_3 removal efficiency as a function of stack

The presence of sulfur compounds in the combustion process can affect the nitrogen oxides as well. Thus a study of sulfur compound oxidation is not only important from the point of view of possibly offering alternate or new means of controlling the emission of the objectionable sulfur oxide, but also with regard to their effect on the formation and concentration of other pollutants.

Emissions of sulfur gases from engineering process strongly influence on

I- Health

Exposure to sulfur dioxide in the ambient air has been associated with reduced lung function, increased incidence of respiratory symptoms and diseases, irritation of the eyes, nose, and throat, and premature mortality. Children, the elderly, and those already suffering from respiratory ailments, such as asthmatics, are especially at risk. Health impacts appear to be linked especially to brief exposures to ambient concentrations above 1,000 $\mu g/\ m^3$ (acute exposures measured over 10 minutes). Some epidemiologic studies, however, have shown an association between relatively low annual mean levels and excess mortality. It is not clear whether long-term effects are related simply to annual mean values or to repeated exposures to peak values. Health effects attributed to sulfur oxides are due to exposure to sulfur dioxide, sulfate aerosols, and sulfur dioxide adsorbed onto particulate matter. Alone, sulfur dioxide will dissolve in the watery fluids of the upper respiratory system and be absorbed into the bloodstream. Sulfur dioxide reacts with other substances in the atmosphere to form sulfate aerosols. Since most sulfate aerosols are part of PM2.5 (fine particulate matter, with an aerodynamic diameter of less than 2.5 microns), they may have an important role in the health impacts associated with fine particulates. However, sulfate aerosols can be transported long distances through the atmosphere before deposition occurs. Average sulfate aerosol concentrations are about 40% of average fine particulate levels in regions where fuels with high sulfur content are commonly used. Sulfur dioxide adsorbed on particles can be carried deep into the pulmonary system. Therefore, reducing concentrations of particulate matter may also reduce the health impacts of sulfur dioxide. Acid aerosols affect respiratory and sensory functions.

II- Environment

Sulfur oxide emissions cause adverse impacts to vegetation, including forests and agricultural crops. Studies in the United States and elsewhere have shown that plants exposed to high ambient concentrations of sulfur dioxide may lose their foliage, become

less productive, or die prematurely. Some species are much more sensitive to exposure than others. Plants in the immediate vicinity of emissions sources are more vulnerable. Studies have shown that the most sensitive species of plants begin to demonstrate visible signs of injury at concentrations of about 1,850 $\mu g/m^3$ for 1 hour, 500 $\mu g/m^3$ for 8 hours, and 40 $\mu g/m^3$ for the growing season (Smith 1981, cited in NAPAP 1990). In studies carried out in Canada, chronic effects on pine forest growth were prominent where concentrations of sulfur dioxide in air averaged 44 $\mu g/m^3$, the arithmetic mean for the total 10 year measurement period; the chronic effects were slight where annual concentrations of sulfur dioxide averaged 21 $\mu g/m^3$ (Canada 1987). Trees and other plants exposed to wet and dry acid depositions at some distance from the source of emissions may also be injured. Impacts on forest ecosystems vary greatly according to soil type, plant species, atmospheric conditions, insect populations, and other factors that are not well understood. Agricultural crops may also be injured by exposure to depositions. Alfalfa and rye grass are especially sensitive. It appears that leaf damage must be extensive before exposure affects the yields of most crops. It is possible that over the long-term, sulfur input to soils will affect yields (OECD 1981; NAPAP 1990). However, sulfur dioxide may not be the primary cause of plant injury, and other pollutants such as ozone may have a greater impact Acid depositions can damage freshwater lake and stream ecosystems by lowering the pH of the water. Lakes with low buffering capacity, which could help neutralize acid rain, are especially at risk. Few fish species can survive large shifts in pH, and affected lakes could become completely devoid of fish life. Acidification also decreases the species variety and abundance of other animal and plant life. Sulfate aerosols, converted from sulfur dioxide in the atmosphere, can reduce visibility by scattering light. In combination with warm temperatures, abundant sunlight, high humidity, and reduced vertical mixing, such aerosols can contribute to haziness extending over large areas.

III- Materials

Sulfur dioxide emissions may affect building stone and ferrous and nonferrous metals. Sulfurous acid, formed from the reaction of sulfur dioxide with moisture, accelerates the corrosion of iron, steel, and zinc. Sulfur oxides react with copper to produce the green patina of copper sulfate on the surface of the copper. Acids in the form of gases, aerosols, or precipitation may chemically erode building materials such as marble, limestone, and dolomite. Of particular concern is the chemical erosion of historical monuments and works

of art. Sulfurous and sulfuric acids formed from sulfur dioxide and sulfur trioxide when they react with moisture may also damage paper and leather.

2. What are the parameters affecting on selection of dust collectors and explains four of them.

The factors affecting selection of dust collectors are:
   a. Concentration and particle size distributions of the airborne dust;
   b. Characteristics of air stream, including temperature, water vapour;
   c. Characteristics of dust: chemical composition, stickiness, abrasiveness;
   d. Disposal methods; and
   e. Initial and operational and maintenance costs.

3. With the help of sketch and on base of (the aim, applications, Limitation, efficiency, advantage and disadvantage), compare between the following filters.
   I. Bag filter   II- Cyclone filter   III- Venturi scrubber   IV- Electro static participating filter.
   (Review Lectures)

4. Explains the impact effects of solid particulate. Discuss the effect of emissions on human health, plants and societies.
   (Review Lectures)

Good Luck

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