Fuels, Refractory & Furnaces

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Lecture No. # 07

Production of Secondary Fuels: Gasification

We will discuss on Gasification; gasification can also be considered to a technology which falls under clean development mechanism, let us see how it falls into that.

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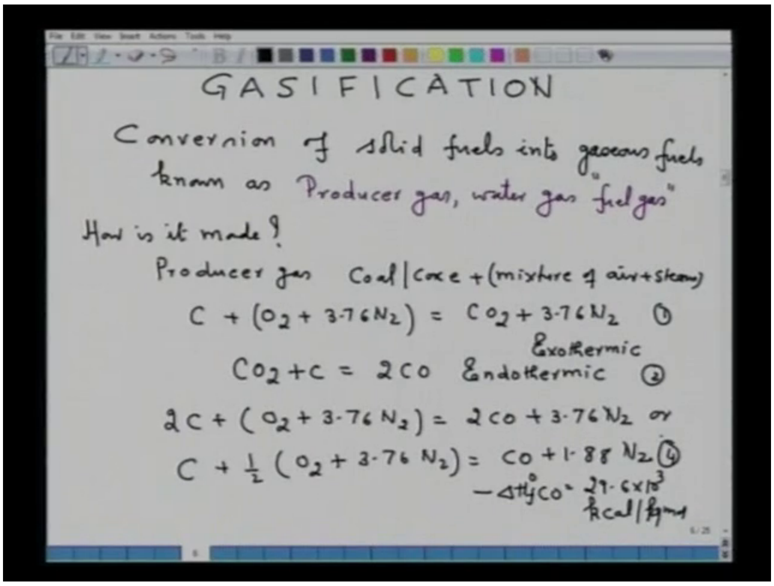

GASIFICATION

Conversion of solid fuels into gaseous fuels known as Producer gas, water gas "fuel gas"

How is it made?

Producer gas Coal | Coke + (mixture of air + steam)

$C + (O_2 + 3.76 N_2) = CO_2 + 3.76 N_2$ ① Exothermic

$CO_2 + C = 2CO$ Endothermic ②

$2C + (O_2 + 3.76 N_2) = 2CO + 3.76 N_2$ or

$C + \frac{1}{2}(O_2 + 3.76 N_2) = CO + 1.88 N_2$ ③

$-\Delta H^\circ_{CO} = 29.6 \times 10^3$ kcal/kg mol

Gasification involves conversion of solid fuels conversion of solid fuels into gaseous fuels. The gaseous fuel known their several names, either say producer gas, water gas or in general we can also call as a fuel gas. All these names they differentiate in the composition of the combustible component of the gaseous fuel. How is it made, how is it made? We will deal with the producer gas, though we know that all other names they differentiate in the composition. So, a producer gas is made by treating coal or coke with a mixture of air plus steam in a high temperature environment.

So, I will just put it say producer gas or for that matter, any fuel gas is made by treating coal or coke plus mixture of air plus steam in a high temperature reactor. And as a result of this reaction for example, if we consider coal and oxygen or air, then the reaction is say for example, C plus O 2 plus 3.76 N 2, that is equal to C O 2 plus 3.76 N 2. Now, this reaction is highly exothermic in nature; it generates a very large amount of heat, now C O 2 in it subsequent rise through the reactor, it reacts with carbon and forms 2 C O, and this reaction is highly endothermic in reaction, this reaction is highly endothermic in nature.

So, the net reaction which will occur, if a sum total the reaction one and reaction two, then we get then we get 2 C plus O 2 plus 3.76 N 2 that is equal to 2 C O plus 3.76 N 2 or we can also write C plus half O 2 plus 3.76 N 2 that is equal to C O plus 1.88 N 2. And this reaction as I given in the earlier lecture heat of formation delta H f naught C O that is equal to 29.6 into 10 to the power 3 kilo calorie per Kg mole, that is this reaction C plus half O 2 plus 3.76 and 2 is equal to C O plus 1.88 N 2 is also exothermic (()), they are so exothermic in nature, so large amount of heat will be generated.

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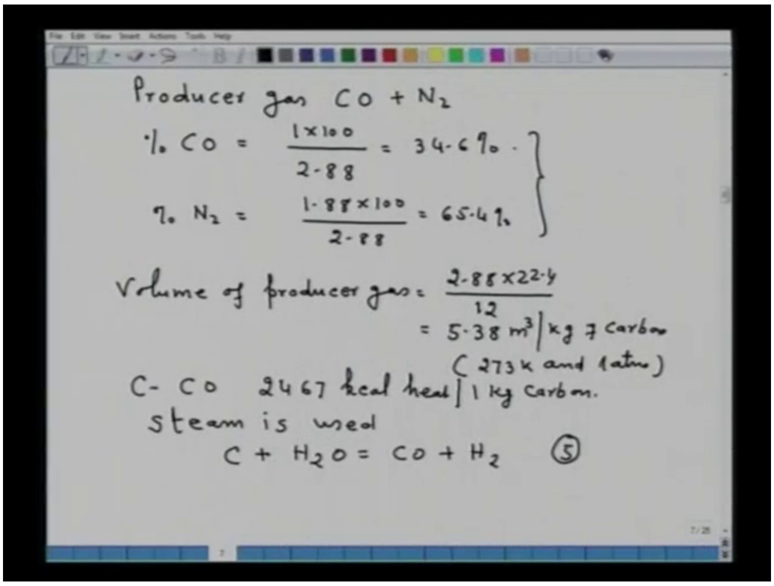

Producer gas $CO + N_2$

$$\% CO = \frac{1 \times 100}{2.88} = 34.6\,\%$$

$$\% N_2 = \frac{1.88 \times 100}{2.88} = 65.4\,\%$$

Volume of producer gas $= \frac{2.88 \times 22.4}{12}$

$= 5.38\ m^3/kg$ of carbon

(273 K and 1 atm)

C- CO 2467 kcal heat/1 kg carbon.

steam is used

$$C + H_2O = CO + H_2 \quad ⑤$$

So, according to equation let us say 4, according to equation 4 the producer gas it consist of C O plus nitrogen, now we can calculate the percentage C O that is equal to 1 into 100 upon 2.88 2.88 is the total number of moles of the gas, which is being produced, so that is equal to 34.6 percent. And if you calculate percentage nitrogen, then that will be equal to 1.88 into 100 upon 2.88 and that is equal to 65.4 percent, so this is what the composition of producer gas. Now, we can also calculate volume of producer gas volume of producer gas and that will be equal to 2.88 moles into 22.4 upon 12, so that will be equal to 5.38 meter cube producer gas per Kg of carbon, and C is at temperature 273 Kelvin and 1 atmospheric pressure. So, this is how one can perceive the composition of producer gas, when air reacts with for example, pure carbon.

Now, this reaction 4, which we have written is highly exothermic in nature, now if you just calculate the amount of heat that is generated, the C to C O it will generate of the order of 2467 kilo calorie heat will be generated on oxidation of 1 Kg carbon; so this heat is not utilized, then it will heat the (()) of the reactor and this heat will go into waste.

Now for example, if you take a large size reactor, where heat losses will be minimum, so internally the reactor will be heated up and that may affect the lining of the reactor. So, in order to compensate, the large amount of heat which is produced it is logical to use steam and therefore, steam is used steam is used to gasify the carbon and in presence of steam the reaction, which is their C plus H 2 O that is equal to C O plus hydrogen. Let us put this reaction number 5, now there are several advantages of using steam, and air that is a mixture of air plus steam for carrying out the for carrying out gasification.

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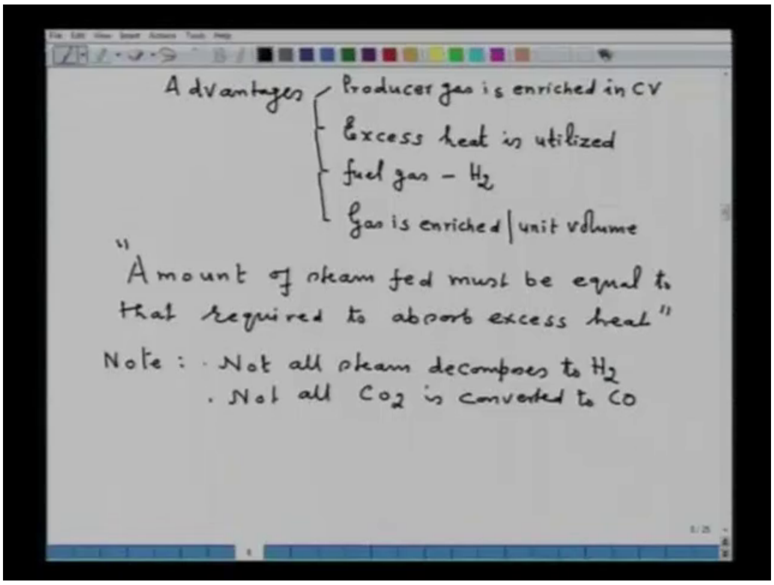

Advantages
- Producer gas is enriched in CV
- Excess heat is utilized
- fuel gas – H_2
- Gas is enriched | unit volume

"Amount of steam fed must be equal to that required to absorb excess heat"

Note : · Not all steam decomposes to H_2
· Not all CO_2 is converted to CO

Now, few advantages are as you are observing in reaction 5, first advantage is the producer gas which is formed producer gas which is formed is enriched in calorific value, because earlier C plus air was giving you C O, now C plus H 2 O gives you C O plus hydrogen, so additionally your producer gas is also containing the calorific value of hydrogen in addition to carbon monoxide; that is advantage number one. Second advantage is that, the access heat which is produced by the reaction C plus half O 2 plus 3.76 N 2 is equal to C O is effectively utilized, so excess heat is utilized excess heat is utilized. You do not need to supply any extra heat, only the heat generated with the reaction C plus O 2 is equal to C O that is used to decompose steam, and hence to enrich the calorific value of the producer gas.

Third obvious advantage is, the fuel gas or producer gas it contains additionally hydrogen also, fourth advantage is gas is enriched on per unit volume basis on per unit volume basis, so these are the certain advantages of utilizing steam. Now, here one precaution is to be taken, you cannot feed amount of the steam indefinitely, because effective is the heat produce by the reaction C plus half O 2 that is equal to C O plus 1.88 N 2 that is an exothermic reaction, whatever amount of heat which is being produced, it will be consumed by C plus H 2 O is equal to C O plus H 2.

So, by doing the heat balance, one has to supply the exact amount of steam, which will satisfy the heat which is produced by the carbon monoxide reaction, so that is the important thing is that, that amount of steam fed amount of steam fed it must be equal to must be equal to that required to absorb excess heat. Now, this is very important in using steam plus air to gasify coal or carbon or whatever you want to gasify, now for this purpose calculation must be done. Because you are not supplying any heat from outside, it has the heat generated within the reactor is utilized for decomposition of steam and that is important.

Now, here please note not all the steam decomposes to hydrogen not all steam decomposes to hydrogen, if you feed excess amount of steam then a situation may come during the operation that, the temperature drops very very fast and you may not be able to carry out any gasification hence, proper feeding of steam is necessary. Second is not all C O 2 not all C O 2 is converted to C O, now why this is important, because as carbon comes in contact with the oxygen, then the first product which forms is the carbon dioxide.

Now, carbon dioxide in presence of excess carbon is not stable, and it immediately converts to C O therefore, the temperature the kinetics of reaction between C O 2 and C, these are all the important issue to get what percentage of C O 2 gets converted into C O, because the objectives to convert C O 2 to CO.

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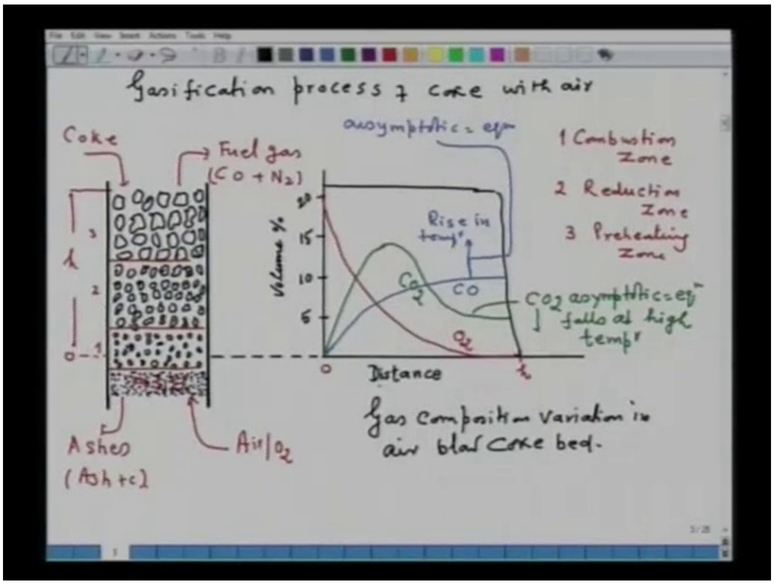

Now, a simple gasification process it can be represented in this particular fashion, say this is a simple gasification process simple gasification process of coke with air. Now, for example, say here supplying coke and here the output is fuel gas or producer gas which contains for example, C O plus nitrogen or any un-reacted carbon dioxide also. Now, the bottom this is ash, so here we have ashes and ashes is a ash plus carbon, and here we can supply air or oxygen, it is simply simple representation of a gasification process, where coke is gasified by air or oxygen.

The motion is counter current, coke is flowing downward and air is flowing upward, so in this this particular zone, let me put this is 1, this is 2, and this is 3, at the market this is, so the zone 1 we call as a combustion zone (Refer Slide Time: 15:46). Now, in this zone C plus O 2 reacts with C O 2. Second zone a reduction zone, and third is preheating zone.

So, at this stage what will happen coke will travel downward, and the hot gasses will move upward, there will be exchange of heat and mass transfer, so on account of that coke gets heated up, it falls down in the reduction zone, the combustion zone, in the combustion zone carbon react with oxygen forms C O 2 the gas goes up, gas reduces with carbon and hence, the gasification process is on. Now, if you want to represent, the volume percent of the gases which are utilizing, so what I do it now, this is a combustion zone, which is if I put at 0 here and this height of the bed if I take as h.

Then what I do this distance, this height of the rector I am presenting on the x axis, I put here at 0 and here somewhere is H. So, I will just close down, so what will happen at a 0 as oxygen comes in contact, all the oxygen towards end or towards the higher part of the reactor, this is the way in which oxygen will vary, it is obvious also, as a oxygen comes in contact, with the carbon here you have the 100 percent oxygen, so 0 point air contains 21 percent oxygen, and as a gases move up the oxygen concentration it continuously decreases.

Now, what happens to say for example, C O 2 if I take C O 2 concentration it will rise up rise up and attains a maximum value and then asymptotic. So, this is about line is C O 2 and this we can call C O 2 asymptotic, that is equilibrium value which will depend upon temperature, and this curve it falls at high temperature.

Because, higher is temperature, C O 2 will react more with carbon into form C O, so as we represent now, the carbon monoxide then the carbon monoxide will go somewhere, this is the curve for carbon monoxide, and this also we can put it say asymptotic equilibrium. And this curve will rise up as the rise in temperature, and you all know that C O 2 plus C is equal to 2 C O it is flavored at high temperature (Refer Slide Time: 19:33). So, this particular diagram it tells you, how the gas composition how the gas composition, vary gas composition variation in air blown, coke, bed, nitrogen will remain constant throughout the process.

Now, as we have seen that C O 2 plus C it reacts and it form carbon monoxide, so in fact the residence time of the C O 2, C is important; from the kinetic point of view more is the residence time higher will be the conversion of C O 2 to C O, and this is being shown in this particular diagram.

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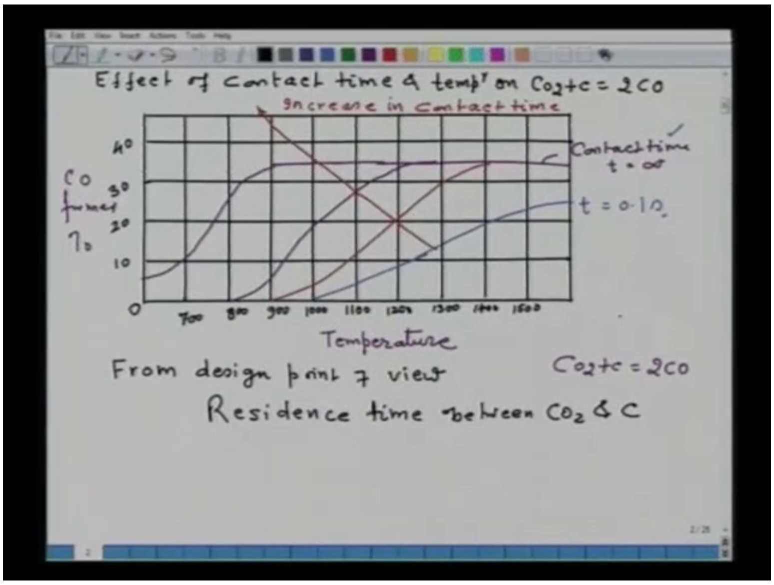

Effect of contact time & temp^r on $CO_2+C = 2CO$

From design point of view

$CO_2+C = 2CO$

Residence time between CO_2 & C

So, this shows here the effect of contact time effect of contact time and temperature and temperature on C O 2 plus C that is equal to 2 C O reactions. So, here it is C O which is formed in percent and here is a temperature, so as said the reaction which you are considering is C O 2 plus C that is equal to C O 2, C O, and we already know higher is the residence time, more will be the conversion of C O for a particular temperature, as a temperature rises the conversion of C O 2 to C O will also go up. Now, the maximum conversion thermodynamically that occur when you blow air is 34.6 percent as we have calculated earlier.

So, for example, if we have a very a large contact time I will say from where, this is say 34.6 which you cannot cross thermodynamically at any temperature. So, here this is this is the contact time, if you say this p that is equal to infinity, is very large contact time occurs, if you have a very large contact time the natural is C O 2 plus C is equal to 2 C O will approach to equilibrium, and this line will approach at a very high contact time.

Now, as you decrease the contact time, so another extreme if I take say the contact time is very small for example, 0.1 second just an order of magnitude, so for 0.1 contact time, (No audio from 22:58 to 23:06) so this I say t just a symbolic 0.1. Second you should not think, because the the composition if you want to read against the blue line it may not tell but, it just says that this is the maximum contact time; it is the minimum contact time.

So, you see when the contact time is very small, then you have to go for a very high temperature for reactions C O 2 plus C 2 to C O 2 takes place. Now, in between say there will be several curves depending on the contact times this this, so if I go in this direction, say this direction if I look at, so in this direction increase in contact time increase in contact time between the reactors. Now, this is the information available to us from the kinetic investigation.

Now, this information are very useful from design point of view how, say from design point of view from design point of view, because you will be operating for example, at a particular temperature, the reactor is refractory line, you have to decide the temperature for example, you want to operate 1000 degree or 1100 degree celsius. Because higher is the temperature, the problem associated with temperature will also be there, so once you have decided the temperature then optimization of residence time is important.

Then you have to choose the reactor dimension, higher is the height or higher is the height of the bed, the contact time between C O 2 which is formed with the combustion zone, with carbon is more, so this sector are to be optimize, so this this particular diagram tells you, that here residence time is important, residence time between C O 2 and C that is the most important.

You can have higher residence time by having a larger height of the bed, but will how high. So, this sector are to be optimized in order to design the reactor size of the reactor, diameter of the reactor, height of the bed, all these are important issue for conversion of C O 2 which is formed due to oxidation of carbon immediately as it comes in contact with air, and it subsequent conversion to C O 2 is more important. Because, whatever C O 2 that goes along with the fuel gas is unutilized, and it does not contribute anything to the calorific value.

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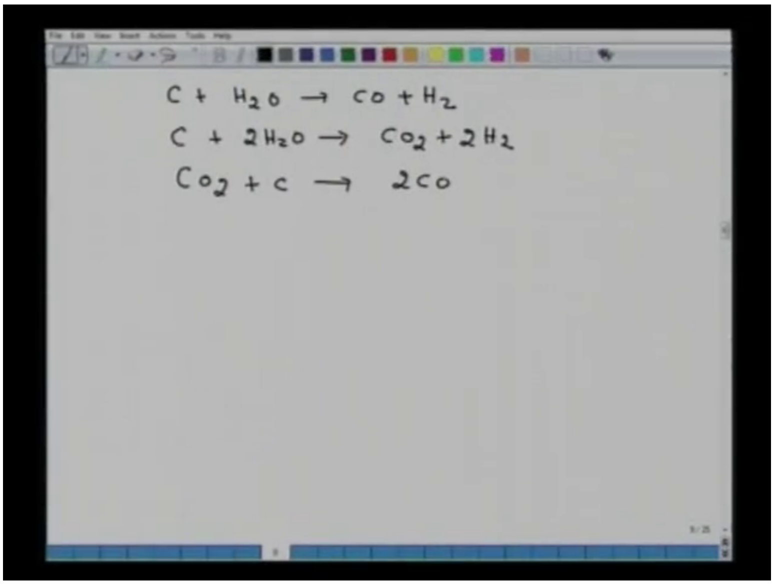

$C + H_2O \rightarrow CO + H_2$

$C + 2H_2O \rightarrow CO_2 + 2H_2$

$CO_2 + C \rightarrow 2CO$

Generation of large amount of heat and heat is utilized by blowing a steam for example, in the reaction say C plus H 2 O that is equal to C O plus H 2 or this reaction can occurs C plus 2 H 2 O that is equal to C O 2 plus 2 H 2, and ultimately C O 2 reacts with carbon that is equal to 2 C O.

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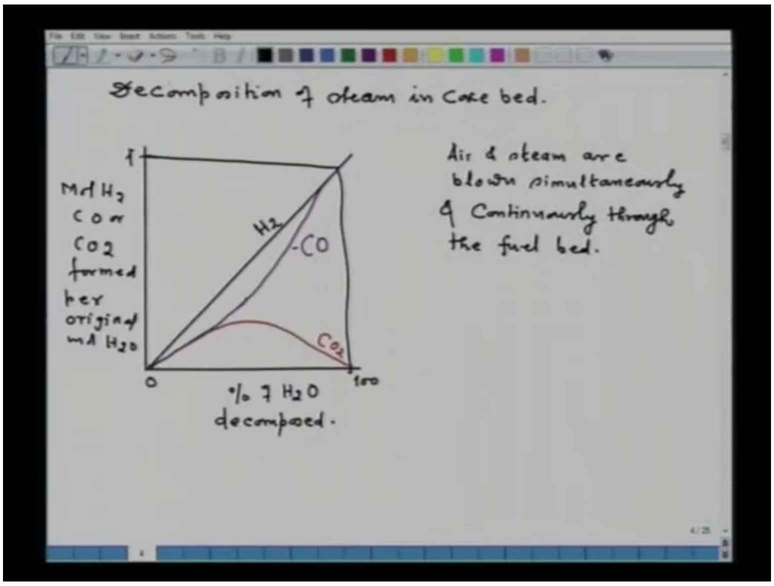

Decomposition of steam in Coke bed.

Air & steam are blown simultaneously & continuously through the fuel bed.

So, let us see the the decomposition of steam in coke bed, so decomposition of steam in for example, coke bed so this axis is say percentage of H 2 O decomposed. So, we take 0 to 100 and 0 to 1, and I want to close down here, now on this y axis I have moles H 2, C O or C O 2 formed per original mole of H 2 O; so this line it represents the formation of hydrogen, naturally more steam decomposes, more H 2 will form. Now, about the C O 2, so C O 2 attains a maximum and then on 100 decomposition it draws to 0 that is the variation of C O 2. Now, the variation of carbon monoxide, this is the variation of carbon monoxide, so that is what the various proportion of H 2 C O and C O 2 are available in the producer gas on decomposition of steam.

Now, in making producer gas, say in making producer gas air and steam are blown continuously, air and steam are blown simultaneously and continuously through the bed, through the fuel bed, coke bed or whatever. Now, it is a dynamic process, air and steam are blown in coke bed is there, and depending on the residence time the reaction take place, and depending on that the producer gas, the composition of the various components in the producer gas are influenced.

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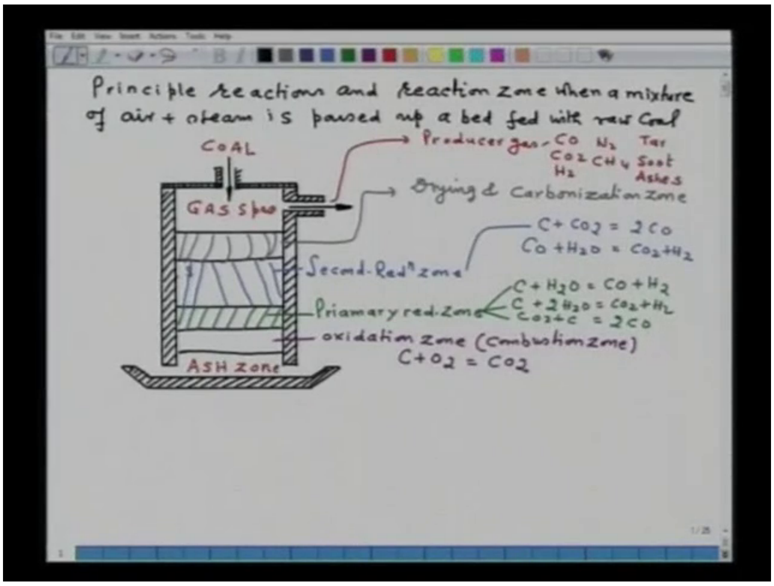

Principle reactions and reaction zone when a mixture of air + steam is passed up a bed fed with raw Coal

Now, if I want to show the principle reactions (No audio from 30:13 to 30:21) principle reactions and reaction zone and reaction zone when a mixture of air plus steam is passed up a bed fed with raw coal. So I will show the various zones here for example, I am charging coal at a steady state, coal flows downward and the gaseous move upward. Now, the zones for example, this is a ash zone, ash continuously is removed, then we have this is the oxidation zone or in short we can also call a combustion zone. Combustion zone means here, carbon is completely burned to C O 2, so as such the reaction in in this oxidation zone consist of C plus O 2 that is equal to C O 2, this is very hot gas it moves up.

And then we have the second zone which is called this one, which is this is one, this is the primary reduction zone primary reduction zone, and in the primary reduction zone the reaction which will occur C plus H 2 O, that is equal to C O plus H 2 or C plus 2 H 2 O that will be equal to C O 2 plus H 2 and C O 2 plus C, that will be equal to 2 C O (Refer Slide Time: 32:06).

So, the primary reduction zone is very important its height the residence time, because the C O 2 will move up, it will react with the carbon and steam which are there, and these reactions will occur, on the top of the primary reduction zone, we have a secondary reduction zone. So, this one I can put it here, say for example this one is secondary reduction zone secondary reduction zone and in the secondary reduction zone the whatever lefts C O 2 we can also react it may form 2 C O and the C O may react with H 2 O that can form C O 2 plus hydrogen (Refer Slide Time: 33:13).

Now, on the top of it we have this particular zone, this is the drying and carbonization zone, because the coal is charged at 25 degree celsius, it gets heated up by the hot gaseous, which are rising up on account of this, in the top portion of the gasifier the volatile matter, cracks decomposes and the methane or the tar which are produced the joint the producer gas. So, that is what the top get, this is what the drying and carbonization here, and this one or other this one is the producer gas space (No audio from: 34:35). So, from here, the producer gas is discharged is cleaned and fed for its subsequent use.

Now, if you use the coal then the producer gas will consist of for example, C O and C O 2 H 2, it may have nitrogen, it may have methane, it may have tar, soot, and ashes. Now, there are certain issues with the gasification by when you use coal, one the ash formation, and the temperature ash formation is very important, that is fusion and clinkering of ash may occur. And second when volatile matter is removed from coal, then tar formation also occur, though tar is a very high calorific value, but then it has to be removed from the gas which is being formed.

If you use coke, then the formation of tar and the methane which occurs, because of the decomposition of volatile matter may not occur, similar is the case with anthracite, anthracite does not contain any volatile matter. So, the formation of tar will not occur and as such the, formation of methane may also not occur. So, we have seen now, the science of gasification and saw various reactions, various requirements for conversion of solid fuel to gaseous fuel.

We have seen residence time is important, the amount of heat which is produced and its utilization by blowing of the steam, is important to take care of the excess heat which is produced; now all that we have done from the science, now the important thing. Now, how it is done in practice, so technology of gasification they have certain important points that are to be noted for developing a technology for gasification.

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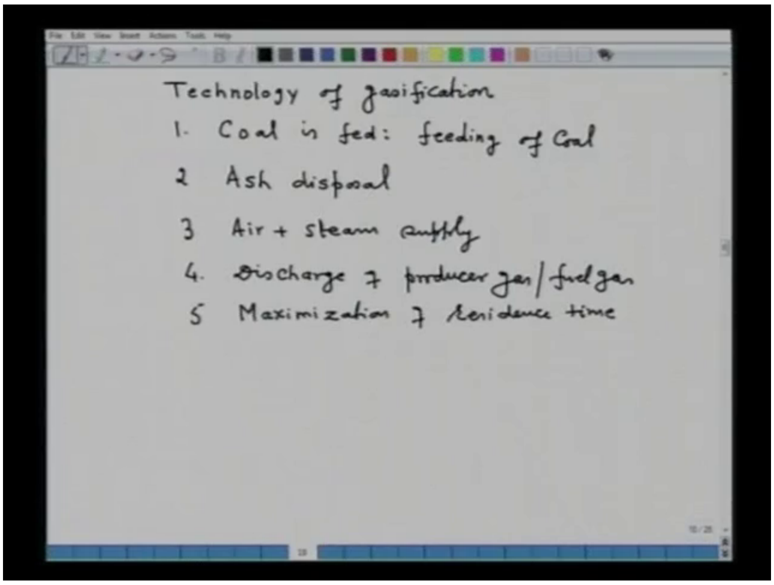

Technology of gasification

1. Coal in fed: feeding of Coal
2 Ash disposal
3 Air + steam supply
4. Discharge of producer gas/fuel gas
5 Maximization of residence time

One we have to see, how coal is fed, that is feeding of coal is important, so you have to deal with few tons of coal, how you are going to fed into the system. Second important thing as you have seen ash is also form and the coal if it contains 20 percent of ash or higher amount of ash, then a large amount of ash disposal will be there and accordingly while developing the technology you must consider, how you are going to dispose the ash.

So, ash disposal is important, ash disposal mechanism is also important, how you are going to dispose the ash during the process, third important thing is that how a mixture of air plus steam is supply air plus steam supply, how it is will be done that is also to be seen. Then fourth, the discharge of fuel gas, discharge of other producer gas or you may call fuel gas, how you are going to discharge, and what is its ultimate use is that the gasifier operators is nearby the consumer or it is away from the consumer. And then what is being planned from the products of gasification, which contains producer gas which contains tar, tar is again very high calorific value product soot, which again contains a very high amount of carbon and so on.

Fourth, fifth important point is the maximization of residence time maximization of residence time, now here the flow velocity of gases which are rising upward that is important. But, once you have decided the size of the reactor then the velocity is also fix, and hence the residence time is also fix however, little bit you can influence by having coke bed. So, following this technology, there are several gasifier has been developed.

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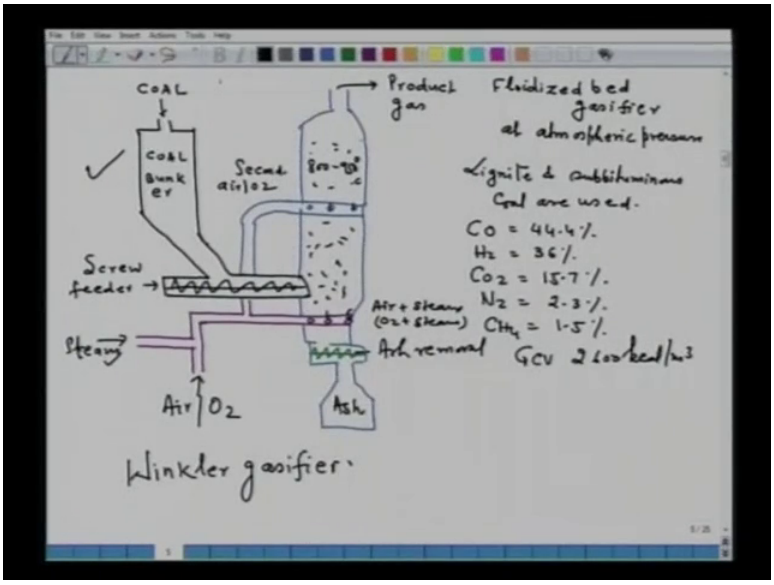

Fluidized bed gasifier at atmospheric pressure

Lignite & subbituminous Coal are used.

$CO = 44.4\%$
$H_2 = 36\%$
$CO_2 = 15.7\%$
$N_2 = 2.3\%$
$CH_4 = 1.5\%$
GCV 2600 kcal/m^3

Winkler gasifier.

I will just describe few for example, if we take a this is a short of a fluidized bed gasifier (No audio from 39:41 to 39:48) fluidized bed gasifier at atmospheric pressure or in short you can call this is a atmospheric gasifier. Now, fluidized bed gasifier means, the coke with the coal which is here is in the fluidized state, say that is the coal bed; now in this particular fluidized get bed gasifier, the gasification temperature is 800 to 850 degree celsius lignite and sub bituminous coal and sub bituminous coal are used.

The producer gas consist of C O say 44.4 percent, hydrogen 36 percent C O 2 15.7 percent, nitrogen 2.3 percent, C H 4 1.5 percent, and these gas has a calorific value, gross calorific value is 2600 kilo calorie per meter cube, this is the typical example, the values here and there may vary depending on the book from you have take from you take it. Now, in this particular gasifier this is the system for charging the coal, coal is fed into the gasifier by a screw mechanism, the screw moves and as a coal fed as a coal falls on the on the distance between this two it is fed into the gasifier.

Now, here you see the mixture of oxygen or air is passed steam is mixed and it is again it enters into the gasifier this is here a mixture of air and steam or oxygen and steam, when oxygen is use then the nitrogen contain with very low, if air is used then nitrogen will be there. So, here in this particular a gasifier this is a part from secondary air or oxygen, so here also the amount of oxygen here air is blown, so that the C O 2 the so that any leftover carbon gets also gasified. So, this is a one type of a gasifier here, the coal is fluidized you can have fixed bed gasifier also.

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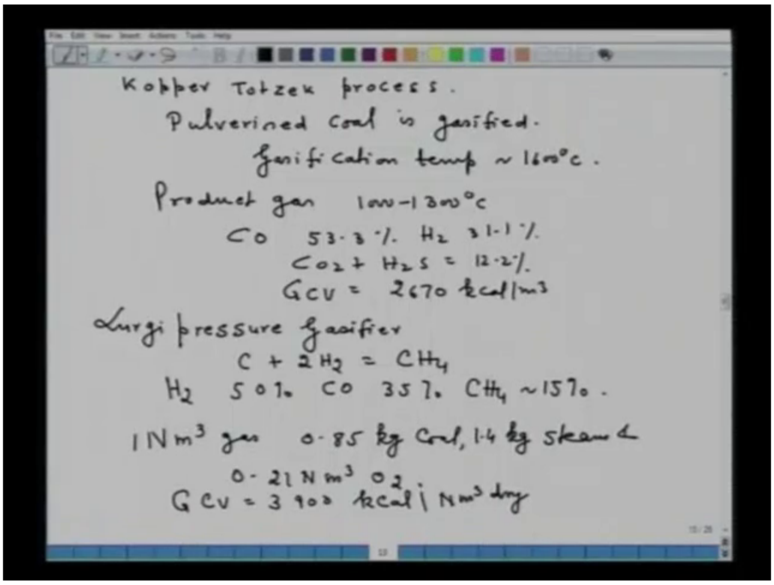

Kopper Totzek process.

Pulverined coal is gasified.

Gasification temp ~ 1600°C.

Product gas 1000-1300°C

CO 53.3 %. H_2 31.1 %.

CO_2 + H_2S = 12.2%.

GCV = 2670 kcal/m³

Lurgi pressure gasifier

$C + 2H_2 = CH_4$

H_2 50%. CO 35%. CH_4 ~15%.

1 Nm³ gas 0.85 kg Coal, 1.4 kg steam &

0.21 Nm³ O_2.

GCV = 3900 kcal/Nm³ dry

Now, in another for example, if you see another say in a Kopper-Totzek process here, pulverized coal gasified pulverized coal is gasified, and the gasification temperature is very high gasification temperature is a 1600 degree celsius, product gas which is discharged at around 1000 to 1300 degree celsius. Now, remember when you very high gasification temperature, then ash will be in the liquid form, so slag will form, so accordingly the disposal of slag is also an important issue.

The composition of producer gas is carbon monoxide 53.3 percent, hydrogen 31.1 percent, and C O 2 plus H 2 S that is 12.2 percent, and accordingly is gross calorific value is 2670 kilo calorie per meter cube, this is another method of a gasification. But, uses fluidized bed, here a very high temperature is used; now still another gasifier that I want to say is about the Lurgi pressure gasifier, Lurgi pressure gasifier. Now, this gasifier is unique in its operation, it operates at a very high pressure, and utilizes the reaction between C plus H 2 that is equal to C H 4. So, in a Lurgi pressure gasifier, the coal is gasified at very high pressure and utilizes the effect of pressure on this reaction, say C plus 2 H 2 that is equal to C H 4.

Now, this reaction there is a volume decrease, so if you increase the pressure more amount of methane will be there in the producer gas, and methane as a very very high calorific value. So, this is also another type of gasifier which works at a high pressure, now in this Lurgi pressure gasifier, the hydrogen contained and go as highest 50 percent, carbon monoxide 35 percent, and C H 4 and go up to 15 percent.

Now, this reaction C plus 2 H 2 is equal to 2 H 4 is equal to C H 4 this will occur at around for example, 20 30 atmosphere, so all that you have to design the reactor which can sustain that high pressure, so these are all the say important issues in this case. Now, for example, here say one normal meter cube gas it may require 0.85 Kg coal, 1.4 Kg steam, and 0.21 normal meter cube oxygen are required, gas will have a gross calorific value of the order of 3900 kilo calorie per normal meter cube dry.

So, as such there are there are many different type of gasifier, because this is in fact a technological issue that cannot be one method, there has to be several different methods also; this is all about the science and technology of gasification. So, you have seen that the producer gas it contains C O 2, C O, H 2, S 2 O, N 2, S O 2 hydrocarbons soot tar and so on.

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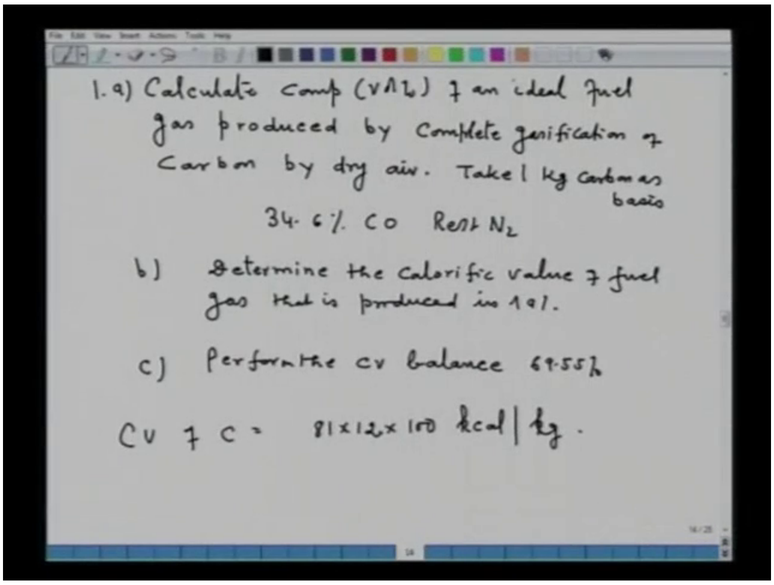

1. a) Calculate comp (v/v %) of an ideal fuel gas produced by complete gasification of Carbon by dry air. Take 1 kg Carbon as basis

34.6% CO Rest N_2

b) Determine the calorific value of fuel gas that is produced in 1a).

c) Perform the cv balance 69.55%

Cv of C = 81 × 12 × 100 kcal/kg.

Now, by way of certain problems I will illustrate the various calculated values, now for examples I will give you one problem, say you are required to calculate say for example, you calculate calculate the composition say in volume percent of an ideal fuel gas of an ideal fuel gas produced by complete gasification of carbon by dry air take 1 Kg carbon as basis. I already gave you the answer, the answer is 34.6 percent C O, and rest is nitrogen, so you can calculate and see that you get the answer though I illustrated in the lecture you can also see that.

You can calculate this is the part a part b now, determine the calorific value of fuel gas that that is produced in 1 a, c c you also perform the calorific value balance, that is how much is the input of the calorific value, and what is the output that is what fraction of the original calorific value of carbon is available in the product gas. Now, say here the answer for 1 b is the calorific value of fuel gas that will be equal to that will be equal to, anyway you can calculate, and see that the answer for question for 1 c, that will be around 69.55 percent 69.55 percent of the original calorific value of carbon is available in the producer gas.

Now, to calculate the calorific value of the carbon you will be using the Dulong formula, hence it is a pure carbon, so just for information calorific value of carbon, that will be equal to 81 into 12 into 100, that will be the calorific value of carbon, in kilo calorie per Kg; about the calorific value of fuel gas that is produced in 1 a. So, you have to calculate the amount of producer gas that already I have calculate in the lecture, and from the heat of combustion of C O and hydrogen you can calculate the calorific value of the fuel gas. And then you divide by this calorific value of carbon, then you will get what fraction of original calorific value of coal is available in the product gas. So, this is how you will be solving this particular problem.

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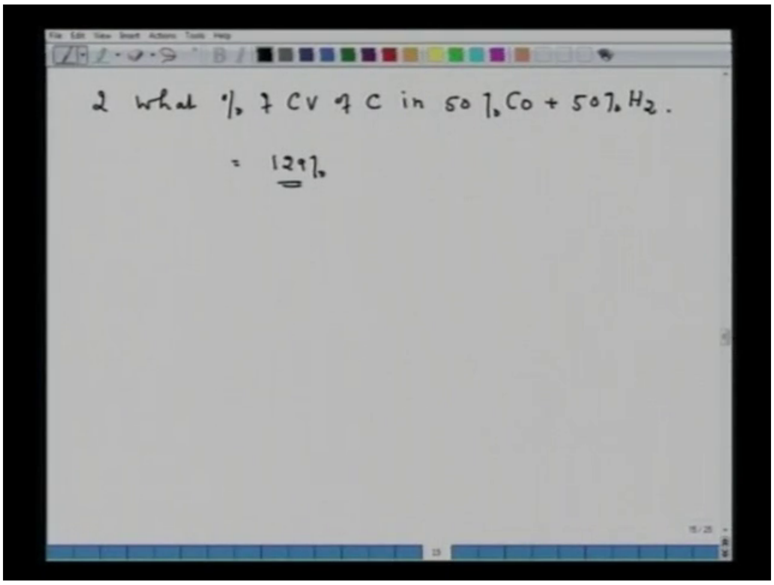

2 What % of CV of C in 50 % CO + 50 % H_2.

= 129 %

I will give you one more problem, that is second one you calculate what percent of calorific value of carbon in a gas of 50 percent C O plus 50 percent hydrogen, all that you have to take now here, 1 Kg mole of carbon react with H 2 O, you get 1 Kg mole C O and 1 Kg mole hydrogen. So, you will calculate the calorific value, and the answer will be getting around 129 percent. Now you have to account for why there is a increasing in the calorific value of the fuel gas. Because it is not 100, it is 129 percent that is you are getting, in the product gas calorific value more than that of carbon and this is obvious, because you are producing hydrogen.

Now, because of the gasification in presence of steam, extra amount of hydrogen is added and as I had said in the lecture, it increases the calorific value and you have seen the product gas which is forming heat has a calorific value higher than that of carbon calculate, get a feel and feel good.