Technologies for Clean and Renewable Energy Production

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Lecture-06

Cleaner Route for Energy Production from Coal

Hi friends, now we will discuss on the topic cleaner route for energy production from coal. In the last class, we have discussed on the conventional route for energy production from coal and we have seen that combustion based thermal power plant is the most conventional route for energy production from coal. And in this process, coal is burnt in a furnace and then flue gas which is having high temperature is passed into the boiler for the production of steam, and then the steam is used in turbine for electricity production.

Now, here we will discuss what are the possibilities to make more cleaner energy than the conventional one, because in the conventional process, we have seen that the emissions are higher, the SOx, NOx and CO_2 emission are higher. So, if we want to reduce the emissions, what can be the possible routes, that part we will discuss in this class. As you know prevention and control these are two important philosophy for the management of something or to achieve our target quality.

So, in this case, we can try to prevent the emission level or we can take measures to control the concentration of the pollutants present in the flue gas by its cleanup. So, one is our prevention that means, that is related with feedstock that is the coal which we are using we may clean it or during the process of combustion when the flue gas is forming at that time, we can take some modification in the process, so, that we can get less emission through this process.

Or we can also use some alternate techniques in place of combustion. So, that way we can control the emission level.

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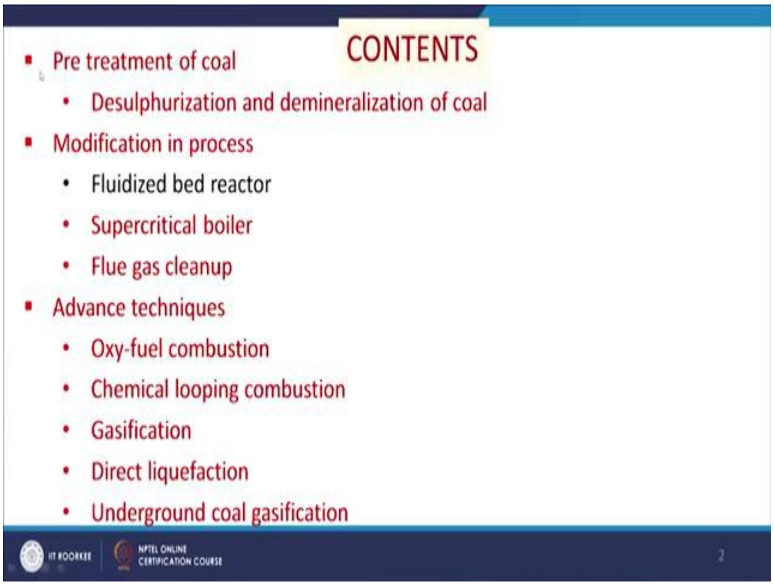

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Now, these are the contents of our discussion, that pre treatment of; the pre treatment of coal that means here we are interested to clean the coal before its application and modification in process, we can use the different types of reactor, improved reactor and then the boiler device that can be of supercritical type and flue gas cleanup. And we can use some advanced techniques like oxy-fuel combustion, chemical looping combustion, and then gasification direct liquefaction and underground coal gasification.

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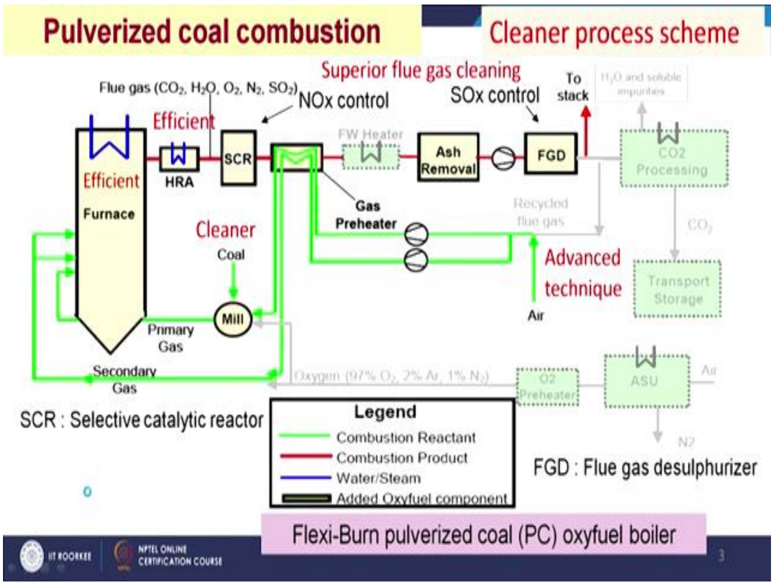

Pulverized coal combustion

Cleaner process scheme

SCR : Selective catalytic reactor

FGD : Flue gas desulphurizer

Flexi-Burn pulverized coal (PC) oxyfuel boiler

Now we will see this is the conventional flowsheet, say, here coal is burnt in the furnace and then flue gas is going and here we are recovering the heat. Then it is going for clean up section and coal is put here. So, this is a conventional process. Now, what we can do, we can clean the coal in higher extent, we can use more efficient furnace or we can use more efficient heat recovery system or we can use more superior quality of gas cleanup processes or some advanced techniques.

As shown here these lines are related with oxy fuel combustion. Oxy fuel combustion, another method which is the replacement of the combustion process. So, here nitrogen is separated at first from the air and so, only oxygen we can use. So, if we use more oxygen, the flue gas will be having more carbon dioxide it will not be having nitrogen. So, once it is not having nitrogen, its capture will be very easy.

So carbon dioxide capture we can get here and the whole process will be more cleaner. So, these are the scopes, which we have to improve the cleanliness of the process or to reduce the emission level. So, we will discuss all those things. At first we will see how the coal is cleaned As of today in the conventional process also coal cleaning is performed to remove the ash and sulphur. So, we have to take more action, if we can reduce the pollutants level like say sulphur, ash content, nitrogen content in the coal.

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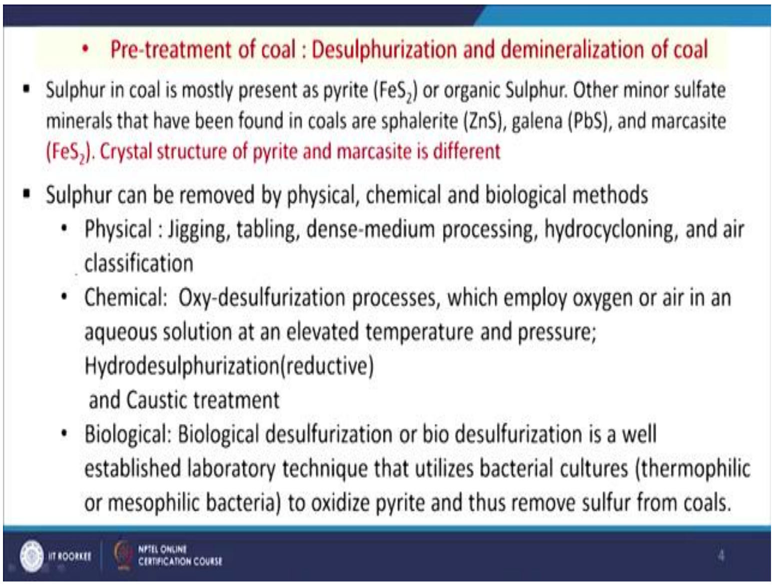

- Pre-treatment of coal : Desulphurization and demineralization of coal
- Sulphur in coal is mostly present as pyrite (FeS_2) or organic Sulphur. Other minor sulfate minerals that have been found in coals are sphalerite (ZnS), galena (PbS), and marcasite (FeS_2). Crystal structure of pyrite and marcasite is different
- Sulphur can be removed by physical, chemical and biological methods
  - Physical : Jigging, tabling, dense-medium processing, hydrocycloning, and air classification
  - Chemical: Oxy-desulfurization processes, which employ oxygen or air in an aqueous solution at an elevated temperature and pressure; Hydrodesulphurization(reductive) and Caustic treatment
  - Biological: Biological desulfurization or bio desulfurization is a well established laboratory technique that utilizes bacterial cultures (thermophilic or mesophilic bacteria) to oxidize pyrite and thus remove sulfur from coals.

And what are those methods used, we will be discussing now, if you consider the sulphur; then sulphur is present in coal in terms of inorganic and organic form. In the inorganic form basically it is pyrites FeS_2 and some others are also there that is ZnS, PbS, and FeS_2 this is this is your marcasite and another is your pyrite. So, pirate and marcasite, these are 2 minerals are having same formula, but they are different in their crystal structure.

So, these are the source of sulphur. So, we can remove this sulphur from the sources by different methods, one is physical and chemical and biological. How we can remove in the physical method, we can use the help of jigging we can use the tabling we can use the dense medium processing, hydrocycloning and air classification. So, in the jigging we take the advantage of the difference in the initial acceleration when different particles start to fall from a certain place from its rest position then initially they possess different velocity.

So, that will be utilised to remove the different particles with different densities and size etcetera, that is the jigging operation and dense media processing, in this case, we use certain slurry that is having certain specific gravity, now coal is heterogeneous sample and it will be having ash, carbon and etc. So number of particles if it has then that will be having different density, say, ρ. Say, different densities are there for coal, say, ρ1, ρ2 ρ3 ρ4 etc.

So, different particles have different density, if we use one slurry solution that is the specific gravity is equal to say ρ3. So, in that case, the lighter than ρ3 that will float and heavier than ρ3 will fall. So, this is a way we can get if ρ4 are higher than this ρ3 then ρ4 will come at the bottom and this will be at the top. So, gradually if we take another solution, which is having lesser density, so, more lighter particles will also come up.

So that way we can clean the coal from the impurities like say, ash contents, mineral contents basically mineral contents which are having higher specific gravity than the coals particle. So, now the chemical methods, these methods the physical method are suitable to remove the minerals, but it is the sulphur which is available in organic form, those are not very easy to separate by this method so chemical methods are used in this case.

So, some examples are oxy desulfurization process, in this case, oxygen in dissolved form in some solution aqua solution at elevated temperature and pressures are used. So that the sulphur of the pyrites is oxidised or organic sulphur can also be oxidised to some extent and then hydro desulfurization where if we supply hydrogen and at high temperature control, if we have good control on it, so, we can get some conversion of the sulphites to the sulphur dioxide.

So, next is caustic treatment. So, SOx as you know it is acidic in nature. So, if we use some alkaline solution, caustic solution in control amount, so, some sulphur can also be removed and then biological methods, some microbes are used for the degradation of the sulphur compound, some example are some thermophilic or mesophilic bacteria.

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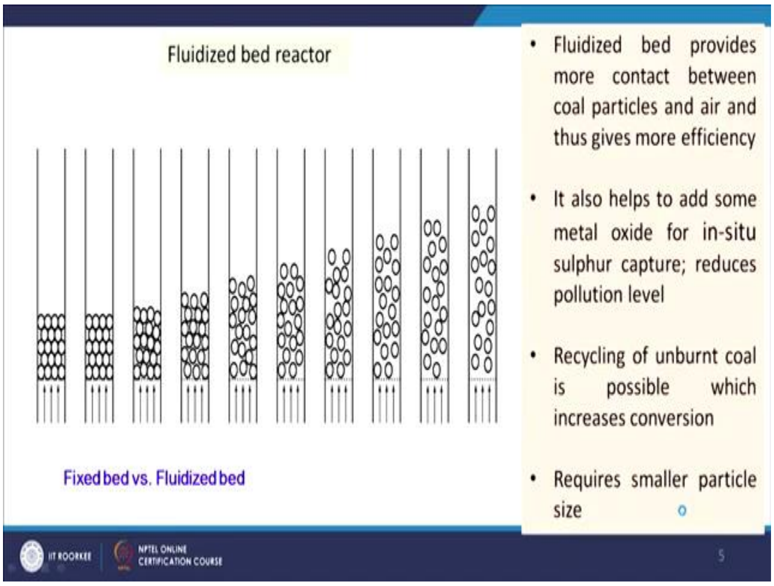

Fluidized bed reactor

Fixed bed vs. Fluidized bed

- Fluidized bed provides more contact between coal particles and air and thus gives more efficiency
- It also helps to add some metal oxide for in-situ sulphur capture; reduces pollution level
- Recycling of unburnt coal is possible which increases conversion
- Requires smaller particle size

Now, we are coming to the changes which you can have during the process, one is Fluidized bed reactor. If fluidized bed reactor is used then we can get more reaction, possibilities of more reactions, how because if you see here it is a fixed bed and these are the fluidized bed. So, in fixed bed the particles are very close and in a fluidised bed the particles are not very close it is separated. So, coal combustion is a solid and gas phase reaction.

So, when the solid particles will be surrounded by more gas molecules, so, there will be good chance of the reaction. So, that that is why we get more chance of reactions in case of fluidized bed reactor and in this case the particle sizes are also less. So, once the particle size is small, then one way we can reduce the loss of the fines of the coal particles, fine coal particles and secondary we can get more interaction of the solid particles with the gas molecules and more rate of reaction.

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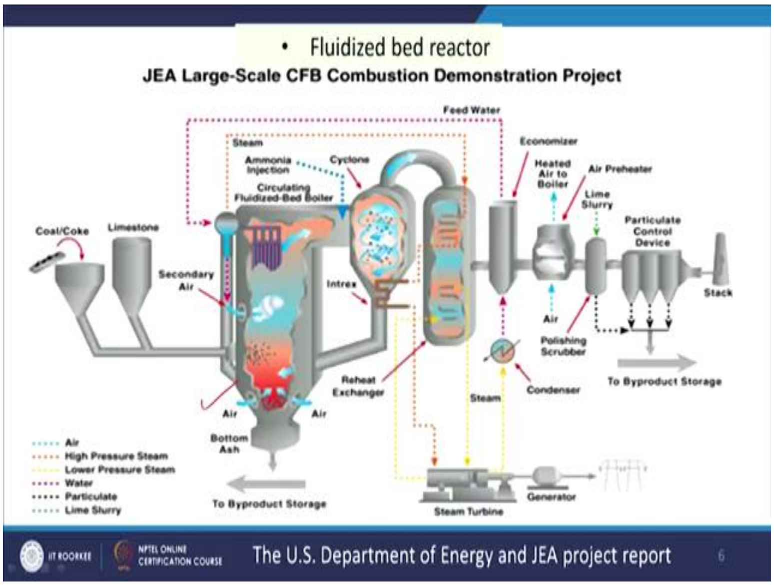
- Fluidized bed reactor

JEA Large-Scale CFB Combustion Demonstration Project

The U.S. Department of Energy and JEA project report

Apart from this, this fluidized bed reactor can also give some; gives us some other advantage like say we can add limestone here with the feedstocks. So, feedstocks and limestone is coming here. So, all our solid particle are fluidized and then in situ SOx capture is possible. In situ SOx capture, so, the limestone will react to this SO_2 and it will be settled here. So, there is one additional advantage and if the fine particles are coming here and it is also getting some recycling possibilities.

So, more conversions of the carbon we will get here in this fluidized bed reactor, but if we use fluidized bed reactor, then we need smaller particles. So, during crushing we have to use more energy. So, on economic aspect this process may have some less efficiency or it may cost more than the conventional one.

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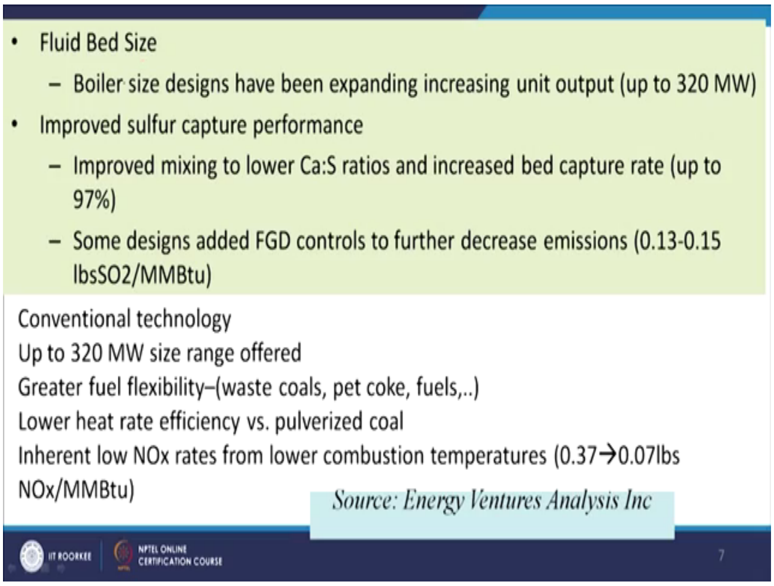
- Fluid Bed Size
  - Boiler size designs have been expanding increasing unit output (up to 320 MW)
- Improved sulfur capture performance
  - Improved mixing to lower Ca:S ratios and increased bed capture rate (up to 97%)
  - Some designs added FGD controls to further decrease emissions (0.13-0.15 lbsSO2/MMBtu)

Conventional technology
Up to 320 MW size range offered
Greater fuel flexibility–(waste coals, pet coke, fuels,..)
Lower heat rate efficiency vs. pulverized coal
Inherent low NOx rates from lower combustion temperatures (0.37→0.07lbs NOx/MMBtu)

Source: Energy Ventures Analysis Inc

Now fluidized bed size we have in market that is up to 320 megawatt power plant is possible by this technology.

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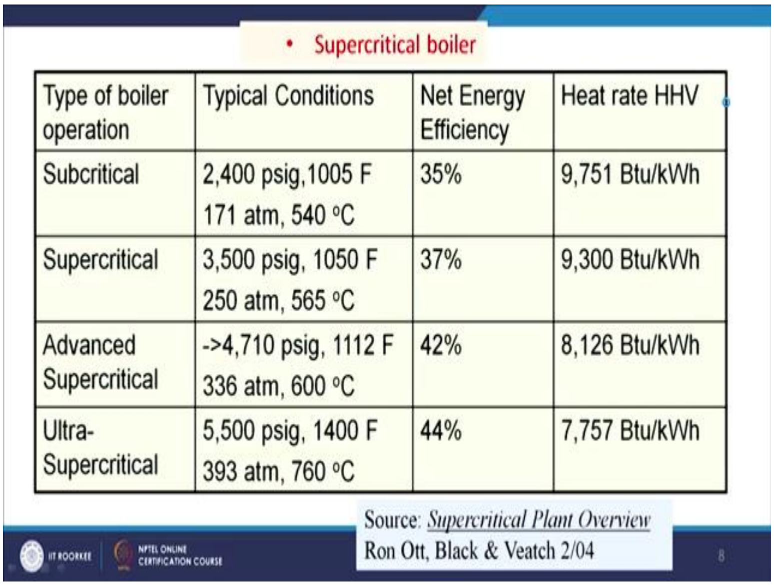

- Supercritical boiler

Type of boiler operation	Typical Conditions	Net Energy Efficiency	Heat rate HHV
Subcritical	2,400 psig,1005 F 171 atm, 540 °C	35%	9,751 Btu/kWh
Supercritical	3,500 psig, 1050 F 250 atm, 565 °C	37%	9,300 Btu/kWh
Advanced Supercritical	->4,710 psig, 1112 F 336 atm, 600 °C	42%	8,126 Btu/kWh
Ultra-Supercritical	5,500 psig, 1400 F 393 atm, 760 °C	44%	7,757 Btu/kWh

Source: *Supercritical Plant Overview*
Ron Ott, Black & Veatch 2/04

And now we will come into boiler part, conventionally sub critical boiler is used at 171 atmosphere and 540 °C. So, in this case we get 35% net energy efficiency and heat rate is 9,751 Btu per kilowatt hour. If we use supercritical, then operational be 250 atmosphere and 565 degrees centigrade and here 37% efficiency we are getting if we use advanced supercritical then 336 atmosphere and 600 °C, we can get 42% efficiency.

If we use Ultra-supercritical 393 atmospheres at 760 °C, then we can get 44% energy efficiency, but you see heat rate is decreasing. So, it is very clear to us, we can improve the efficiency of the process, if we replace the sub critical boiler to advance or ultra supercritical boiler.

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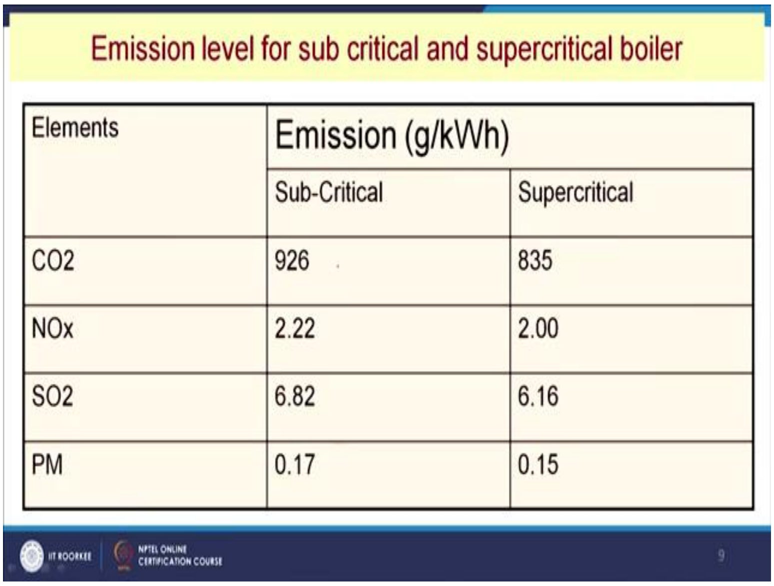

Emission level for sub critical and supercritical boiler

Elements	Emission (g/kWh)	
	Sub-Critical	Supercritical
CO2	926	835
NOx	2.22	2.00
SO2	6.82	6.16
PM	0.17	0.15

In this case, we can improve the emission level like the in case of sub critical CO_2 926 and a supercritical it is 835 gram per kilowatt hour emission in case of carbon dioxide for NOx are also here. So it is very clear that for all the cases, we are getting some reductions in supercritical boiling condition. Now we will come to flue gas clean up, what we can do with the flue gas cleanup. Now, conventional methods also have some cleanup, but we have to apply more advanced technique for the more efficient removal of the pollutants from the flue gas.

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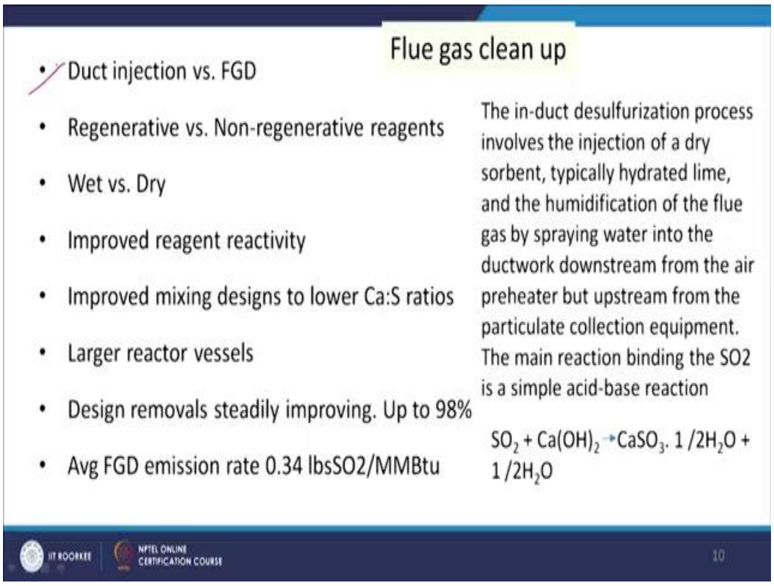

Flue gas clean up

- Duct injection vs. FGD
- Regenerative vs. Non-regenerative reagents
- Wet vs. Dry
- Improved reagent reactivity
- Improved mixing designs to lower Ca:S ratios
- Larger reactor vessels
- Design removals steadily improving. Up to 98%
- Avg FGD emission rate 0.34 lbsSO2/MMBtu

The in-duct desulfurization process involves the injection of a dry sorbent, typically hydrated lime, and the humidification of the flue gas by spraying water into the ductwork downstream from the air preheater but upstream from the particulate collection equipment. The main reaction binding the SO2 is a simple acid-base reaction

$$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 . 1/2H_2O + 1/2H_2O$$

One example is say, duct injection versus FGD, Flue Gas Desulphurization. So, what happens in case of duct injection, we also use some material that is, sorbent is used in duct. Dry sorbent is injected in the duct and then it is humidified by the water downstream of the injection and upstream of the preheater from the particulate collection equipment. So, this is the conventional method. But replacing this if we can use flue gas desulphurization where spray takes place, so scrubbers are used in that case, the efficiency improves for the removal of SOx from the flue gas.

Regenerative and non regenerative reagents, we can use the reagents which are regenerative in nature, so that it will help the economy of the process wet and dry methods are there. So, wet method, flue gas cleanup and dry method is also developed in recent years. So, if we want to use the wet process, then we have to reduce the temperature of the flue gas and in dry process, it can remove the pollutants at high temperature also, that is why there will be some variation in the economy also.

The improved reagent reactivity, the reagent reactivity can be more if we can select a suitable reagent, the reactivity will be more so less reactant requirement will be there. An improved mixing design to lower calcium is to sulphur ratios. So just fluidized bed reactor if we can change the design say, circulatory fluidized bed reactor, so calcium is to sulphur ratio can be reduced and larger reactor vessels also helps to get more removal of pollutants.

And design removals steadily improving up to 98%. So, an example is given here and average flue gas desulphurization emission rate is 0.34 pounds sulphur dioxide per MMBtu. So, this is one; these are some examples, where we have some possibility to improve the efficiency of the cleanup system.

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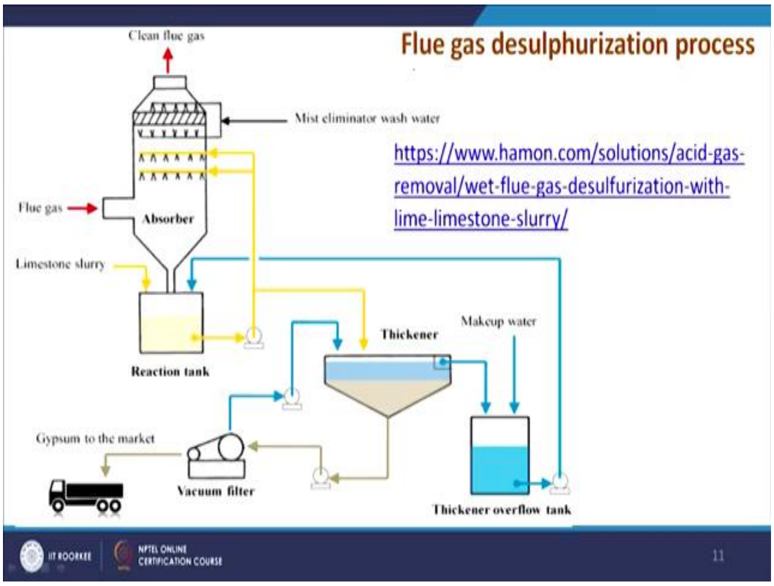

Flue gas desulphurization process

https://www.hamon.com/solutions/acid-gas-removal/wet-flue-gas-desulfurization-with-lime-limestone-slurry/

Now, this is one example of flu gas desulphurization process taken from this reference. So, here we see flue gas is coming. So, we have lime stone slurry, so it is pumped and sprayed here. So we are getting clean flue gas and then this slurry part of it is taken back for thickening and then from this we can get gypsum. And the supernatant from this thickener it is again recycled back to this to reduce the water use. Then after SOx removal, the particulates removal is also important.

So, particulates are removed, different types of devices are used to remove particulates. And in case of coal based power plant, mercury may exist as particulate form. So, that removal is also very, very important. And mercury can be available in oxidised form, in elemental form and in particulate form.

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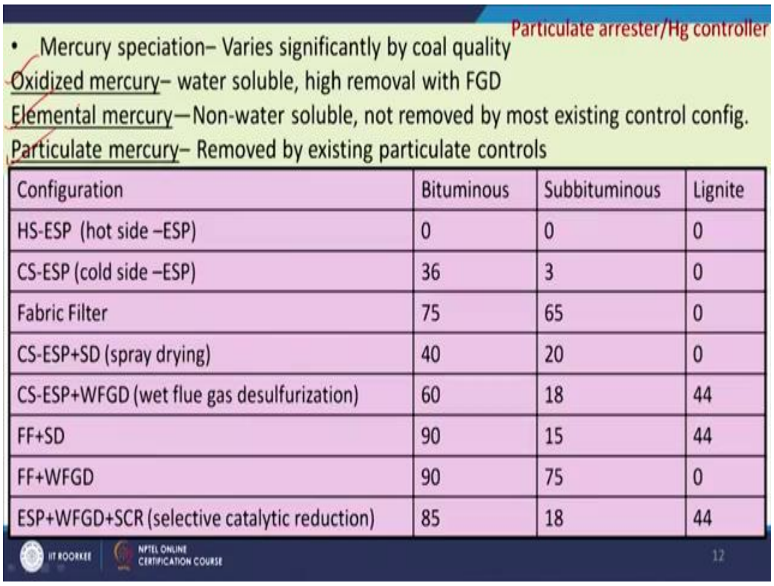

Particulate arrester/Hg controller

- Mercury speciation– Varies significantly by coal quality

Oxidized mercury– water soluble, high removal with FGD

Elemental mercury—Non-water soluble, not removed by most existing control config.

Particulate mercury– Removed by existing particulate controls

Configuration	Bituminous	Subbituminous	Lignite
HS-ESP (hot side –ESP)	0	0	0
CS-ESP (cold side –ESP)	36	3	0
Fabric Filter	75	65	0
CS-ESP+SD (spray drying)	40	20	0
CS-ESP+WFGD (wet flue gas desulfurization)	60	18	44
FF+SD	90	15	44
FF+WFGD	90	75	0
ESP+WFGD+SCR (selective catalytic reduction)	85	18	44

And these different forms of mercury have different solubility, this is water soluble oxidise mercury and elemental non water soluble. So, the techniques to remove this mercury will also be different. So, we will try to develop effective systems for the removal of complete mercury from the flue gas. And some examples are given here, some configurations on ESP and the hot side ESP, cold side ESP, fabric filter and cold side ESP plus spray drying, cold side ESP plus wet flu gas desulphurisation.

Fabric filters plus spray drying, fabric filter plus wet flue gas desulphurization and ESP plus WFGD plus SCR. SCR is selective catalytic reduction. So, these methods have been used for different types of samples and these are the removal level. Now, we will be discussing on the use of advanced techniques in place of conventional combustion method.

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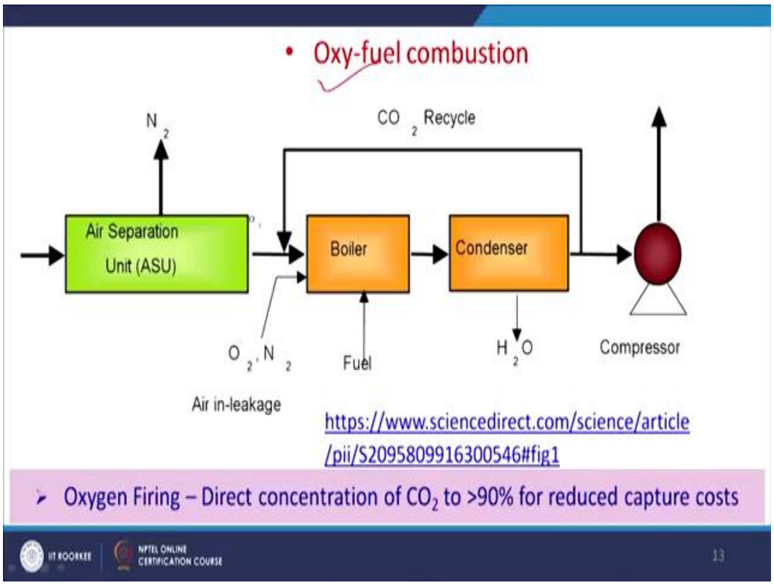

- Oxy-fuel combustion

https://www.sciencedirect.com/science/article/pii/S2095809916300546#fig1

➢ Oxygen Firing – Direct concentration of CO_2 to >90% for reduced capture costs

So, one example is oxy fuel combustion. In oxy-fuel combustions as the term says we will be using oxygen in place of air. So nitrogen will be separated from the air first then oxygen will be used. So, nitrogen is separated from the air and oxygen is used. So, this nitrogen may not be completely removed. So it is used for the combustion process and then the flue gas is formed. So, fuel is added here then flue gas forms it is going to condenser for heat recovery.

So then the flue gas is again recycled back. So, by this recycling partially, we are able to enrich the carbon dioxide concentration in this case. So more than 90% carbon dioxide we can achieve here. So it is very easy to sequester. So, that is why this process is very attractive, but research is going on, the commercial plants are yet to come and then another method is chemical looping combustion.

So in this case, some metal are oxidised in one reactor and in other reactor, metal oxidised reacts with the feedstocks, carbonaceous feedstocks to convert it into CO_2 and H_2O and metal oxide is reduced to metal again. So, if we can use two reactors in a cycle, then that can meet our requirement for the production of energy from the carbonaceous materials in one reactor and other its regeneration, regeneration of the metal to metal oxide.

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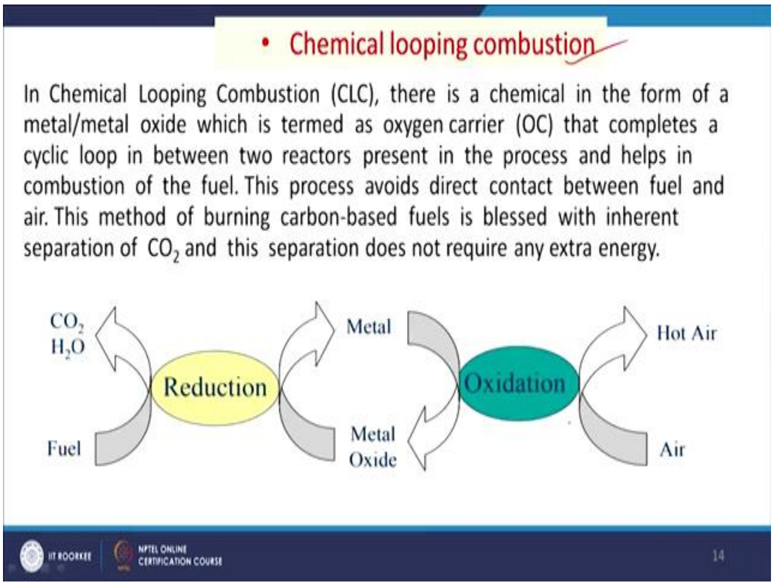

- Chemical looping combustion

In Chemical Looping Combustion (CLC), there is a chemical in the form of a metal/metal oxide which is termed as oxygen carrier (OC) that completes a cyclic loop in between two reactors present in the process and helps in combustion of the fuel. This process avoids direct contact between fuel and air. This method of burning carbon-based fuels is blessed with inherent separation of CO_2 and this separation does not require any extra energy.

So, this is one reduction and another is oxidations. In this oxidation air is used and metal is converted to metal oxide and in reduction metal oxide is reduced to metal and fuel is converted to CO_2 and H_2O. So this is the chemical looping systems, it is very clear to us in this case, when the reaction is taking place, we do not need any air. So, nitrogen is not required and only metal oxides are helping for the conversion.

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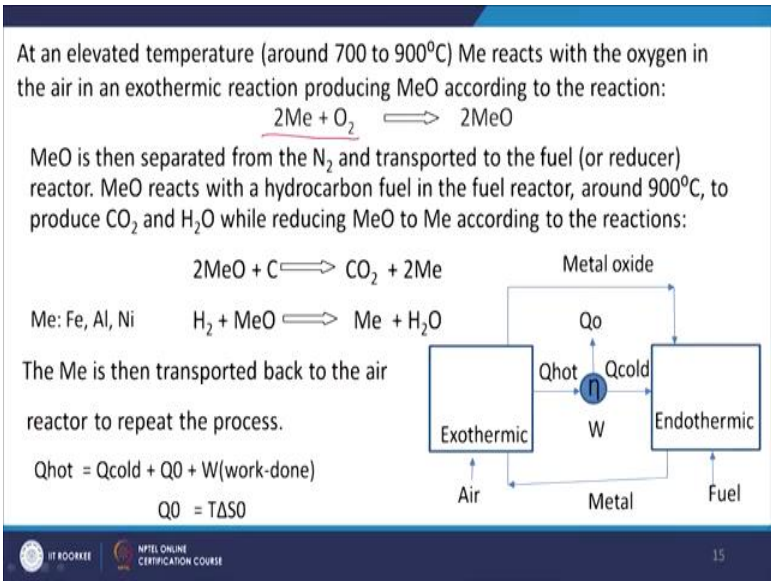

At an elevated temperature (around 700 to 900°C) Me reacts with the oxygen in the air in an exothermic reaction producing MeO according to the reaction:

$$2Me + O_2 \Longrightarrow 2MeO$$

MeO is then separated from the N_2 and transported to the fuel (or reducer) reactor. MeO reacts with a hydrocarbon fuel in the fuel reactor, around 900°C, to produce CO_2 and H_2O while reducing MeO to Me according to the reactions:

$$2MeO + C \Longrightarrow CO_2 + 2Me$$

Me: Fe, Al, Ni

$$H_2 + MeO \Longrightarrow Me + H_2O$$

The Me is then transported back to the air reactor to repeat the process.

$$Qhot = Qcold + Q0 + W(\text{work-done})$$

$$Q0 = T\Delta S0$$

So, in that way that will be more cleaner. So, what happens the metal is oxidised, an example at 700 to 900 °C. So, 2MeO say, Me is the metal and then MeO is the metal oxide and then metal oxide reacts with carbon gives CO_2 and metal it reacts with hydrogen gives metal and H_2O these are the basic reactions. So, we can represent the phenomena in this figure that this is our fuel. So, this is our metal oxide.

So, it will give us H_2O + CO_2 and this metal is coming here and air so it is it is giving us oxidation and we are getting metal oxide. So, this metal to metal formation, this is exothermic process, overall the process is exothermic and here it is endothermic process. So, these two types of processes are going in a cycle. So, we can get some efficiency of the cycle and that can be presented by this that is the Q_{hot}, the amount of heat which is released here and Q_{cold}, overall energy used in this process.

And Q, this is released heat and this is work done during this. So, this is energy balance and we can get this relationship that Q_{hot} is equal to Q_{cold} plus Q_o plus W, What is this Q_o? Q_o is equal to T into ΔSO. So, there may be some entropy change, so, that is equal to T into ΔSO is equal to Q_o.

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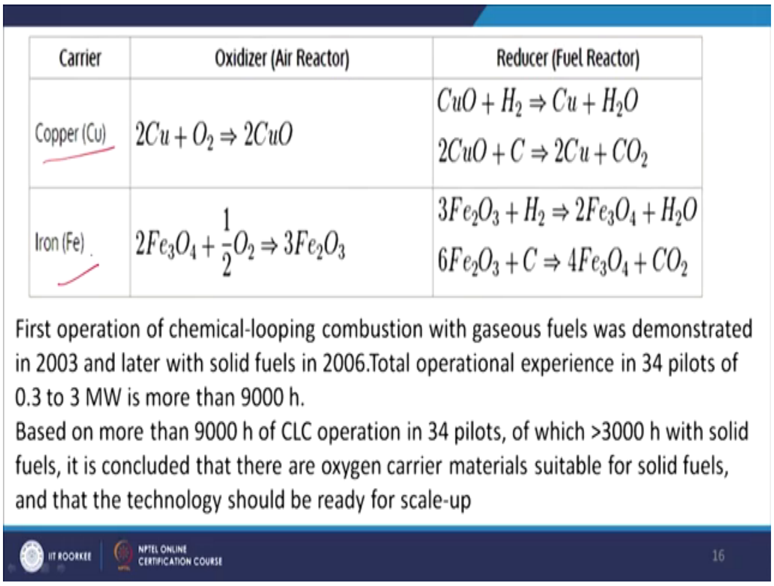

Carrier	Oxidizer (Air Reactor)	Reducer (Fuel Reactor)
Copper (Cu)	$2Cu + O_2 \Rightarrow 2CuO$	$CuO + H_2 \Rightarrow Cu + H_2O$ $2CuO + C \Rightarrow 2Cu + CO_2$
Iron (Fe)	$2Fe_3O_4 + \frac{1}{2}O_2 \Rightarrow 3Fe_2O_3$	$3Fe_2O_3 + H_2 \Rightarrow 2Fe_3O_4 + H_2O$ $6Fe_2O_3 + C \Rightarrow 4Fe_3O_4 + CO_2$

First operation of chemical-looping combustion with gaseous fuels was demonstrated in 2003 and later with solid fuels in 2006.Total operational experience in 34 pilots of 0.3 to 3 MW is more than 9000 h.

Based on more than 9000 h of CLC operation in 34 pilots, of which >3000 h with solid fuels, it is concluded that there are oxygen carrier materials suitable for solid fuels, and that the technology should be ready for scale-up

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So, this is the chemical looping combustion and different types of metals and metal oxides are used like copper, iron. When copper is used this reaction takes place in your oxidizer that is, Cu +O_2 gives 2CuO and CuO + H_2 gives Cu + H_2O in the fuel reactor and 2CuO + C gives 2Cu + CO_2 in the fuel reactor. Similarly, for Fe_2O_4 these are the reactions which take place in fuel reactor and this is in the air reactor. So, this chemical looping system is not yet commercialised in a bigger scale, but demonstration has taken place.

And total you see 34 pilots of 0.3 to 3 mega watt has done in more than 9000 hour and this is the technology was demonstrated in 2003 and later with solid fuels in 2006. Initially, it was demonstrated with gas fuels and 2006 it was demonstrated with solid fuels. And from this data on the demonstration plant, it is very clear that this can be used in commercial scale for the conversion of coal.

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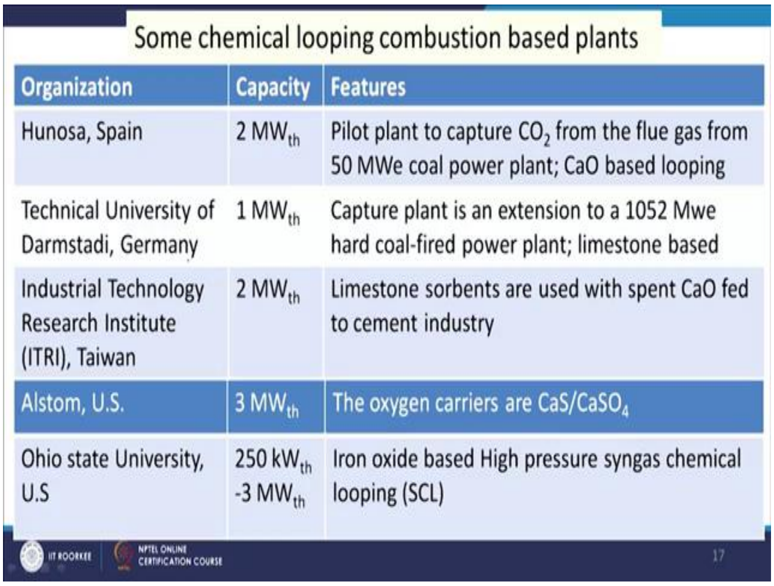

Some chemical looping combustion based plants

Organization	Capacity	Features
Hunosa, Spain	2 MW_{th}	Pilot plant to capture CO_2 from the flue gas from 50 MWe coal power plant; CaO based looping
Technical University of Darmstadi, Germany	1 MW_{th}	Capture plant is an extension to a 1052 Mwe hard coal-fired power plant; limestone based
Industrial Technology Research Institute (ITRI), Taiwan	2 MW_{th}	Limestone sorbents are used with spent CaO fed to cement industry
Alstom, U.S.	3 MW_{th}	The oxygen carriers are CaS/$CaSO_4$
Ohio state University, U.S	250 kW_{th} -3 MW_{th}	Iron oxide based High pressure syngas chemical looping (SCL)

Now, this slide gives us an example of chemical looping applications in thermal power plant. So, this is in Spain, Germany, Taiwan, US and this is also US. These are the capacities and these are the features. So it is clear this one we are having calcium based looping system. Here we are having limestone based chemical looping system. And this ITRI Taiwan is also using limestone sorbents and with spent CaO. And Alstom, U.S they are using CaS $CaSO_4$ system and Ohio state university is using iron oxide based high pressure syngas chemical looping. So, that is for gasification applications.

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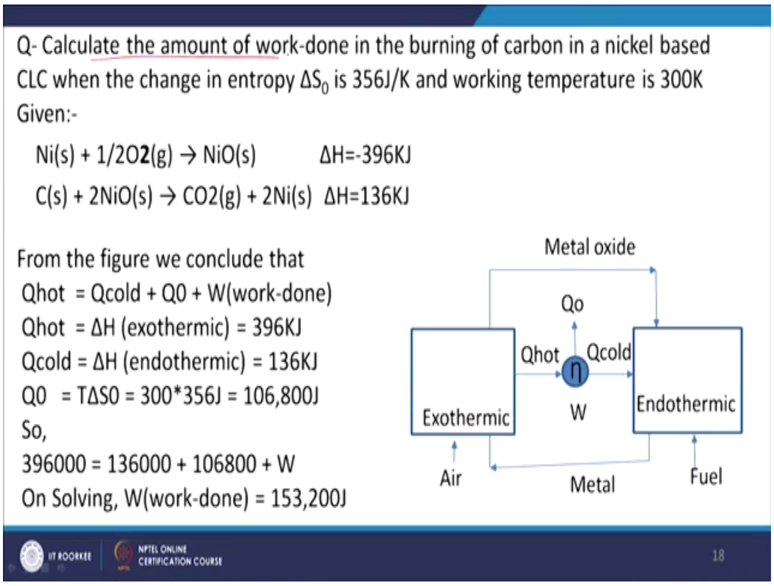

Q- Calculate the amount of work-done in the burning of carbon in a nickel based CLC when the change in entropy ΔS_0 is 356J/K and working temperature is 300K

Given:-

Ni(s) + 1/2O2(g) → NiO(s) ΔH=-396KJ

C(s) + 2NiO(s) → CO2(g) + 2Ni(s) ΔH=136KJ

From the figure we conclude that

Qhot = Qcold + Q0 + W(work-done)

Qhot = ΔH (exothermic) = 396KJ

Qcold = ΔH (endothermic) = 136KJ

Q0 = TΔS0 = 300*356J = 106,800J

So,

396000 = 136000 + 106800 + W

On Solving, W(work-done) = 153,200J

Now, we will see one problem on this. So, calculate the amount of work done in the burning of carbon in a nickel based chemical looping combustion, when the change in entropy is 356 J/K and working temperature is 300 K. So, this is our cyclic process, it is given we have to calculate the work done. These values we have to calculate. So, now if we have nickel based chemical looping, so, what will be the reactions or what will be the reactions here or what will be the reactions here that we will consider first.

So, here nickel will be oxidise to NiO the ΔH equal to -396 KJoule and in this carbon will be reacted to NiO(s). So, then CO_2 + 2Ni(s) So, this reactions is 136 kilo joule. Then how will get Q_{hot} that is equal to $Q_{cold} + Q_o + W$ as we have discussed. So, Q_{hot} is equal to ΔH exothermic that is 396 kilo joule and Q_{cold} ΔH endothermic 136 kilo joule and what is Q_o? T into ΔSO ΔS value is given, T value is given. So, you can calculate the Q_o T ΔS that is equal to this one so, this joule you are getting.

So, then we have the relationship that is Q_{hot} is equal to $Q_{cold} + Q_o + W$ and by rearranging W is equal to this much. So, now, we are able to find out the work done during this process. Next is gasification, another replacement of combustion is gasification. In combustions we use excess amount of oxygen, in gasification we use controlled amount of oxygen.

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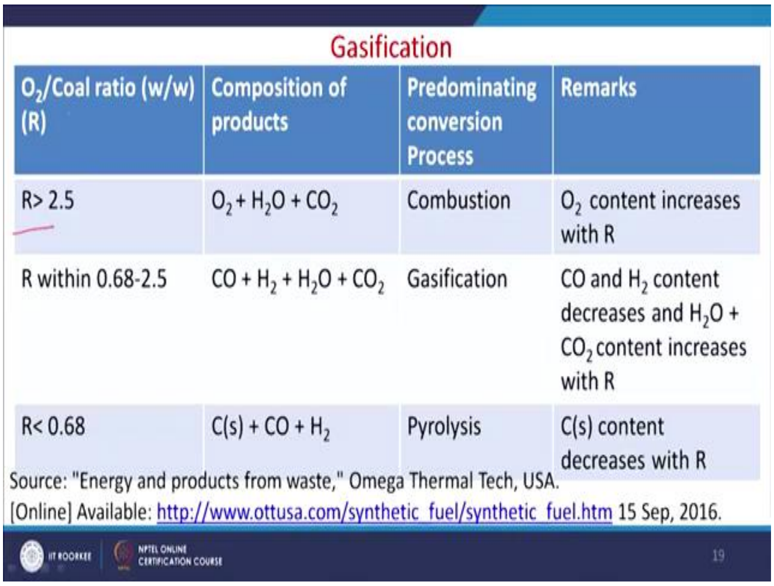

Gasification

O_2/Coal ratio (w/w) (R)	Composition of products	Predominating conversion Process	Remarks
R> 2.5	$O_2 + H_2O + CO_2$	Combustion	O_2 content increases with R
R within 0.68-2.5	$CO + H_2 + H_2O + CO_2$	Gasification	CO and H_2 content decreases and H_2O + CO_2 content increases with R
R< 0.68	C(s) + CO + H_2	Pyrolysis	C(s) content decreases with R

Source: "Energy and products from waste," Omega Thermal Tech, USA. [Online] Available: http://www.ottusa.com/synthetic_fuel/synthetic_fuel.htm 15 Sep, 2016.

So, R that is equal to oxygen by coal ratio, mass by mass ratio, for combustion it is greater than 2.5 and for gasification it is .68 to 2.5 and another is pyrolysis, there is no oxygen in that case we can get R equal to 0.68. So, if we use this gasification method, then what we will get, we will be getting CO and H_2 but in case of combustion we are getting is H_2 CO_2 which is also available in gasification plus oxygen. So, CO H_2 which we are getting here, so, CO_2 concentration will be less. So, carbon dioxide production in gasification plant will be less.

And we are having CO + H_2 rich gas that can be used for the production of electricity as well as for the production of different types of chemicals. So, we will be having an opportunity to capture carbon dioxide in situ in between and also to make the syngas in more economical way. So, I will discuss this in next classes in more detail.

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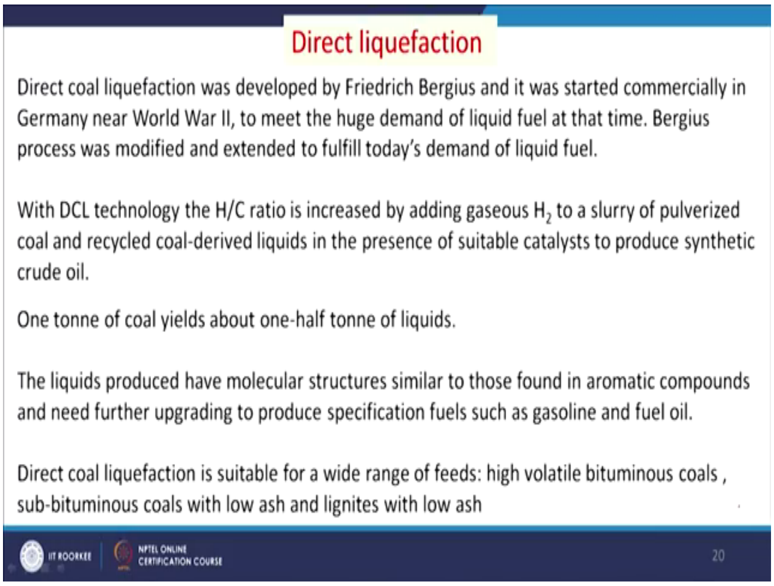

Direct liquefaction

Direct coal liquefaction was developed by Friedrich Bergius and it was started commercially in Germany near World War II, to meet the huge demand of liquid fuel at that time. Bergius process was modified and extended to fulfill today's demand of liquid fuel.

With DCL technology the H/C ratio is increased by adding gaseous H_2 to a slurry of pulverized coal and recycled coal-derived liquids in the presence of suitable catalysts to produce synthetic crude oil.

One tonne of coal yields about one-half tonne of liquids.

The liquids produced have molecular structures similar to those found in aromatic compounds and need further upgrading to produce specification fuels such as gasoline and fuel oil.

Direct coal liquefaction is suitable for a wide range of feeds: high volatile bituminous coals , sub-bituminous coals with low ash and lignites with low ash

Now, direct liquefaction, another replacement of oxidation can be direct liquefaction. How it is because you see in coal, we have seen in our introductory module that it contains very complex structure containing number of aromatic rings. So, if we can break this aromatic ring and can make some hydrogen addition, so, we can get number of organic compounds with aromatic rings and that is available in conventional liquid fuels.

So, direct Coal liquefaction can be possible, may be possible if we use higher pressure and hydrogen and required temperature. So, this is done and efforts are going on to get more scale up version of DCL, already one plant has been commercialised in China and I have discussed this in detail. Next is underground coal gasification, another technology possibilities is underground coal gasification, in this case, gasification will take place.

But that will not take place in any gasification plant on the surface, but it will be taking place underground. So, by that way, we can remove the possibilities of emissions etc. So, that is a philosophy of underground coal gasification.

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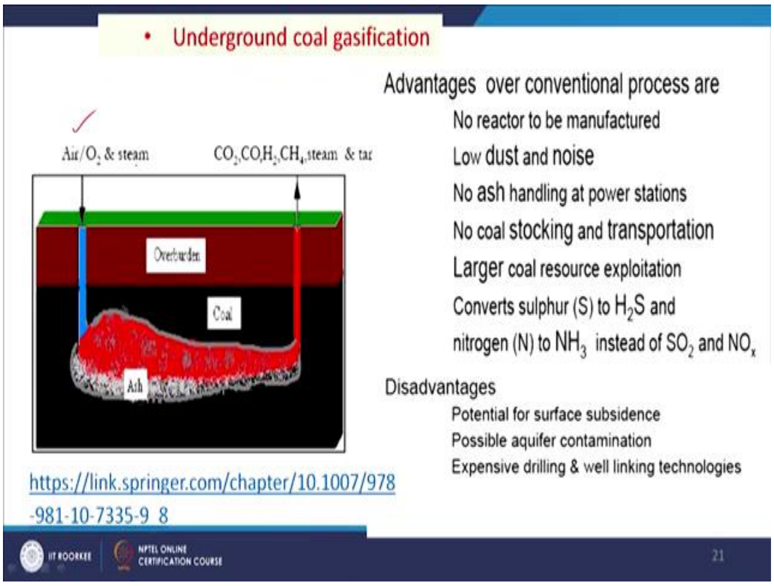

- Underground coal gasification

Advantages over conventional process are

No reactor to be manufactured
Low dust and noise
No ash handling at power stations
No coal stocking and transportation
Larger coal resource exploitation
Converts sulphur (S) to H_2S and nitrogen (N) to NH_3 instead of SO_2 and NO_x

Disadvantages

Potential for surface subsidence
Possible aquifer contamination
Expensive drilling & well linking technologies

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So, in this case, air or oxygen and steam can be sent underground, where coal is available and this coal will be combusted and ash will form and the syngas will form, so that syngas will goes up. So, it will come out as CO_2, CO, H_2, CH_4, Steam and tar. So, this is the concept and people have studied on it mostly on simulation based studies. And some plants are also available for the underground coal gasification around the world.

I will discuss that. But now I will see what are the advantages of these and what are the disadvantage. So advantages over conventional processes are, no reactor to be manufactured, low dust and noise, no ash handling at power stations, no coal stocking and transportations, larger coal resource exploitation, it converts sulphur to H_2S and nitrogen to NH_3 instead of SO_2 and NOx.

And it has some disadvantages that are, a potential for surface subsidence, possible aquifer contamination and expensive drilling and well linking technologies.

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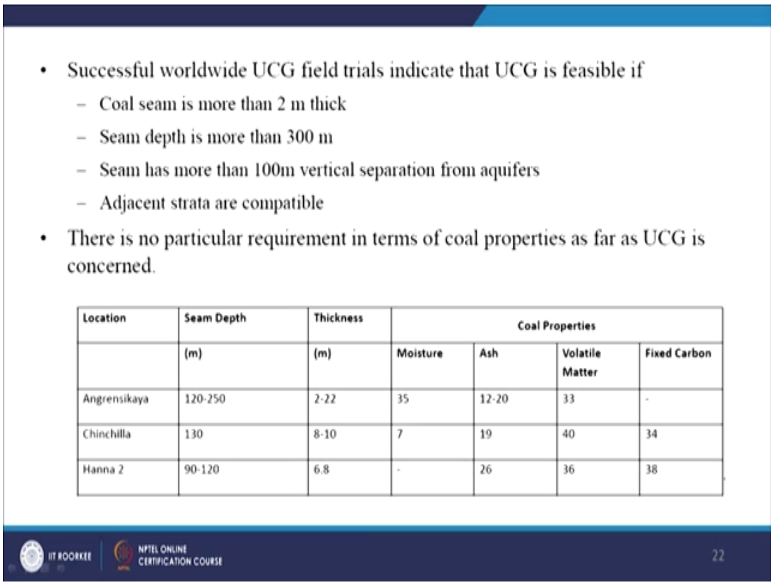

- Successful worldwide UCG field trials indicate that UCG is feasible if
  - Coal seam is more than 2 m thick
  - Seam depth is more than 300 m
  - Seam has more than 100m vertical separation from aquifers
  - Adjacent strata are compatible
- There is no particular requirement in terms of coal properties as far as UCG is concerned.

Location	Seam Depth	Thickness	Coal Properties			
	(m)	(m)	Moisture	Ash	Volatile Matter	Fixed Carbon
Angrensikaya	120-250	2-22	35	12-20	33	-
Chinchilla	130	8-10	7	19	40	34
Hanna 2	90-120	6.8	-	26	36	38

So, on the basis of the data, that people have walked on it, it is evident now, that coal seam is more than two metre thick. In that case, this technology is feasible. It also requires seam depth more than 300 metre and seam has more than 100 metre vertical separation from aquifers. These are the requirement for the UCG and these are some example of the UCG based plants where the seam depth is provided, thickness of the seam is provided and quality of the coal is also provided.

So, it is very clear that this method can be used for any type of coal, the quality of coal does not matter. So, that is the advantage of this technique.

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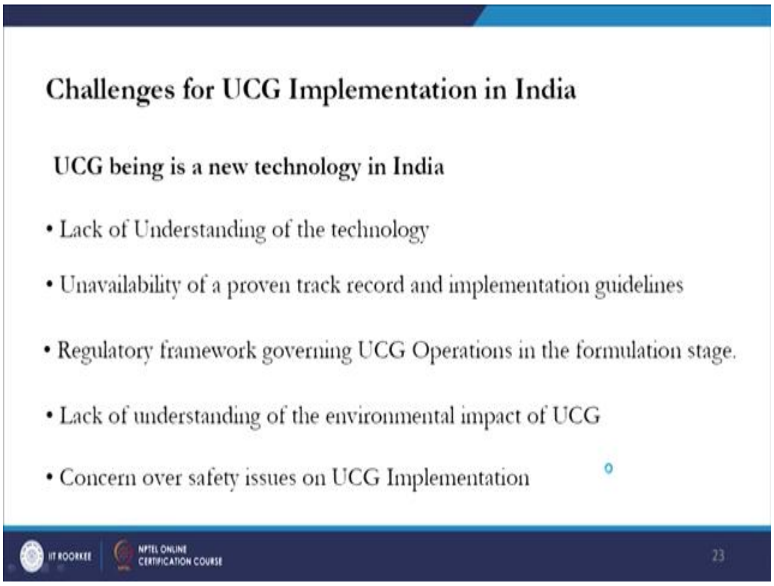

Challenges for UCG Implementation in India

UCG being is a new technology in India

- Lack of Understanding of the technology
- Unavailability of a proven track record and implementation guidelines
- Regulatory framework governing UCG Operations in the formulation stage.
- Lack of understanding of the environmental impact of UCG
- Concern over safety issues on UCG Implementation

But we have some challenges in India that is we lack of understanding of the technology and unavailability of proven track record and implementation guidelines, then regulatory framework governing UCG operations in the formulation stage and the lack of understanding of the environmental impact of UCG and concern over the safety. So these are the issues related with underground coal gasification. So this is not a commercialised one. It is it has some issues also. So far, we have discussed the possible options to produce cleaner energy from the coal. Thank you very much for your patience.