Cryogenic Hydrogen Technology
Prof. Indranil Ghosh
Cryogenic Engineering Centre
Indian Institute of Technology Kharagpur
Week - 02
Lecture 08
Hydrogen Production - 3

Welcome to this lecture on Cryogenic Hydrogen Technology. We were talking about the cryogenic hydrogen production and in it is in continuation to that hydrogen production part and we were talking about the different conventional processes like steam reforming, partial oxidation and auto thermal reaction reforming. And in that context, we have also learned that this resultant you know product that is CO and H2 combination needs certain amount of processing to get the H2. Like both CO and H2 both are you know equally important for ah chemical industries and this production of the I mean hydrogen and CO using this ah steam reforming or partial oxidation or auto thermal reforming they are quite common in nature and ah there I mean out of this as we have learned that the steam reforming processes ah mostly very common. But this partial oxidation is equally you know important we will try to see about it is use ah in coal gasification. So, we will talk about ah this part in this lecture and ah so, let us look into this ah this is the concept is still you know hydrogen production and ah we will be talking about ah the ah synthesis gas processing particularly here comes the role of cryogenics and ah we will see how this cryogenic condensation and methane scrubbing depending on the concentration of CO H2 and CH4 mixture ah you know they are in use.

And finally, ah before that ah you know we will try to have a look into the application of this processes ah which can be you know ah in I mean in future ah it can be used for ah our coal handling. You remember that we have talked about the ah coal for generating the hydrogen. So, in these processes we have this is of course, the steam reforming and then you know we have learned about that it is ah giving us something at ah this product is coming at 850 to 920 as well I was telling that this finally, this product you know here this after this water gap shift reaction this will give you the CO2 CO plus H2 and from there finally, this will be the H2 product which will be basically you know the raw hydrogen here at this point. So, this ah in between you need ah some condensation process or that ah CH4 scrubbing process to generate this raw hydrogen and from there we have to you know finally, get this PSA system to purify this ah mixture to generate the pure hydrogen.

So, we will be looking into this reaction part and also ah we need to keep it in mind that they are coming out this reaction you know taking place around these 850 to 920 degrees

centigrade. Similarly, for the partial oxidation part we have seen that this ah you know this reaction at this you know at the exit of the ah reaction zone is nearly about 1200 to 1400 degree centigrade and in the autothermal the reaction part ah you know we have nearly about 900 to 1100 degree centigrade temperature. So, here again you see that ah after CO2 and H2S removal we have some condensation process that we have talked about this condensation process will generate the raw hydrogen and this raw hydrogen will finally, you know be purified in the PSA pressure swing adsorption cycle to give us the pure hydrogen. So, how this ah you know what is there in it and what is you know getting condensed ah in this process we will try to learn in this ah lecture, but before that ah as I told you that this is of course, the autothermal ah reforming process where we have seen that the ah outlet or the syngas is coming around 900 to 1100 degree centigrade. So, you can understand that these processes are generating ah you know CO plus H2 and they are coming at high temperature.

So, this ah we we will try to discuss about this part in connection to the use of you know ah the hydrogen generation from coal. But this coal is also used ah you know ah this is already we have talked in the first ah you know ah lecture when we are talking about the hydrogen production and in that context we have told that ah you know there are certain advantage ah ah we have told that this is certain there are certain advantage that it is available in I mean low cost and they are abundantly available and of course, there are negative features like they having you know CO2 emissions and etcetera, but ah at the same time this coal is also used for generating the power. So, in many ah in in many ah thermal power plant you will find that this if we look at the salient features that we have the coal fired thermal unit and for generating the ah power and you will find the most ah modern plants are ah where you know this coal is directly being fired or the combustion you know is taking place it is having ah the pulverized coal or powder coal and they are generating either super critical steam that means, coming at super critical pressure and temperature and the overall efficiency is of the order of 36 to 40 percent, but on the other hand it generates the greenhouse gas like SOX ah NOX and CO2 and mercury. So, ah these are definitely ah you know are concerned for us ah as we ah you know ah more and more concerned about our ah environment. This release of this gases from the thermal power plant ah you know we cannot ah accept it any longer, but there are so many thermal power plants in India and in abroad and we have seen that there is a good amount of coal reserve in many parts of the globe.

So, if we have to think of you know protecting our nature, but at the same time if we want to use this conventional fossil fuel for some more time before we ah you know confident or if you are we are you know ah used to with the ah use of ah renewable energy resources and generation of hydrogen this coal can be a good source of hydrogen production. So, but

at the same time it is not ah helpful in for the environment. So, if we have to take care of this ah environment and hydrogen simultaneously what we need to look at that we have to reduce the emission of this greenhouse gases and not only that we have to ah you know ah we have to think about enhancing the overall efficiency of this process. So, is there any chance that we can rectify the use of ah you know using ah use of coal or is there any process which can be helpful in ah you know ah utilizing this coal in a better way. So, that is what we are now trying to look into here at this point ah we will be talking about ah you know integrated gasification combined cycle or IGCC ok.

So, what does it gas this ah you know process means ah you know it is basically a kind of clean coal technology ah unlike that ah you know where this conventional ah coal use of pulverized coal or powder coal is directly burned and you know it was generating ah the steam ah basically this coal is fired and then finally, you know the steam is produced and that steam will be you know used to generate or run the turbine to generate the power that is what is the thermal power plant ah you know that is how it works. But ah this process where integrated gasification combined cycle ah you know works it is basically why do we call it as clean coal technology because you will find that this gasification is integrated with this process. So, when we are ah trying to ah you know ah use this coal we are trying to you know instead of burning it directly like ah you have seen that the coal is burned you know to generate ah the steam in a steam engine we are mostly familiar with the old fashioned you know steam engine where the coal will be burning and you know that will generate steam and that will run the ah you know that engine, but those are obsolete these days ok. But ah if we look at this gasification part or the partial oxidation part so, where instead of directly burning the coal what we are doing is that we are mixing it with the oxygen part and we are trying to generate a syngas. So, here this syngas generation CO plus H2 and that will come at quite high temperature.

So, that high temperature as we have learned that you know this PO ah partial oxidation reaction. So, if we are ah taking this coal and then we are partially oxidizing it that is basically what we are doing is the gasification we are trying to do and that will generate not only the syngas it will also generate a high temperature. So, that high temperature will you know ah basically that radiation zone if you look at and radiation zone followed by the convective zone we can put our ah this water to generate the steam in that process and ah at the same time we also have this ah syngas that can also be used for generating the power. So, here ah instead of directly burning the coal to generate the steam we have you know ah generated the CO content of it plus H2 content of it as well as we have created a high temperature, but of course, we need ah you know additionally you know this oxygen for this kind of integrated gasification combined cycle. So, this gasification or the partial oxidation will generate some CO plus H2 which can you know be again fired to generate

another you know ah what is called the steam I mean first of all the steam will be used for you know generating the power as well as this CO plus H2 can either you know generate ah this H2 we can take out this H2 and store it for longer time and otherwise you know this CO plus H2 will also be used as a fuel to generate the another ah I mean steam turbine to produce the ah power.

So, this is what is ah you know is needed I mean that means, this co generation of this CO2 sorry CO plus ah H2 and power and hydrogen is possible with this use of coal. So, this is a better ah I mean effective way of utilizing the coal and that is why it is called the clean coal energy ah technology it is a because another ah and there is another reason for that I will just tell you in a short while ah. This overall efficiency is again improved from the earlier process and here this this greenhouse gas you know emission is a bit less compared to the other processes because here we have the possibility of you know removing CO2 in bulk from the process and of course, we have ah you know the generation because we are using this oxygen you know this generation of you know x is bit less in this process and this ah like elements like mercury and etcetera will be ah removed with the ah along with the slug that is where being formed. So, the I mean in a nutshell this is an integrated gasification or IGCC ah process is ah you know bit advantages over the conventional one and this processes are you know in the new newer generation of ah this ah thermal power plants since 1995 onwards they are in use. So, this ah is about the generation of hydrogen using ah if anyone is interested about generating ah the hydrogen from coal ah one can think about this particular process where gasification we have talked about it while talking about the utilization of coal and there this ah you know we have talked only about the partial condensation, but along with that this partial condensation if we can try to you know bigger scale ah if we look into it we can you know generate the steam along with that and generate power ah if it is a big plant ok.

So, now we will ah talk about ah ah what is called as we have learned in the earlier processes ah where we are talking about this ah I will go back to that where ah we have talked about the raw gas or this raw hydrogen formation from the water gas shift reaction or even steam reforming after the steam reforming we have you know or the partial oxidation also we have talked about this ah you know this mixture where methane CO and H 2 would be there and from there depending on the I mean extent this CH4 basically this natural gas ah I mean component that is the methane if it is ah in large quantity or in small quantity that will be determining the processes ah as we have ah talked early I mean in the earlier slides. So, that is basically ah I am sorry. So, we are talking about the cryogenic condensation part this cryogenic condensation is when you have the less methane content. So, we have talked about the steam reforming we have talked about the partial condensation ah sorry partial oxidation and there we have seen that it is generating the CO plus H2 along

with that ah it is not that you know all the ah I mean every amount of the methane for example, in the natural gas and it is getting utilized. So, that means, some amount of methane may come along with the product.

So, depending on its quantity you know we decide whether we should go for this cryogenic condensation or we should go for methane scrubbing. So, this is ah a typical cryogenic condensation ah this picture has been taken from this industrial gas processing by edited by ah H. W. Haring 2007, but it looks bit you know ah complicated, but we will just look into ah the saline features of this kind of processes this is basically a cryogenic process where you will find that it is harnessing the difference in the boiling point of hydrogen and all other components ok. So, the hydrogen normal boiling point H2 is ah 20.3 Kelvin roughly and then we have the CO and then we have ah the what is called ah CH4 this methane normal boiling point is 111.7 and this is 81.65 Kelvin. So, these are the normal boiling points of this components. So, if we look at this ah you know this 20.3 K is quite low from this 81.65 or ah methane at 111.7. So, ah here ah this let us look into this ah ah I mean basically the different components here there are ah plate fin heat exchangers ah then we have 1 and 2 are this component 1 and component 2 are basically the bridged aluminum plate fin heat exchangers this 2 are the heat exchangers multi-stream heat exchangers. Then we have ah the separator this component 3 is basically a separator and component 4 is the hydrogen stripper whereas, this 5 is CO CH4 separator or I mean separation separation column.

So, these are basically ah typical chemical ah you know ah industry equipments ah, but of course, this heat exchangers are quite common in ah our thermal engineering applications. So, here what we see is that we have the raw synthesis gas that means, we have a mixture of CO plus CH4 plus H2 and that is coming and getting cooled in this ah heat exchanger number 1 and number 2 and they are cooled to such an extent that ah you know when it comes over here ah this will be ah you know ah cooled down and it will separate ah from H2 H2 will be coming out. So, this is what is that raw hydrogen we have talked about so far, this raw hydrogen will be coming out whereas, this other part that is CO CH4 mixture will stay back this CO CH4 is again you know we cannot throw it out just like that. So, here ah in this ah hydrogen stripper whatever remaining part of the hydrogen which is there in the CO CH4 mixture will be taken out from this column and that will you know come out as fuel gas. So, that means, you know this is basically the H2 which we could not recover completely ah you know and we have we could not put it in the raw hydrogen.

So, that part will be coming from this hydrogen stripper and that will come as to gas and we will burn it ah you know to ah I mean in in the steam reforming reaction if you remember that we have said that it needs some fuel to burn and that fuel was coming partly

you know from the PSA ah tail gas as well as you know sometime we have this fuel gas coming from this kind of ah separation processes . So, here ah then you know this ah a part is getting separated. So, we have on this side is CO plus CH4 mixture and on this side, we have separated the hydrogen these are the typical columns and here this CO CH4 mixture will be coming over here and again this will be separated into CO and CH4. So, as we understand that CO plus CH4 if we have you know mixture then CO boiling point is 81.65 as we have understood and this is having you know 111.7. So, this is low boiling lower boiling point this is the higher boiling point component the higher boiling point component will be at the bottom of the column as we have learned earlier and the lower boiling point component will be on the top. So, from here we will have the CO part and this CO will be going back. So, as a product ok, but ah there is something component 6 that is basically the compressor part here we will find that this ah initially we told that this you know raw synthesis gas is getting cooled. So, who is providing that ah cooling it is basically this you know this compressed CO part will be expanded I mean compressed part will be expanded and then it will be cooled down and while it is getting evaporated that provides the refrigeration to the incoming high pressure this ah synthesis gas. So, as a result what we find is that this is basically the CO product, but it is also providing the refrigeration necessary refrigeration for the condensation of this ah you know ah raw synthesis gas, but ah as we have also learned that this is meant for low methane content when the reaction is such that you know this CH4 slippage is ah bit less and that is you know ah in those cases we can go for this cryogenic condensation, but if it is such this is the boiling point of ah you know ah the normal boiling point of CO that is 81.65 already we have written it ok. So, now let us go back to our discussion on the other part where we have talked about that the ah methane scrubbing will be necessary where you know we have ah slightly higher methane content in the raw synthesis gas. That means, this ah raw synthesis gas where it is basically the CO plus H 2 along with the methane , but if methane is less in quantity we can go for condensation as we have shown earlier, but if the methane content is ah slightly higher we should go for a methane scrubbing part again this diagram has been taken from the industrial gas processing and one can you know look into this book part other you know ah part that we have talked about . So, now let us ah look into the different components we have ah we have the heat exchanger then followed by one and two are the heat exchangers again these are ah plate fin heat exchangers this is sorry this is PF plate fin heat exchanger. So, this would be PFHX and ah then we have this 3 is the scrubbing column CH4 scrubbing column 4 is hydrogen stripper and 5 is basically the CO CH4 ah you know separator.

So, here the ah point is that ah again we have earlier we were you know ah we were in the other process we have seen that we were condensing the gas and condensation was ah you know ah by condensation we were trying to separate the hydrogen from rest of the component, but here what we are trying to do is that we will use CH4 liquid and sub cooled

CH4 where this ah you know ah all other component like CO CH4 part will be you know scrubbed or it will be dissolved in it. So, here what we need is a supply of you know cold sub cooled methane from here and that will dissolve the CO CH4 part and remaining the hydrogen part will be coming from here as raw hydrogen. So, this raw hydrogen is basically produced here by scrubbing the CO CH4 using ah sorry CO CH4 ah part will be scrubbed with the help of this CH4 part ok or the liquid methane will be necessary. So, that is generated here you can just try to follow it, but first of all you know this raw hydrogen is coming out and at the bottom of it what we have is the CO plus CH4 mixture along with that some amount of hydrogen may be there. So, we have the hydrogen you know ah what is called ah stripper. So, this will you know from the top of it you will have ah what is called the hydrogen the part would be there a small bit of it and that will you know will come as ah flue gas you can see that this is what is you know giving you the flue gas, but at the bottom of it you have the CO and CH4 mixture. So, this CO CH4 mixture will now come to this ah separator separation column where the bottom product would be the methane liquid and on the top part you will have the CO. So, this CO will go back again you know as a CO product and here you in addition to this compressor you can find that there are expanders. So, this expander will also generate some amount of cooling and here what we have is the liquid methane. So, this liquid methane is coming you know to this methane pump and finally, that will be taken inside and what we have you know all this cold component will be placed inside ah cold box while talking about the cryogenic processes or liquefaction this will be dealt in details.

So, that is about this is the cryogenic separation processes which are basically integral part of any ah I mean ah hydrogen production unit where ah be it ah say steam reforming or partial oxidation or auto thermal reformer. So, reforming process you will have this syngas and syngas ah you know from the syngas processing is done either with this methane scrubbing and ah by you know condensation process. These are of course, ah some of the cryogenic processes there are other you know process by which ah probably the CO2 will be removed and etcetera. So, that is about ah this ah separation processes or you know ah the syngas processing. So, these are the references you should ah refer to I mean many of this ah discussion has been made from this industrial gas processing and then you can also read this book on cryogenic hydrogen technology.

And in conclusion we can say that ah we have learned about the processing ah part and ah I mean where we have talked about the syngas processing and we have also talked about the better utilization of this coal ah where this coal gasification can be added with the thermal I mean ah ah power generation process and that will enhance the ah I mean that will enhance the ah efficiency of the thermal power plants. Ah So, this is about this

hydrogen ah production part in the next ah lecture we will try to ah talk about the coke oven gas and from there how do we produce hydrogen. Thank you for your attention.