Waste to energy conversion
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Lecture – 15
Energy production from waste through pyrolysis – 2

Hi friends. Now we will discuss on the second part of the module; Energy Production from Waste through Pyrolysis. In the first part of this module we have discussed on the fundamentals of pyrolysis reaction mechanism different products applications of bio oil and catalytic pyrolysis and in this module, we will discuss on the pyrolysis reactors and utilization of pyrochar and gases. As the pyrolysis is one thermo chemical conversion process like other two thermo chemical conversion process like incineration and gasification.

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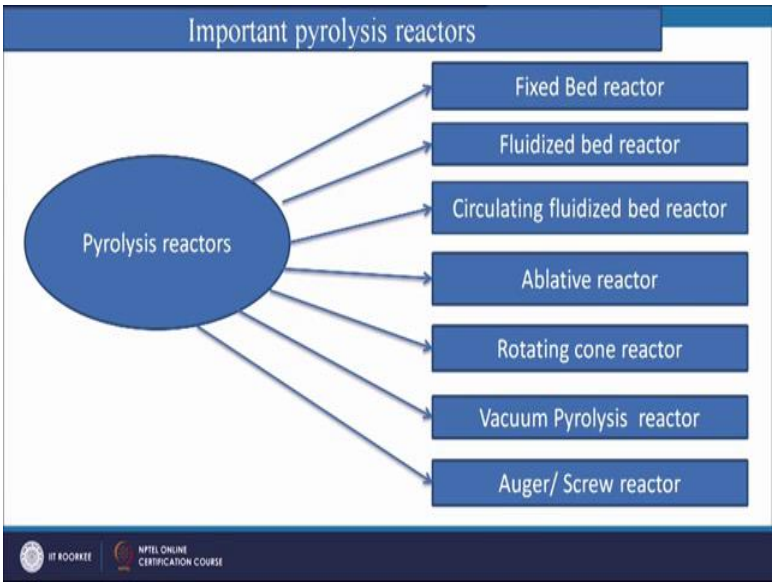

In this process also the first reactor was fixed bed reactor and then fluidized bed reactor and circulatory circulating fluidized bed reactor was developed.

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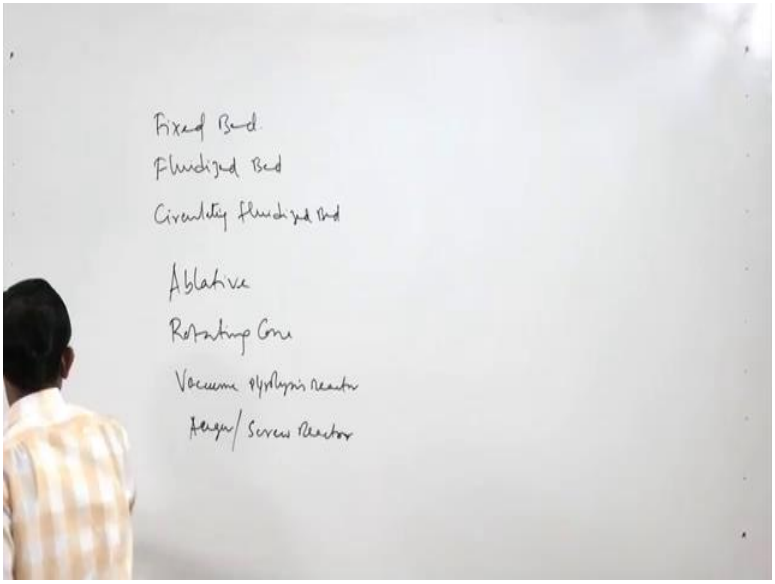

In these three reactors, there is fixed bed fluidized bed and circulating fluidized bed some sweep gas is used in case of combustion and gasification combusting agent and gasifying agent are use, but in this reactors no such agent is used, but inert gas is use to carry the pyro vapor which can be further condensed there after some development kin with the reactor to avoid the use of inert gases. So, ablative reactor and then came rotating coned reactor then came vacuum pyrolysis reactor and auger or screw reactor.

Now, we will discuss one by one on this reactors at first we will see the fixed bed reactor in the fixed bed reactor.

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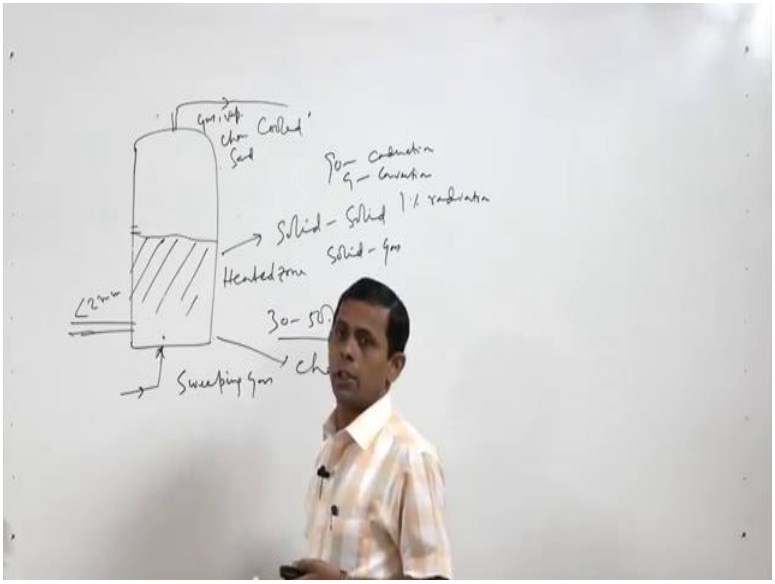

Now, waste or biomass can be put from the site of the fixed bed and in this case this zone will be heated zone and we need to send one inert gas that is sweeping gas and as the temperature is maintained here biomass and waste is coming here. So, pyrolysis will take place, but here the diameter of the particles may be bigger no limitation on the diameter of the particles. So, when it is coming in this hot gas then the vapors will be created through pyrolysis and it will goes off and further it will be cooled and we will get bio oil and the gasses it gives 30 to 50 percent of bio oil and gives more char because it is gets more residents time.

We are not using here any heat transfer media like sand unlike other fluidized bed and circulating fluidized bed say sand is used. So, that it has high heat transfer coefficient and. So, rate of heat transfer is more in those reactors, but here the rate of heat transfer is less and basically solid gas; gas to solid heat transfer takes place there is no solid; solid heat transfer that is why the time requirement is higher residents time is higher as a result the char production is also high here more char is produced and less bio oil is produced, but this is very simple process and it is reliable, but because of low oil production bio oil production which is more desirable in pyrolysis reactions this is not commercially used much.

Next the fluidized bed reactor came in fluidized bed reactor the biomass or the waste is put from the bottom and the sweeping gas is also from the bottom and particle size of

this is very less than 2 millimeter. So, because of this very low particle size and supplying from the bottom it gets more mixing with the hot gas and residents time is also less due to that reason the bio oil production is more in this case we can get around 70 to 75 percent bio oil and rate of heat transfer is also very high in this case because particle size is less and we not we use some sand.

So, sand is used. So, sand helps solid to solid heat transfer and gas solid as usual it is also there. So, convection conduction and radiation all the 3 mode of heat transfer acts on these and ninety percent conduction nine percent convection and one percent heats radiation and heating takes place this gas which goes off that can be recycled because these will also carry the char this is also will carry gas vapor char and sand also.

So, this can be recycled back. So, that is why the heated recycle gas hot inlet gas both helps for the heating of the material as a result the pyrolysis of the material the design is simple the advantage is that the design is simple it is easy to operations and it can suitable for a can be suitable for a large scale production for the main disadvantage of this process is that it requires smaller particle size minus less than 2 millimeter, next we will come to circulate fluidized bed reactor.

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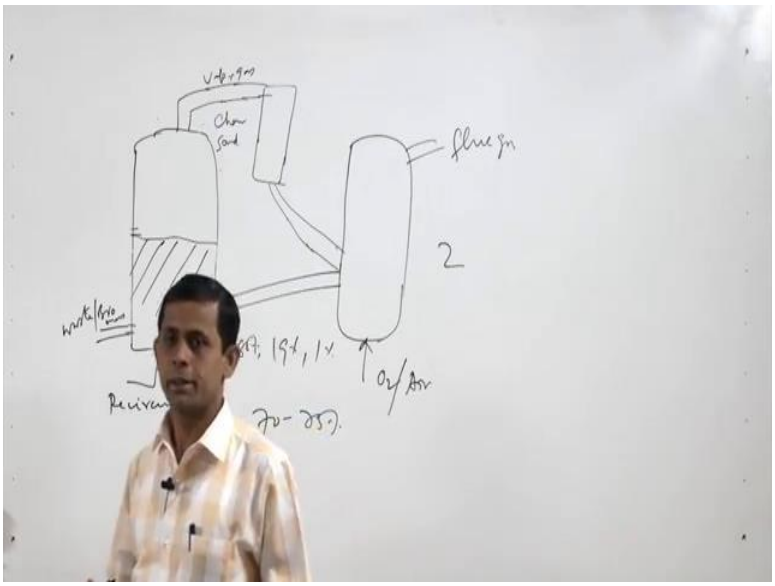

In circulatory fluidized bed reactor, 2 chambers are used. In the first we put biomass or waste and here we put recycling gas re circulating gas re circulating gas where from it comes it comes from the second chamber.

So, here the pyrolysis takes place. So, pyro char along with vapor gas char and sand. So, all comes from the top of this pyrolyzer because high velocity is maintained here. So, it is coming then it is separated then it is separated and this part is send to others chamber that is chamber 2 and we pass here oxygen or air or we pass here air. So, air helps the combust the sand char it coming here and mix some flue gas that gas is used for heating here and the material which is produced here that can also be recycle here the sand is recycled here. So, this is the development of the fluid bed reactor the some part is recycle the solid is recycle. So, heat transfer is taking place here through the conduction convection and radiation and this char or the sand which is returned that can act as some catalyst also that will be having some catalytic activity.

So, due to this reason here the bio oil production is also very high 70 to 75 percent bio oil production.

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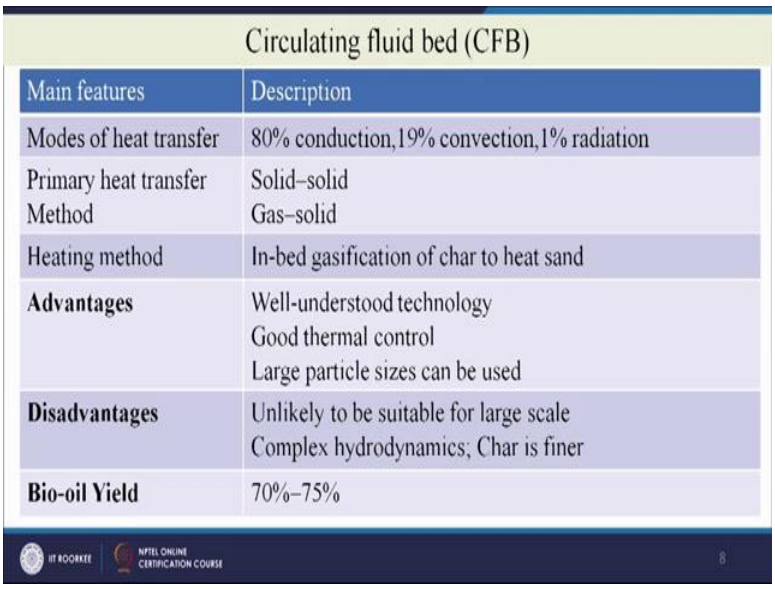

And here conduction mode contribution of the conduction mode of heat transfer reduces from ninety to eighty percent with respect to fluidized bed due to the circulating if and conduction mode is eighty percent, but convection mode increases from ten to nineteen percent and radiation remains same around one percent. So, this is the mode of heat transfer in this reactor and here some in bed gasification takes place and heat it is and helps for the heating of this. So, these are the basic features of this, but this reactor has

some disadvantage that is this complex hydrodynamics in it and it is unlikely to be suitable for large scale production.

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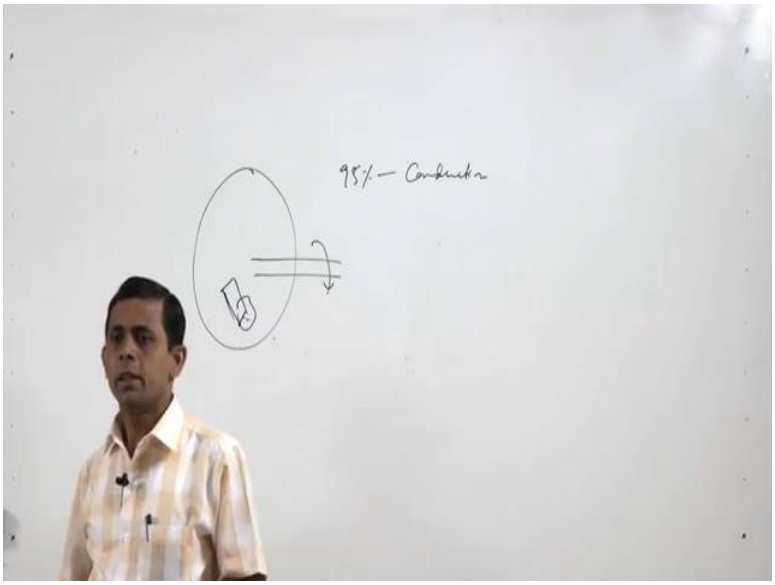

Next we will come on the ablative reactor in ablative reactor one hot plate is used and it is rotated this is rotated and biomass is put on it and waste is put on it and it is pressed and it is pressed.

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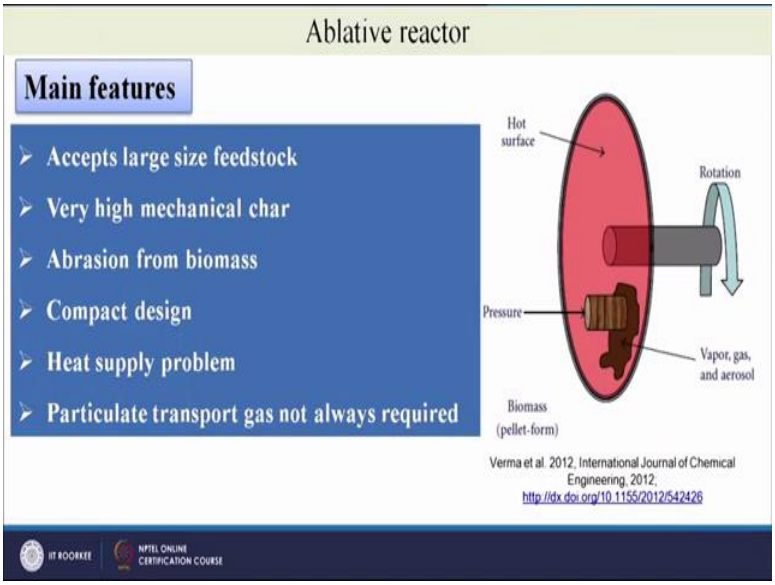

So, due to s zone here, so this is pressed. So, hot plate increases the temperature here and the biomass are waste is converted to vapor gas and aerosol one disadvantage of this

process is that how to heat the system like other cases we use hot gases, but here we are not using any hot gas we are heating the plate only. So, how the plate will be heated that is the main problem here and this is advantages that this is a compact reactor it is a compact reactor and it does not require any sweeping gas. So, that is another important advantage of this reactor, but disadvantage is that how to heat the biomass.

So, that is our main disadvantage and this is not commercially used it and in this case we see maximum heat transfer takes place through conduction. So, ninety five percent is conduction four percent convection and only one percent is radiation and solid heat transfer takes place there is no gas solid heat transfer in this case and inert gas is not required, but this reactor is costly and low reaction rate. So, these are the disadvantage of this reactor system. Next we will come to rotating cone reactor.

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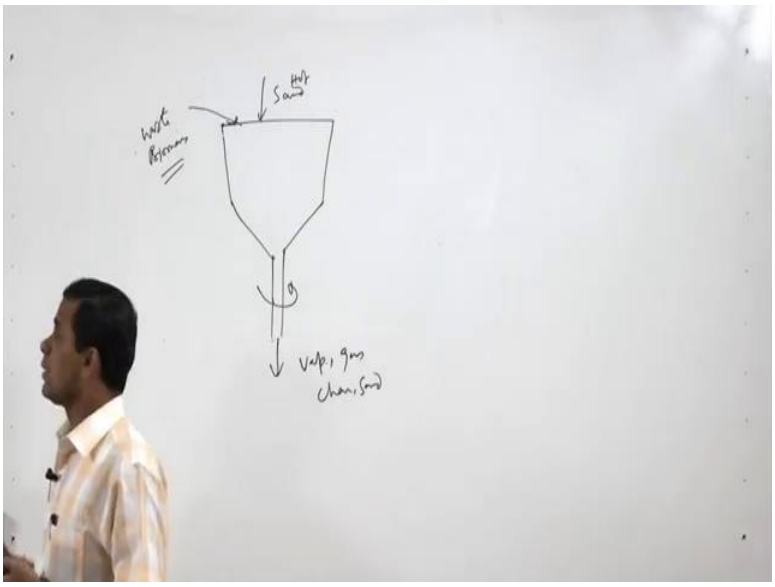

In rotating cone reactor on cones have reactor is used in this cone shape reactor, it is rotated and we add waste or biomass from the top and also sand there is hot sand we also put hot sand and this and there is some scientifically action on it.

So, the material the waste biomass and hot sand get mix. So, heat transfer is very fast. So, as the hot sand is used and the material by the product comes out from the bottom, it takes less time and we get here vapor gas char sand and after separation sand is can be added from the top once again, in this process, we can get around 65 percent of bio oil, but this reactor system also has some disadvantage it is difficult for scalar, next we will

come to vacuum pyrolyzer. So, vacuum pyrolysis reactor in case of fixed bed pyrolysis reactor.

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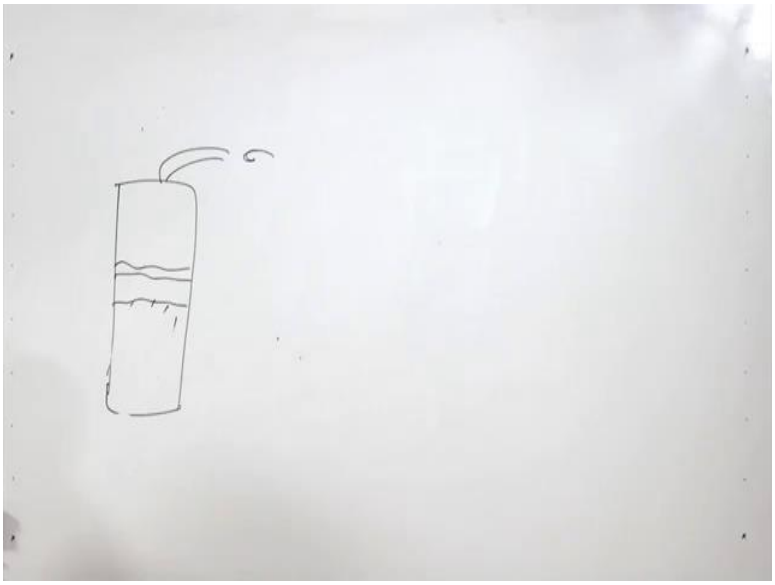

We had seen that material is in a lower part of this reactor. Now if you do not flow this sweeping gas in spite of that if we put some vacuum here we can put some vacuum here and material can be put into trays different rays as shown here the different rays.

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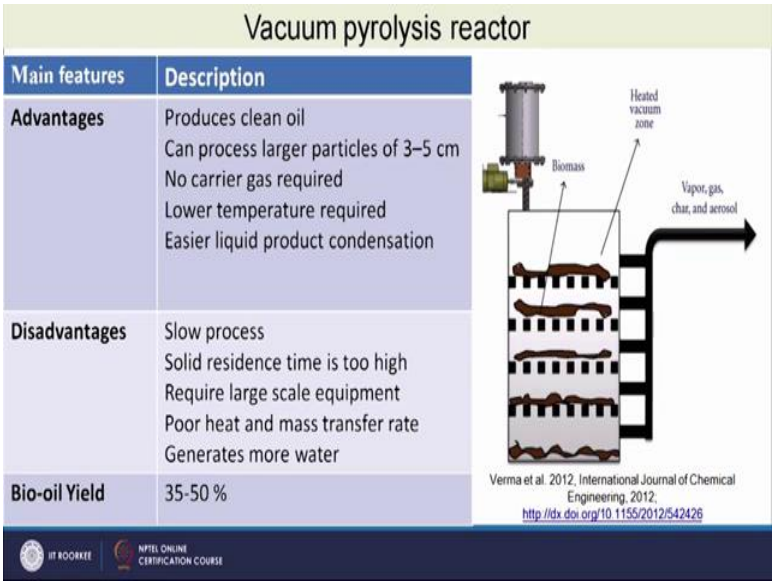

So, this material can be put in different rays and some vacuum is created here. So, that we do not need to provide any inert gas to carry the vapor produced inside the pyrolyzer

we can put the material from the top in this case like fixed bed reactor, but due to the application of vacuum it generates vapor at lower temperature and its easier for liquid productions. So, these are the advantages and disadvantages are that this is low process solid residence time is too high just like fixed bed.

So, it requires large scale equipment and generates more water here bio oil production is also similar to fixed bed reactor say 35 to 50 percent that is why this is also not very widely used. Next, another development on this pyrolysis reactor is auger or screw type reactor.

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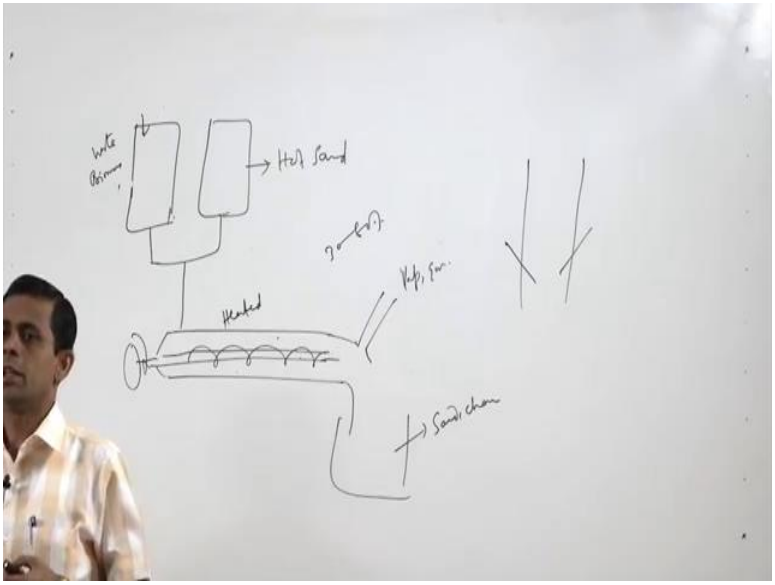

In screw reactor we use to tank, one containing hot sand and another is containing waste or biomass.

So, these two are mixed after mixing it goes to a screw. So, we have some screw shaft and it is going to the screw. So, from the other end when the material is coming inside and it is giving by some motor action and this it is giving the screw is giving forward movement this material. So, this is also hot in heated this is also hot sand. So, after mixing this hot sand and waste it is coming to screw and it is going forward direction and pyrolysis is taking place here. So, from that of the vapor gas goes up and from the bottom we collect sand and char here of the sand is added advantage of this reactor is that we do not need any inert gas flow and it can gives around say 30 to 60 percent of bio oil production.

Next we will go on plasma reactors. So, after ablative rotary cone and this screw reactor the people are trying to develop new type of reactors which are which may be more efficient and just like plasma gasification plasma pyrolyzer is also being attempted to be developed and in this case the condition will be different the plasma will be produced in the reactor just like plasma gasifier by applying high voltage by high applying high voltage across to electrode and that under certain conditions those plasma will help to vaporize the materials which is inside this the waste and biomass. So, the vapor will form that can we condensed further and then bio oil can be produced.

So, this is the mechanism for the plasma reactors and 30 to 40 percent bio oil can be produced from this reactor. Now we will see different reactors and we will compare some parameters.

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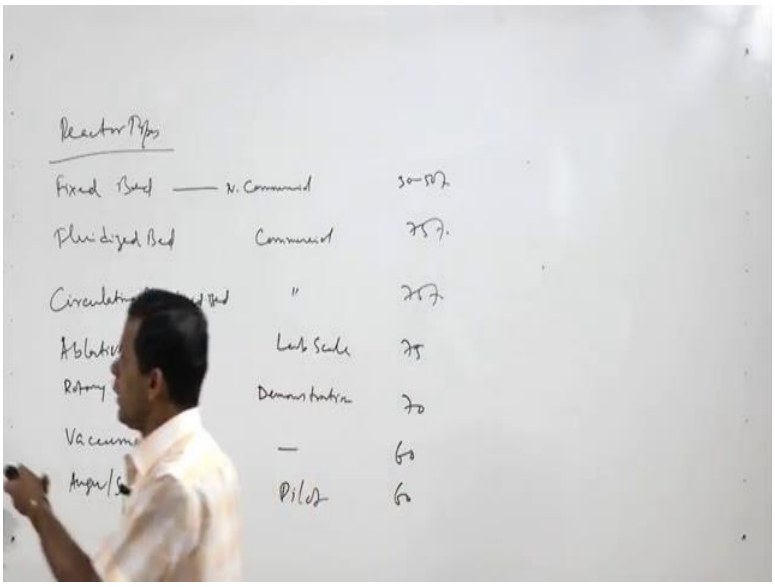

So, type of reactors fixed bed fluidized bed circulating fluidized bed ablative rotary cone vacuum and auger if these are a type of reactors then if we see which one is commercial. So, fixed bed is not commercial fluidized bed commercial circulating fluidized bed also commercial ablative is lab scale rotary cone rotary cone is demonstration scale vacuum is also in not in widely reported vacuum is not widely reported and auger is in pilot skill this is in pilot skill.

So, these are the status of in which level this reactors have been matured and applied next we see the bio oil productions. So, fixed bed that is 30 to 50 percent, here around 75

percent, this is also 75 percent ablative will give us about also 75 percent rotary cone rotary cone is giving us 70 percent and vacuum will give it is similar to this slightly say 60 percent and auger is also is giving us 60 percent. So, these are the bio oil production.

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Comparison of various types of pyrolysis reactors

Properties → / Reactor ↓	Status	Bio-oil yield (wt%)	Complexity	Feed size specification	Inert gas requirements	Specific reactor size	Scale up
Fluid bed	Commercial	75	Medium	High	High	Medium	Easy
CFB	Commercial	75	High	High	High	Medium	Easy
Rotating cone	Demonstration	70	High	High	Low	Low	Medium
Ablative	Laboratory	75	High	Low	Low	Low	Difficult
Auger	Pilot	60	Medium	Medium	Low	Low	Medium
Vacuum	None	60	High	Low	Low	high	Medium

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And here if we see the complexity out of this reactors the maximum complexity is it see a these circulating fluidized bed and rotary cone then for fluidized flow bed is medium auger it is medium and ablative is high complexity and vacuum is also high complexity. So, one is complexity parameter and another important parameter is specific reactor size.

So, reactor size is also medium for fluidized bed CFG is medium rotating cone is low ablative is low auger is low and vacuum is high. So, each of scale of if we think about then; obviously, that fluidized bed is easy for scale up CFBG for scale up, but ablative is not. So, easy it is middy difficult and auger is medium that screw reactor is also not. So, easy for scale up, but it is medium it can be done. So, and feed size specification fluidized bed is highly very very particle size should be less than 2 millimeter. So, highly specific to feed size, but others like say rotary cone it is having feeds as satisfaction is high, but ablative has no that of specification for feed size any feed stock can be used.

So, pyrolysis vacuum can also be any feed stock can be used. So, this stable gives us some comparison on this feed size specification inert gas requirement specific reactor size etcetera on the basis of this information; it seems that the auger has screw type reactors which is having the medium scale up difficulty and medium complexity and

medium size specifications that may be of superior, but as it is developed in later stage. So, in future this reactor make it more interest as on today the fluidized bed reactor is mostly used in commercial application now we will see some reactors used in pyrolysis processes there are some report available on 2012, on the basis of this report it seems that as for an 2 thousand twelve different types of pyrolysis reactors have been used in different countries here the Canada, UK, Netherlands, Germany, USA, China in different countries the pyrolysis reactors have been used and all those reactors is having capacity more than 10 kg per hour.

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Pyrolysis bio-oils production processes in 2012 (above 10 kg/h)

Host/ organization	Country	Technology	Capacity kg feed/h	Capacity kg bio-oil/h	Applications	Status
ABRITech/ Advanced Biorefinery Inc., Forespect	Canada	Auger	70–700		Fuel	Operational Commissioning
Agri-Therm/ University of Western Ontario	Canada	Fluid bed	420		Fuel	Upgrade
Biomass Engineering Ltd.	UK	Fluid bed	250		Fuel and products	Construction
BTG	Netherlands	Rotating cone	250	200	Fuel and chemicals	Operational
BTG Bio Liquids EMPYRO	Netherlands	Rotating cone	6500	5000	Fuel	In design phase

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So, here we see that these reactors are either in operational or commissioning stage or up gradations or in design stage or under construction stage. So, it seems that this technology is gradually coming up it is developing and different technologies like say fluid bed auger rotating cone ablative all have been used, but fluid bed has been used in maximum cases and separating fluid bed and fluid bed have been used in many cases . So, now, we will discuss on the application of char produced through the pyrolysis process.

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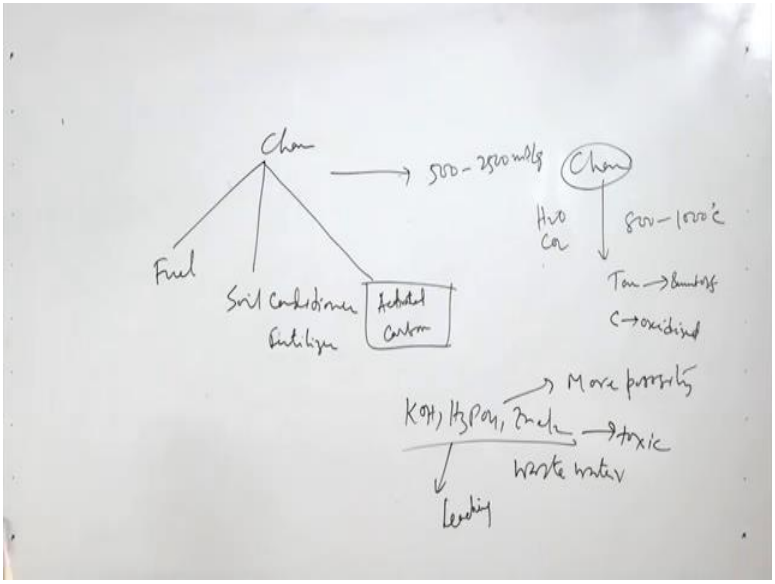

So, char which is produced from pyrolysis process that can be used for different applications it can be used for the fuel solid fuel this char which is produced we have discussed in the previous module that its heating value is more than the biomass and waste which we used for the pyrolysis process.

So, this can be used for a fuel solid fuel and can be used a soil conditioner soil conditioner or fertilizer the p h of this char is around eight to nine. So, basic nature it has it has some basic nature. So, any soil which is acidic in nature this will help to neutralize the p h and condition the soil second is this is continuing carbon and porous in nature. So, carbon high porous carbon is present in this char and the this materials porous carbon remains for a longer time in soil it remains for a longer time in soil as a result it helps the diffusion of oxygen into the soil. So, that way it helps us the soil conditioning.

Third application of char may be activated carbon production all though this char is having some porous structure, but further porosity can be increased by activation. So, activated carbon can be produced by further activation of it. So, for the activation of these char there are 2 basic methods, one is physical another is chemical methods in case of physical method this char is hearted let say 800 to 1,000 degree centigrade in presence of some oxidizing agent H_2O or CO_2, this char is it. So, due to this reason the star present in it is burnt off and carbon presenting char carbon presenting char is also further oxidized as a result the skeleton up this char gets more porosity. So, by this physical

method we can increase the porosity of this char and the porosity can be achieve say 500 to 2500 meter cube per gram.

But in chemical method we use some chemical like say potassium hydroxide phosphoric acid zinc chloride. So, this 3 chemicals have been reported to use for the activations of this pyro char and it gives more porosity it gives more porosity, but these have some disadvantages these are the chemicals and did not cell to particularly is very toxic also and it requires washing several times washing and when washed it generates large number of waste waster third is if to washing is not complete it then also it will there will some possibility of leaching, because of this 3 difficulty the chemical method is not getting. So, interest the physical method is becoming superior then the chemical one.

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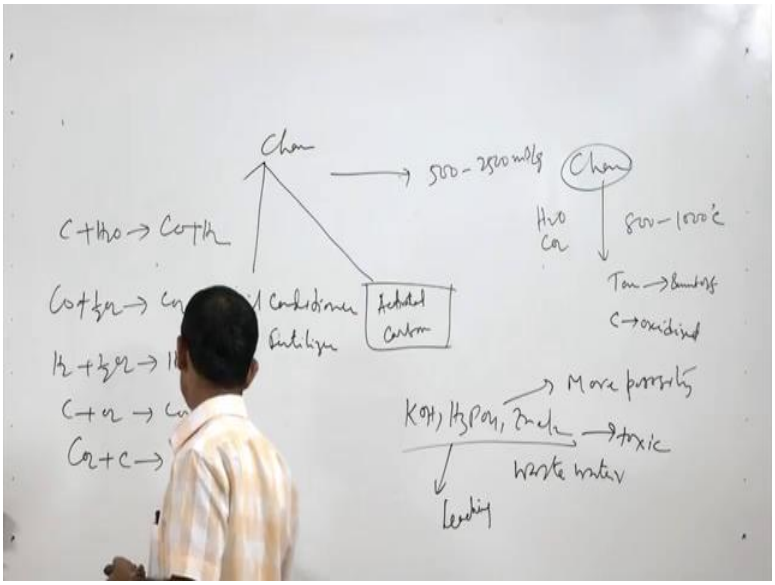

The reactions which take place during physical methods is that C plus H2O then it will give CO plus H2CO plus half O2 it will give CO2 and then H2 plus half O2, this will give H2O and C plus O2, it will give CO2 and CO2 plus CCO2 plus C, it will give 2 CO. So, these are the reactions which takes place in case of physical activation now we will discuss on the utility of the gas produced through the pyrolysis process. So, gas which is produced through pyrolysis it contains CH 4 CO H2 CO2, etcetera and it is heating's value is around 6.42; 9.8 mega joule per k g.

So, this gas can further be used for heating something in this case it is used for the heating of the gas in the pyrolysis reactor. So, these are the applications important

applications of this gaseous products are as hydrogen and CO is present we can separate the hydrogen and it can be used for other application or COH2 can be used for other applications after this in this module.

Thank you very much for your patience.