Fuels, Refractory & Furnaces

Prof. S.C. Koria
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture No. # 02
Characterization of Fuels: Concepts

In the last lecture, we have seen the importance of energy and the contribution of fossil fuel for the energy production, energy consumption and energy utilization. In this context, we can also say that fuel is energy because fuel contains energy. Now, let us proceed further to characterize the fuel.

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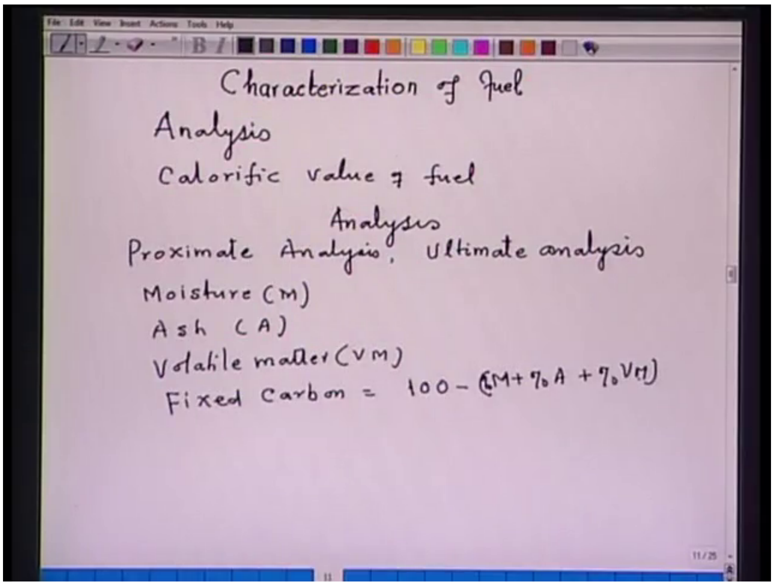

Now, by characterization of fuel we mean, one is the analysis. Because you want to do some calculations, say how much amount of fuel is required for a particular objective. Then, you must know the analysis of the fuel. Another… that is important from the characterization of fuel point of view is the calorific value of the fuel. Calorific value of the fuel. Now, let us take first analysis of fuel.

Now under the analysis of fuel, that is, let me be very clear; under the fuel, I am meaning here solid fuel, for example, coal; liquid fuel, that is, the fuel oil which is derived from petroleum and natural gas. So, about the analysis, say one; the two types of analysis are done on solid fuel. One is a proximate analysis. One is the proximate analysis and another is the ultimate analysis. In the proximate analysis, the following are determined. Moisture, in short we will write M. Now, moisture in the fuel is determined by taking one gram of sample. It is heated in a furnace for one hour at 105 degree Celsius. In some books, this temperature may vary. But, it does not matter; plus, minus five degree could be there. So, one gram of fuel, we heated for one hour around 105 degree Celsius. Then, the weight loss is expressed in terms of percentage moisture.

Another important constituent is the Ash. We will note as ash. And, ash in fact is the residue after complete combustion in the furnace. That means, again we take here one gram of the fuel and the fuel is completely incinerated. And, the residue which is left is expressed in terms of percentage of ash.

Third constituent determined is volatile matter. In short, we will put V M. Now, volatile matter is, in fact loss in weight of one gram of sample heated for seven minutes at 950 degree Celsius in the absence of air. I repeat once again. Volatile matter is a loss in weight of one gram of sample heated for seven minutes at 950 degree Celsius in the absence of air.

Now this volatile matter; it does not include moisture. So, remember, while determining the volatile matter, moisture in the fuel has to be subtracted. So, that is how the volatile matter is determined. The fixed Carbon; fixed Carbon is in fact that is equal to, is determined by hundred minus percentage moisture plus percentage ash plus percentage volatile matter. So, that is how the fixed Carbon is obtained. Now, this proximate analysis of the fuel or of the solid fuel, it can be reported in several ways.

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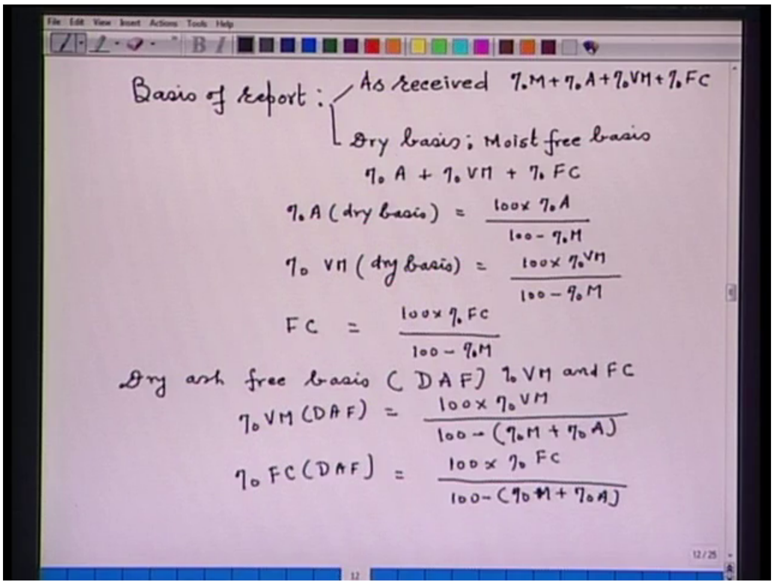

Now, the basis of report, say one way is that "as received". One way is "as received". Now, in the "as received condition", the proximate analysis of fuel will consist of percentage moisture plus percentage ash plus percentage volatile matter plus percentage fixed Carbon.

Another way of reporting proximate analysis is on the dry basis. And, this dry basis is also called moist free basis. And, proximate analysis on dry basis contains percentage ash plus percentage volatile matter plus percentage fixed Carbon. Remember, the total of all the constituent should be equal to hundred; say on dry basis, percentage ash.

On dry basis, it can be calculated upon hundred into percentage ash upon hundred minus percentage moisture. That will be percentage ash on dry basis. Now, similarly percentage volatile matter on dry basis. That will be equal to hundred into percentage volatile matter upon hundred minus percentage M. And then, fixed Carbon accordingly will be equal to hundred into percentage fixed Carbon upon hundred minus percentage M. So, in fact fixed Carbon can also be determined by subtracting the percentage ash on dry basis plus percentage volatile matter on dry basis from hundred, you will get the fixed Carbon on dry basis.

Now, another method of reporting is dry ash free basis dry ash free basis. In short, it is also called DAF basis. That means dry ash free basis. And, under dry ash free basis, the proximate analysis consists of volatile matter in percent and fixed Carbon. So, the percentage volatile matter on DAF basis, that will be equal to hundred into percentage volatile matter upon hundred minus percentage moisture plus percentage ash. That will determine the percentage volatile matter on dry ash free basis. Now percentage free Carbon on dry ash free basis; that will be either you can determine hundred minus percentage volatile matter on dry basis. Or, it can also be determined by hundred into percentage fixed Carbon upon hundred minus percent M plus percent A. So, that is how one can report the proximate analysis on different basis. Now, the whole idea of reporting the proximate analysis on different basis; it depends upon what is ultimate use of the coal for the any objective.

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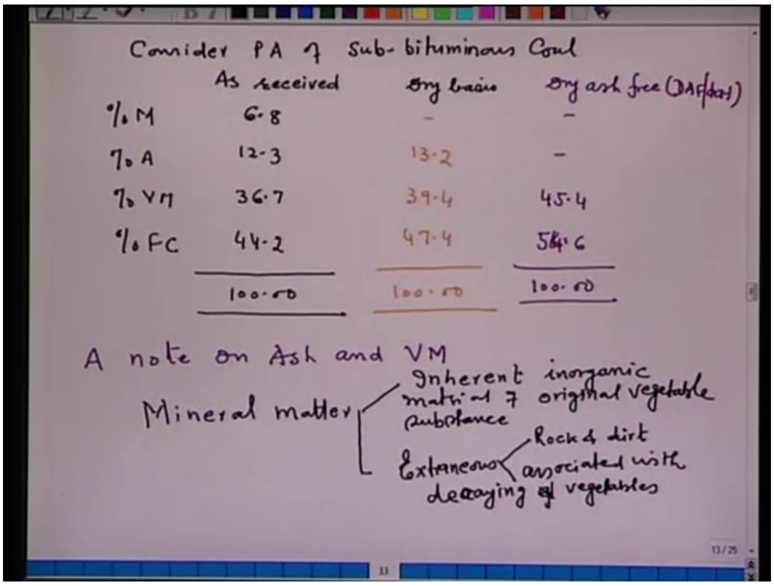

Let me illustrate by an example. So, consider the proximate analysis of sub bituminous coal. You consider proximate analysis of sub bituminous coal; say percentage moisture, percentage ash, percentage volatile matter and percentage fixed Carbon as received. As received, the analysis is 6.8 percent moisture, 12.3 percent ash, 36.7 percent volatile matter and 44.2 percent fixed Carbon and the total should always be hundred percent.

Now, suppose if you want to calculate on dry basis, say we want to report proximate analysis on dry basis; as I suggested the formula earlier, then percent ash on dry basis will be 13.2, volatile matter will be 13.4. And, fixed Carbon will be 47.4. And, this makes again hundred percent. So, whatever basis you choose, the sum total of all constituent should be equal to hundred percent. Now, suppose you want to calculate on dry ash free basis insure, it is called DAF basis or sometimes it is also written DAF basis. So, if you want to calculate on that, then the volatile matter becomes 45.4 percentage. And, percentage fixed Carbon becomes

54.6 percent. And, the total again becomes hundred percent. So, that is how you can report the proximate analysis in different forms; dry basis, dry ash free basis.

Now, just I want to tell something on a note on ash and volatile matter. ash and volatile matter. You know, coal does not contain ash. Coal, in fact contains mineral matter. And, ash is residue after complete incineration of coal. That means ash and mineral matter are not identical. In fact, mineral matter is greater than ash. So, the important point to remember is that ash is not a constituent of coal, but it is formed on complete incineration of coal. As I said the mineral matters, which are present in coal, they are of two types. One is an inherent inorganic material of original vegetable substances; because coal is a plant origin. And, plant contains organic as well as inorganic matter.

Another type of mineral matter that are present that are extraneous in nature. That are extraneous in nature. And, extraneous could be say rock and dirt, during mining operation. Because when coal is ploughed down from the earth crust, then it is subjected to mining. And, along with some rock and dirt, there also mix. They also constitute the part of the ash. Then also extraneous metal, they are associated; they are also associated with decaying vegetables and they are intimately mixed. So, in fact the extraneous mineral matter they can, I mean extraneous type of mineral matter can be removed by coal washing. So, what is the important message that I want to give here is that the mineral matter and ash are not identical. And, some formulas are available which can determine mineral matter.

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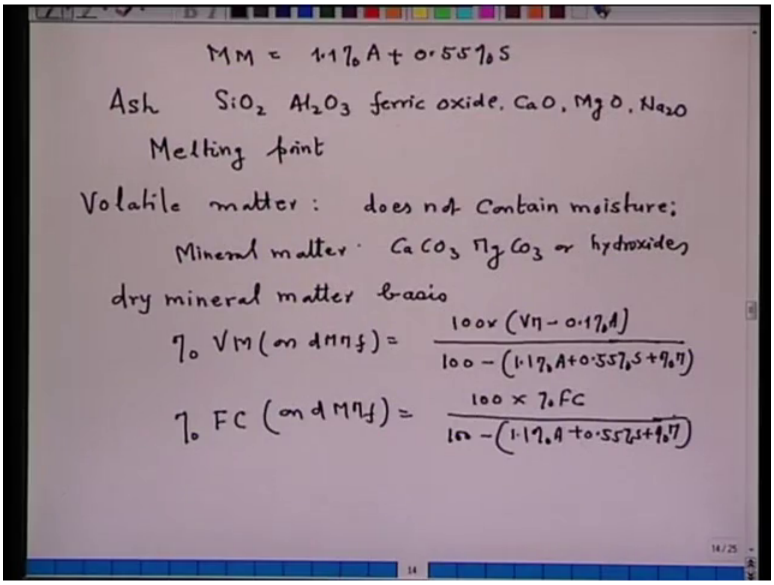

So, in fact mineral matter in coal; that is equal to 1.1 percentage ash plus 0.55 percent Sulphur. So, that is how from the given analysis of ash and Sulphur, one can determine the mineral matter. Now, A ash is a very important component of the coal because it is formed during complete incineration of the coal. So, whatever ash is present in the coal, the same will be available in the furnace when coal is combusted for deriving thermal energy. So, from that point view, the ash is very important.

Now, let us see what the ash contained? Ash, in fact it comprises of Sio2, Al2O3, then it may have ferric oxides, then calcium oxide, magnesium oxide, Na2O, all may. Ash may be comprised of all these compounds. Now, for metallurgical applications, ash is very important because whatever the amount of ash that is present in the coal that will be transferred on combustion into a combustion appliance, for example, furnace or if it is used in some metallurgical function.

Now, for example, the coal is used to convert coke. And, coke is used in the blast furnace for iron making. So here, whatever ash contained in the coal is the same amount of ash will be transferred into the coke. So, if you have higher amount of ash in the coal, then coke will also contain higher amount of ash. What will happen? If that coke is used in the blast furnace, then ash has to be removed. And, in the blast furnace ash is removed in the form of slag. So, higher amount of ash in the coke which is due to higher amount of ash in the coal, the volume of slag in the furnace will also be larger. There are several applications; for example, deduction of iron ore in corex process.

There also, whatever amount of ash in the coal that is released during combustion. Another example, for example, for another example is, say that rotary kiln are used for cement production and directly reduced iron. And, another important feature of you says ash is the melting point melting point of ash. Now, the melting point of ash is again a very important thing. The melting point of ash should be greater than operating temperature of the furnace. In that case, ash will be in the solid form and the removal is easier. Now, if the melting point of ash is smaller than the operating temperature of the furnace, in that case what will happen? Ash will be molten and it contains all high refractive oxide, Sio2, Al203 I O two l two, o3 and so on. What will it do? It will be highly viscous and it may choke the passage of air.

Now, another issue is that of volatile matter volatile matter. Now, important thing in volatile matter does not contain moisture. Volatile matter does not contain moisture. So, the volatile matter; it does not contain the moisture, but it contains the water which is found due to chemical reaction between Hydrogen and Oxygen.

Now, when volatile matter is reported on dry ash free basis, then volatile matter it also contains the contribution of volatiles of the mineral matter because the mineral matter mineral matter, for example, that could be Calcium Carbonate, Magnesium Carbonate or hydroxides. So, as such when a coal is subjected for volatile matter determination, then the volatile constituents of these mineral matters Co2, H2o will also be counted in determination of volatile matter. So, actual volatile matter can be obtained by subtracting the volatile matter with the volatile of mineral matter. So accordingly, the actual volatile matter can be obtained by calculating the proximate analysis on dry mineral matter free basis.

So, dry mineral matter, dry mineral matter free basis; now in the dry mineral matter free basis, we subtract the contribution of volatiles of mineral matter. And then, we report on the dry mineral matter free basis as follows. So, we calculate them; percentage volatile matter on dry mineral matter free basis, that is equal to hundred into volatile matter minus 0.1 percent A. Now, the 0.1 percent A is estimated to be contribution of volatiles from mineral matter. That is where the 0.1 percent A is the ash. Divide by 100 minus 1.1 percent A plus 0.55 percent Sulphur plus percentage moisture. That is how we will be reporting percentage volatile matter on dry mineral matter free basis. Similarly, we can also report then, percentage fixed Carbon on dry mineral matter free basis that will be equal to hundred into percentage fixed Carbon upon hundred minus 1.1 percent A plus 0.55 percent Sulphur plus percentage M. So, that is how one can report that the proximate analysis on dry mineral matter free basis, in order to know what is the actual volatile matter which is coming from the coal. So, now the same example which I had took in that. Example, percentage Sulphur was equal to zero.

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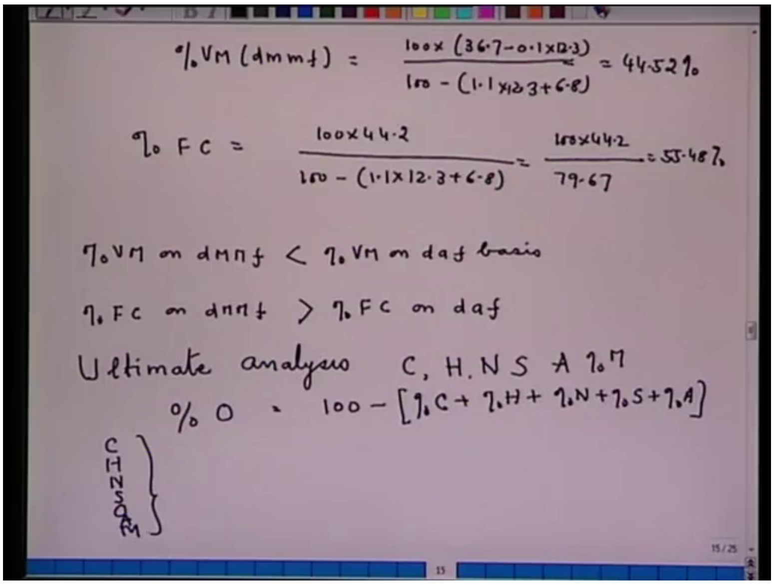

So, we can calculate now. The percentage volatile matter on dry mineral matter free basis; that will be equal to hundred into 36.7 minus 0.1 into 12.3 that is equal that upon 100 minus 1.1 into 12.3 plus 6.8. So, if you solve, this thing will be coming equal to 44.52 percent is the volatile matter, actual volatile matter. And similarly, percentage fixed Carbon that will be equal to hundred into 44.2 upon hundred minus 1.1 into 12.3 plus 6.8. So, that will be equal to hundred into 44.2 upon 79.67. So, that is equal to 55.48 percent.

Now, what this calculation says that percentage volatile matter on dry mineral matter free basis percentage volatile matter on dry mineral matter free basis is smaller than percentage volatile matter on dry ash free basis. Now, this is obvious because in the dry ash free basis, the contribution of volatile for mineral matter is also there. That is where the percentage volatile matter on dry ash free basis was greater than percentage volatile matter on dry mineral matter free basis; because in dry mineral matter free basis, we are reducing the amount of volatiles which are coming from mineral matter. Now similarly, the percentage fixed Carbon on dry mineral matter free basis is greater than percentage fixed Carbon on dry ash free basis. That you can see also from this analysis. Now, why it is so because fixed Carbon, it does not include the ash contained. That is why the percentage fixed Carbon on dry mineral matter free basis is greater than percentage fixed Carbon on dry ash free basis. So, that is about the proximate analysis

Now, next thing is the ultimate analysis ultimate analysis. Now, in fact ultimate analysis is required for all combustion calculation. Based on the proximate analysis, if you want to calculate how much amount of air is required for a given composition of coal, you cannot calculate. So, in order to calculate the amount of air or amount of energy that the coal has, you have to know what is the elemental analysis of the coal. And, this elemental analysis of coal in fact is termed ultimate analysis.

Now in the ultimate analysis, Carbon, Hydrogen, Nitrogen and Sulphur; they are determined and reported on dry basis. Then, ash percentage moisture; they are determined from the proximate analysis. Then percent O percent O is determined from hundred minus percentage Carbon plus percentage Hydrogen plus percentage Nitrogen plus percentage Sulphur plus percentage ash. That is how you determine the percentage Oxygen.

So, the ultimate analysis, complete ultimate analysis will consist of Carbon, Hydrogen, Nitrogen, Sulphur, O, ash and moisture. This is how the ultimate analysis of a coal consists of. Now, say Carbon, Carbon is determined by completely combusting the coal, collecting the amount of Co2 and it is absorbed in KoH solution. And, that is a Carbon, from Carbon, from the absorption reading the Carbon is determined.

Hydrogen is determined together with Carbon by completely combustion and whatever amount of water that is produced. From that, the calculation of Hydrogen in the coal is determined. Of course, you have to subtract the correction for moisture of coal and water of dehydration of minerals. That is important. Now in this relation, I have to say that Carbon contained, it rather determines the rank of the coal. As you have noted in the previous lecture that has to go from pit to another side, the Carbon contained of the coal increases. That means the rank of the coal increases. So, the Carbon contained determines the rank of the coal.

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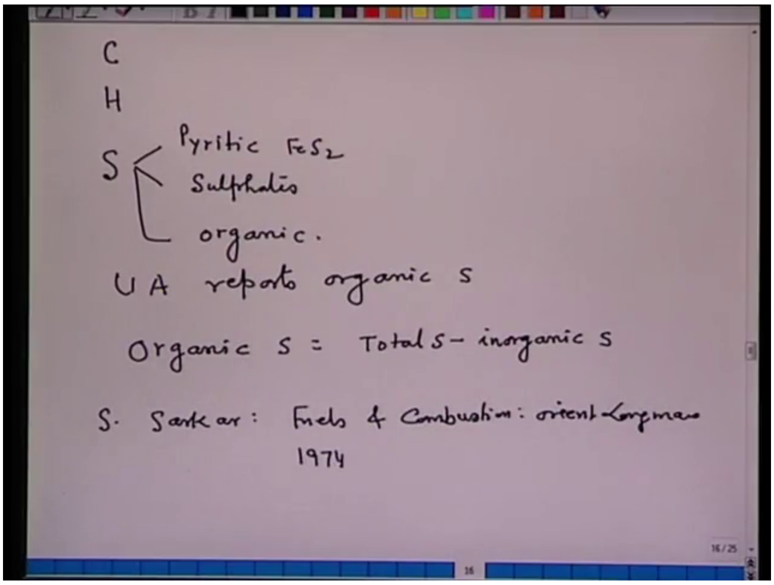

As regard the Hydrogen; Hydrogen, it does not determine the rank of the coal. That means Hydrogen contained is not related with the rank of the coal. As you have seen also in the last lecture beyond, between us stage Hydrogen contained drastically decreases from 5 percent to as low as 1.2 percent in the another side. So, Hydrogen contained, in fact has no relation with the rank of the coal. Now, as regard as Sulphur; now Sulphur in the coal is present as pyritic; means, for example, FeS2, pyritic Sulphur, then it is also present in the form of Sulphates, then it is also present in the form of organic.

Ultimate analysis reports organic Sulphur. Let me write down ultimate analysis reports organic Sulphur. In bond method, total Sulphur is converted into Sulphate form, then pyritic and Sulphate, Sulphur are determined by analytical methods. And, organic Sulphur, that is equal to total Sulphur minus inorganic Sulphur. Sulphur contained of the coal is again a very important; because it will also determine the so-called incomplete combustion, the amount of So2 that is produced, amount of So3 that have been produced. So, in that connection, Sulphur contained of the coal is a very important. Now, Sulphur contained has no relation again with the rank of the coal.

So, if you want to know the detail how the analysis is done, you can consult a book which is a "Sarkar" for detailed reference. That is, "Fuels and combustion fuels and combustion": orient Longman, year 1974. There you can find the details about details about this, how this analysis is done. Now again, the basis of report of ultimate analysis is very important because for all combustion calculation, you have to be very clear what basis has been given in a particular problem for combustion calculation. So, let me illustrate that different basis of reporting ultimate analysis.

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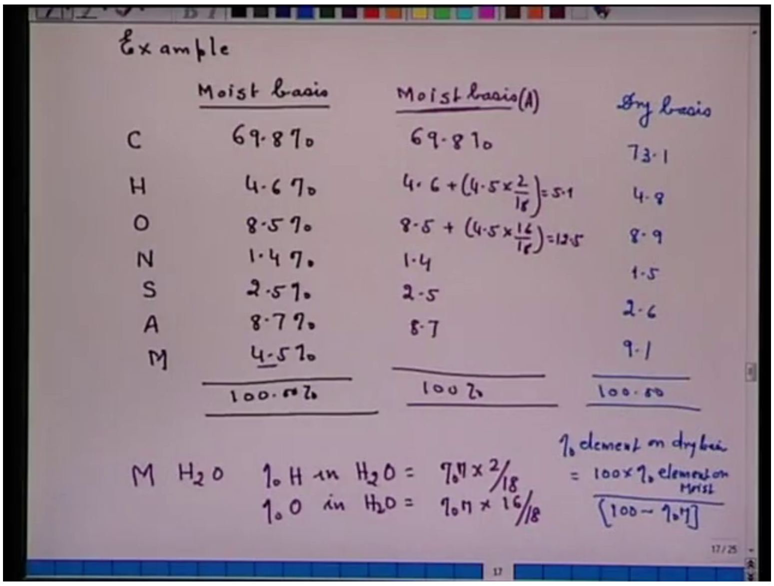

Now, let me give you an example: take moist basis moist basis or you can call "as received" analysis. Now, here it is Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, ash and M. Another second example: so, here Carbon 69.8 percent, Hydrogen 4.6 percent, Oxygen 8.5 percent, Nitrogen 1.4 percent, Sulphur 2.5 percent, ash 8.7 percent and moisture 4.5 percent. Again important, total should become equal to 100.00 percent. That is the most important; total should always be hundred percent.

Now the moisture of the coal, say moisture of the coal M, it contains H 2 O. right. So, percentage H percent H in H 2 O that will be equal to percent moisture into 2 upon 18; similarly, percent O in H2O that will be equal to percent M into 16 by 18, so what I can do now? The moisture which I have written here on moist basis, that is 4.2 percent, I can calculate the H and O contained in this moisture. And, I can further report ultimate analysis by telling that this is on the moist basis.

So, another way of reporting ultimate analysis on moist basis is Carbon will remain as 69.8 percent; Hydrogen will be 4.6 plus 4.5 into 2 by 18; Oxygen will be 8.5 plus 4.5 into 16 by 18. Rest, Nitrogen will remain 1.4, Sulphur will remain 2.5 and ash will be 8.7. So, this total again has to become hundred percent. And, it is… so, this comes out to be equal to 5.1 and this comes out to be equal to 12.5. So, what I wanted to listed from here that ultimate analysis on moist basis, it can be reported in two ways. But, in the second way which I have written here, moist basis shall put it moist basis A in that. I have to write that the moisture contained of the coal is 4.5 percent.

Now if I want to calculate, now the proximate, the ultimate analysis on dry basis. If I want to calculate ultimate analysis on dry basis and what will I do say percent element on dry basis; that will be equal to hundred into percent element on moist basis divided by hundred minus percentage moisture. So, if I do that, I multiply each Carbon, Hydrogen, Oxygen and recalculate the proximate, the ultimate analysis on dry basis that comes Carbon 73.1 percent, Hydrogen 4.8 percent, Oxygen 8.9 percent, Nitrogen 1.5 percent, here it is 2.6 percent and ash is 9.1. And, this sum, again, become equal to hundred percent. So, what message that I want to give through this analysis that ultimate analysis as well as proximate analysis, it can be reported on different basis. So, while converting from one basis to another basis, one should be careful, particularly for ultimate analysis.

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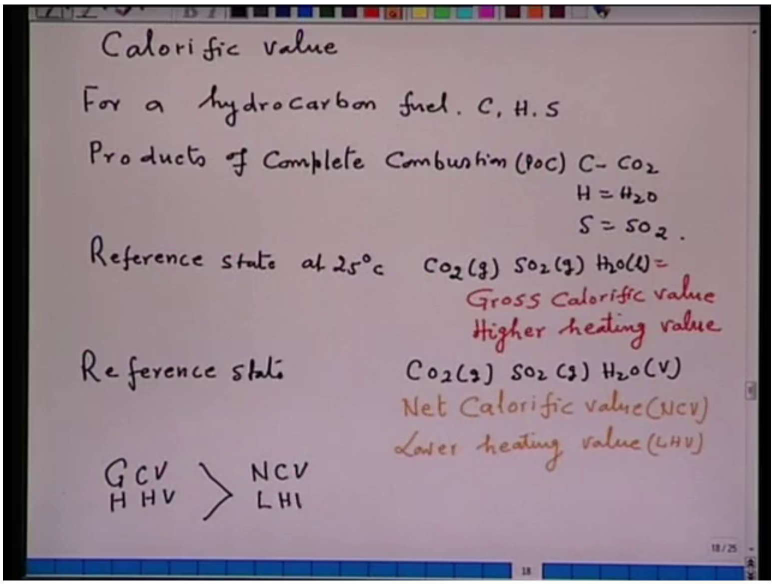

So, let us take another part of characterization of fuel. That is the calorific value. that is the calorific value. Calorific value of coal is the amount of heat liberated on complete combustion at the referenced state of products of combustion. That means, you take 1 kilogram of coal or 1 gram of coal or per unit of coal; on complete combustion, the amount of energy that is released or that is obtained at the state of the products of combustion is the calorific value of the fuel. Now, for a hydrocarbon fuel for a hydroCarbon fuel which contains, for example, Carbon, Hydrogen and Sulphur; let me tell you here, also that in a coal, there are combustible component and there are incombustible component. The combustible component of coal are Carbon, Hydrogen and Sulphur; whereas, non-combustible component of coal are Oxygen, Nitrogen, ash and moisture. So, for determination of calorific value of the coal, you have to consider the components which are combustible. And, combustible components are Carbon, Hydrogen and Sulphur. Now, the products of complete combustion, if I write products of complete combustion products of complete combustion, they put as P O C; say Carbon is Co2, H is H2o and Sulphur is So2.

Now, say reference state; reference state of this P O C; for example, reference state is at 25 degree Celsius in which Carbon dioxide Co2 is gaseous state, So2 gaseous state, H2o is liquid state. So, in that case, this is called gross calorific value. in some books, it is also called higher heating value. Reference state is chosen, then I have Co2 gaseous state, So2 gaseous state, but H2o will be in the vapor state. And, in this particular case, this is called net calorific value or in short NCV. It is also called in certain book as a lower heating value. In short form, L H V. So, while using the calorific value of coal one has to be very clear, what is the state of products of combustion. Accordingly, the calorific value will differ by an amount equal to latent heat of condensation. Therefore, the gross calorific value or higher heating value of coal will always be greater than net calorific value of coal or lower heating value of coal because of the latent heat of condensation.

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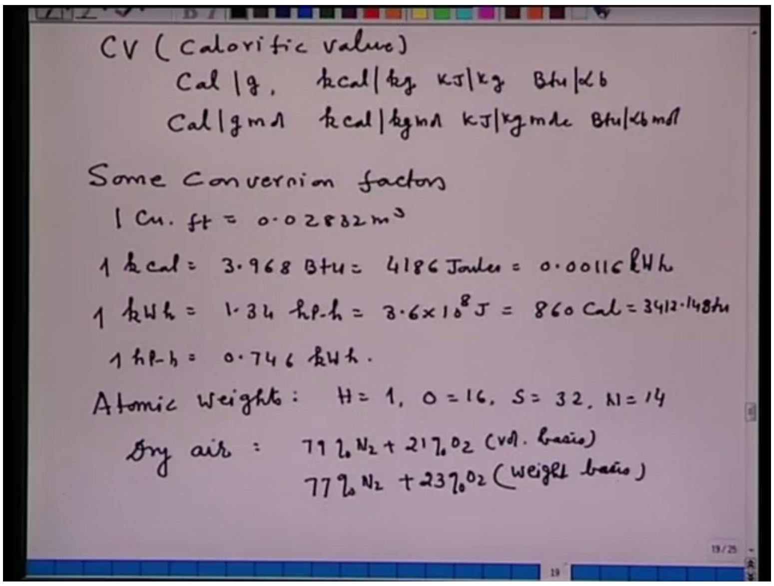

Now calorific value, in short I am writing C V, which is calorific value. It can be expressed as calorie per gram or kilo calorie per kilogram or kilo joule per kilogram or Btu per pound or one can also express calorie per gram mole. All sort of things you will find in the literature; kilo calorie per kilogram mole or kilo joule per kilogram mole or B t u per pound mole. Btu is in F P S system, which means British thermal units. Now, some conversion factor I am giving here. some conversion factors, say one cubic feet that is equal to 0.02832 meter cube. One kilo calorie that is equal to 3.968 British thermal unit. That is equal to 4186 joules. That is equal to 0.00116 kilo watt hour. And, one kilo watt hour that is equal to 1.34 horse power hour. That is equal to 3.6 into 10 to the power eight joules. That is equal to 860 kilo calorie. And, that is equal to 3412.14 British thermal units. Also, one horse power hour; that is equal to 0.746 watt hour.

Now in all my subsequent lectures, I will be using these values as well as the atomic weights values. I am giving also atomic weights of some elements. For example, Hydrogen I will be using as 1, though in some book there are for 1.008. For O, I will be using 16; for Sulphur, I will be using 32; for Nitrogen, I will be using as 14. The composition of dry air; In all my subsequent lecture till the end of this course, the composition of dry air, I will be using 79 percent Nitrogen plus 21 percent Oxygen. This is on volume basis. On weight basis, 77 percent Nitrogen plus 23 percent Oxygen; this is on the weight basis. These are some of the composition that I will be using it.

Now this calorific value, it can be determined experimentally or by theoretical consideration. Now in an experiment, rather in the laboratory, a bomb calorimeter is used. In the bomb calorimeter, a unit mass of coal is completely combusted at constant volume. And, the rise in temperature of the water is noted. And, from the rise in temperature of water, calorific value of coal is calculated. Now, mind you, in this calculation we are calculating calorific value of coal at constant volume because that coal is combusted at constant volume.

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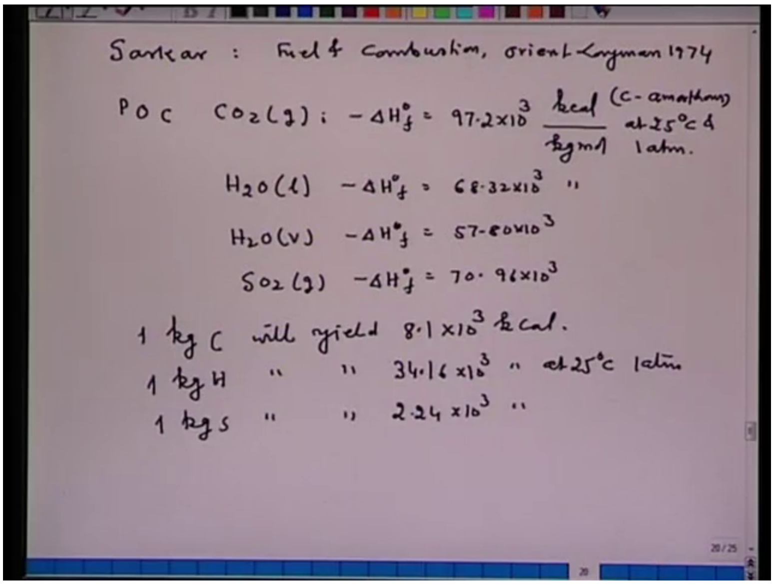

Now, if you want to go for further details on this, you can consider the book, for example, "Sarkar"; the reference I already given which is…, I give once again; "Fuel and combustion", Orient Longman in 1974. So, if you want to determine theoretically; the theoretically calorific value of the coal can be determined from the heat of formation of product of combustion. So, let us take it. The products of combustion Co2 gaseous, it is heat of formation that is equal to 97.42 into 10 to the power three kilo calorie per kilogram mole.

Now, these values are at 25 degree Celsius and one atmospheric pressure. All the values which I am listing, they are at 25 degree Celsius and one atmospheric pressure. Now, in this heat of formation of Co2, the Carbon is in amorphous state. If Carbon is not in the amorphous state, then its value is slightly different. Similarly, products of combustion H2o is in the liquid minus delta H naught f that is equal to 68.32 into ten to the power three kilo calorie per kilogram mole. H2o vapour minus delta H naught f that is equal to 57.80 into ten to the power three. So2 gas minus delta H naught f that is equal to 70.96 into ten to the power three kilo calorie per kilogram mole at one atmospheric pressure and 298 kelvin.

Now, what I do now? I find out, say one kilogram of Carbon one kilogram Carbon, on complete combustion will yield 8.1 into ten to the power three kilo calorie. Similarly, one kilogram Hydrogen will yield on complete combustion 34.16 into ten to the power three kilo calorie at 25 degree Celsius and one atmospheric pressure. Similarly, one kilogram Sulphur will yield 2.24 into ten to the power three kilo calorie at 25 degree Celsius and one atmospheric pressure. Now if I want to express these values in terms of percent element, and I say that the calories value of the coal is the sum of combustible component of the coal.

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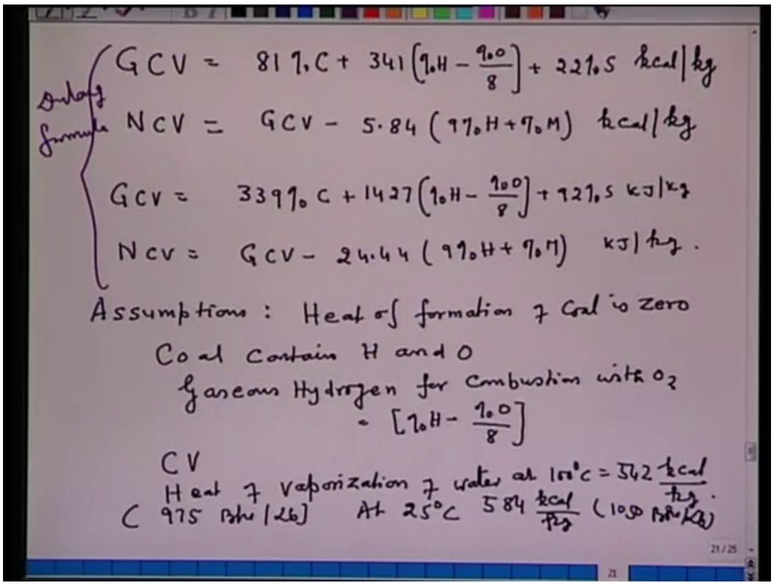

And, if I add them together and express it in terms of percentage, then I get the following formula, say gross calorific value. That is equal to 81 percent Carbon plus 341 percent Hydrogen minus percentage Oxygen upon 8 plus 22 percent Sulphur. And, that is the kilo calorie per kilogram. Similarly, N C V; that is equal to G C V minus 5.84, 9 percent H plus percent moisture on kilo calorie per kilogram.

Now similarly GCV, when I want to express in kilo joule per kilogram, then GCV is 339 percentage Carbon plus 1427 percent Hydrogen minus percent O upon 8 plus 92 percent Sulphur. Now, the units are kilo joule per kilogram. Similarly, then NCV; that will be equal to GCV minus 24.44 9 percent H plus percent M.

Now, in the expression 9 percentage is coming the H content of coal is equivalent to moisture that has been written here; because directly you have to substitute the value of H and M. So, the units also here are kilo joule per kilogram. Now, certain assumptions that are made in the formula, certain assumption that are made in the formula, first of all heat of formation of coal is zero. Heat of formation of coal is zero; that means we are, we have not considered in calculation of the calorific value, the bonds which will be broken and the amount of heat that is required. What we have considered in the calculation or in deriving the formula is that the elements are present in free state, number one.

Number two: in a coal, it contains Hydrogen and Oxygen also. The calorific value determines what part of Hydrogen has reacted with the gaseous Oxygen. So, accordingly there will be reaction between H and O of the coal internally. And accordingly, the H2o will form. So, one has to subtract the O equivalent of H. That means, the available Hydrogen for reacting with gaseous Oxygen. That will be the available gaseous Hydrogen available gaseous Hydrogen for combustion; O2 of air; that is equal to percent H minus percent O by 8. And, that is where this percent H minus percent O by 8 has been available.

Third assumption is that calorific value of coal is sum total of the combustible elements. Number four: heat of vaporization of water heat of vaporization of water at 100 degree Celsius; that is equal to 542 kilo calorie per kilogram, equal to 975 B t u per pound, whereas at 25 degree Celsius, these values are 584 kilo calorie per kilogram or 1050 B t u per pound. And, these formula which I have written here, they are called the Dulong formula; Dulong formula for calculation of the calorific value of coal.