Technologies for Clean and Renewable Energy Production
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Lecture-07
Gasification of Coal -1

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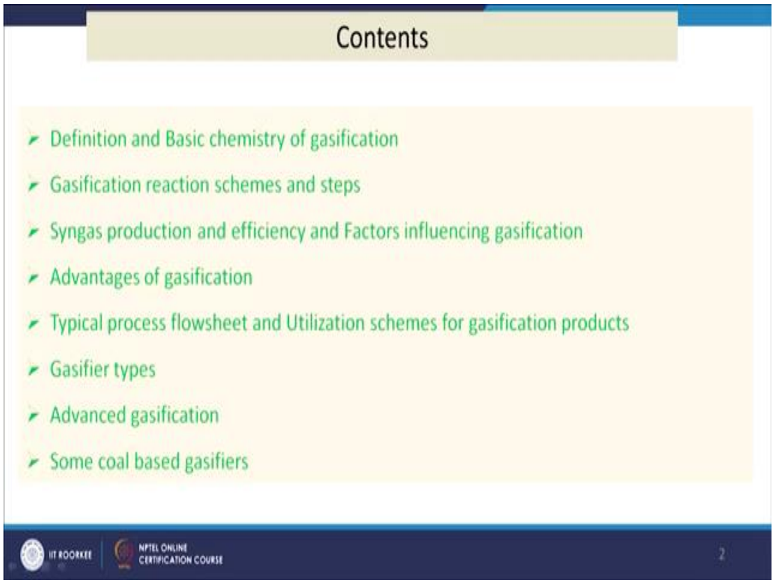

Hi friends now we will discuss on the topic gasification of coal. We will cover this topic in two classes and in the first class we will discuss on and the contents of the first class are definition and basic chemistry of gasification, gasification reaction schemes and steps then syngas production and efficiency and factors influencing gasification, advantages of gasification, typical process flowsheet and utilization schemes for gasification products, gasifier types, advanced gasification and some coal based gasifiers.

Now we will see what is gasification, as we have discussed in the introductory module in the previous class also, the gasification is the process which uses controlled amount of oxygen and converts carbonaceous materials into carbon monoxide and hydrogen rich gas that is called syngas. See in this process sometimes steam is used, for coal steam is used but for biomass steam requirement may be very less. Because coal is having more carbon so steam is required for this process with the coal.

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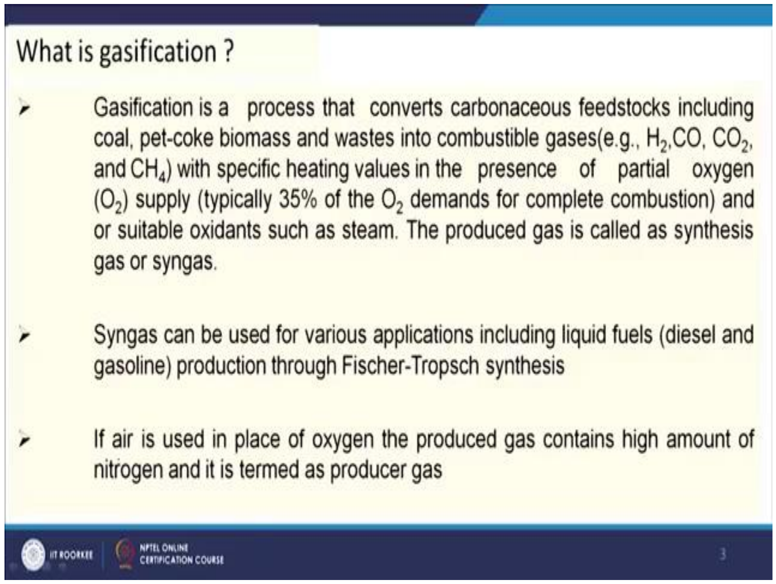

And the syngas can be used for various applications including the liquid fuel production through the Fischer-Tropsch synthesis and if air is used in this process in place of oxygen then the syngas contains more amount of nitrogen and that is called a producer gas.

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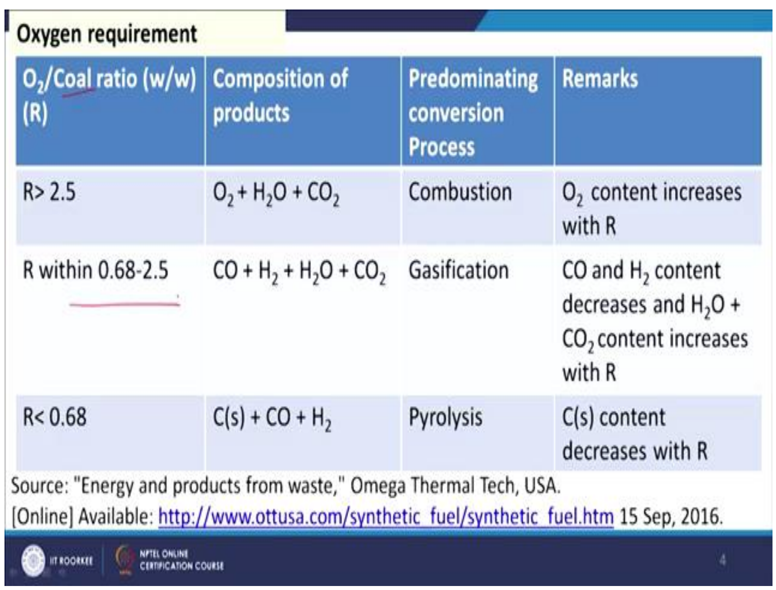

As we have already discussed in the previous class that for oxygen and coal ratio for gasification is within .68 to 2.5 and in this case these are the products but we increase the R then what will happen, we will be getting more CO_2 and we reduce the R-value will we get more CO and H_2.

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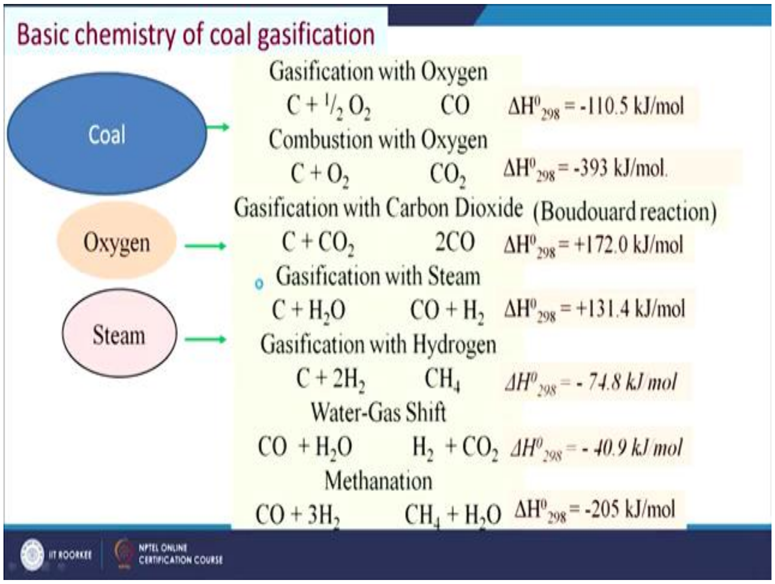

So, this is the basics of the gasification process now we will see the chemistry, the reactions what happens in whatever reactions takes place in case of gasification process, so we have here feedstocks coal we have oxygen and we have steam. Now these schemes show us the elemental reactions the coal is having carbon it is having hydrogen it is oxygen, sulphur, nitrogen etcetera but we are considering the major components of the coal that is carbon we are considering in this case.

So, the first reaction carbon plus half O_2 controlled amount of oxygen so CO where we are terming it as gasification with oxygen so heating value is -110.5 kilo Joule per mole. Combustion with oxygen can take place C + O_2 then CO_2 so this is again exothermic reaction. So, these two reactions are exothermic reactions which provides us heat which are required for other reaction say gasification with carbon dioxide C+ CO_2 so that is 2CO, it is endothermic reaction and C + H_2O that will also give a CO + H_2 again endothermic reaction.

And gasification with hydrogen that is exothermic reactions but this heat is very less. So, C + $2H_2$ is equal to CH_4 and at the same time under the same condition some water gas shift reaction takes place CO + H_2O reacts to form H_2 + CO_2 and some methanation also take place that is CO + $3H_2$ gives CH_4 + H_2O, these two reactions are also exothermic in nature. So, overall if we see it is having both exothermic and endothermic reactions.

So, initially we need to provide oxygen the reactions that energy will be released that will be used for these reactions.

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Comparison of gasification product gases

Properties	Syngas	Producer gas
Typical major compositions		
H_2	20-30 %	13-19 %
CO	40-60 %	18-22 %
CO_2	5 to 15%	9-12 %
CH_4	0-5 %	1-5 %
Heavier hydrocarbon	-	0.2-0.4 %
Nitrogen	0.5 -4 %	45-55 %
Water vapour	8-12 %	4 %
Typical Heating value	9.3 to 14.9 MJ/m^3	4.5 to 6 MJ/m^3

Now what are the composition of the syngas and producer gas, here it is provided hydrogen CO CO_2 CH_4 these are the ranges for syngas hydrogen is 20 to 30% and producer gas 13 to 19% CO for syngas 40 to 60% and producer gas 18 to 22% CO_2 5 to 15% for syngas and 9 to 12% for producer gas and CH_4 0 to 5% for syngas and 1 to 5% for producer gas. Heavier hydrocarbon may be present in this and nitrogen in case of syngas 0.4 0.5 to 4% and here 45 to 55% water vapour 8 to 12% for syngas and 4% producer gas.

Now the heating value which is most important in our case. So, for syngas it is 9.3 to 14.9 mega Joule per meter cube where it is 4.5 to 6 mega Joule per meter cube in case of producer gas. Now we will see the mechanism of the gasification, how the gasification takes place? What is the mechanism? If we apply heat and controlled amount of oxygen then what type of changes are going to take place?

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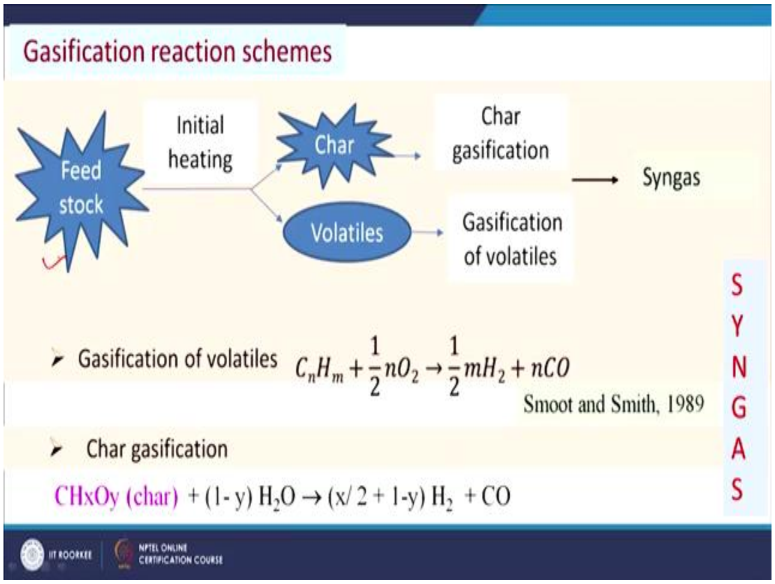

See if we have feedstock then initially you are heating so then will be char and volatiles formation, volatiles will be going off. So, that volatiles will be further gasified, char will be further gasified and ultimately it will give us syngas. So, how these gasification taking place, the representation of this process is your C_nH_m + 1/2 nO_2 that is 1/2 mH_2 + nCO and char gasification, charge gasification means it will be having carbon hydrogen oxygen we are ignoring other impurities in this case.

So, then it will give this is an empirical formula this is a formula so which is explaining that this will be hydrogen production and this will be the CO production from this char.

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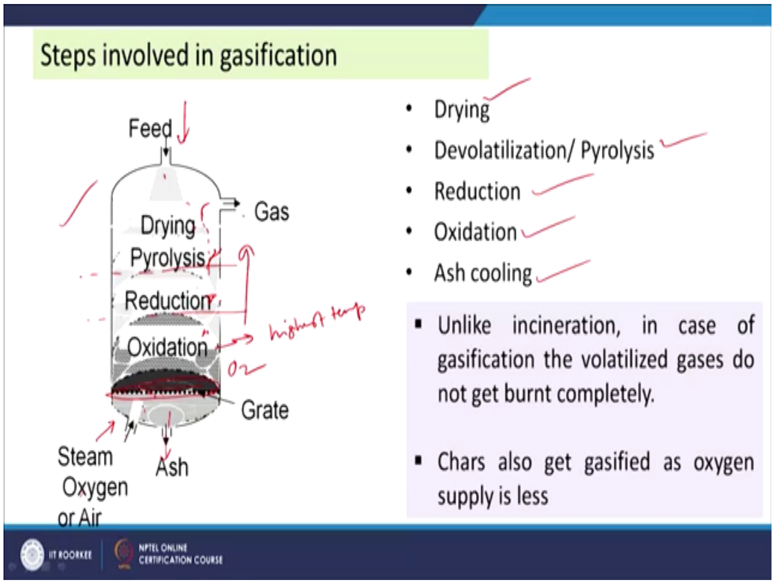

Now you see what is happening will be trying to understand more inside the mechanism on the mechanism okay so this is the gasifier, we are putting feed here and we are putting oxygen or air and steam here. So, gradually feed is getting down and gas goes up. So, here is a grate, this grate is there, so solids are falling and it is getting in contact with hot gases and different types of processes are going on changes are going on and ultimately ash is formed and ash is stored on this grate or something.

It is passed through the opening of this grate and here ash collection takes place. And what are the different types of changes on the on the coal, when it is getting entry here it is coming in contact with gradually increasing temperature why because oxygen is provided here so maximum oxygen is available in this zone. As you go up oxygen concentration reduces. So, once oxygen concentration reduces then there will be less combustion the temperature will also fall.

So, temperature is highest in this case oxidation zone high temperature and then the temperature is gradually reducing. So, oxidation after this say it is stopped then reduction will take place if oxygen is not available then heat is available endothermic reaction will go on and then reduction will take place. And here pyrolysis will take place high temperature is there oxygen is not there so pyrolysis take place and here we will be having drying, only the moisture will goes up volatiles will goes up and then this volatile will be gasified.

And char will be gasified at this temperature and here char gasification, volatile gasification will take place so this is a different types of phenomena which is going on inside the gasifier that is drying, devolatilization and pyrolysis and then reductions, then oxidation and ash cooling. So, unlike incineration in case of gasification what is happening the volatiles are not completely converted combusted because the volatiles are produced here say so it is going off it is getting less chance to be converted more.

So, for fixed bed type of reactor fixed bed type of gasifier the flue gas is sorry the syngas which is coming out that will not be of that pure it will be having some volatiles.

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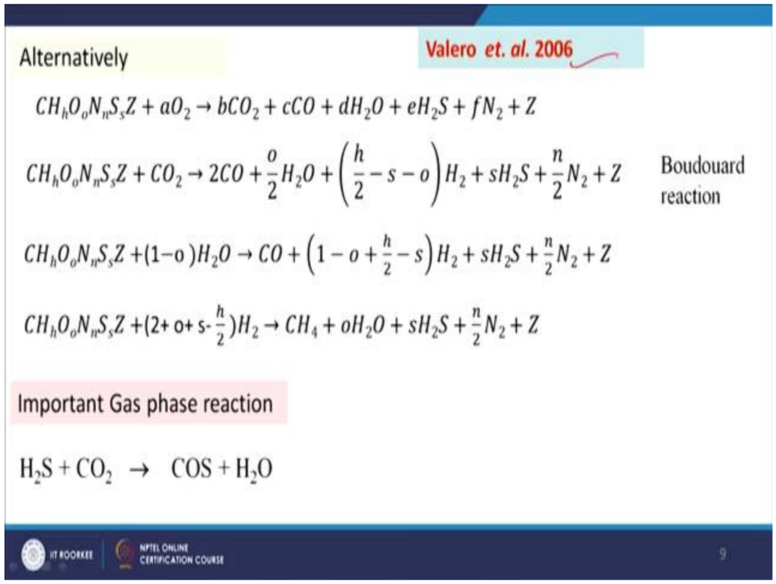

So, tars will be available with this. In 2006 Valero they have presented this phenomenon nicely considering the presence of ash as well as sulphur nitrogen etcetera they have given the molecular presentation of the coal that is $CH_hO_oN_nS_sZ$ + aO_2 and this is converted to CO_2 CO H_2O H_2S N_2 and Z, Z is our ash. So, this is the reactions they have proposed and they have shown the mass balance and how to calculate a; how to calculate h o n s Z etc.

So, this is one reaction that is your reactions with oxygen then reactions with carbon dioxide similar presentation they have provided and then reactions with steam, steam gasification, these are the proposed reactions and then reactions with hydrogen so these are the proposed reactions. So, if we use this scheme of reactions we can predict the compositions completely what is the H2S compositions what is nitrogen compositions what is CO what is CO_2 etc.

And important gas phase reactions which take place here that is your H_2S + CO_2 COS + H_2O is formed. Now we will discuss about the syngas production and efficiency.

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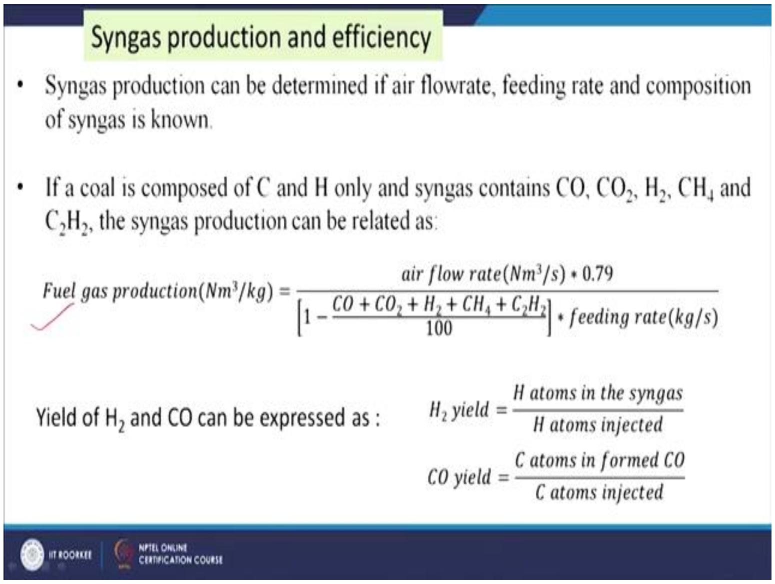

What is the syngas production? What will be the fuel gas productions or syngas production? that can be calculated on the basis of nitrogen balance and the expression is fuel gas production normal meter cube per kg is equal to air flow rate in normal meter cube per second into .79 divided by 1 - CO + CO_2 + H_2 + CH_4 + C_2H_2 by 100 into feeding rate. Now we are assuming that the syngas is containing these gases only it is not having any sulphur or any nitrogen in that case this formula we are using.

So what is this 1 - this by this that equal to 100 that is equal to 100 - CO - CO_2 - H_2 - CH_4 - C_2H_2 divided by 100 that means this is nothing but the nitrogen available in this as we are providing controlled amount of oxygen. So, we are assuming that all oxygen is consumed so remaining will be nitrogen. So, 100 minus this is equal to nitrogen so this is the percentage of nitrogen. So, percentage of nitrogen into we are getting feeding rate and here flue gas production is given.

So that will be the nitrogen available in the fuel gas and this is the nitrogen available in the feedstock. So, nitrogen balance is there we are assuming that 79% is nitrogen. So, that way we are getting this relationship. Now we can determine the yield of hydrogen and carbon monoxide as hydrogen yield is equal to hydrogen atoms in the syngas divided by hydrogen atoms injected in the feed and CO yield that is carbon atoms in the formed CO by carbon atoms injected.

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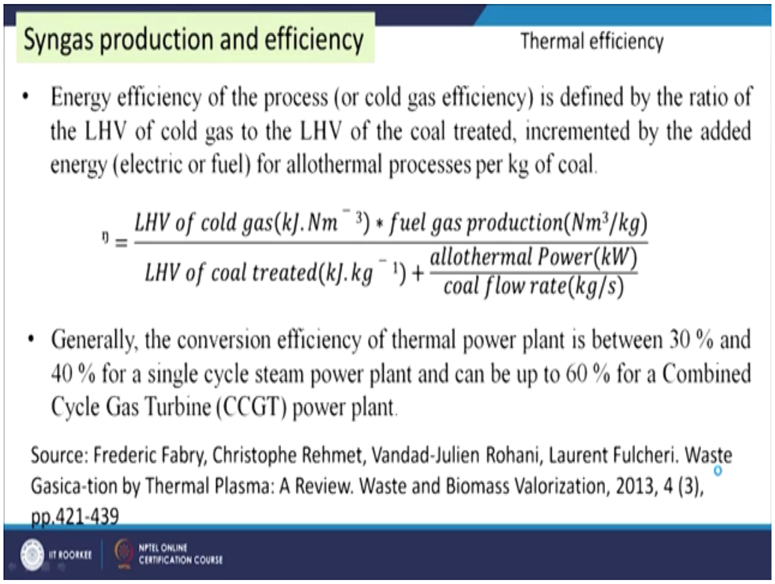

Now we will see the efficiency, efficiency is related with heat so obviously LHV of cold gas that is kilojoule per normal meter cube into fuel gas production that is normal meter cube per kg / LHV of the coal treated + all thermal power by coal flow rates that means for unit amount of coal how much energy associated with this process is required. For example say for size reductions for grinding is required so that energy is needed so that is also considered here.

So, all thermal energy divided by coal flow rate so this is the expressions of the efficiency of the syngas production process. The conversion efficiency of thermal power plant is between 30% and 40% for a single cycle steam power plant as you have discussed in our previous class. And this can be increased up to 60% for a combined cycle gas turbine power plant also we have seen that this is the thermodynamic limit thermodynamically that is 63% efficiency can be increased.

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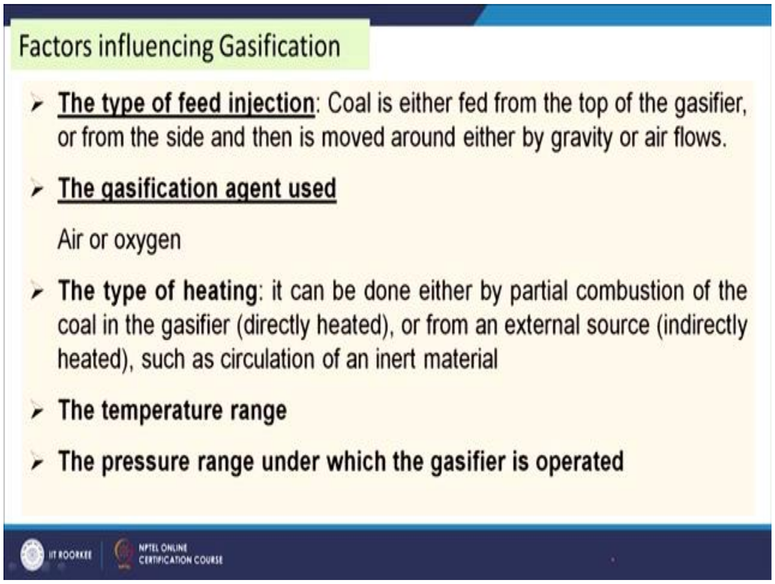

Now we will see the factors which influence the gasification process, the type of feed injection. What type of feed we are injecting? So, coal may be at the top feed or maybe side feed. So, if we change the feeding coal feed positions then efficiency will be change because it will be getting different time to be in contact with the hot gas. And the gasification agent air or oxygen may be used as you have discussed that if we use air more nitrogen will be available in the syngas resulting producer gas and their energy value will also be less.

The type of heating, what type of we are heating? it can be done either by partial combustion of the coal in the gasifier directly or from an external source also indirect heated also possible. So, both these cases efficiency will change. And the temperature range at what temperature we are using in a gasification reactor that will also influence the performance and the pressure range under which the gasifiers are operated so these are different parameters which influence the performance of the gasification process.

So different types of gasifiers have been tested and developed and used for the coal gasification and different efficiency have been achieved also.

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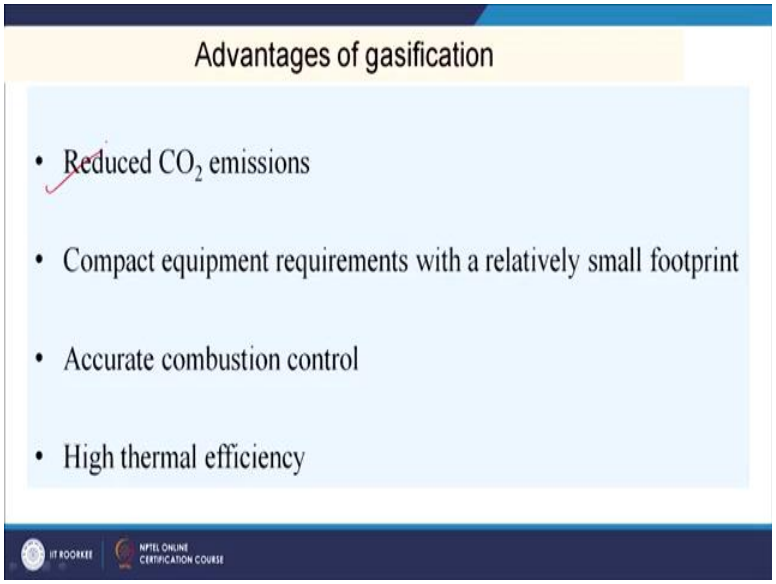

Now what are the advantage of this process? It reduces carbon dioxide emission and complete combustion is not taking place so carbon dioxide emission is reduced with respect to combustion method. Compact equipment requirements with a relatively small footprint, the equipments are very compact and footprint requirement is less. And then accurate combustion control, as we have already discussed it that we have controlled amount of oxygen we are providing and high thermal efficiency, we will get more efficiency in this method than the combustion process.

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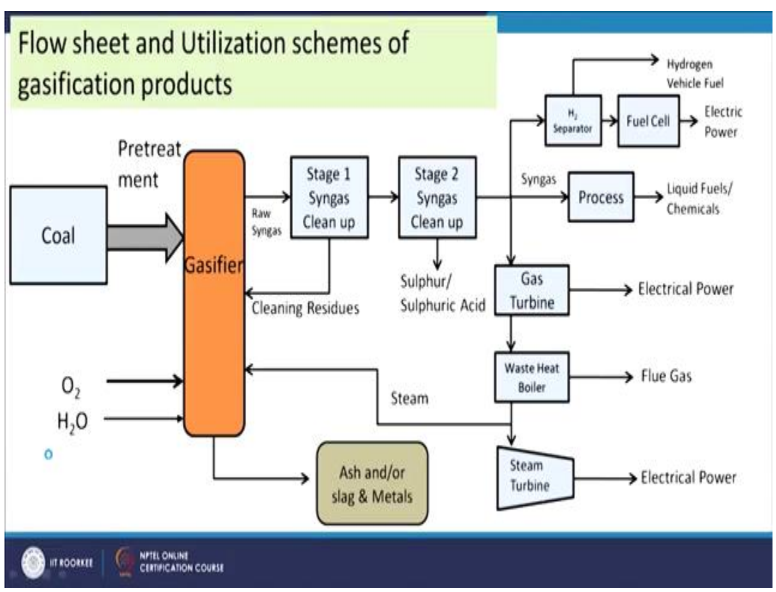

Now we will see that how we will use this, the flowsheet and utilization schemes of gasification products. So, we have coal here then we are sending it to gasifier with steam and oxygen then we will get syngas. So, syngas has to be cleaned up first, the first stage of cleaning so we are removing the particulates here and then second stage of cleaning we are removing the sulphur here then it is coming as a pure syngas.

And syngas there will be some conditioning and then utilization so that is you can go for processing that is that is liquid fuels and chemical synthesis. We can separate the hydrogen from the syngas and hydrogen vehicle fuel it can be used, hydrogen can be used in fuel cells for electric power or syngas can be sent to gas turbine so it will be electrical power production and then gas turbine exhaust can further be heated by using some additional fuel and then it can be sent to waste heat boiler.

And steam can be produced and can be electricity generated from the steam turbine. And this condensed from the boiler the steam can be passed here for the gasification and that the bottom what will get that ash that will be slag or metal recovery. So, these are the different processes or schemes which can be used for the utilization of products of the gasification process. So, apart from electricity generation we can have number of opportunities to utilize the products which is generated through the gasification.

So, we will be having more opportunity to make the process more economic and polygeneration option is utilized and recommended for application. Now we will see major types of gasifiers for coal gasification.

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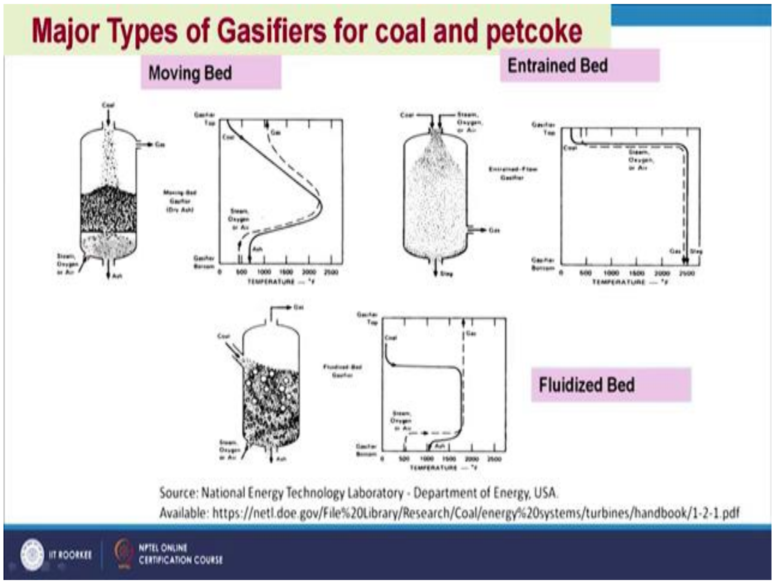

So, on the basis of the feed inlet gas collection and the operating conditions different types of gasifiers are reported out of which moving bed, fluidized bed and entrained bed are the major 3 important gasifiers which have been used widely for the gasification of coal and other carbonaceous feedstocks. In the moving bed coal is feed at the top and the particle size is higher say 5 to 50 millimetre particle size.

So, it falls from the top and from the bottom oxygen, air and steam is sent so reaction takes place as I have discussed in the previous slide also. So, gradually it falls and ash is getting out from the bottom. So, if we see the temperature profile across the height of the gasifier then this will be the nature. So, if we increase the height from the bottom so gradually temperature will increase and will attain maximum then again it is decreased.

Because oxidation is taking place at the middle of this so that is having the maximum temperature it is around 1800 °C temperature it can give. But if we see the fluidized bed coal is put here so here steam, oxygen or air then there will be some fluidization of the particles will be taking smaller particles here and then that will be in fluidized form and due to this reason what will be the temperature profile across its height?

This is, see it will gradually increase remain constant most of the part and then it is decreased after this part it will be constant and it is decreased this part will temperature will drastically decrease. And another is entrained flow reactor here we send coal and then steam, oxygen or air very finer particles are used. The particle size is much smaller than this fluidized bed and both all these coal, steam and or air or air or oxygen flows in the same direction so it gets less residence time and as collected here and gas goes from this at the bottom.

Due to this feature that if we see the temperature distribution along the height of it, it is almost constant and maximum on this. But not maximum here we will we will get maximum temperature because oxidation is single in certain zone. But here are uniformly distributed the phenomena. So, these are the temperature profile across the height of the gasifier for different types of gasifiers.

And this we have already come to know that here the less time is less residence time and smallest particle size with respect to this three gasifiers. But this fluidized bed gasifiers have some advantage that it can in situ capture of sulphur.

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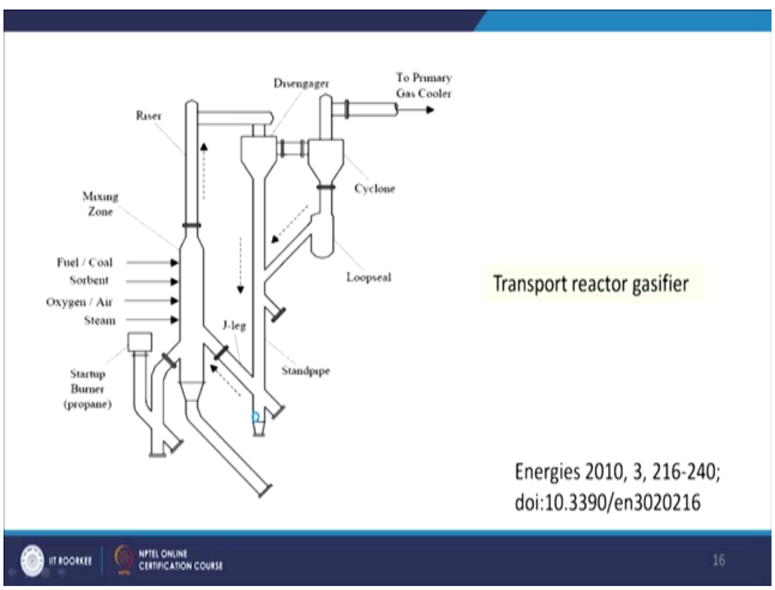

So, that is why transport reactor gasifier has been developed by KBR so in this case we have the intermediate properties both the fluidised bed and entrained bed properties are available here how? We are putting here fuel then absorbent we are putting some adsorbent also that is to capture the sulphur and then oxygen or air and steam all are here in coming into this reactor. Then it is going up this riser section very small time it is getting for contact.

Then it is coming to this so it is falling again and the gas is coming here particulate separation it is coming back. So, that way here we are getting the benefits of fluidized bed we are getting the benefits of entrained bed. So, both features are available in transport reactor so in this case we do not need to use very finer particles than that of entrained bed. Now we will see the comparison of this type of gasifiers.

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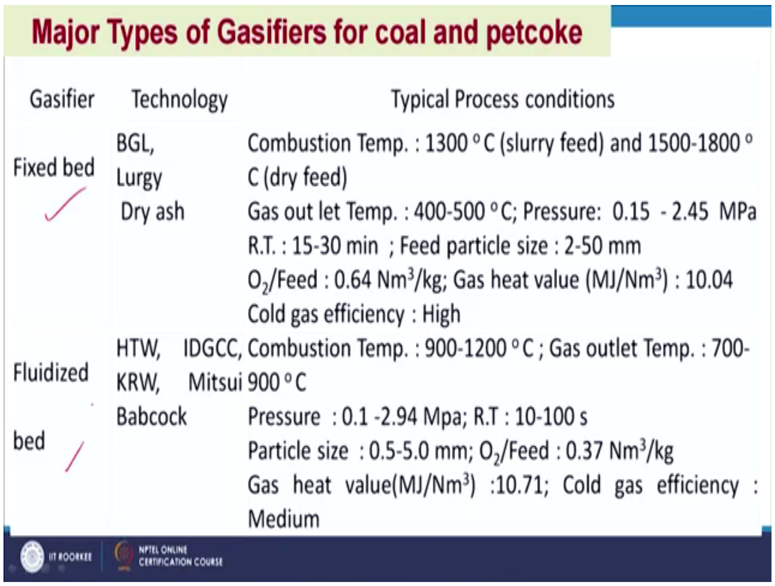

So, fixed bed, fluidized bed you see these are the technology licensers BGL, Lurgy, dry ash that is the fixed bed and HTW, IDGCC and KRW and Mitsui Babcock. So, these are the technologies licensers and typical process conditions for these are the combustion temperature is 1300 centigrade and slurry feed if it is and if it is a dry feed then 1500 to 1800 °C. But gas outlet temperature is less 400 to 500 °C and pressure is this much and particle size already discussed.

Cold gas efficiency is high, for fluidized bed the combustion temperature is more but lesser than this and gas outlet temperature is more than this one. And pressure requirement also this one and residence time is less, particle size is less, coal gas efficiency is medium. If we go for entrained bed gasifier then 1500 °C reaction temperature, gas outlet temperature is also higher than other two types of gasifiers.

Then pressure requirement this and retention time is also lesser and these are the particle size less than 200 mesh very fine particles are required. Now we see the transport reactor it is in between so temperature is 900 to 1050 °C gas outlet temperature 590 to 980 and residence time 1 to 10 second just like your entrained bed and size is less than 50 microns. So, we do not need to get 200-270 microns and it is also it is having 50 micron size.

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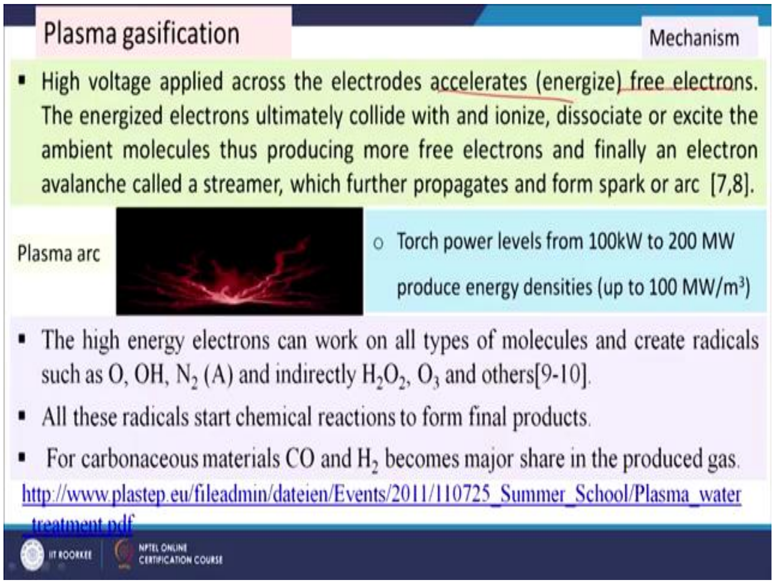

Now we will see the advanced process in gasification’s, the plasma gasification is one of the advancement in the gasification process, in this case we use high voltage across the two electrodes. So, in that case the electrons are emitted then electron accelerates free electrons electrodes accelerates free electron and free electrons helps to oxidize or ionize the ions adjacent ions and molecules and then number of electrons are produced which forms a avalanche that is called streamer.

So that is called the plasma in this case torch power levels from 100 kilowatt to 200 megawatt and produce energy densities up to 100 mega watt per meter cube. So, in these cases different free radicals are formed which converts the different types of components present in the coal to its oxidized form. So, C is converted to CO_2, H is converted to H_2O, N is converted to NO_2, S is SO_2 like this but typically it has been shown that CO and H_2 gas remains in higher concentration.

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Some coal based gasifiers

Country	Plant Name	Technology	Products	Syngas cleaning	Year
Japan	Unspecified IGCC plant	ICGRA	Electricity		2004
Netherland	NUON (Dem colec BV)	Shell	Electricity	Sulfinol	1994
Netherlands	Buggenum IGCC plant	Shell	Electricity		1994
South Africa	Sasol Chemicals Ltd.	Lurgi Dry Ash	FT Fluids	Rectisol	1955, 1977, 1982
Spain	Puertollano GCC plant	PRENFLO	Electricity	MDEA	1997
USA	Eastman Chemical Co.	Texaco	Methanol & chemicals	Rectisol	1983
USA	Dakota Gasification Co.	Lurgi Dry Ash	SNG	Rectisol	1984
USA	SCE Cool Water	Texaco	Electricity	Selexol	1984

These are some coal based gasifiers around the world so China, Germany, Italy, Netherland and South Africa, Spain and USA in these countries different gasifiers are the plants are there;

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Some coal based gasifiers

Country	Plant Name	Technology	Products	Syngas cleaning	Year
Australia	Esperance gasification plant	Texaco	F-T liquids /electricity		2007
China	Shanxi Coal to ammonia Plant	Lurgi Dry Ash	Ammonia	Rectisol	1987
China	Beijing town gas plant	Texaco	Town gas & Elec.		1995
China	Yima coal to methanol plant	Lurgi Dry Ash	Ammonia	Rectisol	2000
China	Caojing power plant	Shell	Electricity, syngas		2004
China	Demonstration project	BGL	Syngas		2006
Germany	Rheinbraun	HTW	Methanol	Rectisol	1988
Italy	Suleis IGCC Project	Shell	Electricity		2004

Where the gasification process is in practice and different types of products they are producing. There somewhere we are getting say FT fluids and then electricity somewhere ammonia, somewhere town gas and electricity, somewhere ammonia taking some syngas, methanol okay. And then we are getting somewhere FT fluids and methanol and chemicals and SNG and then electricity. So, some diesel and electricity is also produced by some plants.

And different types of cleaning options are also used rectisol, sulfinol, MDEA etcetera. So, I will discuss this in next class okay so thank you very much for your patience.