Sustainable Materials and Green Buildings
Professor B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi
Lecture 8 - Role of cement in sustainability and calculation of chemical exergy

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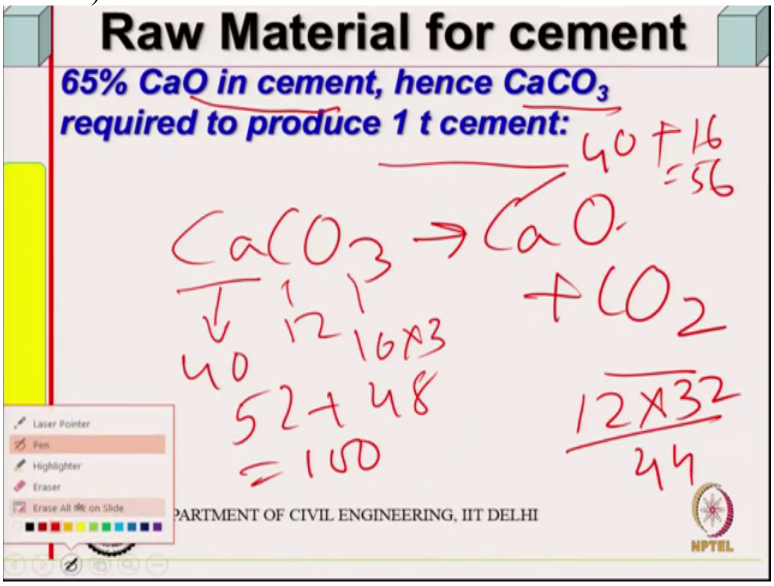

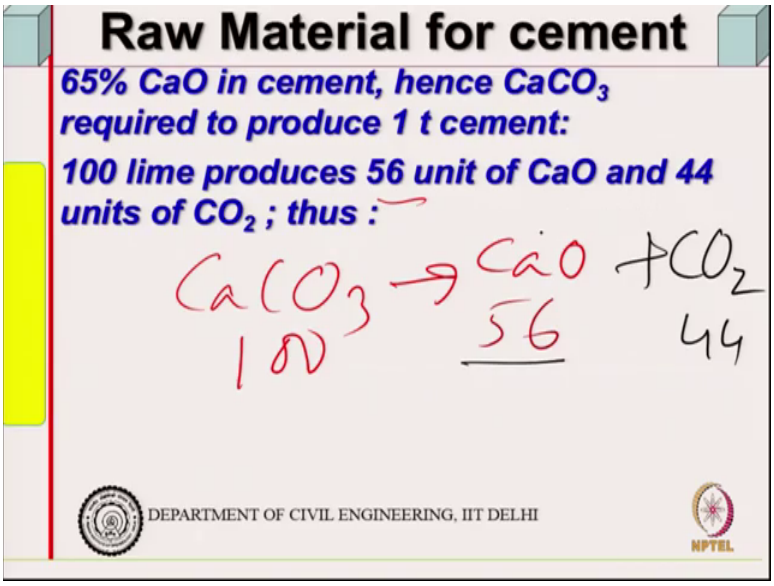

Raw Material for cement

65% CaO in cement, hence $CaCO_3$ required to produce 1 t cement:

100 lime produces 56 unit of CaO and 44 units of CO_2 ; thus :

1t clinker requires 100/56×0.65=1.16 t lime, and produces app. 0.51 CO_2

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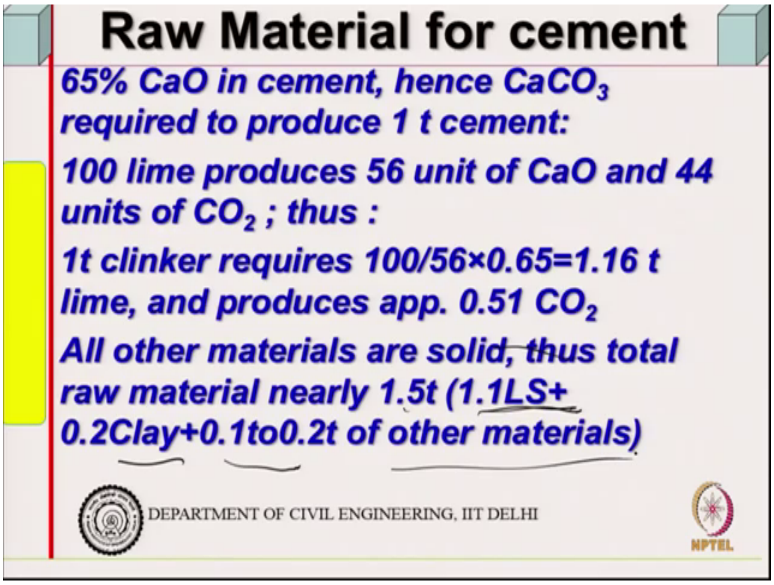

Okay, so we continue with the cement. Typically, ordinary Portland cement will have 65 percent calcium oxide. So if I want to find how much calcium carbonate I require for 1 ton of cement, that will be simply from the reaction, because calcium carbonate breaks down into calcium oxide and carbon dioxide. This has got a molecular weight 40, this is 12 and this is 16 into 3. So we will make it 52 plus 48, 100. 40 plus 16, this is 16, 56.

And this is 12 plus 32, 44, right, this is what it is. So if I want to produce 1 ton of cement, right 1 ton of cement, then I require to, you know I can calculate it because 0.65, 1 ton of cement will have 0.65 ton of calcium oxide, 0.65 ton of calcium oxide, right 0.65 ton of calcium oxide. Okay, let us see this, quickly look at this. 100 lime produces 56 unit of calcium oxide, that is what we have seen.

Calcium Carbonate had the molecular weight of 100, you know, calcium carbonate, we said it was 100 produces calcium oxide, 56, 56 plus CO2, 44. So 56 you know and 44 units of, thus if I look at this so 1 ton of clinker requires how much calcium carbonate? 100 by, you know 56 unit of calcium oxide, so 56 units of calcium oxide is equal to 100 units of calcium carbonate. 0.65 ton of calcium oxide will require 1.16 ton of, 1.16 ton of calcium carbonate, only from the calcium oxide, right.

So raw material you require 1.16 ton for calcium oxide containing raw material, okay. Plus I have got rest of the things, so 1 ton of cement I want to produce. The 0.35 tons would be, 35 tons would be other materials. There will be some amount of (evolut) you know, the some amount of material that will also be lost from there like magnesium carbonate will have also carbon dioxide contribution.

Some nitrous oxide, sulphur dioxide et cetera, is also produced, little amount, moisture also little bit will evaporate out, right. So but anyway we can see that 1.16 plus 0.35, that is 1.35is the rest, because 0.65 was calcium oxide in cement, 0.35 will be less. 1 ton of cement will have 0.35 tons of other materials, leaving all the details a little bit away because there are smaller compounds.

So, my total raw material requirement will be this plus 0.35, which would be 1.51, 1.51. So you will need 1.5 around 1.51 tons of raw material to produce 1 ton of cement, 1 ton of cement right, 1 ton of cement. And you will produce how much carbon dioxide? Carbon dioxide that you will produce is, you know you produce like from 100, you produce 44.

From 1.16, how much you will produce? From 1.16 so from 100, let me just write it like this. From 100 you produce 44, so 44 divided by 100 and you are using now 1.16 tons of calcium carbonate. So this will give you how much? This will give you some value, like 0.51. So 1.16 into 0.44, you know into 44 yeah,44 would give you, you can even just, we can just quickly calculate it out.

Write 1.16, right, so if you 44 percent of that actually 0.44, something like this, somewhere 0.52 or 0.51 around that, that will become tons of carbon dioxide you will produce. You can say that you can produce that much of carbon dioxide. So approximately 0.51 carbon dioxide. So all other materials are solid. Thus total would be nearly 1.5 ton that is what I was saying, maybe 1.16 limestone combination, 0.2 clay, 0.1 to 0.02 are other materials.

So that is how it is. So, so you require nearly 50 percent more raw material, nearly 50 percent more raw material and nearly 50 percent of, 51 percent of it goes as carbon dioxide, you know what 1 ton of cement means direct production because of clinkerization is around 1.51 ton of carbon dioxide. So 1 ton of cement would actually produce 0.51 tons of carbon dioxide just because of clinkerization, chemical reaction.

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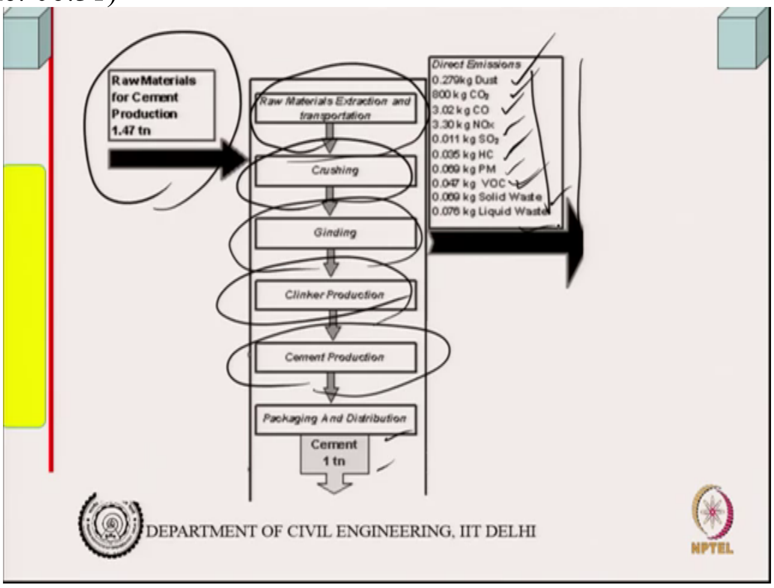

I have not taken something else, not yet, I have not taken something else, right. So this is what it is diagrammatically; raw material cement, this gives you 1.47 because I have taken 0.65, some people might take 0.6, you know so there can be some variations, so this diagram taken from cement technology's ideas. Raw materials extraction and transportation, first process; crushing is the next process, grinding is the next process, clinker production is the other process; cement production, packaging, distribution, cement 1 ton.

And what it produces then? Some amount of dust, so 1.47 tons approximately of that order, it produces around 2.2719 kg, not in terms of tons anymore, that will be too much. So that much dust; 800 kg of carbon dioxide, that is 0.8 tons right, 0.51. So half, near half, near half, because magnesium carbonate, I have not taken into account. There will be some amount of magnesium carbonate also.

There will be loss on ignition, so some free carbon could also be wherever be small amount, then carbon monoxide also comes in, NOX comes in. Sulphur dioxide, hydrocarbons, particulate matter, volatile organic compounds, solid waste because I have not taken one thing here, the fuel. The fuel will have, you know fuel two things NOX is produced at high temperature, nitrogen is an inert material, but since you are heating up to a very high temperature, nitrogen and oxygen can react and form NOX depending upon the situation right, nitrous.

Sulphur would be there, volatile organic compound will be there in the fuel. Fuel that is used for production or burning, yeah burning process. So all this comes, solid waste and some liquid waste, so that is typical some idea. So you can see that what you are producing, you are producing dust, you are producing carbon monoxide and carbon dioxide, NOX, sulphur dioxide, some hydrocarbons and then particulate matter, volatile organic compound, et cetera, et cetera. But then large quantity is of course the carbon dioxide is 800 out of, 0.8 tons out of 1.7 so nearly 50 percent you produce there. In fact, it could be more, because of fuel it will be coming, depending on fuel it will coming, so we will see that.

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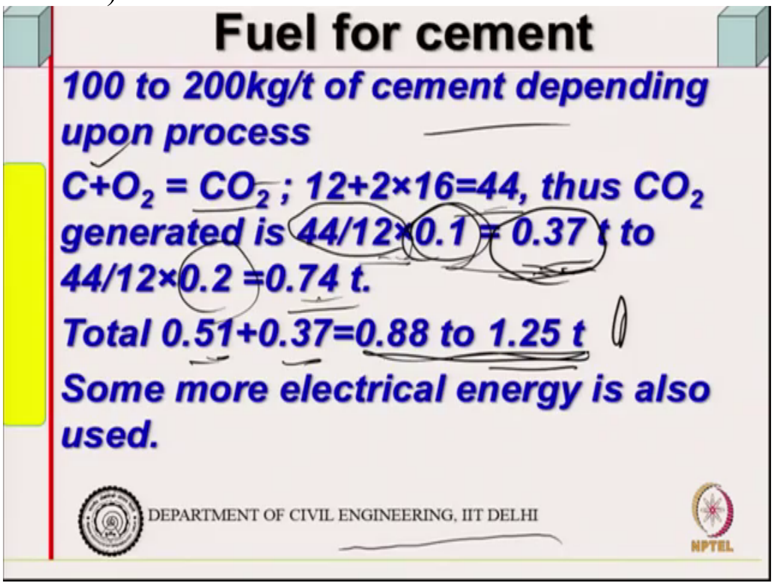

So fuel generally required is 100 to 200 kg, per ton of cement depending upon the process. An efficient process will require less fuel, somewhat less, so generally 100 to 200 kg of, you know, per ton of cement, that is what you need, fuel. And the fuel will burn to, carbon to carbon dioxide, some portion, some of course we will see that fuel what are those.

So 44, thus carbon dioxide generated is, the fuel if I say percentage of carbon is known in my fuel. So depending upon type of fuel you are using, type of burning process you are using. And you cannot use any you know, you cannot just heat them up. You need uniform burning. So what is done? Fuel is fed together which are often mixed up together. Then you do, you know the clinkerization or pre-heating process.

You know, then you do pre-heating process. Basically the heat, the waste heat from the kiln also, hot gases goes to the pre heater, there is some recovery etc. etc. So you actually you know, basically mixing is required, well mixing is required. So I could not have used electrical furnace which would have different you know burning would be, so technologically it is not possible. So this if you look at it, 44 by 12, right.

So 100 kg we said is 0.1 ton, I need 100 kg of fuel means 0.1 ton. So if I use 0.1 ton, then I get 0.37 tons of, and let us say this 100 kg is pure carbon. The fuel those are used are usually petcoke, petroleum coke, right. That you get from destructive distillation of the crude, from the crude when you actually, you know petroleum refineries what they do? They actually not destructive distillation sorry, the fractional distillation they do.

So the one that comes down below, that is the largest solid mass. The others are different temperature, different things will come out right, like your gasoline and petrol etc, they separate out, whatever is left is the petcoke. So that petcoke has got high carbon content. Furnace oil sometime or some very high good varieties of coal with very low ash content and so on. So that will be then grinded together so, if I use 100 kg or 100, 0.1 ton then I would generate 0.37 carbon dioxide, because 1 you know 100 kg means all carbon let us say.

12 unit of carbon produces 44 unit of carbon dioxide. So 0.1 ton will produce this or if I am using 200 kg then 0.74. And I am already at 0.51 from the clinkerization process. So you see 0.51 plus 0.37 will make it 0.88, and if I add 0.74 to 0.51 it will give you 1.25, right. That is why on an average, of course some electrical energy is also used, you know various kinds of system here and there, they are also used.

So that is what people say, what is the average of this one? Roughly around 1 ton. So one ton of cement, OPC cement produces 1 ton of carbon dioxide on an average, it could be less, 0.75 to even 1.25. Some process they might need even slightly less. So that is why you know some people will, you know people say 1 ton of cement produces, on an average it is expected that it will be around 1 ton. 1 ton of cement will produce 1 ton of, right.

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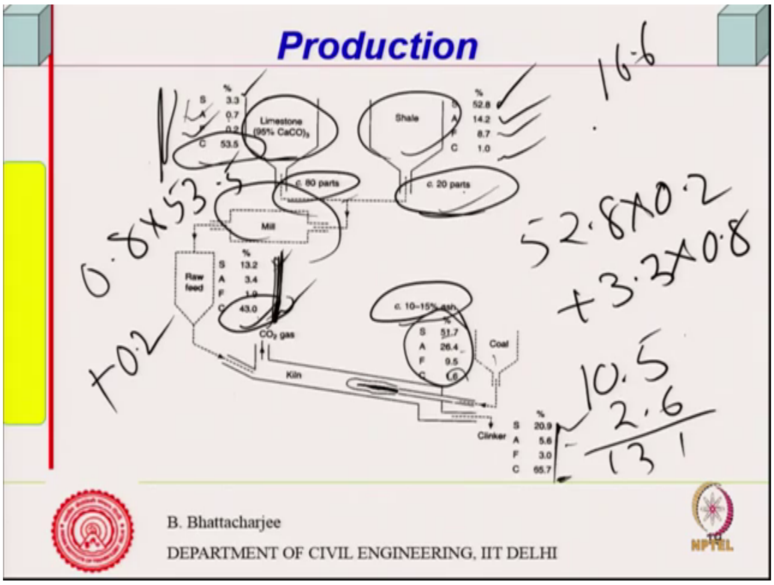

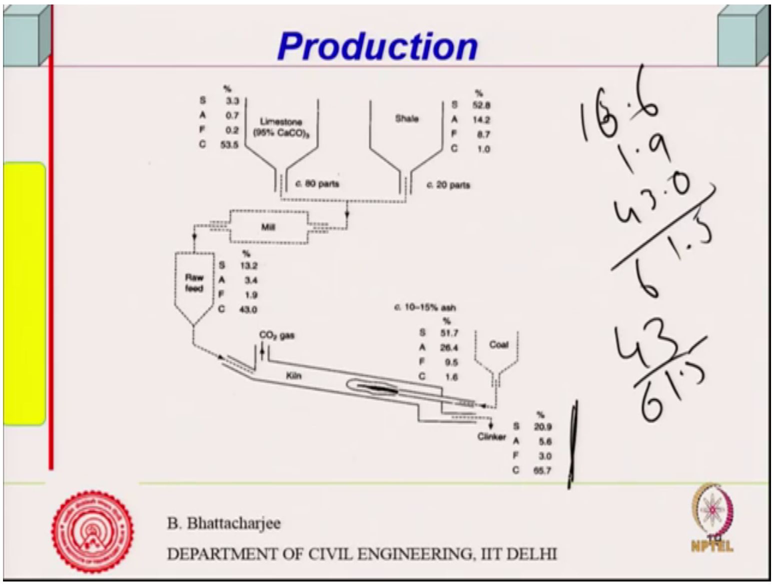

So if you see that limestone 95 percent calcium carbonate, shale right. So this is 80 parts, this is 20 parts. That is what the raw feed, typically you know quarried, you know land quarried material would be there. So this will have silica 52 percent, alumina 14.2, iron 8.7, calcium 1 percent or so. Typically similar could be the composition. This will have 3 point silica, 3.3; alumina is 0.7, iron 0.2 and calcium 53.5 percent.

So this could be some typical composition of the shale and the limestone, shale and the limestone, right. Now then I mix them into 80 to 20 parts to go to the mill, right. Then raw feed etc., and from there it goes to the burner. The point that is, here is, some of this material like nowhere limestone you will get pure limestone. In nature pure limestone will not be available. And what is abundant in the earth crust? Clay or clay minerals, you see, earth crust is full of clay minerals, right, so impurities are also clay minerals.

That is why we will have some silica, some alumina, some iron, minimum at least this. You might have some of the other things coming as impurities in the system, so this are the small quantities. So this is what it would be there. Although you do not like to have everything lined, that never happens. And somewhere they select the quarry having appropriate proportions of lime and clay. Otherwise they just mix shale from nearby places.

So 20 parts, 80 parts if you calculate this out, you will find out, so it will be 53.5 into 0.8, and this will have silica 0.2 into 52.8, you can calculate the proportion of each of the compound now, components now, this is what it would be. And that go to the mill and then the final product that would have 13.2 2. How? Because 52.8 into 0.2 plus 3.3 into 0.8, how much does it make, how much does it make? 10.5, roughly around 10.5 from this.

And this is 2.6, 13.1 here, I think I have done the calculations more or less ok, and this is important, c is important, c would be 0.8 into 53.5. 0.8 into 53.5 plus 1 into, 1 into 0.2 so 0.2. So rest all are simple. So that is how the raw feed, and then this is the kiln. And then if you are the coal of course, coal if you are using coal for burning, so coal goes in, you know coal goes in. And then this will have some ash left, 51 percent etc. So, then you can, from this you can actually calculate out because this will have silica, alumina 9 point and unburnt carbon is 1.6 and these are percentages in this one, 10 to 15 percent ash is there, so you can actually find out final product would be you know silica was 13, this was 43, and limestone was 43 and some small ash might come from here also, put together, this will show you something of this kind, right.

So because percentage-wise if you see even in this one, 43 plus 2 let us say 45 plus 3, 48 plus 13 would make it 50, 60 something. Out of which 43 is the limestone. This sum total how much it is? 13 point 2 plus 3.4 is 16.6 plus, this was 1.0, 16.6 plus 1.9 plus 43.0, right, 61.5. So 43 out of 61.5 you know so 1.16 is to 1.10 that is what we said to like 6.65, because final 1.16 that gives me 0.65, so this this will be fit into that kind of ratio. So that is the final product of the clinker will come if you calculate yourself. So that is what it is, okay.

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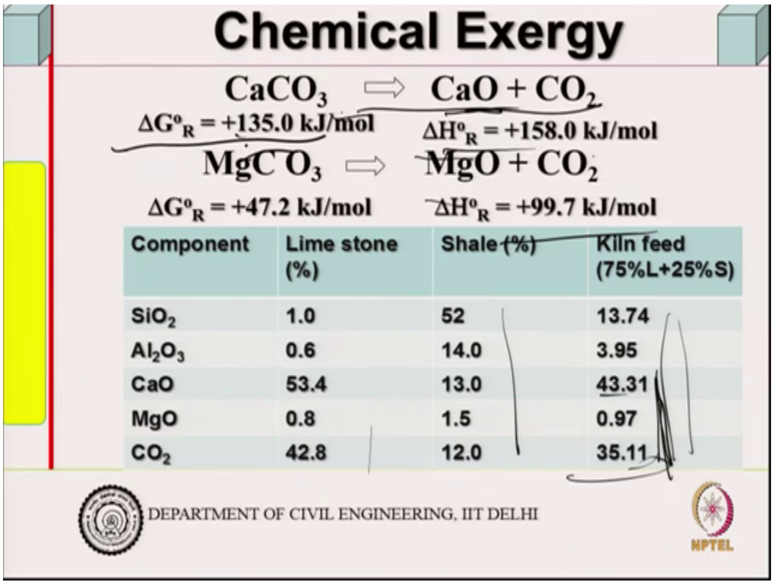

Now some more things. These are the two compounds, so I will come to this, state this a little bit later. Magnesium carbonate, now from the chemistry we know, the chemistry we know, the you know amount of kilojoules you require per mole, enthalpy changes, or amount of energy you require to which would be required to break this, amount of energy required to break this. Because you are giving energy, so how much energy required from chemistry we know, for calcium carbonate, calcium oxide to carbon dioxide you want to make, this the delta H R, change in enthalpy, the heat content.

So you have to at least supply this, but the efficiency of the system will be there. There is something called free energy. I am not going to do the thermodynamics part of it okay, but let me just quickly explain. This is the change in heat content of the material, internal heat of the material. Now, while changing this internal heat of the material, from this level to this level once you have changed it, you have raised it to higher (poten) higher energy level.

So it can come back to its, back to its original level again. But then it will not be able to release all the energy, because of some of the energy will get converted into what is called energy, disorder. So the free energy is the one, how much of the free energy you are getting to the system? Free energy is enthalpy minus whatever is lost through entropy, you know. So if you want to calcium oxide and carbon dioxide you are producing, supposing I am in an ideal (situate), I am again because they will try to automatically react.

They try to go to the calcium carbonate stage, you have given energy to break this. Then try to come back to their natural state that is what happens. I mean, obviously if you add water calcium hydroxide, carbon dioxide will go to calcium carbonate as you know. So, supposing I am able to, you know this will have a tendency to go back to calcium carbonate stage. Suppose I am trying to do that, it, you know I will not get this, this energy I will not get back.

I will get only part of it because part of it will be lost in entropy changes. Disordered changes you know, which is q by t. Okay, I do not think I will go into that. Similarly for magnesium carbonate, this is the amount of kilojoules per mole required. So typically the components could be something like this. Kiln feed could be something like this, let us say shale is you know, shale is 25 percent.

So silicon oxide to calcium oxide, this carbon oxide has been taken (togeth) together here. 43 etc, etc. so something like this. And one can calculate out how much is the this change. One can also calculate out this. Now I am not really I am not going to the thermodynamics part of it. But for the process, it is you know the process where entropy losses or it is called this, you know where I take care of the entropy or work potential, I call it exergy.

Sometime I mentioned this in the last class. So there are two kind of efficiencies, energy efficiency and exergetic efficiency. So for the process, exergetic efficiencies are very important. Energy efficiency is always important for our purpose, but some of them you cannot help it because chemically natural process it is this. But your fuel system you can always look into how it is, how efficient the fuel system and your process overall, how efficient it is.

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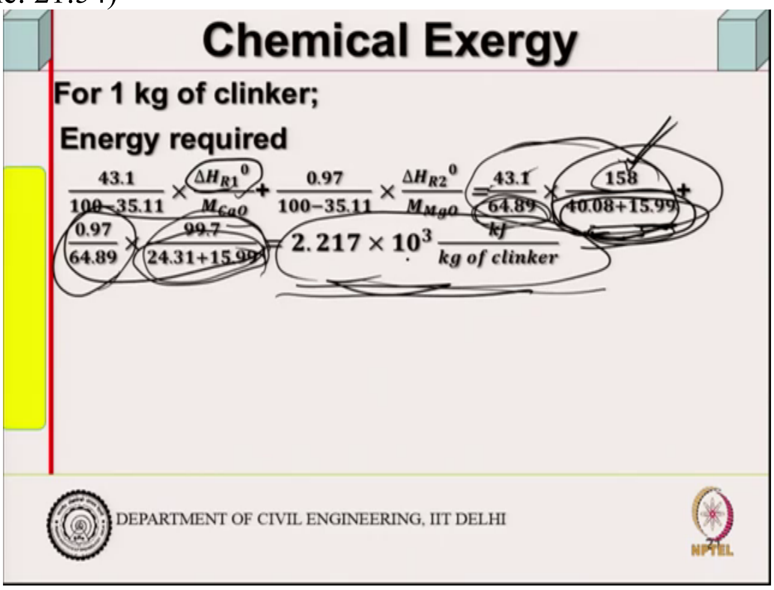

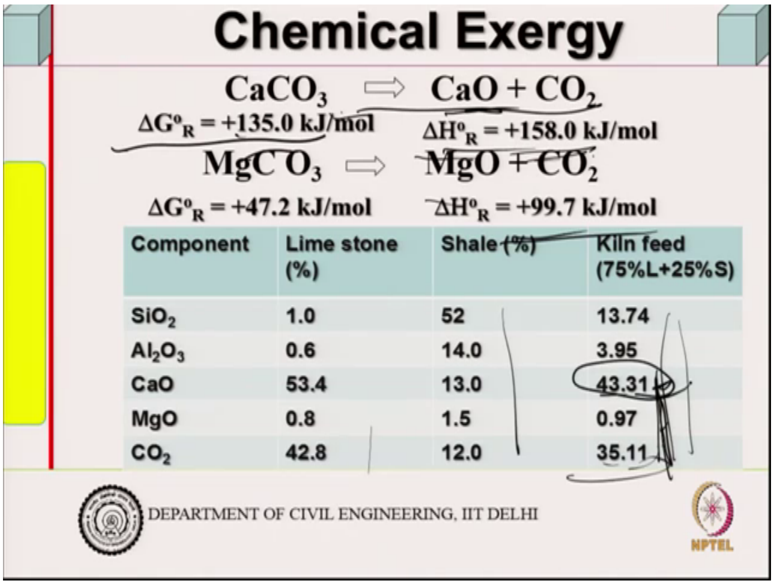

So 1 kg of clinker one can show how much energy would require, because for this combination of 43 calcium oxide, for 43 calcium oxide, 100 minus 35 because 35 is the carbon dioxide going out, divided by production of calcium oxide requires this much kilojoules of energy. So this much kilojoules, I can find out. So this is the 100 minus 35 is a solid part and it requires you know like how much, this is for magnesium or calcium only.

This totally both for magnesium and calcium both are taken into account. Yeah, so this is calcium oxide. For calcium oxide, this is the delta H for calcium (ox) so molecular weight of calcium oxide and this is the, how much was, how much was this? 158, yeah. This was 158, this is 99.7. So this is for magnesium, this part is for magnesium and this part is for calcium. So 43.1 percent was calcium oxide.

In the cement you will have, you know percentage-wise 64.89 something like that is being conceived. Summing up, leaving out the carbon dioxide part of it. So sum total will give something like this, that is the part of the cement. Solid 100 minus 35, so one can actually calculate out how much energy kilojoules per kg of clinker required. This will work out to be 2.217 because 158 is required for, 158 is the enthalpy change is required for calcium oxide per mole, right.

So if you have you know I mean for 1 ton of cement, how much calcium oxide is there, and that divided by molecular weight. So the molecular weight comes into picture. There40 is the calcium oxide, is more precisely taken, 40.08 and 15.99 instead of 16. So this is the molecular weight. So for one mole this is the heat required, right. One mole this is the heat required, so 158 kilojoules will be produced from these many Kgs.

From 43.1 kg, how much will be produced? Because 43.1 was a sum total. Here if you sum it up, yeah this is the 43.31 calcium oxide. So this is, this and the proportion of calcium oxide in the system is 64.89 because exact calculation has been done. So this is the amount of heat that your enthalpy change is required for calcium carbonate to calcium oxide.

This is for the magnesium part of it, how much was it? Magnesium percentage is, magnesium is 99.7 is the heat, you know enthalpy changes and, magnesium is 99.7, total 64.89 is the solid mass actually. And this is the magnesium oxide molecular weight. So this way if you calculate out you get 2.217 into 10 to the power 3 kilojoules per kg of clinker. So, you can calculate this out you know, calculate this out. This is the energy required or enthalpy change required, not energy. Enthalpy change required to produce you know 1 kg of clinker, 1 kg of clinker, so this is how, this is per kg of clinker.

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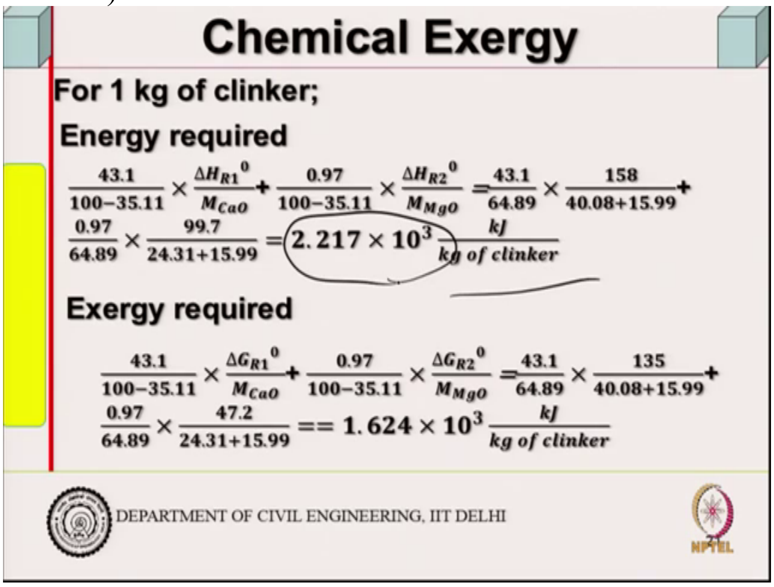

One can do also exergetic calculation, I am not really interested in this right now. So this one can calculate out.

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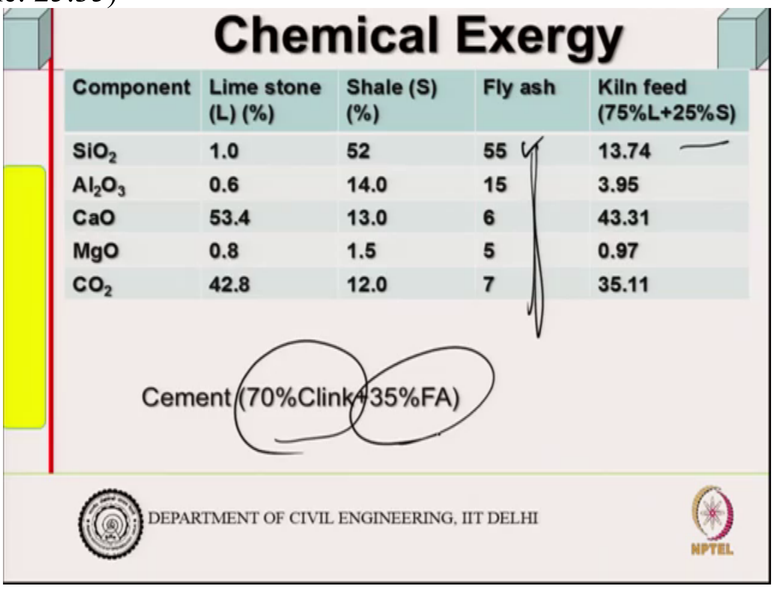

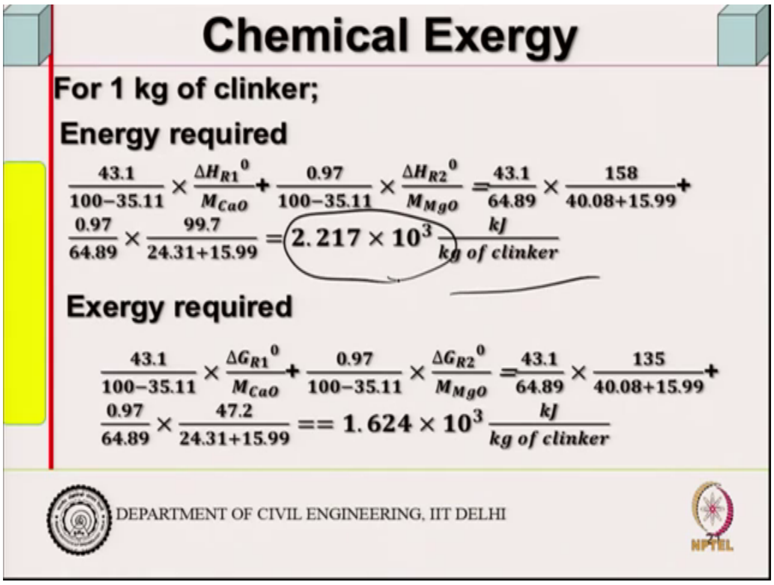

Supposing I use fly ash, supposing I am using, I use fly ash some 25 percent then fly ash would have different combination, obviously I am saving onto the enthalpy or energy part of it also because the fly ash is straightaway available.

I am just adding it or grinding it. So therefore you can see that 70 percent clinker and 35 percent fly ash. 75.75 multiplied by this much and enthalpy changes will be there, the other one would not have anything. We are obviously ignoring the grinding part of it. So when you use such material such as fly ash, obviously your energy required will be reduced.

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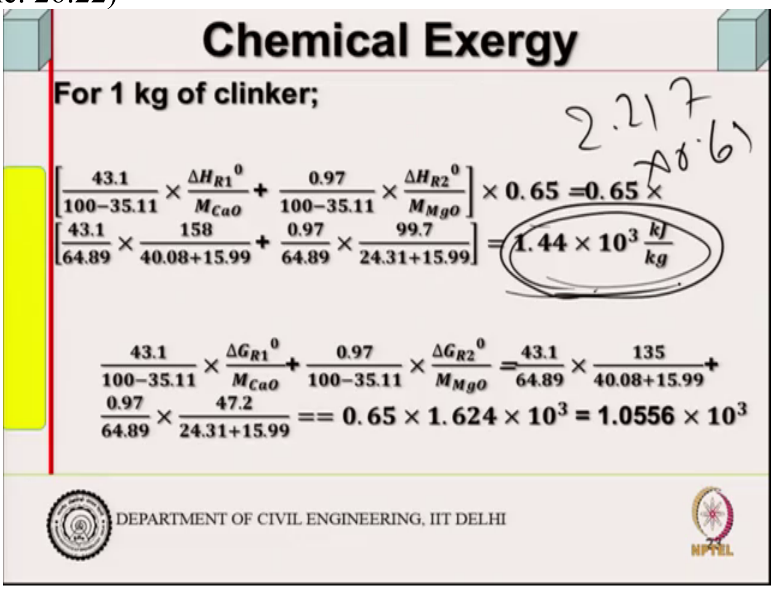

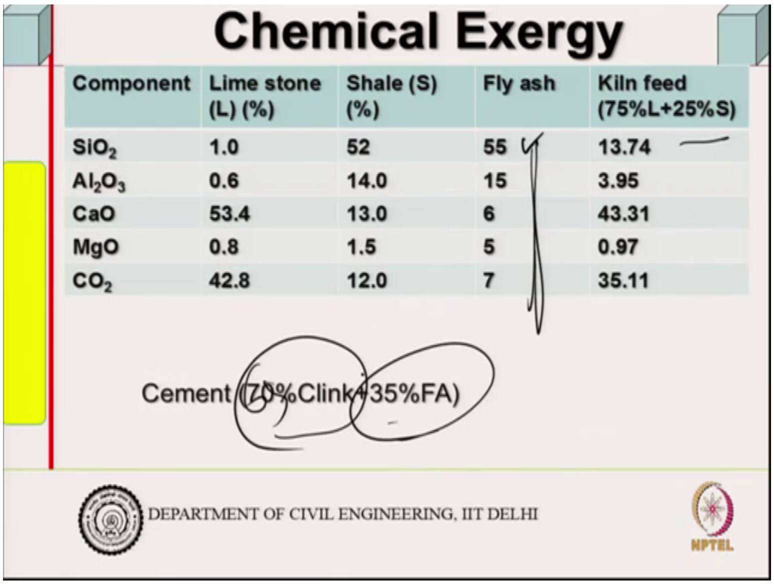

I do not think I will, so you can see that it is point, you know how much was the percentage? I said 65 and 75, 35 it will be. So I am multiplying everything by 0.65. So 2.217 multiplied by 0.6, 2.217 into 0.65 that is what it will be. So using those materials which are already waste material which I can add directly, obviously will save into my energy, besides wastes are also absorbed. So eco footprint scenario, you know this would be much more advantageous. Okay I do not think I will look into this.

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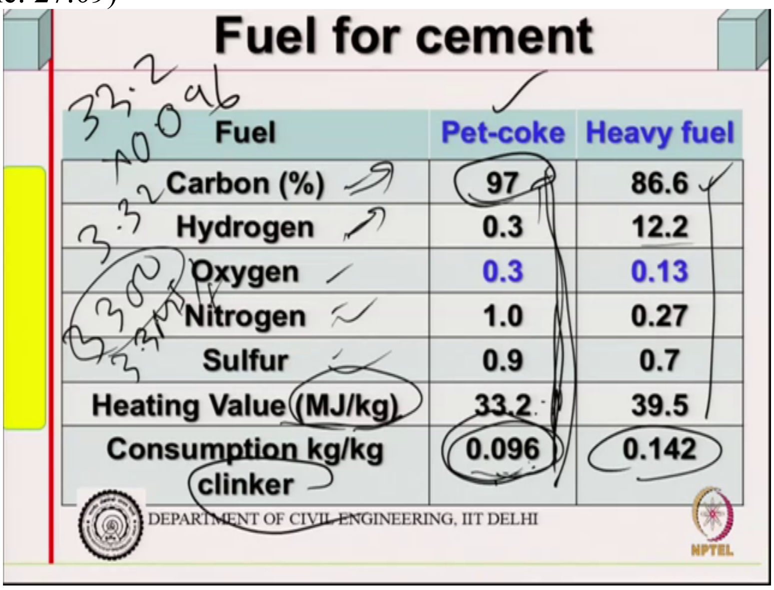

Typical fuel for cement. Petcoke would have 97 percent carbon. They are heavy fuel like furnace oil and similar sort of thing; 86, so this is very much preferred actually, this is very much preferred. In fact in India, most of it they use. But there is something more than that. I will just come into this. There is something more. Most of the cement plant, I mean at least two major plants I have looked into in India which like Ambuja Cement for example in Gujarat, Ambuja Nagar or Wadia of ACC which I have, which I happened to have visited.

Similar ones must be there elsewhere also. They actually use all sorts of alternative fuels, which I will come and discuss later on. So for example Ambuja Cement there are lot of plastic and paint factories. So all those can be used as alternate fuel as long as they are, they do not produce any toxic, you know do not release any toxic gases to the atmosphere, toxic gases to the atmosphere. So they practically use all, they practically use all.

You know the not only that the double advantage they get is the people who are supposed to dispose those waste, now they do not have to dispose, they might give them free of cost, right. All that they have to do is analyse them for their chemical and mineralogical composition and all that and see as per standard how much is the toxic emissions out of those, kind of toxic gases emission out of those after burning, so based on that they do.

This is obviously would be I know relatively this comes from the petroleum, I mean you know refineries. Now so generally they will have carbon, hydrogen, oxygen, nitrogen, sulphur. So when you heat them up, obviously this goes to carbon dioxide, this is water, no problem and the oxygen some part is a very small but at high temperature they produce that NOX, not this oxygen, atmospheric oxygen as well and sulphur dioxide. So that is how they come.

And in this one obviously, there might be other compositions of fuel of varieties of kind. But alternate fuel when we talk about, we will see that what is the advantage. So there is something called heating value, megajoules per kg. That is important, how much heat you are getting. We have seen the energy required, which is around 2.217 into 10 to the power 3, was it kilojoules or megajoules? Kilojoules per kg, kilojoules per kg, right.

So it would be kilojoules, so this how much you would need, the how much fuel you would need, that would you know that you can find out from this. Plus the efficiency factors would be there, so will efficiency factors will be there. So consumption per kg of per kg of clinker is therefore. Since, this will be less because this has got more carbon, right. And typically the consumption is 0.96 kg per kg of clinker.

Now multiply this by this, how much megajoule megajoules you are getting? 33.2 into 0.96, right. How much it would be? Even if I take it to be 0.1, it would be 3.3, roughly around 3.2 megajoules or 3.3 you know around 3 megajoules you will have. Which means that 3300kilojoules right, 3000 you know 3000, this is 3300 kilojoules per kg, which would mean actually per ton how much it will be? I should multiply this by1000, which will mean 3.3 megajoules per ton, am I right?

So 0.96 multiplied by 33.2 because this is megajoules per kg is the heating value. So it will generate that much heat. So multiply by this, roughly I have multiplied by 0.1. 0.096 is 1, so which will give you 3.32 megajoules per kg of clinker per kg of clinker right, per kg of clinker, okay. I mean per, this is heating value sorry, heating value per kg of this petcoke.

So, I need 0.096, so this will give me, multiply by this two, I will get 3.32 megajoules, you know because this is this much I have used for 1 kg of I require for 1 kg of clinker, I need 3.0, I mean I will generate 3.32 megajoules. From this you know it is coming that, 3.32 megajoules for 1 kg of clinker that will be generated that would be, you know if I want to generate 1 kg of clinker, I need from the pet-coke this is what I need, I will get the energy.

And this, this is for 1 ton, I will just multiply this. So 3.3, 3.3 into 10 to the power 3. And how much was the requirement from enthalpy? 2.217. You know that is why I was trying to calculate it out because if I would do this…

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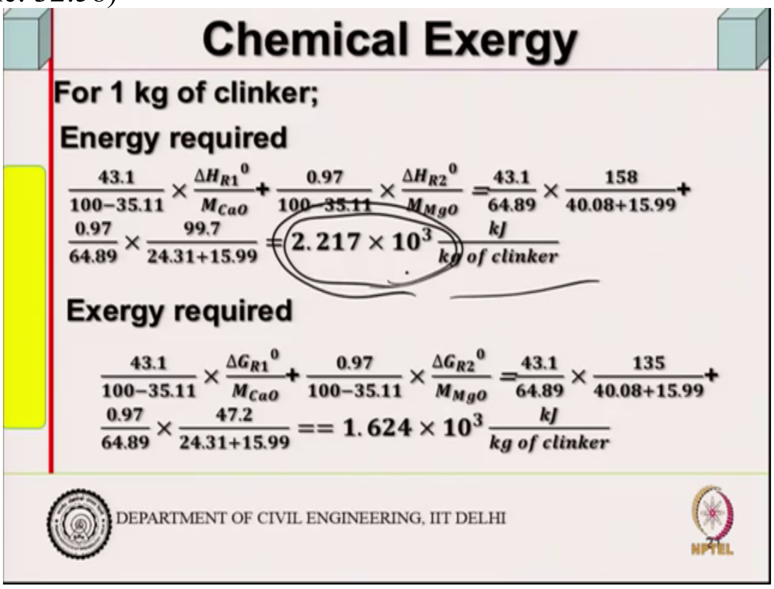

2.217 kilojoules actually. So you can see the orders changes, there are lot of here and there, there will be lot of losses and efficiency you can see. So anyway, so is the typical composition of somewhere.

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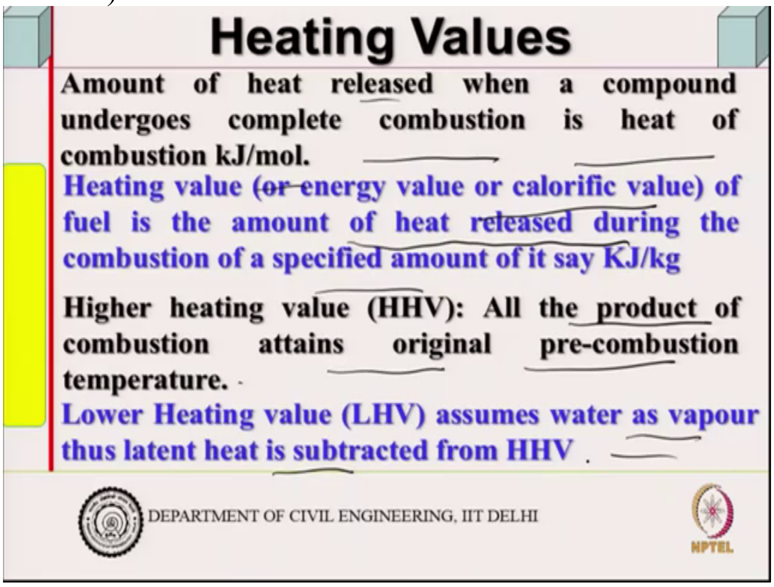

We define two terms called heating values: amount of heat released when a compound undergoes complete combustion is heat of combustion in kilojoules per mole, that is what we know. Heating value or calorific value of fuel is the amount of the heat released during the combustion of a specified amount of it say kilojoules per kg, right. So this is calorific value in other words.

Now there are two heating values, higher heating value and lower heating value right, lower heating value. So all the products of combustion attains original pre-combustion temperature. That means you have a you know like pet-coke you burn it, the heat is generated. Even the fuel gases at the top, if it comes to the ambient temperature, then this heat is all utilised. That is upper limit, but actually this will not be the case.

Assumes water vapour as vapour, so latent heat goes, water remains as vapour, and some gases which is at high temperature, that heat you know so the lower heating values assumes the water vapour, particularly the water vapour because some less amount of heat actually you can realise because latent heat of vaporisation will not be available for your work, obviously there are other efficiency losses like hot gases going out, some energy has gone there. So this is you know this is important for raw material because higher the heating values, they will require less fuel and obviously you know lesser carbon dioxide production.

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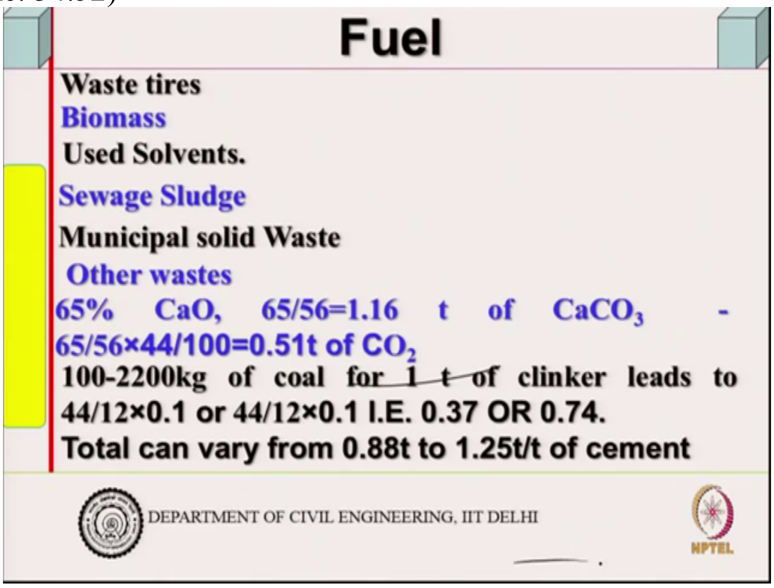

So the alternative fuels that are there, people are using. Waste tires, biomass, used solvents, sewage sludge, municipal solid waste, all other waste, and so that is what we talked about. Now advantages, this is what we looked into and this is what we have looked into.

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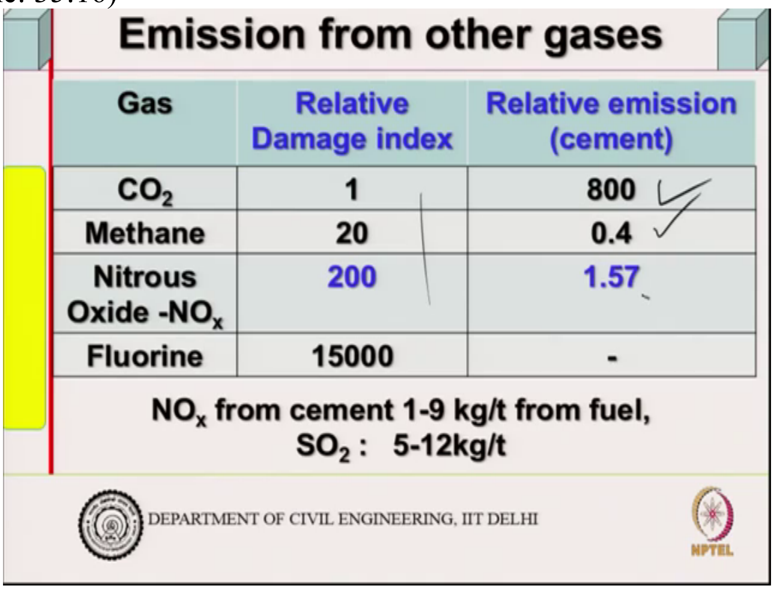

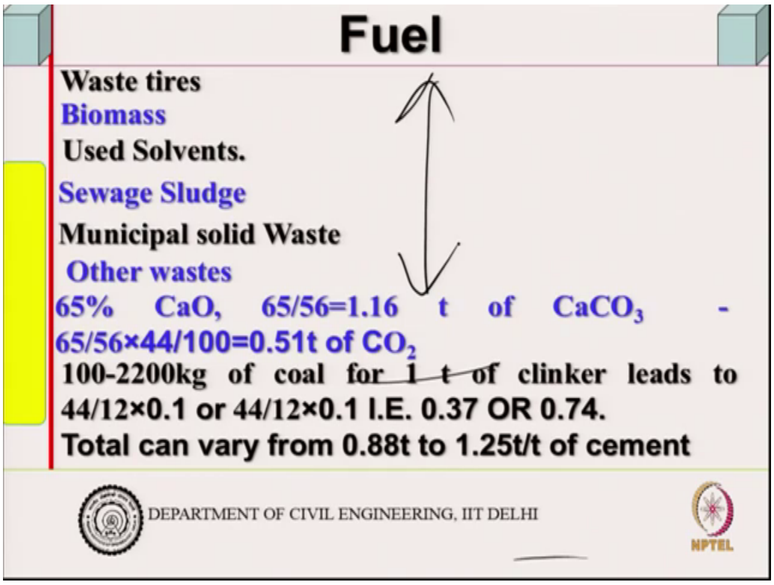

Now we will come back to this in the next class but just I want to finish here. Advantage of using this is whenever you take this into account, whenever you use this sort of material, they do not go into accounting. So the eco footprint of the factory will come down. Supposing I am using waste material, this is does not go into accounting, and the factory gets the advantage which is eco footprint comes down. So, all the environmental control organisation, they really encourage this, right. So we will just come into this.

So, damage index from various gases is something like this, I think I mentioned, right. So this we will look into. So relative emission from cement comes out to be 800, I have shown you earlier, methane was you know hydrocarbons and nitrous gases are 1.57. So I think this gives you, so we will look into that in the next class.