Fundamental of Combustion (Part 2)
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Lecture - 78
Data Reduction – Scale and Temperature Factor

Let us start this lecture with a thought process from Barry commoner.

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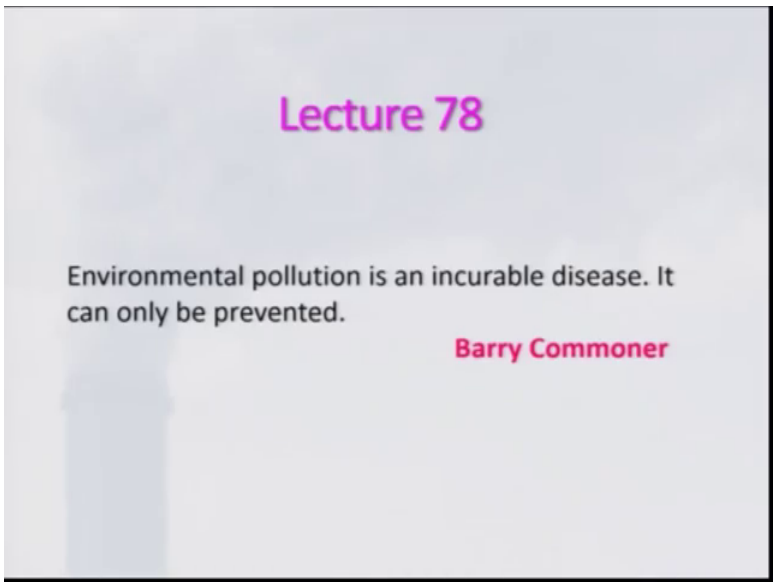

Who says the environmental pollution is an incurable disease. It can only be prevented because the magnitude of environment pollution is so high is that it is really difficult to cure this disease. And, let us recall that what we learnt in the last lecture. We basically looked at how does the combustion system produce the pollutants which will be affecting the atmosphere adversely; in the process we learn that the pollutants like your SOX, NOX, COX unburnt hydrocarbons and also the some of the radicals and particulates are basically emitted from the combustion systems.

And, we are using the various combustion systems for development of industries. And, also for our transportations and other facilities and their uses are increasing at an alarming rate as a result that we are polluting the atmosphere. And, we have also seen that the how does this chemical pollutants affecting the atmosphere and causing also health hazard. So, we will today look at basically discuss more about the chemicals from the combustion sources.

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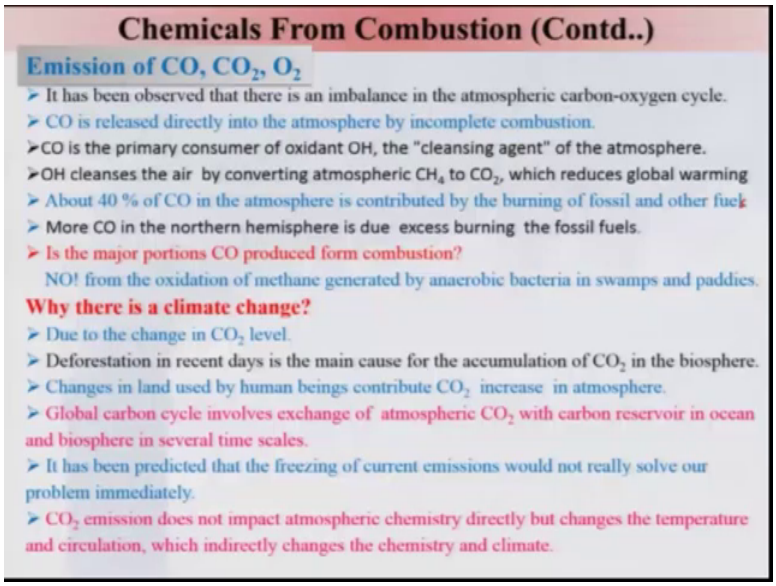

The emission of CO and CO 2 and oxygen's and it has been observed that there is a imbalance of carbon oxygen cycle in the atmosphere. Because, the nature works in a cyclic manner that we must keep in mind, because a mother nature works of it is own way we should not hamper or tamper the cycle which is going on. So, therefore, our effort must be that we will minimize the uses of combustion system for the sustaining life on this beautiful earth.

At the same time we will have to work hard for developing our systems or combustion systems such that the emissions or the chemical emissions from the combustion system can be minimized. Let us look at like carbon monoxide is released directly into atmosphere by incomplete combustion that we already know.

And, this is the carbon monoxide basically is the primary consumer of OH, OH is radical and it reacts with any molecules and it is a being there in the atmosphere from varies sources. And which act as a cleansing agent of the atmosphere but however, the amount of oh oxidant in the atmosphere is limited. Now, if you produce more amount of carbon monoxide, then that is basically consumed by the carbon monoxide itself.

But however, the nature makes some of the methane due to the fermentation or biomass which are there in the nature. So, that produces atmospheric methane and other hydrocarbons and OH was is basically suppose to react with the methane or other unburnt hydrocarbons to produce the carbon dioxide.

So, that atmosphere can be cleaned cleansed and that can lead to the reduction in global warming right. So, therefore, if you produce the more amount of carbon monoxide, then it will cause a imbalance in the nature. About 40 percent of carbon monoxide in atmosphere is contributed by the burning of fossil and then other fuels like a biomass, but of course, the 60 percents are produced by the other activities of the nature.

And, more CO in the northern hemisphere is being measured, which is due to excess burning of fossil fuels in the northern region, because of the activities are more human activity. Is the major portion of carbon air produced from the combustion certainly known as already I have told that 40 percent of carbon monoxide in the atmosphere called due to the combustion system. And, rather the more amount of carbon monoxide are formed form the oxidation of methane generated by the anaerobic bacteria in swamps and paddy fields. During the decomposition of these biomass and as a result this you know there is a great concern for climate change, that we could observe in our today.

And, question there is a why there is a climate change? Which is a great concern for worldwide how to contain it? And we will be discussing some of the regions, but however, the regions given here need not to be complete in respect, but these are all various kind of ideas people put forwarded by the research end. Climate change is caused due to the change in carbon dioxide level in the atmosphere and of course, with the industrialization across the globe, the deforestation is a global phenomenon of course, in India it is a very black ant and abusive in nature. Due to the increase population and also the people become in human to the due to the market driven metalism philosophy being adopted by the people as the market driven metalism makes a man maniac.

So, although our scriptures says that we should take care of forest. Forest land should be more, because nature works from the forest sea from the river deforestation in recent days is the main cause of accumulation of carbon dioxide in the biosphere because, more the trees will be there. So, that can absorb the carbon dioxide and is because it lacked as a seen for the carbon dioxide and there is a cycle which really being maintained by the nature will not be affected by the man-made interference in the work of nature. And changes in the land used by human being contribute a carbon dioxide increase in atmosphere.

Because, the people become land grabber and they want to really use the land for their purpose is only living a side the other living beings to be perished. The global carbon cycle involves exchange of atmosphere carbon dioxide with carbon reserve in ocean and biosphere in several time scales, which we have not really understood fully. And, then also the effort must be made to maintain that global carbon cycle which is taken care by the Mother Nature. So, it has been predicted that the freezing of current emission even it is not possible to do that really would not really solve our problem immediately.

But, of course, if look at political it is not really possible to bring the current emission level to 0 level because of activity so, much that you cannot really do it is impossible to do, but even if you do under ideal condition, it would not really solve the problem of environmental pollution immediately, because it has gone beyond repair. And however, will have to reduce to it so, that it can at least lead to the can the catastrophic termination of the life on this earth may be avoided. Carbon dioxide emission does not impact the atmospheric chemistry directly, but changes the temperature circulation, which indirectly changes the chemistry of atmosphere so, also the leading to the climate change.

So, these are the reasons what I have given up of course, the this is a hot topic which is being research by large number of people across the globe. And it is cannot really discuss in, but I just to give a overall view I have just mention some the thing which is related to the combustion generated pollutants.

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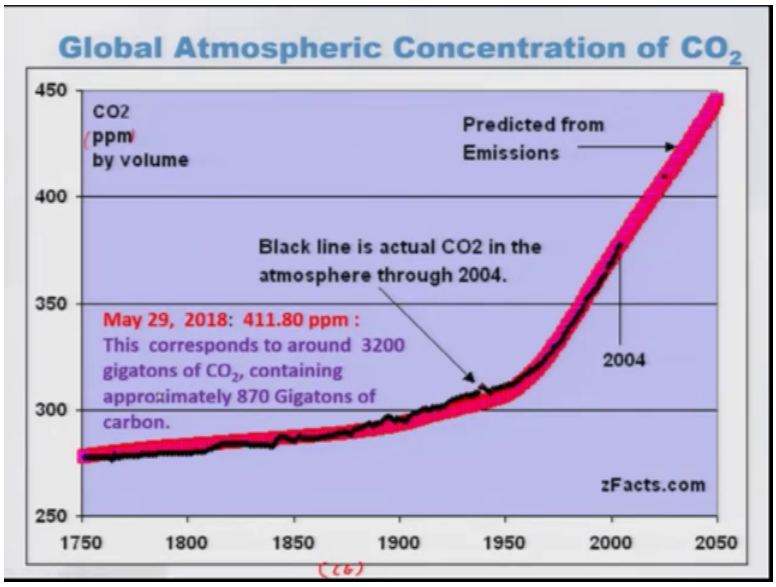

There is a great concern for global atmospheric concentration of carbon monoxide, which I have shown here these are carbon monoxide ppm by volume right; ppm is basically parts per million. If look at 750 C E that is C E right Common Era, that level was around maybe 275 it remains almost constant of course, increasing little at a slower slow.

Then, but around 1950 or onwards it started increasing at a faster rate. And these are all predicted the red color is predicted emission and this kind of a black one is basically the actual carbon dioxide data from the atmosphere. And, if you look at it is really going well according to prediction and if you look at the data, it is really very alarming and people say that it will go beyond 450; that means, maybe there will be catastrophic extinction of the life on this beautiful earth so, if you look at it is increasing. Now, today in 2018 that is this that as may 29 right it is 400 11.8 ppm something around here right.

And, this correspond to around 3200 gigatons of carbon dioxide, containing approximately 870 gigatons of carbon being there in the atmosphere what people have calculated, which is a quiet huge number. And, of course, you may say this is a ppm level, but still if you look at amount of carbon present in the or carbon dioxide present in the atmosphere is quite huge in number. And it may leads to a very catastrophic extinction of life on this beautiful earth of course, there is a lot of theories are there one has to look at.

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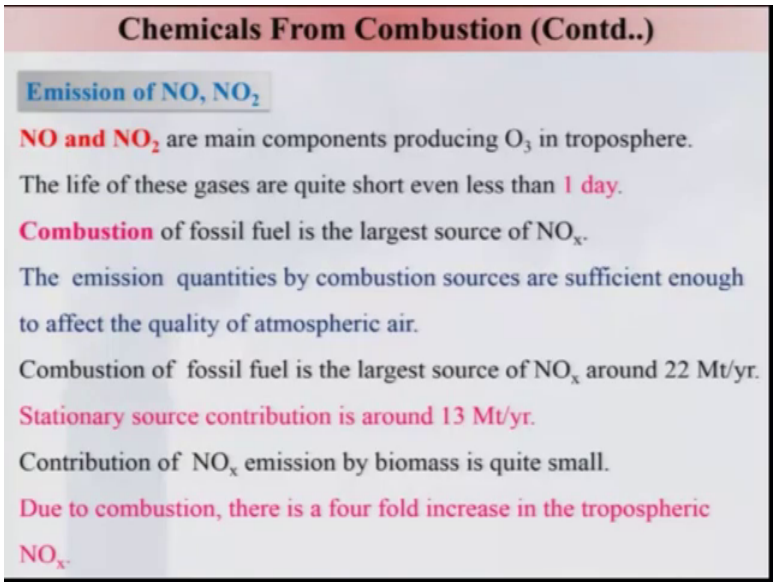

Now, let us look at emission of NO, Nitrous, Nitrous Oxide, Nitric Oxide and from this. So, if you look at these are the main components of producing O 3 in the troposphere. Ozone layer protect us from the (Refer Time: 13:08) of the UV rays coming from the sun and so, we will have to really protect this ozone layer such that we can have a good life in this beautiful earth. The life of these gases are quite short even less than 1 day.

But however, it is quite reactive and combustion of fossil fuel is the largest source of the NO x emission in the atmosphere. The emission quantities by the combustion sources are sufficient enough to affect the quality of atmospheric air. Therefore, we should be concerned about it and we will have to find out how to reduce it? Combustion of fossil fuel is the largest source of NO x around 22 megatons per year. And, this number may be little ballpark number and this might have increased today and this will little whole number.

And, stationary source of contributor is around something 13 megaton per year. And, NO x emission by biomass is quite small, that is why people are proposing to use the basically biomass mixed with the coal and other solid fuels or that is they can reduce the NO x emission from the solid fuel combustion system. What people have observed that there is a fourfold increase in tropospheric NO x level and that is caused due to the combustion.

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Major Sources of NO Emission

Source category	Emissions (million tons per year)	%
Motor vehicles	7.8	17.53
Aircraft, trains, ships	2.0	4.49
Off-highway vehicles	1.9	4.27
Coal	3.9	8.76
Fuel oil	1.3	2.92
Natural gas	4.7	10.56
Wood	0.1	0.22
Total fuel combustion	21.7	48.76
Industrial processes	0.2	0.45
Agricultural burning	0.3	0.67
Solid waste disposal	0.4	0.90
Miscellaneous	0.2	0.45
Total	44.5	100

So, I am giving you some numbers, which is about the NO emissions from various sources like, if you look at the motor vehicle is the largest one 78 million tons per year. And, which amounts to 17.53 percent about all total combustion sources combustion sources is the 21.7 million tons per year. The next is of course, the coal which is little higher and agricultural burning are also not really very much and total amount is something 44.

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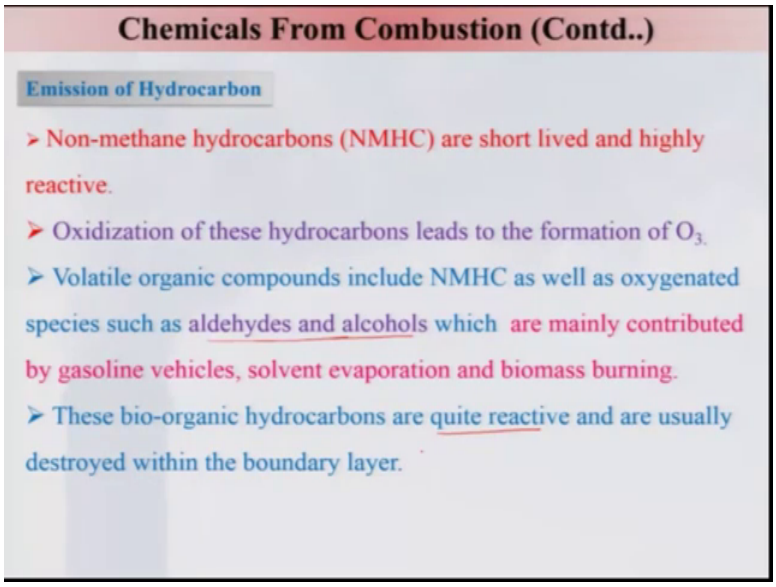

And, emissions of hydrocarbons is another important one and which is basically due to the unbent hydrocarbon, as a also sometimes the fuel are being let out due to the malfunctioning of the fuel systems. So, there is a two one is the of course, the methane hydrocarbons, there is a non-methane hydrocarbons; which are having a short lived and highly reactive in nature. So, oxidation of these hydrocarbons leads to the formation of ozone layer.

And ozone particularly in the on the near the ground level and that causes a lot of problem for to the people. And volatile organic compounds that include the NMHC that is Non-Methane Hydro Carbons. As well as oxygenated species such as aldehydes and alcohols, which is also causes a lot of problems. And, these are the aldehydes and alcohols are basically mainly contributed by gasoline vehicles due to the solvent evaporation and mass biomass burning, because of these are causing and this really causes a lot of problems in the atmosphere.

And, this bio organic hydrocarbons are quite reactive in nature are usually destroyed within the boundary layer of atmosphere, but however, it causes the disease and other problems health problems.

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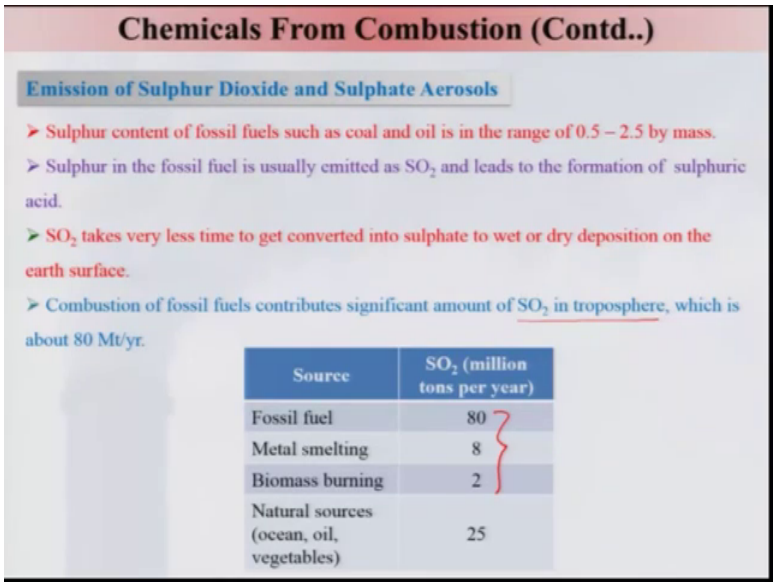

And emission of sulphur dioxide and sulphate aerosols, which are great concern for the people due to and sulphur content of fuels such as coal and oil is in the range of 0.5 to 2.5 by mass. Fortunately Indian coal, coal does not contain sulphur, but however, the Chinese coal contains large amount of sulphur and they are using for the power plant.

Therefore, they are emitting large amount of SO x to the atmosphere. Some researcher study says that the India will be affected adversely, because of transport of SO x from the China to India due to the global current that is prevailing due to the climate. And, sulphur in the fossil fuel is usually emitted as SO 2 and leads to the formation of sulphuric acid. And, this sulphuric acid effects the structures and building and also skin diseases and some problem comes to the thing due to the sulphuric.

Acid SO 2 takes a very less time to get converted to sulphate to wet or dry deposition on the earth surface that is a good part of it. And combustion of fossil fuels contributes significant amount of sulphur dioxide in troposphere, which is about 80 megaton per year, what people have estimated. And so, if you look at the source of sulphur dioxide fossil fuel is basically 80 mega tons per year and metal smelting you can get also 8

million tons per year of course, biomass burning causes 2 million tons per year across the globe.

And, beside these like oil vegetables or vegetation's and even ocean to some extent that gives around 25 million tons per year. So, therefore, if you look at the combustion is really causing a major source of the SO x emission in the atmosphere. So, therefore, that is a great concern which need to be abated. Now, we will be looking at how to quantify the emission level?

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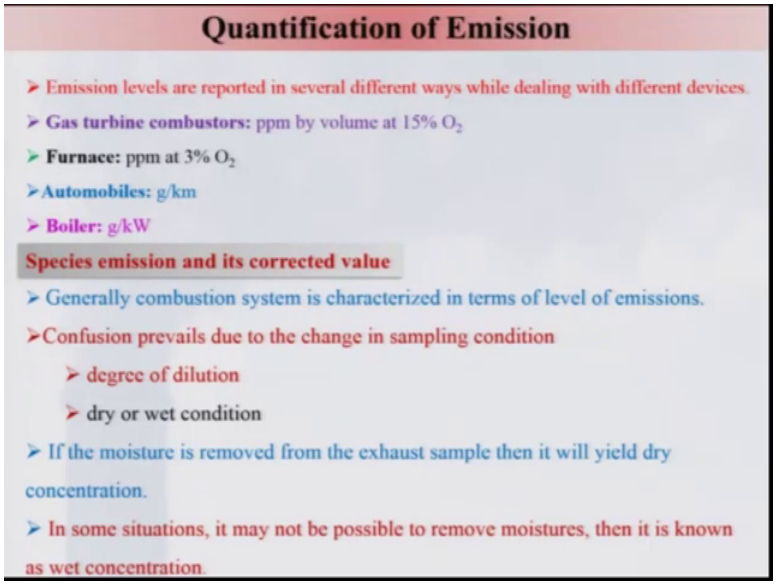

Because, emission levels are reported in several different ways, while dealing with different devices; for example, we are using the automobile engines and we are also let us say using the furnaces in a process industries. And, similarly we are having power plants; we are producing energy and also emitting different people report the emission level in different ways. For example, gas turbine engine people put express the emission level as ppm; ppm means parts per million by volume at 15 percent oxygen level, because oxygen level also will be different. So, the ppm will be different.

And, this is a standard way by which the gas turbine combustor people will be coating or measuring and expressing in terms of ppm by volume at 15 percent of oxygen. But however, the furnace in people will be coating the in terms of ppm level at 3 percentage of oxygen.

And, now days of course, the gas turbine combustors and other places also people are going for emission index, which is independent of this oxygen level. In auto engines basically that is being express the emission level is being express in terms of gram per kilometer and but in case of boiler or the power plant the emission level is expressed in gram per kilowatt or gram per megawatt power level.

So, species emission and it is corrected value is very important, because if you are reporting in certain values, then you will have to also report in different value beside this in the combustion there will be also the water will be there in the adjust gas. If, water can be removed before the combustion before you are taking the measurements of emission then of course, that is known as dry.

As I told that if it is generally the combustion system is characterized in terms of emission level and of course, the confusion prevailed due to the change in sampling condition due to the 2 reason; one is degree of dilution. As, I told like a dilution particularly the oxygen level and the dry or wet condition, as I told earlier that in case of the burning of hydrocarbon fuels there will be a water formations. And the therefore, water will be there in the gaseous phase in the product itself or in the flue gas.

So, when you consider the emission measurements without really removing the water content, then we call it as a wet condition and when you remove the water content and then measure the emission level we call it as a dry condition. As, I told earlier that is a moisture is removed from the exhaust sample then it is yield a dry concentration. And, if some certain situation it may not be possible to remove moisture then it is known as wet concentration.

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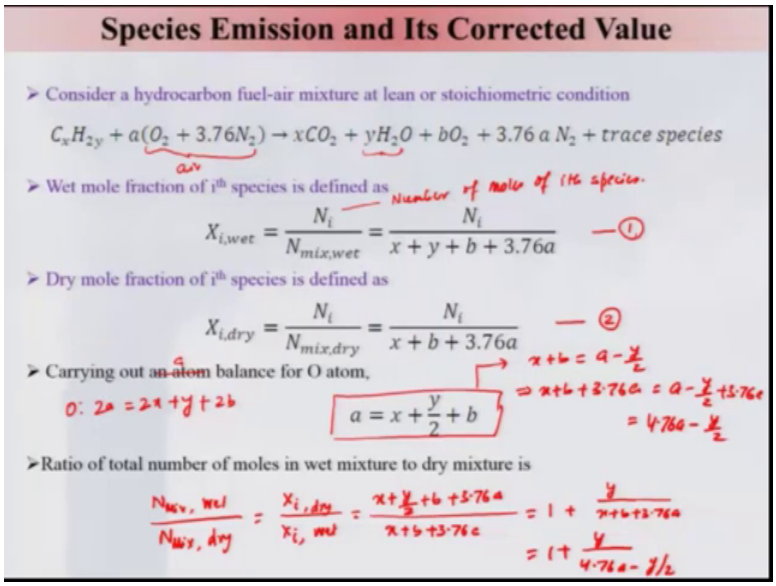

Now, we look at the species emission and how to express it such that it can be also corrected for particular values. For this purpose let us consider a hydrocarbon fuel air mixture at lean or stoichiometric condition. And of course, you cannot apply this thing whatever will be doing for the rich condition, that is not a part of this course because it is quite complex. Let us consider a hydrocarbon fuel and depended by C x H 2 y is reacting with a molecules of air.

And such that the product C x moles of C O 2 is being formed and y moles of water and b moles of oxygen 3.76 into a moles of N 2 of course, there will be several trace species. And, if you look at like we are interested to basically find out the mole fraction of particular species in the product. That is i th species, keep in mind that we can consider the mix wet wet product or we can consider the species, when the water at the moisture is there right, then we call it is a weight mixture.

And if the moisture is being removed from the product gas at the flue gas and then we measure the constituent like CO or CO 2 O 2 any other species then we call it as a dry. Let us now look at this wet mole fraction of i th species, that can be defined as X i of wet mixture is equal to N i, N i basically number of moles of i th species and divided by N mixture of wet; that means, under what condition what will be.

So, then if you look at on the denominator that will be x plus y and b is for oxygen and of course, y is for water and 3.76 a. Similarly, we can also express the dry mole fraction

of i th species as X i dry which is equal to N i divide by N i mixture dry. And, this is N i divided by x plus b plus 3.76 a. In case of dry mixture the basically y would not be there, because water is not there. And, that is the difference between the wet mixture fraction of i th species and dry mixture fraction of i th species. Carrying out a balance for O atom, we will get basically if you look at 2 a is equal to 2 x plus y plus 2 b, then a I can write down as this.

So, ratio of total number of moles in the wet mixture to dry mixture, if I take this as a equation 1 and this is as a equation 2, then I can get basically as N i mixture wet divided by N mixture dry is equal to basically X of i dry X i wet. And that is equal to x plus y divided by 2 plus b plus 3.76 a keep in mind that we are basically taking this equation, one which is the in the case of basically in the numerator. And then that is equal to that is divided by x plus b plus 3.7 6 a, which is equal to 1 plus y divided by x plus b plus 3.76 a.

From this equation I can write down x plus b is equal to a minus y by 2 and if I can write down on the left hand side x plus b plus 3.76 a is equal to a minus y by 2 plus 3.76 a is equal to basically 4.76 a minus y by 2. So, similarly I can write down is equal to 1 plus y 4.76 a minus y by 2. So, now with this, we can get basically the a values, which is easily we can get these values and but before doing that let us now look at by using equation 1, we can have the mole fraction for O 2, that is wet mixture right wet.

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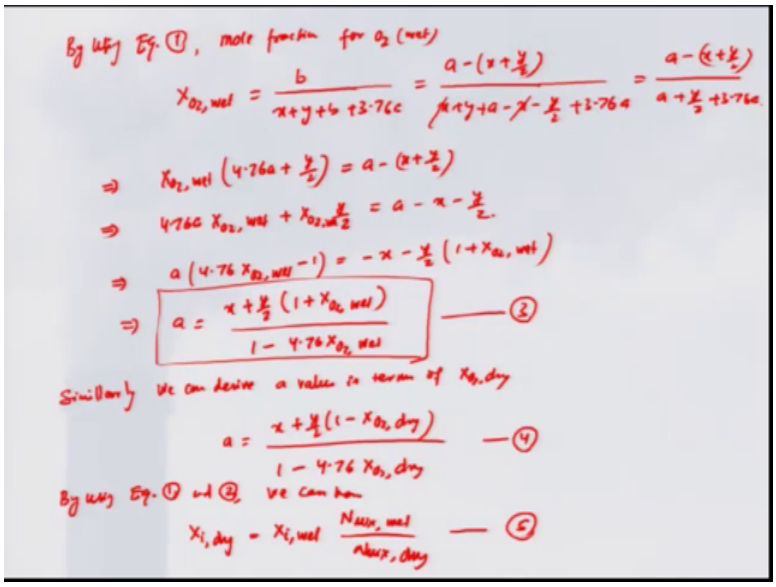

So, I can write down X O 2 wet is equal to b divided by x plus y plus b plus 3.76 a. And b I can write down as a minus x plus y by 2 divided by x plus y plus a minus x minus y by 2 plus 3.76 a. So, this will cancel it out and you will get basically you will get is a minus x plus y by 2, divided by a plus y by 2 plus 3.76 a. Now, if we will simplify further I will get X if I will simplify further I will get X O 2 wet into a basically that will be 3.76 a plus a that is 4.76 a plus y by 2 is equal to a minus x plus y by 2 in the bracket.

Now, if I will simplify further what I will get I will get basically I can take all this out of this a I can take this to the other side, that is 4.76 a X O 2 wet plus X O 2 y by 2 is equal to a minus x minus y by 2. So, if I simplify this I will get basically I can take a all to the one side I will get a is equal to 4.76 X O 2 wet minus 1, minus x, minus y by 2 1 plus X O 2 wet. So, therefore, I can write down a as x plus y by 2 1 plus X O 2 wet divided by 1 minus 4.76 O 2 wet so, this is my equation 3.

Similarly, we can derive a values in terms of X O 2 dry that is basically equal to a is equal to x plus y by 2 1 minus X O 2 dry divided by 1.476 X O 2 dry and this is your 4. Now, by using this equation 1 and 2, we can have basically X i dry is equal to X i wet N mixture wet divided by N mixture dry this is my equation 5. So, let us now as simplified further and express this N mixture of wet in terms of mole fraction of the oxygen and also the a values right.

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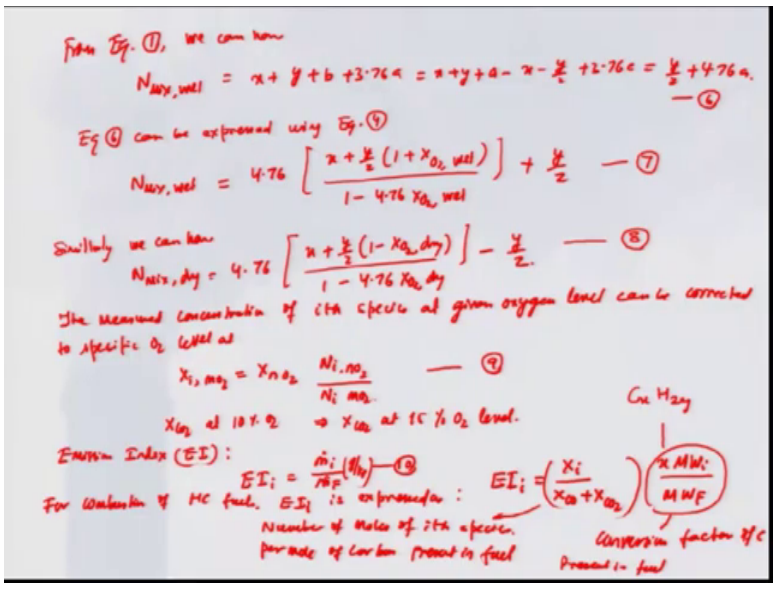

From equation 1, we can have N mixture wet is equal to x plus y plus b plus 3.76 a that is already we know. And in this case what will do in place of basically b I can write down as simply I can write down and x plus y plus a minus x minus y by 2 3.76 a we have already done that which is nothing, but your y by 2 plus 4.76 a and this is your 6.

So, what we will do we will basically substitute the values of a and then get the equation 6 can be express using equation 4, that is N mixture wet is equal to 4.76 I will just put the values of a, that is x plus y by 2, 1 plus X O 2 wet divided by 1 minus 4.76 X O 2 wet plus y by 2.

Similarly, we can have N mixture dry is equal to 4.76 x plus y by 2 1 minus XO 2 dry 1 minus 4.76 X O 2 dry minus y by 2 this you can say equation 7 and this is 8. And, if you look at if I know the values of basically mole fraction of the mixture dry, I can find out the mole fraction of the oxygen dry or vice versa in terms of this.

So, as I told earlier, that we are now can express the major consented of I S species at a particular oxygen level in and that can be done by using the expression equation 5, we can cast that in terms of oxygen level as compared to wet and dry. So, the majored concentration of i th species at given oxygen level can be corrected to specific oxygen level as X i m oxygen level is equal to X n oxygen level N i n o 2 level divided by N i m o 2 level. For example, like suppose you are measure the mole fraction of C O at let us say 10 percent of the oxygen level then, you can to convert that into 15 percent which is the standard for the gas turbine engine.

So, therefore, you can use this formula 9 and you can do that. For example, like if you are measuring of CO 2 at let us say 10 percent of oxygen and you want to convert that into X co 2 at 15 percent of oxygen level. Therefore, you can really do this using formula equation 9 beside this the emission of a combustor or a engine is expressed in terms of emission index. Emission index if you look at it is basically the normalized indicator of emission level, emission index is defined as E I is basically E I of i th species is equal to m dot i by m dot F equation 10.

And the good thing about this emission index is that it is independent of the oxygen level present in the product gas or the flue gas. So, that is why it is being used for mo for combustors or the engine in modern time. And for combustion of hydrocarbon fuels the E I E of I is expressed as E I X i divided by X c o plus X c o 2 x M W i by M W F. And,

this is if you look at if I consider that C x H 2 y and this x is basically the mole fraction of carbon x is basically moles of carbon in moles of hydrocarbon fuel of that is represented by C x H 2 y. And this portion is basically number of moles of i th species per mole of carbon present in fuel.

And, this portion represents basically conversion factor of carbon present in fuel in terms of mass. So, therefore, this is being a used very much and keep in mind that unit of E I this unit is basically the the emission index is basically unit less. However, it is being expressed in terms of gram per kg; that means, gram of the emission per unit kg of fuel being consumed. This is for the convenience it is being used, but; however, emission index is basically non-dimensionlised number.

So, this is being used profusely for expressing the emission in combustor and or engines now a days, because of fact that it is not having the problem of the oxygen level present in the flue gases, whenever you are measuring. So, with this we will stop over and in the next lecture we will be discussing about the how to control the emission level.

Thank you very much.