Module 4.3
Gas concentration measurement

Quadrant 2

List of animations/Videos:
1. http://www.chromedia.org/chromedia?waxtrapp=dwobkOsHqnOxmOIlEcBcCoFhE&pane=kafacDShqnOxmOIICOoAR&flash=rvdkkOsHqnOxmOIlEcBcCoFhEjBH&w=750&h=750 (thermal conductivity detector)
2. http://www.youtube.com/watch?v=FEcA93SL2Zo (thermal conductivity detector)
3. http://www.youtube.com/watch?v=CrlDk-R_92g (Flame ionization detector)
4. Opacity measurement is explained in this video http://www.youtube.com/watch?v=GXYIaiM-jEI
5. Active Diesel Soot Measurement by Laser Opacity is explained in this video http://www.youtube.com/watch?v=ExS04LswEjU
6. Particle Measurement with the AVL Micro Soot Sensor is explained in this video http://www.youtube.com/watch?v=nRlFUmIuDa4

Illustrations:
1. IR measurement of gas concentration – schematic view is presented http://www.hitech-inst.co.uk/infrared_sensors.php
2. LIDAR test bed facility diagram is provided http://www.nist.gov/pml/Div686/sources_detectors/differential-absorption-lidar.cfm

List of questions (FAQ):
1. What is gas concentration?
2. What is gas concentration measurement?
3. How does an orsat apparatus work?
4. What is a Ringleman chart?
5. How does a gas chromatograph work?
6. What measures can be taken to reduce the opacity of a discharge?
7. List the emissions that are significant for measurement and performance study.
8. Explain the methods of measuring the following invisible emission
   a. Oxides of nitrogen
   b. Carbon monoxide
   c. Unburned hydrocarbons
   d. Aldehydes
9. What is smoke and classify the measurement of smoke?
10. Explain the method of measurement of smoke by comparison method
11. What is opacity measurement?
Quadrant 3

Wiki links/reference links/other university web courses

12. Exhaust gas analyser details are presented.
   http://www.testo.in/online/abaxx-?$part=PORTAL.IND.SectorDesk&$event=show-from-menu&categoryid=42785220&utm_source=google&utm_medium=cpc&utm_campaign=Flue+Gas+Analysers+Search
13. Exhaust gas analyser details are presented.
14. Working of orsat gas analyser is explained in this site
15. Working of orsat gas analyser is explained in this site
   faculty.ksu.edu.sa/naeem/.../Orsat%20Gas%20Analysis%20Experiment.d..
16. Gas chromatography experimental details are presented
   http://teaching.shu.ac.uk/hwb/chemistry/tutorials/chrom/gaschrm.htm
17. Smoke opacity instrument details are presented
   http://www.dieselnet.com/tech/measure_opacity.php
18. Optical dust and opacity meter technical details are presented
19. The study and design on prototype opacity meter is presented.
20. Wide product range for smoke measurement is presented
   http://www.sokken.co.jp/en/smoke/
Quadrant 4

Numerical problems:

1. Gaseous pollutant NO₂ has a concentration, on volume basis, of 21.62 ppmv in air sample at 30°C and at 1 atm. Express this in mg/m³. Molecular weight of NO₂ is Mc = 46.

Solution:

\[ T = 30 + 273 = 303 \text{ K} \]
\[ Mc = \text{Molecular weight of NO}_2 = 46 \]
\[ \text{Concentration of NO}_2 = 21.62 \text{ ppmv} \]
\[ \text{Concentration of NO}_2 \text{ in mg/m}^3 = 21.62 \times 12.185 \times \frac{\text{Mc}}{T} = 40 \text{ mg/m}^3 \]

2. It is desired to measure the smoke put out by a system, for which a sampling tube is to be designed. Calculate the diameter of a sampling tube in mm, if the largest smoke particle diameter is expected to be 1 µm. Particle density is 2000 kg/m³. The sample air velocity in the free stream is \( V_0 = 2 \text{ m/s} \) and flow rate through sample tube is not to be less than 150 ml/s. The sample gas is air at 1 atmosphere pressure and 25 °C. Also, calculate the Stokes number and determine whether the tube diameter calculated above is OK. Assume iso-kinetic sampling.

Solution:

\[ D_p = \text{particle diameter (largest)} = 1 \times 10^{-6} \text{ m} \]
\[ \rho_p = \text{particle density} = 2000 \text{ kg/m}^3 \]
\[ V_0 = \text{sample air minimum velocity in the stream} = 2 \text{ m/s} \]
\[ D_s = \text{diameter of sampling tube?} \]
\[ Q = \text{Flow rate of gas (minimum)} = 150 \times 10^{-6} \text{ m}^3/\text{s} \]

Diameter of sampling tube = \( \left( 4 \times \frac{Q}{\pi x V_0} \right)^{1/2} = \left( 4 \times 150 \times 10^{-6} \right) / (\pi \times 2) ^{1/2} = 0.0097 \text{ m} = 9.7 \text{ mm} \)

Kinematic viscosity of air at 1 standard atmosphere and 25 °C = \( \mu = 18.5 \times 10^{-6} \text{ m}^2/\text{s} \)

Stoke number = \( D_p^2 \times \rho_p \times V_0 / (18 \times \mu \times D_s) \)

\[ = (1 \times 10^{-6})^2 \times 2000 \times 2 / (18 \times 18.5 \times 10^{-6} \times 0.0097) = 0.0012 \]

Since, this is less than 0.010, calculated \( D_s = 9.7 \text{ mm} \) is OK.

3. An opacity meter is used for in situ measurement of smoke by a double ended system in which opacity measured is 50%. The path length is 10 cm. The temperature of the gas is 30°C. It has been found that the soot density is \( \rho_s = 650 \mu\text{g/m}^3 \). What is the extinction cross section of soot particles? If the soot particle mean diameter \( D_p = 0.25 \mu\text{m} \), and particle density \( \rho_p = 2400 \text{ kg/m}^3 \), determine the number density of soot particles.

Solution:

Opacity of gas = 50%

\[ Tr = \text{Transmittance of the gas} = 100 - 50 = 50\% \]
L = Path length = 0.1 m
m_p = Mass of each particle = ?
D_p = Mean diameter of soot particle = 0.25 x 10^{-6} m
\rho_p = particle density = 2400 kg/m^3
\rho_s = soot density = 650 x 10^{-6} g/m^3
\beta = extinction coeff. = (-1 x ln (Tr))/L = (-1 ln (0.5))/0.1 = 6.93 m^{-1}
\beta = extinction coeff = soot density x extinction cross section = \rho_s \times \sigma_e
Extinction cross section = \sigma_e = \beta / \rho_s = 6.93 / (650 \times 10^{-6}) = 10661 m^2/kg
Mass of each particle = m_p = \rho_p \times \pi \times D_p^3 / 6 = 2400 \times 3.14 \times (0.25 \times 10^{-6})^3 / 6
= 19.62 \times 10^{-18} kg
Soot density = Number density x mass of particle i.e. \rho_s = N \times m_p
Number density N = \rho_s / m_p = 650 \times 10^{-6} / 19.62 \times 10^{-18}
= 33.13 \times 10^{12} particles / m^3

**Multiple choice questions**

1. The major exhaust emission from CI engine compared to SI engine is
   a. Nitrogen oxide
   b. Hydrocarbon- unburnt
   c. Particulate emission
   d. Oxides of carbon

2. Alcohol is the major source for the emission of
   a. Hydrocarbon
   b. Aldehydes
   c. Nitrogen oxides
   d. Soot

3. Chemiluminescence analyzer is used for measuring
   a. NO_x
   b. Carbon monoxide
   c. Hydrocarbon
   d. Carbon dioxide

4. Non-dispersive infra-red analyzer (NDIR) is widely accepted to measure
   a. NO_x
   b. Hydrocarbon
   c. Carbon monoxide
   d. Carbon dioxide

**Answer table**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>c</td>
</tr>
<tr>
<td>2</td>
<td>b</td>
</tr>
<tr>
<td>3</td>
<td>a</td>
</tr>
<tr>
<td>4</td>
<td>c</td>
</tr>
</tbody>
</table>
Fill in the blanks with most appropriate word:

5. Typically _________ is used as carrier gas in gas chromatograph
6. Non-dispersive infra-red analyzer (NDIR) is widely accepted to measure ----
7. ------ gas is generally considered to be the rich indicator of air-fuel mixture.
8. Higher the level of ----, leaner is the air-fuel mixture.
9. Higher the level of ----- in the exhaust gas, more efficient the engine is.

Answer table

5. Helium  
6. CO   
7. CO   
8. O₂   
9. CO₂

True/false

10. Typically helium is used as carrier gas in gas chromatograph  
11. The output of the chromatographic detector can be processed electronically and displayed on a chart recorder
12. In the gas chromatograph, the time of appearance of the spike in the display, indicates the particular component of the gas, and the height of the spike indicates the quantity present.
13. Ringleman charts are used in air-pollution measurements
14. High HC emission levels are often caused by a fault in the ignition system
15. HC and CO are high and CO₂ are high and CO₂ and O₂ are low. This could be caused by a lean mixture.

Answer table

10. T  
11. T  
12. T  
13. T  
14. T  
15. F

Assignment questions and solutions

1. Why gas concentration measurement is important?
Ans: Gas concentration measurement is important
a. To establish acceptable levels of contamination of atmosphere taking into account meaningful biological data in both human and animal subjects
b. Measurements must be performed in different locales to find the offending sources and degree of control required. On the basis of such measurements control standards can be framed and an enforcement mechanism can be started.
c. Periodic sampling and measurement are needed for use in proper legal proceedings against violators.

2. List the different techniques that are possible to measure the concentration of the constituent gases in the engine exhaust.

Ans: Thermal conductivity detector
Infrared spectrometer (GCIR)
Mass spectrometer (GCMS)
Flame ionization detector (FID)

3. List the various gas concentration measurement methods available.
Ans: A few of the methods available for gas concentration measurement are listed below.
(i) Non separation methods:
   a. Non Dispersive Infrared Analyzer (NDIR)
   b. Differential Absorption LIDAR (DIAL)
   c. Chemiluminescence NOx detector
(ii) Separation methods:
   a. Gas chromatography
      i. Thermal conductivity detector
      ii. Infrared spectrometer - GC IR
      iii. Mass spectrometer- GC MS
      iv. Flame ionization detector – FID
   b. Orsat gas analyser

4. Present the emission limits of combustion products commonly met with in exhaust gases from IC engines.
Ans: The following table presents the emission limits of combustion products commonly met with in exhaust gases from IC engines:

<table>
<thead>
<tr>
<th></th>
<th>CO (g/km)</th>
<th>HC + NOx (g/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS I</td>
<td>2.72/3.16</td>
<td>0.97/1.30</td>
</tr>
<tr>
<td>BS II</td>
<td>2.20</td>
<td>0.50</td>
</tr>
</tbody>
</table>
5. Why combustion products measurement is required? Also, mention some of the methods available for combustion products measurement.

Ans: The measurement and analysis of products of combustion is important not only for air-pollution-control applications but also for maintenance of most efficient burning rates and energy utilization. Following are the methods available for combustion product measurement:
   a. Orsat apparatus
   b. Gas chromatograph
   c. Nondispersive infrared absorption method

6. What is smoke? Also briefly explain a smoke measurement method.

Ans: Smoke is one of visible emissions in IC engines. The smoke, which is due to incomplete combustion, is a visible indicator of the combustion process. Smoke in diesel engine can be divided into three categories, namely, blue, white and black. Visible method of analysis is used for quantifying the above three types of smokes. A method known as light extinction method, used to measure smoke level or smoke density, is explained: the intensity of a light beam is reduced by smoke which is a measure of smoke intensity. A continuously taken exhaust sample is passed through a tube which has light source at one end and photocell at the other end. The amount of light passed through this column is used as an indication of smoke level or smoke density.

7. What is smoke level or smoke density?

Ans: the smoke level or smoke density is defined as the ratio of electric output from photocell when sample is passed through the column to the electric output when clean air is passed through it.

Self answered questions and answers:

1. Discuss the Chemiluminescent NOx analyzer with a neat diagram
   Ans: Please visit web resource nptel.iitm.ac.in/courses/IIT-MADRAS/Mechanical _Measurements (Sub module 4.3 Gas concentration measurement)

2. With a neat schematic diagram discuss gas chromatograph
   Ans: Please visit nptel.iitm.ac.in/courses/IIT-MADRAS/Mechanical _Measurements (Sub module 4.3 Gas concentration measurement)

3. Explain thermal conductivity detector with a schematic diagram
Ans: Please visit nptel.iitm.ac.in/courses/IIT-MADRAS/Mechanical_Measurements
(Sub module 4.3 Gas concentration measurement)

Test your skills/knowledge:
1. Visit a vehicle pollution measuring center and study how pollution is measured.
2. Visit a nearby chemical industry, steel industry or foundry, and study the pollution measurement and pollution control equipments that are used.
3. Learn the different methods of pollution control.