Basic Environmental Engineering and Pollution Abatement

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Lecture 60
Tutorial 12

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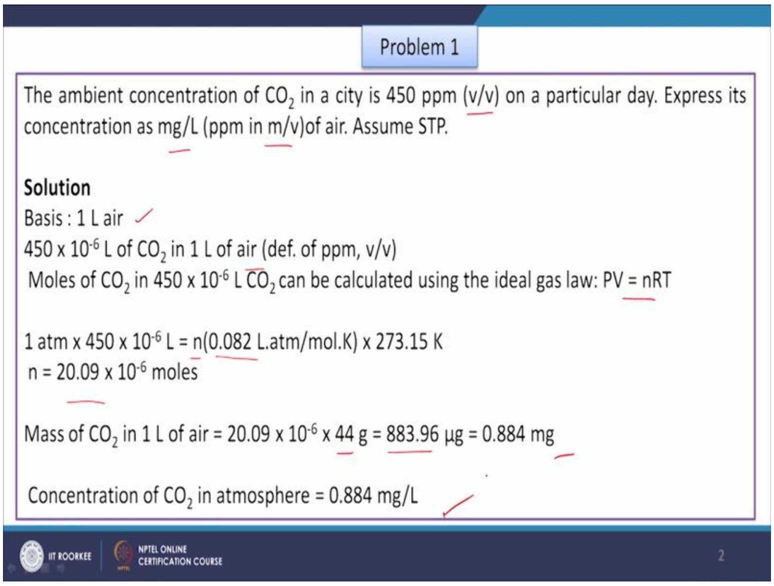

Problem 1

The ambient concentration of CO_2 in a city is 450 ppm (v/v) on a particular day. Express its concentration as mg/L (ppm in m/v)of air. Assume STP.

Solution

Basis : 1 L air
450 x 10^{-6} L of CO_2 in 1 L of air (def. of ppm, v/v)
Moles of CO_2 in 450 x 10^{-6} L CO_2 can be calculated using the ideal gas law: PV = nRT

1 atm x 450 x 10^{-6} L = n(0.082 L.atm/mol.K) x 273.15 K
n = 20.09 x 10^{-6} moles

Mass of CO_2 in 1 L of air = 20.09 x 10^{-6} x 44 g = 883.96 μg = 0.884 mg

Concentration of CO_2 in atmosphere = 0.884 mg/L

Hello everyone. Now, we will have a tutorial session and, in this class, we will solve some numerical problems based on our discussion made in the last 4 classes. Problem number 1, the statement is the ambient concentration of CO_2 in a city is 450 ppm volume by volume on a particular day. Express its concentration as mg/L or ppm in mass by volume of air. Assume STP.

So, this is a very simple question which is associated with the change of unit and the concept of ppm in one case, volume by volume and in other case mass by volume. So, that conversion we have to do.

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Moles of CO_2 in 450 x 10^{-6} L CO_2 can be calculated using the ideal gas law: PV = nRT
1 atm x 450 x 10^{-6} L = n(0.082 L.atm/mol.K) x 273.15 K
n = 20.09 x 10^{-6} moles
Mass of CO_2 in 1 L of air = 20.09 x 10^{-6} x 44 g = 883.96 μg = 0.884 mg
Concentration of CO_2 in atmosphere = 0.884 mg/L

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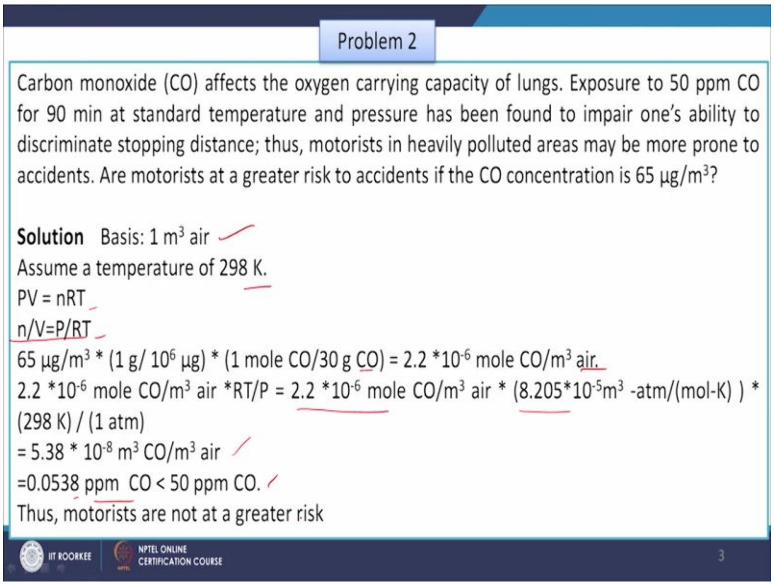

Problem 2

Carbon monoxide (CO) affects the oxygen carrying capacity of lungs. Exposure to 50 ppm CO for 90 min at standard temperature and pressure has been found to impair one's ability to discriminate stopping distance; thus, motorists in heavily polluted areas may be more prone to accidents. Are motorists at a greater risk to accidents if the CO concentration is 65 μg/m^3?

Solution Basis: 1 m^3 air

Assume a temperature of 298 K.

PV = nRT

n/V=P/RT

65 μg/m^3 * (1 g/ 10^6 μg) * (1 mole CO/30 g CO) = 2.2 *10^{-6} mole CO/m^3 air.

2.2 *10^{-6} mole CO/m^3 air *RT/P = 2.2 *10^{-6} mole CO/m^3 air * (8.205*10^{-5}m^3 -atm/(mol-K)) * (298 K) / (1 atm)

= 5.38 * 10^{-8} m^3 CO/m^3 air

=0.0538 ppm CO < 50 ppm CO.

Thus, motorists are not at a greater risk

Next problem, problem number 2, the statement is carbon monoxide CO affects the oxygen carrying capacity of lungs. Exposure to 50 ppm CO for 90 minutes at standard temperature and pressure has been found to impair one's ability to discriminate stopping distance, thus motorist in heavily polluted areas may be more prone to accidents. Are motorist at a greater risk to accidents if that CO concentration is 65 μg/m^3.

So, this is also a similar type of question where the CO concentration is given in different units. So, what is the user concentration and at the concentration at which the impact will be visible. So, those two concentrations are given in different unit.

So, we have to convert these units into a single one. So, not in different units. So, that we have to do so, again we have to take a basis.

Basis: 1 m^3 air
Assume a temperature of 298 K.
PV = nRT
n/V=P/RT
65 μg/m^3 * (1 g/ 10^6 μg) * (1 mole CO/30 g CO) = 2.2 *10^{-6} mole CO/m^3 air.
2.2 *10^{-6} mole CO/m^3 air *RT/P = 2.2 *10^{-6} mole CO/m^3 air * (8.205*10^{-5}m^3 -atm/(mol-K)) * (298 K) / (1 atm)
= 5.38 * 10^{-8} m^3 CO/m^3 air
=0.0538 ppm CO < 50 ppm CO.
Thus, motorists are not at a greater risk

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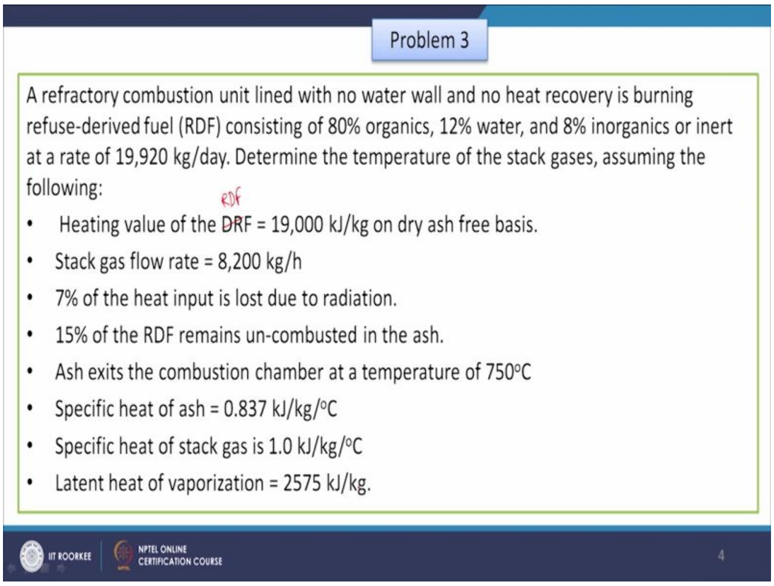

Problem 3

A refractory combustion unit lined with no water wall and no heat recovery is burning refuse-derived fuel (RDF) consisting of 80% organics, 12% water, and 8% inorganics or inert at a rate of 19,920 kg/day. Determine the temperature of the stack gases, assuming the following:

- Heating value of the ~~DRF~~ RDf = 19,000 kJ/kg on dry ash free basis.
- Stack gas flow rate = 8,200 kg/h
- 7% of the heat input is lost due to radiation.
- 15% of the RDF remains un-combusted in the ash.
- Ash exits the combustion chamber at a temperature of 750^{o}C
- Specific heat of ash = 0.837 kJ/kg/^{o}C
- Specific heat of stack gas is 1.0 kJ/kg/^{o}C
- Latent heat of vaporization = 2575 kJ/kg.

Now, we will see problem number 3, the statement is a refractory combustion unit lined with no water wall and no heat recovery is burning refuse derived fuel consisting of 80 % organics, 12 % water and 8 % inorganics or inert at a rate of 19,920 kg/day. Determine the temperature of the stack gases assuming the following heating value of the RDF is equal to 19,000 kJ/kg on dry ash free basis. Stack gas flow rate is equal to 8200 kg/hour, 7 % of the heat input is lost due to radiation, 15 % of the RDA remains un-combusted in the ash. Then ash exists the combustion chamber at a temperature of 750 ^{o}C, specific heat up ash is equal to 0.837 kJ/kg/^{o}C, specific heat of stack gas is 1.0 kJ/kg/^{o}C, latent heat of vaporization is 2575 kJ/kg. So, this information are provided we have to determine the temperature of the stack gases. Now, this is a problem related to incineration of the waste materials.

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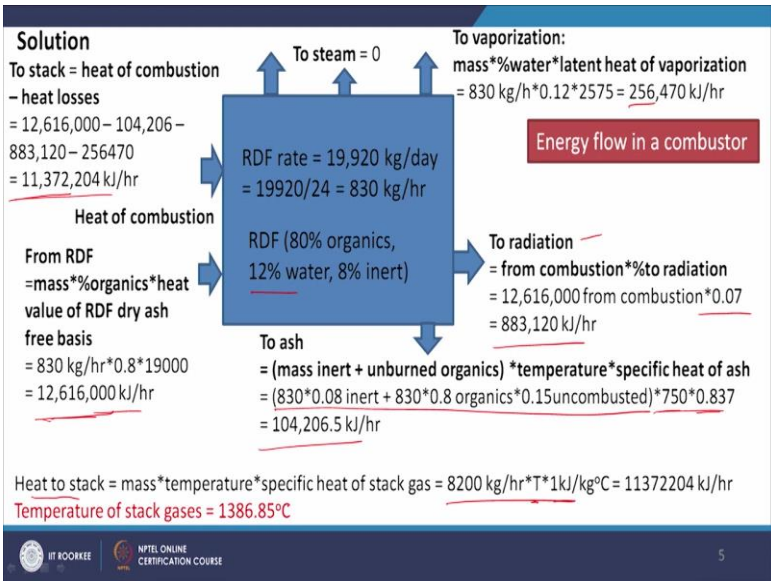


Solution

To stack = heat of combustion – heat losses
= 12,616,000 – 104,206 – 883,120 – 256470
= 11,372,204 kJ/hr

To steam = 0

To vaporization:
mass*%water*latent heat of vaporization
= 830 kg/h*0.12*2575 = 256,470 kJ/hr

Energy flow in a combustor

RDF rate = 19,920 kg/day
= 19920/24 = 830 kg/hr

RDF (80% organics, 12% water, 8% inert)

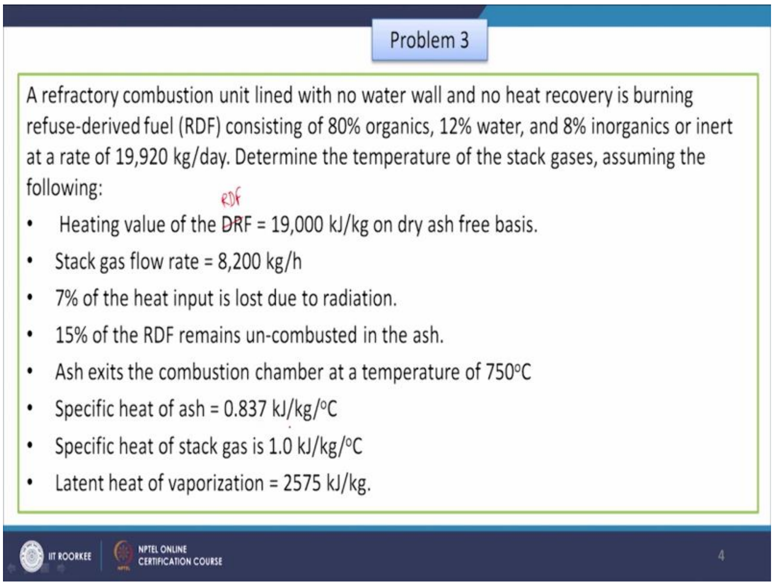
Heat of combustion

From RDF
=mass*%organics*heat value of RDF dry ash free basis
= 830 kg/hr*0.8*19000
= 12,616,000 kJ/hr

To radiation
= from combustion*%to radiation
= 12,616,000 from combustion*0.07
= 883,120 kJ/hr

To ash
= (mass inert + unburned organics) *temperature*specific heat of ash
= (830*0.08 inert + 830*0.8 organics*0.15uncombusted)*750*0.837
= 104,206.5 kJ/hr

Heat to stack = mass*temperature*specific heat of stack gas = 8200 kg/hr*T*1kJ/kg°C = 11372204 kJ/hr
Temperature of stack gases = 1386.85°C



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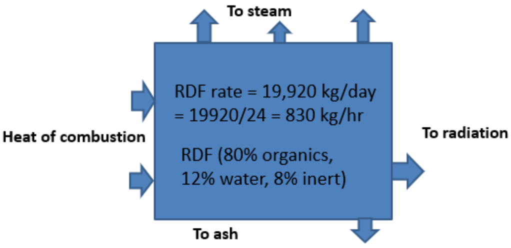
- Specific heat of stack gas is 1.0 kJ/kg/°C
- Latent heat of vaporization = 2575 kJ/kg.

So, here, we will see this is your combustion chamber and that furnace, but in this furnace, the boiler part is not included that means it is the refractory furnace. So, water tubes are not installed in the wall of this furnace it is given so, there is no steam formation basically. So, heat which is generated that will be going through the flue gas. So, no steam will be generated in this furnace.



RDF feed rate = 19,920 kg/day = 19920/24 = 830 kg/hour.

Heat of combustion From RDF =mass*%organics*heat value of RDF dry ash free basis

= 830 kg/hr*0.8*19000 = 12,616,000 kJ/hr

Heat liberated from ash = (mass inert + unburned organics) *temperature*specific heat of ash

= (830*0.08 inert + 830*0.8 organics*0.15uncombusted) *750*0.837

= 104,206.5 kJ/hr

Loss due to radiation = from combustion*%to radiation

= 12,616,000 from combustion*0.07

= 883,120 kJ/hr

Heat required for the vaporization of water = mass*%water*latent heat of vaporization

= 830 kg/h*0.12*2575 = 256,470 kJ/hr

Heat associated with stack gas = heat of combustion – heat losses

= 12,616,000 – 104,206 – 883,120 – 256470

= 11,372,204 kJ/hr

Heat to stack = mass*temperature*specific heat of stack gas = 8200 kg/hr*T*1kJ/kg°C = 11372204 kJ/hr

Temperature of stack gases = 1386.85°C

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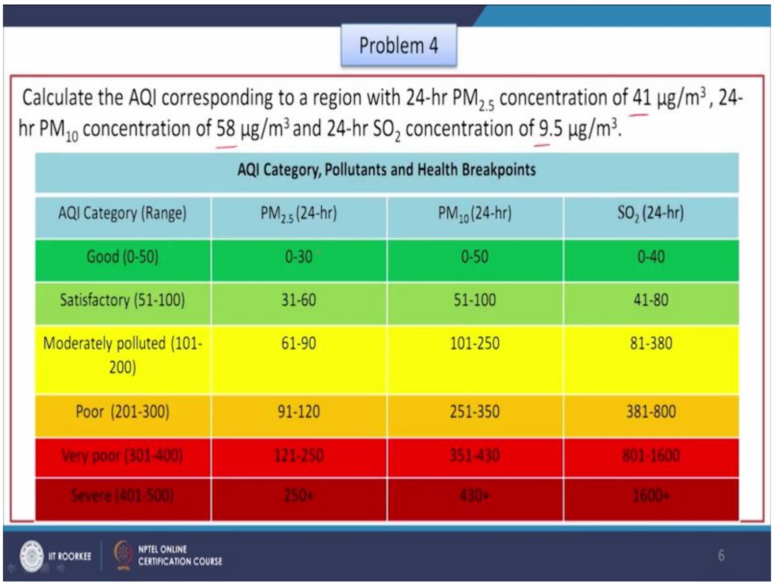

Problem 4

Calculate the AQI corresponding to a region with 24-hr PM$_{2.5}$ concentration of 41 µg/m^3, 24-hr PM$_{10}$ concentration of 58 µg/m^3 and 24-hr SO$_2$ concentration of 9.5 µg/m^3.

AQI Category, Pollutants and Health Breakpoints

AQI Category (Range)	PM$_{2.5}$ (24-hr)	PM$_{10}$ (24-hr)	SO$_2$ (24-hr)
Good (0-50)	0-30	0-50	0-40
Satisfactory (51-100)	31-60	51-100	41-80
Moderately polluted (101-200)	61-90	101-250	81-380
Poor (201-300)	91-120	251-350	381-800
Very poor (301-400)	121-250	351-430	801-1600
Severe (401-500)	250+	430+	1600+

Next problem is problem number 4, the statement is calculate the air quality index corresponding to a region with 24 hour PM$_{2.5}$ concentration of 41 µg/m^3, 24 hour PM$_{10}$ concentration of 58 µg/m^3 and 24 hour SO$_2$ concentration of 9.5 µg/m^3. And here, AQI category pollutants and health break points are given. So, this is a problem related to the determination of ambient air quality index.

So, we have already discussed in our previous classes for Indian methods, how to calculate these AQI? So, we have also discussed that, at least 3 quality parameter has to be considered here 3 are there and out of that 1 must be $PM_{2.5}$ or PM_{10}. So, both $PM_{2.5}$ and PM_{10} are available here.

So, we can calculate the AQI and for the calculation of that, we need some parameters that is I_{HI}, I_{Lo} and then B_{HI}, B_{LO} and C_P. C_P is given here for different pollutants. So, that is this is for $PM_{2.5}$ and this is for PM_{10} will also given and for SO_2 also given. So, we will be using this and for this we will be calculating the corresponding B_{HI} and B_{LO} and I_{HI} and I_{LO} from this table and then we will get the individual index and we will find out the maximum value of that individual index that will be our overall value of the ambient air quality index.

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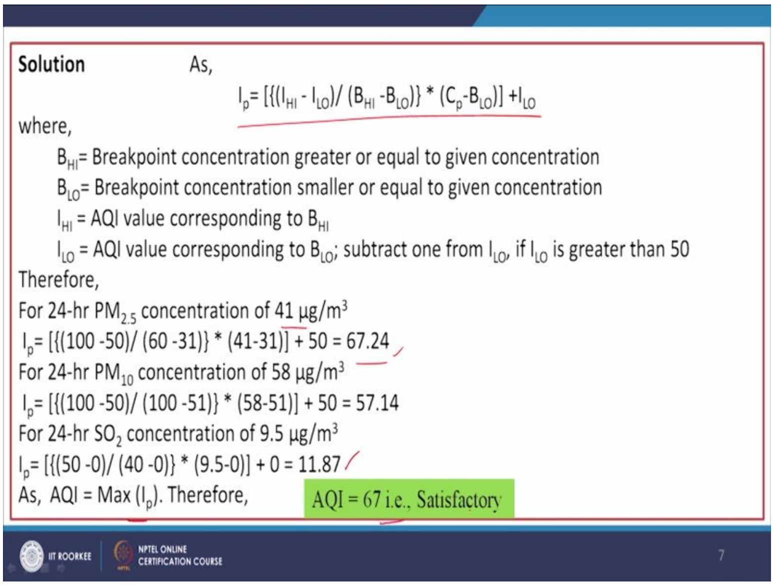


Solution As,

$I_p = [\{(I_{HI} - I_{LO})/ (B_{HI} - B_{LO})\} * (C_p - B_{LO})] + I_{LO}$

where,

B_{HI}= Breakpoint concentration greater or equal to given concentration

B_{LO}= Breakpoint concentration smaller or equal to given concentration

I_{HI} = AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}; subtract one from I_{LO}, if I_{LO} is greater than 50

Therefore,

For 24-hr $PM_{2.5}$ concentration of 41 µg/m^3

$I_p = [\{(100 - 50)/ (60 - 31)\} * (41-31)] + 50 = 67.24$

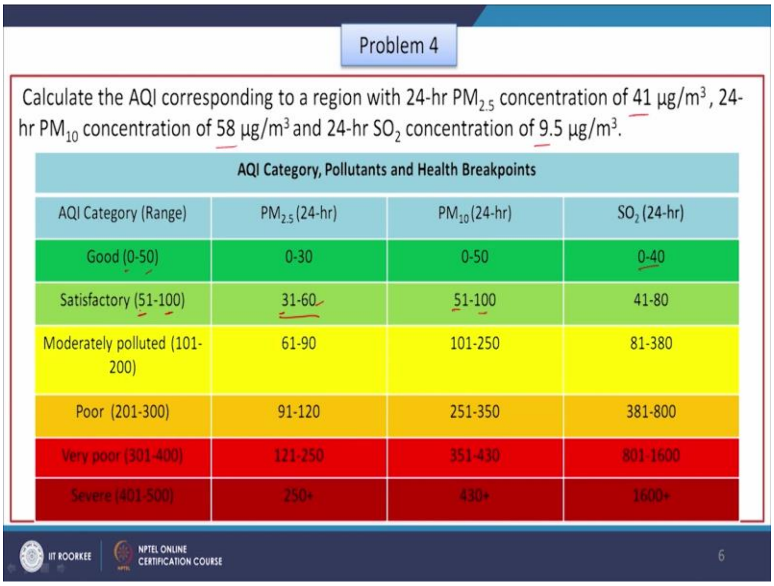
For 24-hr PM_{10} concentration of 58 µg/m^3

$I_p = [\{(100 - 50)/ (100 - 51)\} * (58-51)] + 50 = 57.14$

For 24-hr SO_2 concentration of 9.5 µg/m^3

$I_p = [\{(50 - 0)/ (40 - 0)\} * (9.5-0)] + 0 = 11.87$

As, AQI = Max (I_p). Therefore, AQI = 67 i.e., Satisfactory



Problem 4

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Very poor (301-400)	121-250	351-430	801-1600
Severe (401-500)	250+	430+	1600+

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I_p= [{(I_{HI} - I_{LO})/ (B_{HI} -B_{LO})} * (C_p-B_{LO})] +I_{LO}

Where, B_{HI} breakpoint concentration greater or equal to given concentration, B_{LO}, breakpoint concentration smaller or equal to given concentration, I_{HI} equal a value corresponding to B_{HI}, I_{LO} is AQI value corresponding to B_{LO} and we know that, when we are considering I_{LO}. So, for that for the calculation of I_{LO}, we will subtract 1 from the I_{LO} value if LO is greater than 50. So, this is already discussed in our previous class the same process will apply.

Therefore,

For 24-hr $PM_{2.5}$ concentration of 41 µg/m^3

I_p= [{(100 -50)/ (60 -31)} * (41-31)] + 50 = 67.24

For 24-hr PM_{10} concentration of 58 µg/m^3

I_p= [{(100 -50)/ (100 -51)} * (58-51)] + 50 = 57.14

For 24-hr SO_2 concentration of 9.5 µg/m^3

I_p= [{(50 -0)/ (40 -0)} * (9.5-0)] + 0 = 11.87

As, AQI = Max (I_p). Therefore,

AQI = 67 i.e., Satisfactory

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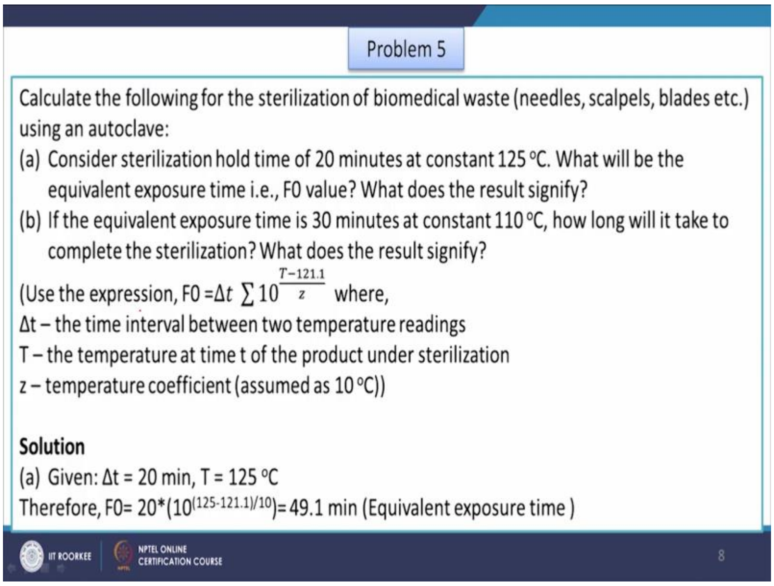

Problem 5

Calculate the following for the sterilization of biomedical waste (needles, scalpels, blades etc.) using an autoclave:

(a) Consider sterilization hold time of 20 minutes at constant 125 ^{o}C. What will be the equivalent exposure time i.e., F0 value? What does the result signify?

(b) If the equivalent exposure time is 30 minutes at constant 110 ^{o}C, how long will it take to complete the sterilization? What does the result signify?

(Use the expression, $F0 = \Delta t \sum 10^{\frac{T-121.1}{z}}$ where,

Δt – the time interval between two temperature readings

T – the temperature at time t of the product under sterilization

z – temperature coefficient (assumed as 10 ^{o}C))

Solution

(a) Given: Δt = 20 min, T = 125 ^{o}C

Therefore, $F0 = 20*(10^{(125-121.1)/10}) = 49.1$ min (Equivalent exposure time)

Now, problem number 5, the statement is calculate the following for the sterilization of biomedical waste, needles, scalpels, blades, etc. using an autoclave. Considered sterilization hold time of 20 minutes at constant 125 ^{o}C, what will be the equivalent exposure time that is FO value, what does the result signify? Second part if the equivalent extra time is 30 minutes at constant 110 ^{o}C, how long will it take to complete the sterilization? What does the result signify?

$$F_o = \Delta t \sum 10^{\frac{T-121.1}{z}}$$

Where Δt is a time interval between two temperature readings and this is nothing but the duration basically and T is the temperature at time t of the product under sterilization, that is sterilization temperature and z is a temperature coefficient assumed as 10 degrees centigrade. So, we have discussed this in the previous class as well. So, here, we have to calculate the F_O for two different conditions, so, we will do that.

So, for the first case,

$F0 = 20*(10^{(125-121.1)/10}) = 49.1$ min (Equivalent exposure time)

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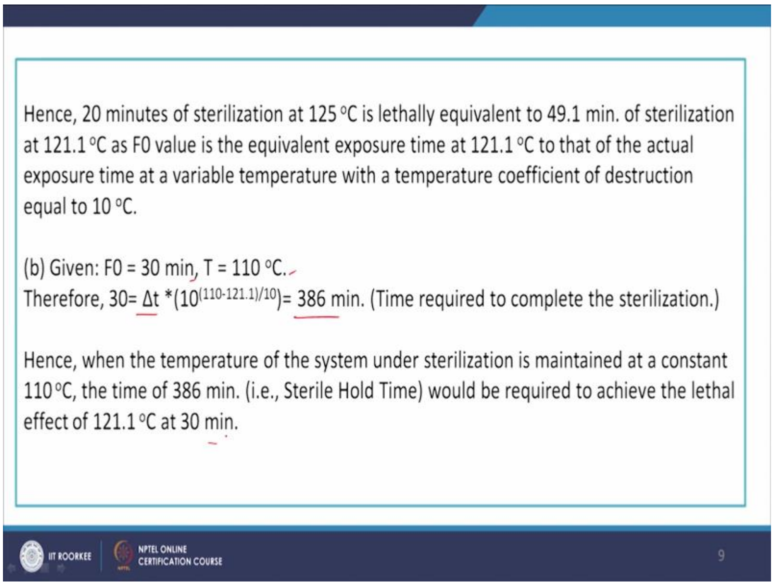

Hence, 20 minutes of sterilization at 125 °C is lethally equivalent to 49.1 min. of sterilization at 121.1 °C as F0 value is the equivalent exposure time at 121.1 °C to that of the actual exposure time at a variable temperature with a temperature coefficient of destruction equal to 10 °C.

(b) Given: F0 = 30 min, T = 110 °C.

Therefore, $30 = \Delta t * (10^{(110-121.1)/10}) = 386$ min. (Time required to complete the sterilization.)

Hence, when the temperature of the system under sterilization is maintained at a constant 110 °C, the time of 386 min. (i.e., Sterile Hold Time) would be required to achieve the lethal effect of 121.1 °C at 30 min.

Hence 20 minutes of sterilization at 125 degrees centigrade is lethally equivalent to 49.1 minutes of sterilization at 121.1 °C as F_O value is the equivalent exposure time at 121.1 °C to that of the actual exposure time at a variable temperature with a temperature coefficient of destruction is equal to 10 °C.

Now, for the part b

F0 = 30 min, T = 110 °C.

Therefore, $30 = \Delta t * (10^{(110-121.1)/10}) = 386$ min. (Time required to complete the sterilization.)

Hence, when the temperature of the system under sterilization is maintained at a constant 110 °C, the time of 386 min. (i.e., Sterile Hold Time) would be required to achieve the lethal effect of 121.1 °C at 30 min. So, very prolonged heating is required. So, that is not feasible. So, normally the temperature is maintained at 121 degrees centigrade and more than that.

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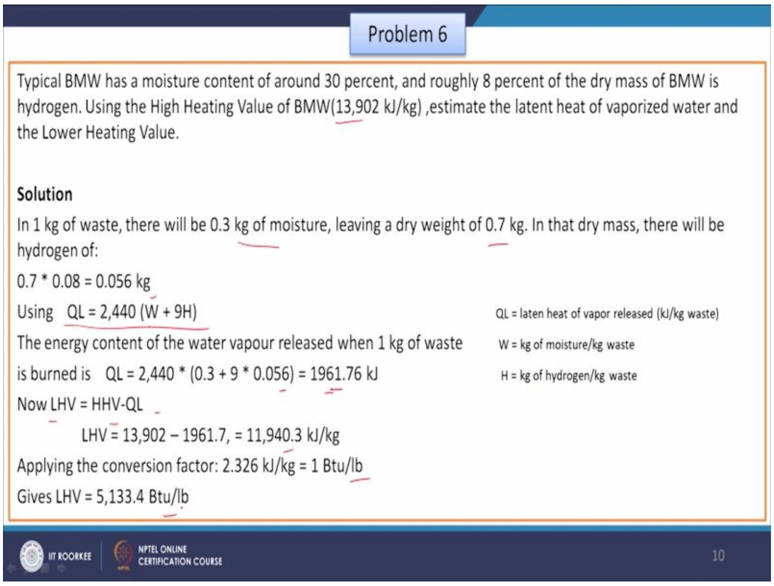

Problem 6

Typical BMW has a moisture content of around 30 percent, and roughly 8 percent of the dry mass of BMW is hydrogen. Using the High Heating Value of BMW(13,902 kJ/kg) ,estimate the latent heat of vaporized water and the Lower Heating Value.

Solution

In 1 kg of waste, there will be 0.3 kg of moisture, leaving a dry weight of 0.7 kg. In that dry mass, there will be hydrogen of:

0.7 * 0.08 = 0.056 kg

Using QL = 2,440 (W + 9H)

QL = laten heat of vapor released (kJ/kg waste)
W = kg of moisture/kg waste
H = kg of hydrogen/kg waste

The energy content of the water vapour released when 1 kg of waste is burned is QL = 2,440 * (0.3 + 9 * 0.056) = 1961.76 kJ

Now LHV = HHV-QL

LHV = 13,902 – 1961.7, = 11,940.3 kJ/kg

Applying the conversion factor: 2.326 kJ/kg = 1 Btu/lb

Gives LHV = 5,133.4 Btu/lb

Now, problem number 6, the statement is typical biomedical waste has a moisture content of around 30 % and roughly 8 % of the dry mass of BMW is hydrogen. Using the high heating value of BMW 13902 kJ/kg estimate the latent heat of vaporized water and the lower heating value.

In 1 kg of waste, there will be 0.3 kg of moisture, leaving a dry weight of 0.7 kg. In that dry mass, there will be hydrogen of:

0.7 * 0.08 = 0.056 kg

Using QL = 2,440 (W + 9H)

QL = laten heat of vapor released (kJ/kg waste), W = kg of moisture/kg waste, H = kg of hydrogen/kg waste

The energy content of the water vapour released when 1 kg of waste is burned is QL = 2,440 * (0.3 + 9 * 0.056) = 1961.76 kJ

Now LHV = HHV-QL

LHV = 13,902 – 1961.7, = 11,940.3 kJ/kg

Applying the conversion factor: 2.326 kJ/kg = 1 Btu/lb

Gives LHV = 5,133.4 Btu/lb

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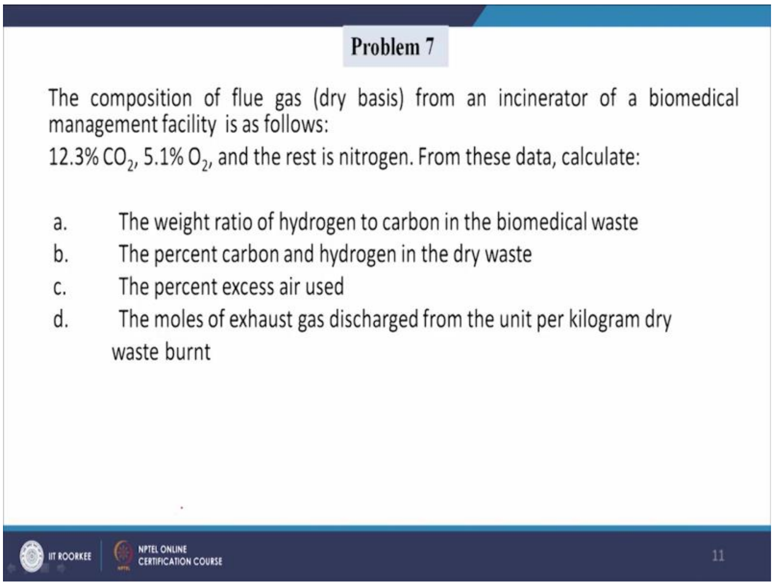

Problem 7

The composition of flue gas (dry basis) from an incinerator of a biomedical management facility is as follows:

12.3% CO_2, 5.1% O_2, and the rest is nitrogen. From these data, calculate:

a. The weight ratio of hydrogen to carbon in the biomedical waste
b. The percent carbon and hydrogen in the dry waste
c. The percent excess air used
d. The moles of exhaust gas discharged from the unit per kilogram dry waste burnt

Now, we are moving to problem number 7, the statement is the composition of flue gas dry basis from an incinerator of a biomedical management facility is as follows, 12.3 % CO_2, 5.1 % O_2 and the rest is nitrogen. From this data calculate the weight ratio of hydrogen to carbon in the biomedical waste. The percent carbon and hydrogen in the dry waste, the percent excess air used, the moles of exhaust gas discharged from the unit per kilogram dry waste burnt. So, this is a problem of incineration. So, we will be solving it.

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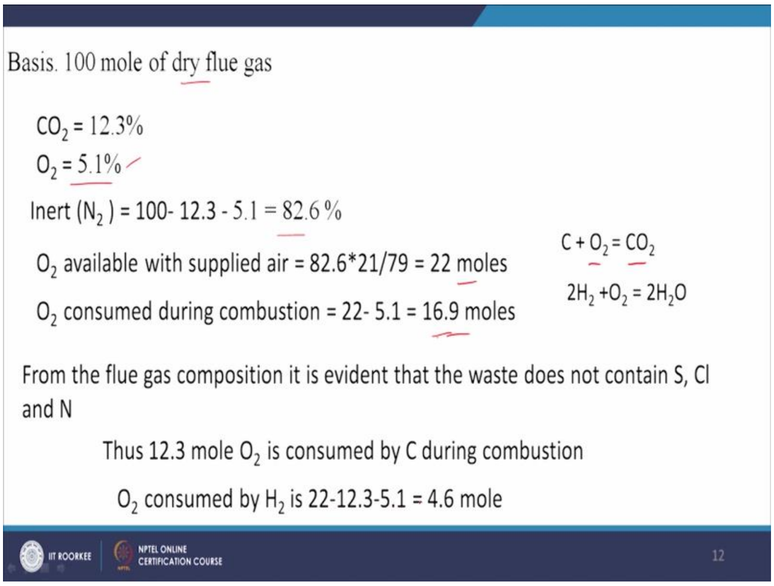

Basis. 100 mole of dry flue gas

CO_2 = 12.3%
O_2 = 5.1%
Inert (N_2) = 100- 12.3 - 5.1 = 82.6 %
O_2 available with supplied air = 82.6*21/79 = 22 moles
O_2 consumed during combustion = 22- 5.1 = 16.9 moles

$C + O_2 = CO_2$
$2H_2 + O_2 = 2H_2O$

From the flue gas composition it is evident that the waste does not contain S, Cl and N

Thus 12.3 mole O_2 is consumed by C during combustion

O_2 consumed by H_2 is 22-12.3-5.1 = 4.6 mole

Basis. 100 mole of dry flue gas

CO_2 = 12.3%

O_2 = 5.1%

Inert (N_2) = 100- 12.3 - 5.1 = 82.6 %

O_2 available with supplied air = 82.6*21/79 = 22 moles

O_2 consumed during combustion = 22- 5.1 = 16.9 moles

From the flue gas composition, it is evident that the waste does not contain S, Cl and N

Thus 12.3 mole O_2 is consumed by C during combustion

O_2 consumed by H_2 is 22-12.3-5.1 = 4.6 mole

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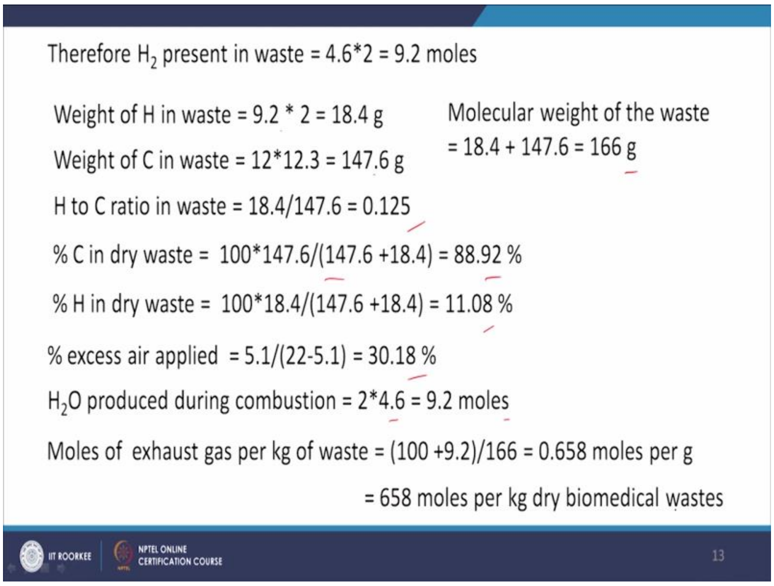


Therefore H_2 present in waste = 4.6*2 = 9.2 moles

Weight of H in waste = 9.2 * 2 = 18.4 g

Weight of C in waste = 12*12.3 = 147.6 g

H to C ratio in waste = 18.4/147.6 = 0.125

Molecular weight of the waste = 18.4 + 147.6 = 166 g

% C in dry waste = 100*147.6/(147.6 +18.4) = 88.92 %

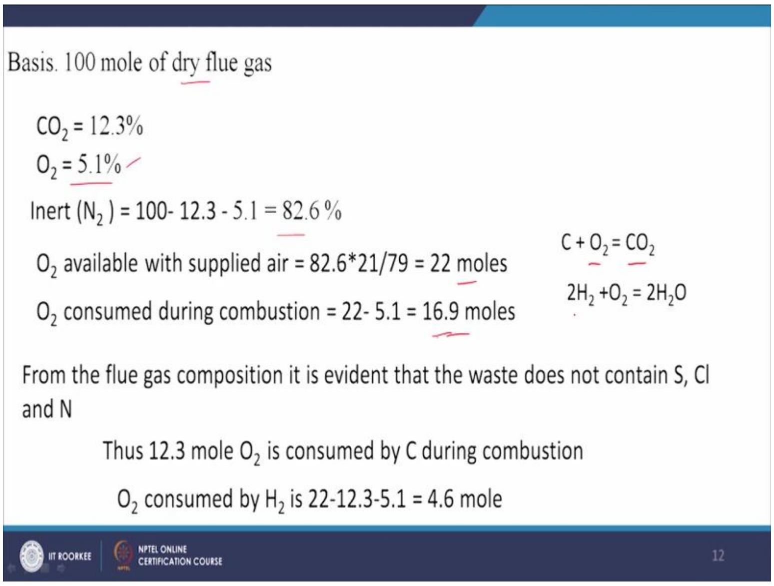
% H in dry waste = 100*18.4/(147.6 +18.4) = 11.08 %

% excess air applied = 5.1/(22-5.1) = 30.18 %

H_2O produced during combustion = 2*4.6 = 9.2 moles

Moles of exhaust gas per kg of waste = (100 +9.2)/166 = 0.658 moles per g

= 658 moles per kg dry biomedical wastes



Basis. 100 mole of dry flue gas

CO_2 = 12.3%

O_2 = 5.1%

Inert (N_2) = 100- 12.3 - 5.1 = 82.6 %

O_2 available with supplied air = 82.6*21/79 = 22 moles

O_2 consumed during combustion = 22- 5.1 = 16.9 moles

$C + O_2 = CO_2$

$2H_2 + O_2 = 2H_2O$

From the flue gas composition it is evident that the waste does not contain S, Cl and N

Thus 12.3 mole O_2 is consumed by C during combustion

O_2 consumed by H_2 is 22-12.3-5.1 = 4.6 mole

Therefore, H_2 present in waste = 4.6*2 = 9.2 moles

Weight of H in waste = 9.2 * 2 = 18.4 g

Weight of C in waste = 12*12.3 = 147.6

H to C ratio in waste = 18.4/147.6 = 0.125

Molecular weight of the waste = 18.4 + 147.6 = 166 g

% C in dry waste = 100*147.6/ (147.6 +18.4) = 88.92 %

% H in dry waste = 100*18.4/ (147.6 +18.4) = 11.08 %

% Excess air applied = 5.1/ (22-5.1) = 30.18 %

H_2O produced during combustion = 2*4.6 = 9.2 moles

Moles of exhaust gas per kg of waste = (100 +9.2)/166 = 0.658 moles per g

= 658 moles per kg dry biomedical wastes

Now, we have solved all the numerical problems we decided to discuss in this class. And with this, we are at the end of the course. And I hope you have enjoyed the course. And thank you for taking this course. And best wishes for those who will opt for the examination and certificates. Thank you once again for taking this course. Thank you very much.