FOOD SCIENCE AND TECHNOLOGY

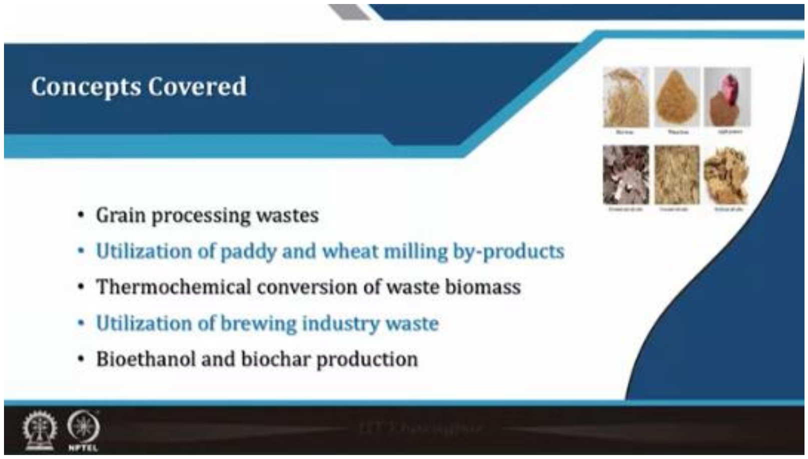
Lecture57

Lecture 57: Grain Processing by-products and Waste Utilization

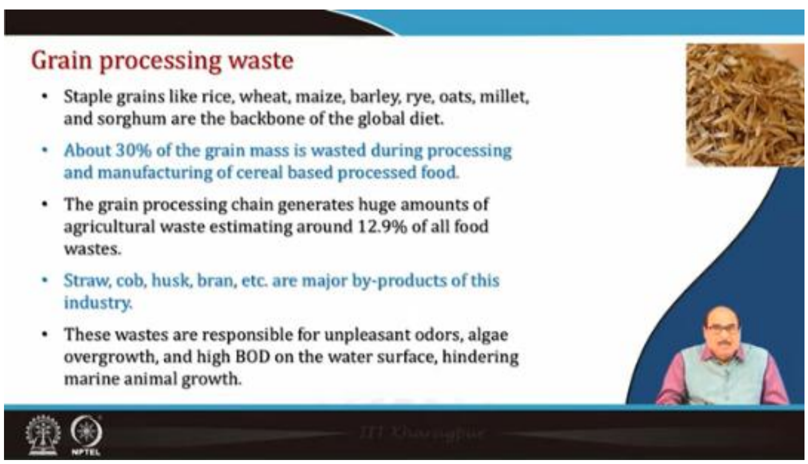
Hello everybody, Namaste.

As you know, we are in Module 12, where we are discussing the circular economy in the food industry. In the earlier class, we talked about the circular economy concept. What does it mean? That is: make, use, reuse, and that is the concept.

So, in today's lecture, we will talk about grain processing byproducts and waste utilization, that is, how this circular economy can be used in the grain processing industry.

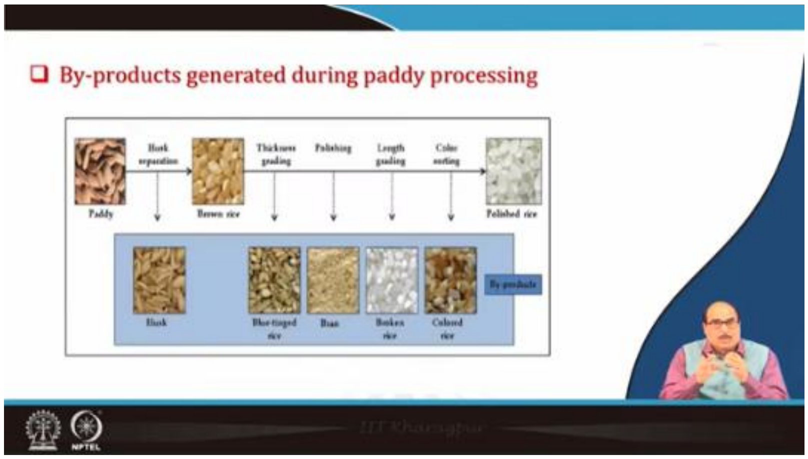


I will tell you something about this. So, we will discuss grain processing wastes: what are the different types of grain processing waste? Then, we will talk about the utilization of paddy and wheat milling byproducts. Thermochemical conversion of waste biomass, particularly from the grain milling industry or grain harvesting after the biomass, etc., which you obtain, can be converted into valuable material. Then, we will also talk about the utilization of brewing industry waste, and bioethanol and biochar production from agricultural biomass.

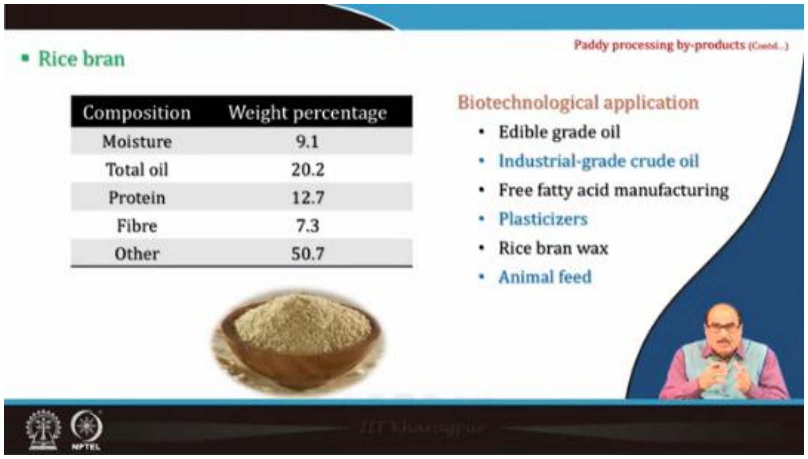


So, let us see what the different types of grain processing waste are. You know, staple grains like wheat, rice, maize, barley, rye, oats, millet, sorghum, etc., are the backbone of the global diet. They are the major staple food for the majority of the population globally. When they are harvested and used for various purposes, it is estimated that approximately 30 per cent of the total grain mass, including the grain and other material of the crop, is wasted during the processing and manufacturing of various processed products.

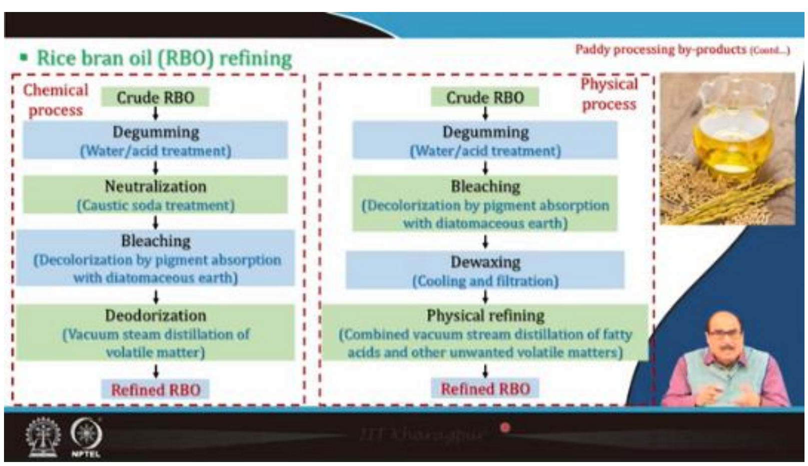
So, the grain processing chain generates huge amounts of agricultural waste, estimated at around 12.9 per cent of all food waste. So, you can say 13 per cent of the food waste is from the grain processing chain. Straw, cob, husk, bran, etc., are the major byproducts of this industry, and these wastes are responsible for unpleasant udder, algae overgrowth and high BOD value of the water surface, hindering the marine animal growth, etc.



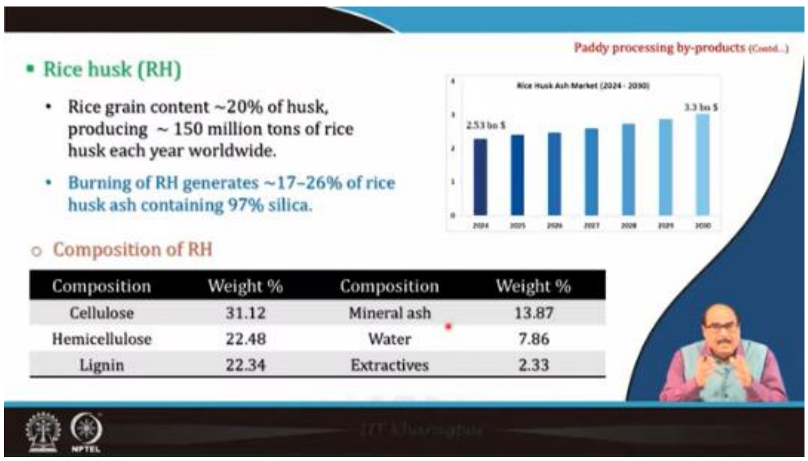
So, the major byproduct, let us take one by one, first, we will talk about paddy processing. So, after the paddy is harvested, you get the straw, etc., and then from the paddy, it is milled. After drying, it is milled. So, if you get the first, you get the husk and you get the brown rice. This brown rice contains bran, and then the polishing occurs, and you get bran and the rice. During the polishing and subsequent milling, etc. polishing and milling, there might be some broken rice. So, you get broken rice. So, these are, maybe you can say, the husk, blue-tinged rice that contains some thick grading and some amount of even bran, etc., bran, broken rice. Coloured rice, etc., that is, after the colour sorting, you get coloured rice and then finally, polished rice. So, this is in the value chain, the by-products, basically, you can say the major by-products: husk, blue-tinged rice, bran, broken rice, and coloured rice. Although before the rice whole crop, that is, even after harvesting, you get the straw, and this straw can also be used for various purposes, and that is being used nowadays.



So, I am concentrating mainly on the paddy and its milling by-products. So, one of the major by-products of the paddy milling, as I told you, is rice bran. This rice bran has major industrial applications, and if you look at the composition of rice bran, you find it contains moisture at around 9 per cent. Then, total oil: it contains a high amount of very good quality oil, about 20 per cent, 12 per cent protein, and 7 per cent fibre. Other materials, like cellulosic materials and all those things, are about 50 per cent. So, half of the bran is a very good component and a valuable product. So, it can be used for various purposes, like biotechnological application of rice bran, which may be for making edible grade oil, or for making industrial grade crude oil. Even then, it can be used for manufacturing fatty acids, it can be used as a plasticiser, it contains a good amount of wax, etc., and rice bran wax can also be used for animal feed. So, this one byproduct of the rice milling industry itself is a very valuable component, and it has a lot of uses.

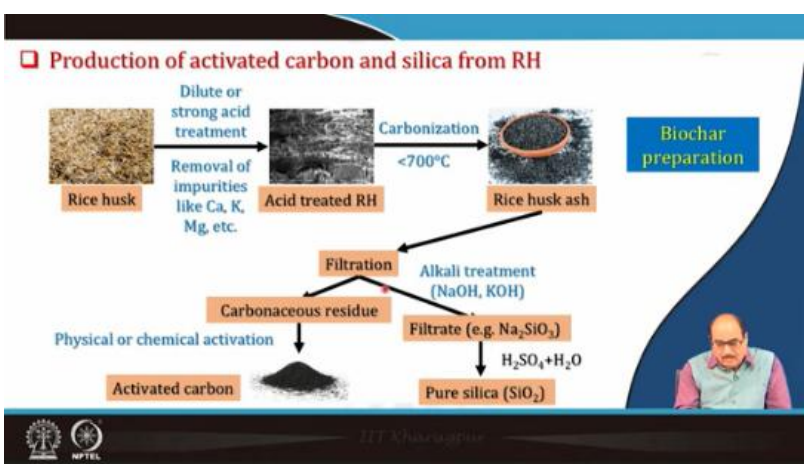


Then, one major use in the industry is that there is already rice bran oil. So, rice bran oil from the rice bran is extracted by the solvent extraction method, and then this oil is subjected to refining, resulting in crude rice bran oil, which contains gums, etc. So, degumming is then neutralised to neutralise the free fatty acids. So, caustic soda treatment is given, then it is blanched and deodorised, and you get a refined rice bran oil. So, it is the chemical process for refining rice bran oil. Then also it can be refined by physical methods like and in here that is the neutralization is mainly that the it is replaced with that physical refining it contains de-gumming, bleaching, de-waxing and then finally, it is physical refining where combined vacuum steam distillation of fatty acids and other unwanted volatile matter etcetera is there. So, there is a complete value chain, and now in the market, even refined brown rice oil is a very popular oil. It has a very good quality of fatty acids, and that is the polyunsaturated fatty acids, etc. So, that is even more valuable.

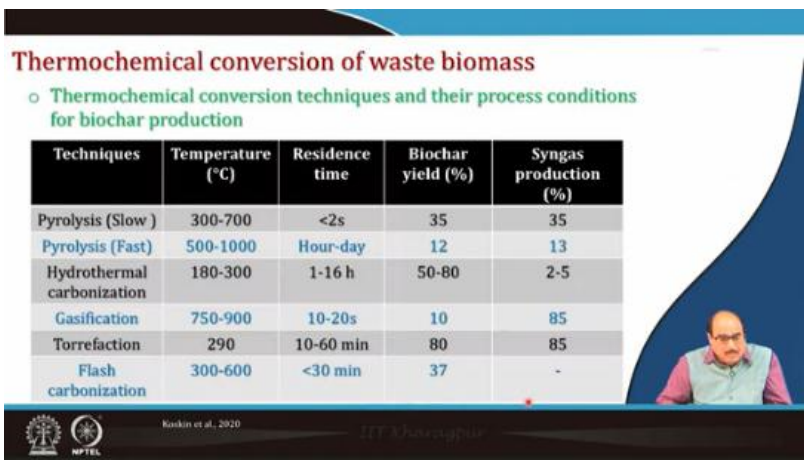


Then, let us talk about rice husk that as you see that the grain rice grain or paddy grain contains about 20 percent of husk producing around 150 million tons of rice husk each year worldwide and then burning of rice husk generates about 17 to 26 percent of the rice husk ash containing around 97 percent silica. So, that is one silica is a very valuable industrial product. So, if you look at the rice husk market projections from 2024 to 2030, you will see that in 2024, it was to the tune of about 2.53 billion US dollars and in 2030, it is expected to be about 3.3 billion US dollars. So, if you look at the composition of rice husk, it contains around 31 per cent by weight cellulose, about 22.5 per cent hemicellulose, 22.3 per cent lignin, about 14 per cent ash mineral, 8 per cent water and other extractives, about 2.3 per cent. So, again, this has a very valuable component here.

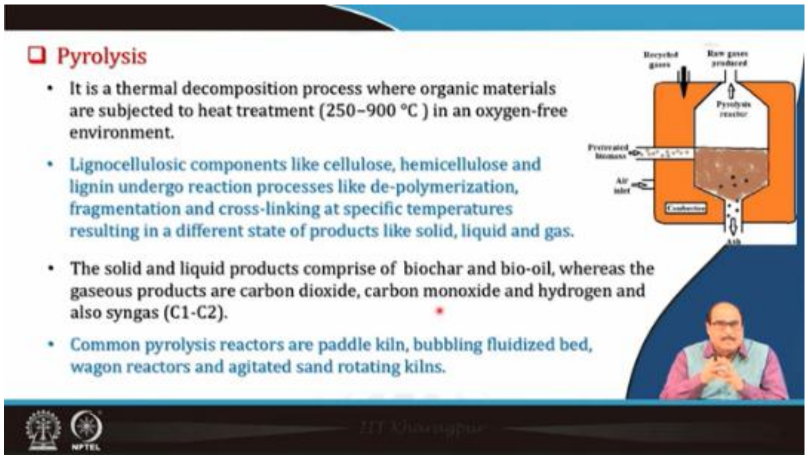
So, this rice husk can be used in one day, after which the rice husk can be burnt in limited oxygen conditions at less than 700 degrees Centigrade, and it can be generated into biochar. Also, it can be burnt at 780 degrees Celsius, less than 780 degrees Celsius, it you get converted into ash, as I talked about, completely organic matter is burnt. And then also it can be burned in an aqueous environment, which gives the hydrochar. So, all these components of rice husk, such as biochar, hydrochar, etc. they have various industrial applications they They are used in fact, they can be used for various purposes in different sectors. They can be used as cleaners and polishers in metal industries, soil stabilisation and geotechnical purposes. They can be used for wastewater treatment, for fillers, composite bio fertiliser or even activated as a source of activated carbon. They can be used for fuel for boilers, kitchenware, pharma, concrete, ceramics, etc. or even insulating rice brick or building materials, etc., or even they can be used as a raw material for other industries, etc. So, here you see the rice husk, which is sometimes even wasted and thrown away, creating pollution, etcetera. So, in the circular economy, this has great scope for utilizing this rice husk. And rice bran and the whole paddy crop, etcetera, similarly other parts.



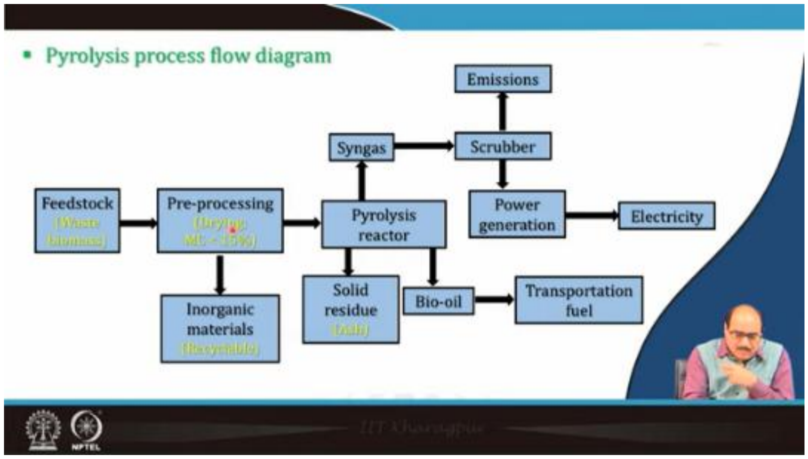
Now, just from the rice husk, let us discuss how one can produce activated carbon and silica from the rice husk. In fact, silica has very good applications even in semiconductor, conductor, or other industries, such as sensors and all those things. So, here you see the rice husk. First, the husk is treated with either dilute or strong acid, and through this acid treatment, impurities like calcium, phosphorus, magnesium, etc., are removed. Our purpose here is to purify the silica. So, the acid-treated rice husk is then carbonized at less than 700 degrees Celsius, and one gets rice husk ash. That is, in brief, you can say the method for biochar preparation. Then, this rice husk ash, which is obtained, is given alkali treatment with sodium hydroxide or potassium hydroxide. It is filtered, and you will get a carbonaceous residue, which is again given physical or chemical activation, and you get activated carbon. So, after that is the filtration, carbonation, and after alkali treatment, the filtrate, which is basically sodium silicate, and then sodium silicate is further allowed to react with sulfuric acid and water-diluted sulfuric acid in a specified reactor, and you get pure silica. So, this is, in brief, the method, and of course, some industries are doing it. So, this is again a very valuable rice husk as a very valuable component which can be utilised.



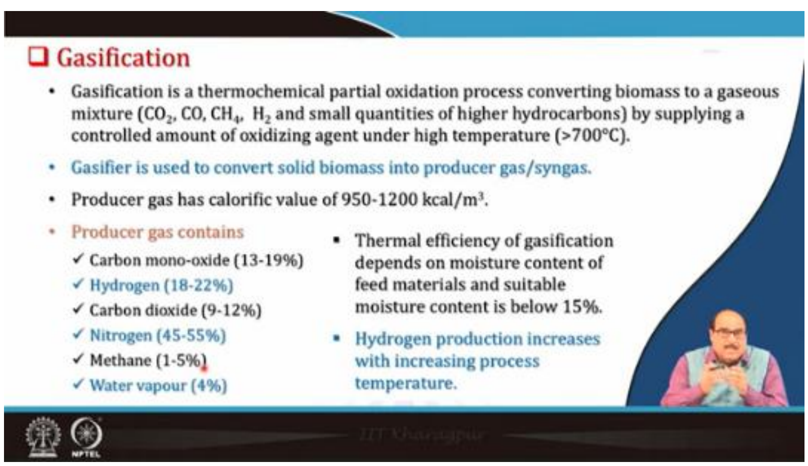
So, then now let us talk about thermochemical conversion of waste biomass, particularly the husk and other biomass straw, etc., whether it is rice straw, paddy straw, and all those things. All these products can be converted by thermochemical or other processes into valuable products. So, thermochemical conversion techniques and their process conditions for biochar production, if you see that number one is the techniques are it may be slow pyrolysis where the temperature may be 300 to 700 centigrade for 2 seconds residence time, and it may give about 35 percent biochar yield and even 35 percent syngas production will be there, that is the. Then, if you go for the fast pyrolysis at around 500 to 1000 degrees Celsius for a day, then it results in 12 per cent biochar yield and 13 per cent syngas. Then, hydrothermal carbonisation at 180 to 300 degrees Celsius for 1 to 16 hours Yields 50 to 80 per cent biochar and 2 to 5 per cent syngas. Gasification at 750 to 900 degrees Celsius for 10 to 20 seconds yields 10 per cent biochar and 85 per cent syngas and torrefaction at around 290 degrees Celsius for 10 to 60 minutes. Yields 80 per cent biochar and 85 per cent syngas. And then final flash carbonation at 300 to 600 degrees Celsius for less than 30 minutes yields around 37 per cent biochar.



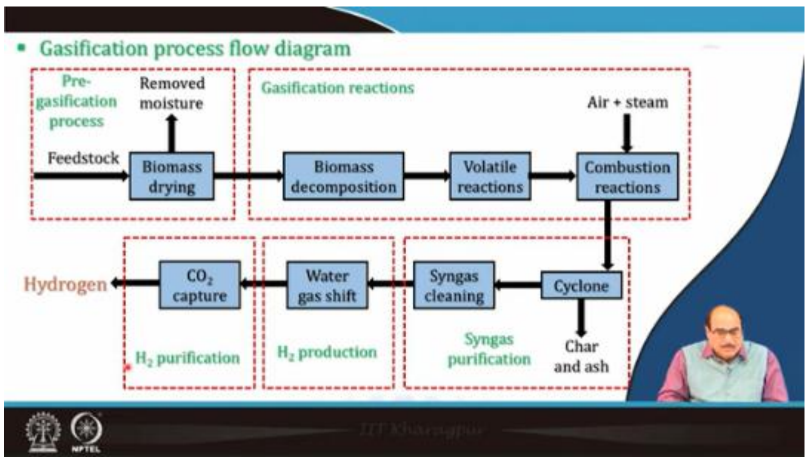
So, let us take these processes; we will cover some more important ones like pyrolysis. It is a thermal decomposition process where organic materials are subjected to heat treatment of around 250 to 900 degrees Celsius in an oxygen-free environment, you can see here it is a pyrolysis reactor, where pre-treated biomass is subjected to this, and the combustion has an air inlet, temperature thermo-control is there, then combustion takes place, raw gases (pyrolyzed gases) go, and you get ash. So, lignocellulosic components like cellulose, hemicellulose, and lignin, etc., undergo reaction processes like depolymerization, fragmentation, and cross-linking at a specific temperature, resulting in different states of products like solid, liquid, and gas—all types of products you get. And the solid and liquid products comprise biochar and bio-oil, whereas the gaseous products are carbon dioxide, carbon monoxide, hydrogen, and also syngas, that is, C1, C2. Then common pyrolysis reactors are paddle clean, burning fluidised bed, wagon reactor and agitated sand rotating kilns, etc. Because of the time constraints, I cannot go into all these details, but the purpose here is to tell you what these reactors are and how they can be utilised.



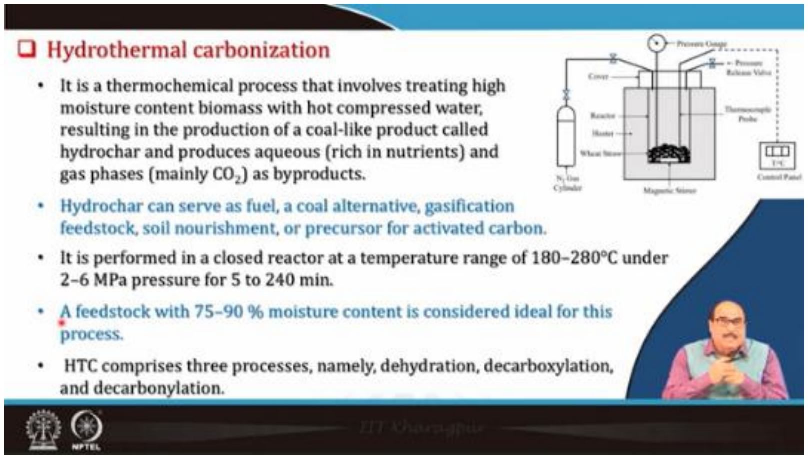
So, this is a paralysis reaction flow diagram of a paralytic reaction that involves feedstock waste biomass, which may be straw, paddy straw, wheat straw, husk and all those materials. Then it is preprocessed, like normally drying, it is dried to less than 15 per cent moisture content, and then it is passed to the paralytic reactors. And from the paralytic reactors, it may be solid residue ash or even liquid residue, as you use it, it is biooil, and then this biooil can be used for transportation fuel. And, then it is from the pyrolytic reactors that it goes to syngas, which is a combination of CO and hydrogen gas, etc., syngas. It can be sent to the scrubber, where the gases are used for power generation, and electricity can be generated. And, after drying that inorganic material, you can also make it recyclable. So, this is the brief on the pyrolytic process program, explaining how the pyrolysis reaction occurs.



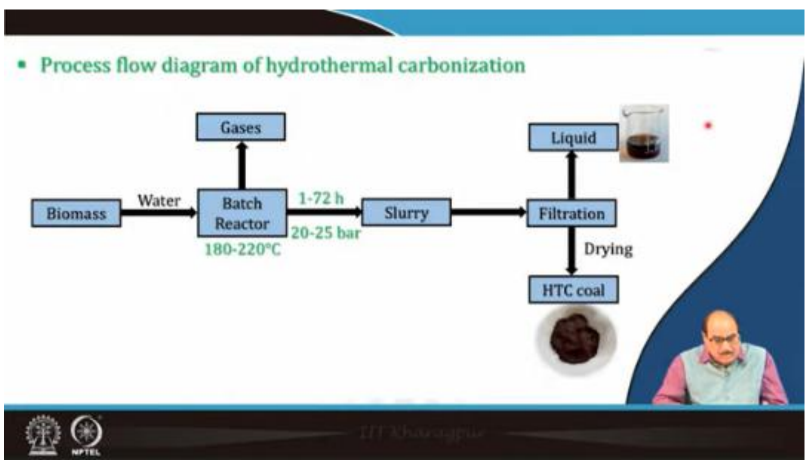
Then, we talk about another process, which is gasification. Gasification is a thermochemical partial oxidation process converting biomass to a gaseous mixture that includes carbon dioxide, carbon monoxide, methane, hydrogen, and small quantities of higher hydrocarbons. By supplying a controlled amount of oxidising agent under high temperature, that temperature may be more than 700 degrees Celsius. A gasifier is used to convert solid biomass into producer gas and arsine gas. Producer gas has a calorific value of around 950 to 1200 kilocalories per cubic meter. This producer gas contains carbon monoxide, hydrogen, carbon dioxide, nitrogen, methane, water vapour, and so on. The thermal efficiency of gasification depends upon the moisture content of feed materials, and a suitable moisture content for this thermal gasification is less than 15 per cent. Hydrogen production increases with increasing process temperature. If you increase the temperature of the gasification process, you will get more hydrogen.



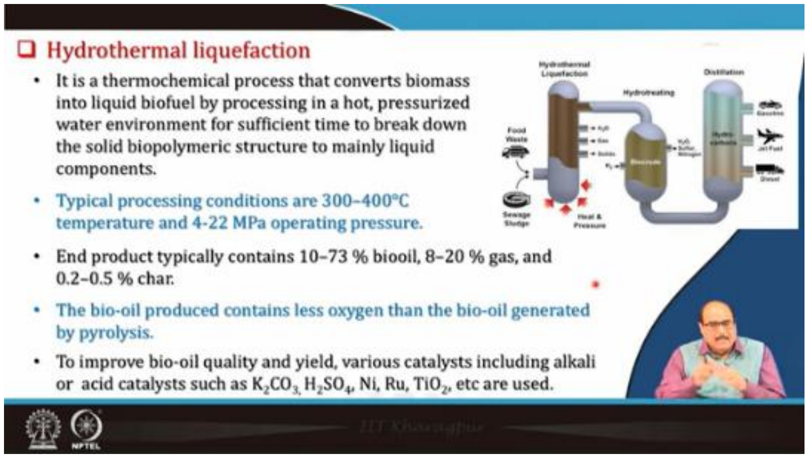
So, the gasification process flow chart, again, I have tried to give you here in brief. You take the pre-gasification process, that is, feedstock, and then you get biomass drying; it is dried, and the moisture is removed. It is then sent for the gasification reaction, where it is allowed to decompose, where volatile reactions occur, volatiles go out, and then it is combusted. It is sent to the combustion system, where air and steam are given. There, with the help of a cyclone system, char and ash are separated, and syngas is produced. And when syngas is further subjected to cleaning treatment, it is even passed through a water gas shift, whether for hydrogen production or CO_2 capture. That is in the hydrogen purification, and you get the hydrogen gas. So, by the gasification process, it is one thing that the biomass can be used even to generate pure hydrogen gas, and this hydrogen gas can be used for various industrial applications.



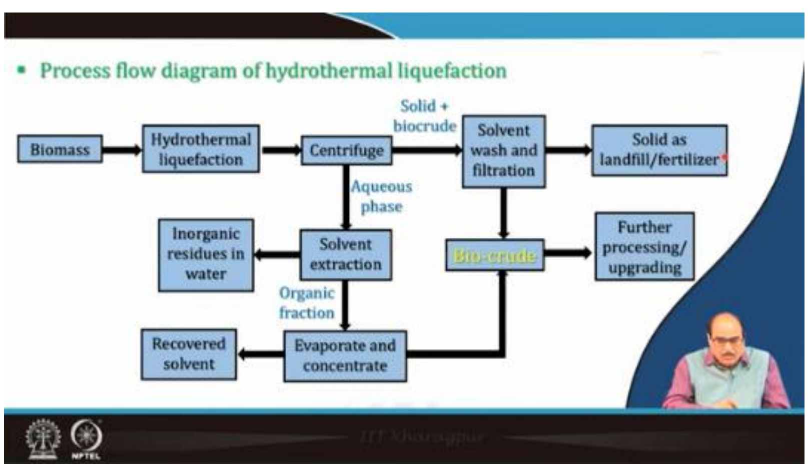
Then, hydrothermal carbonisation is a process that involves treating high-moisture-content biomass with hot compressed water. resulting in the production of a coal-like product called hydrochar, and the process produces aqueous and gaseous materials. Aqueous materials are normally rich in valuable nutrients, whereas the gaseous phases are mainly carbon dioxide, and these two are byproducts. Hydrochar can serve as a fuel. a coal alternative, gasification feedstock, soil nourishment, or precursor for activated carbon preparation, as you have seen in the earlier slide, also.



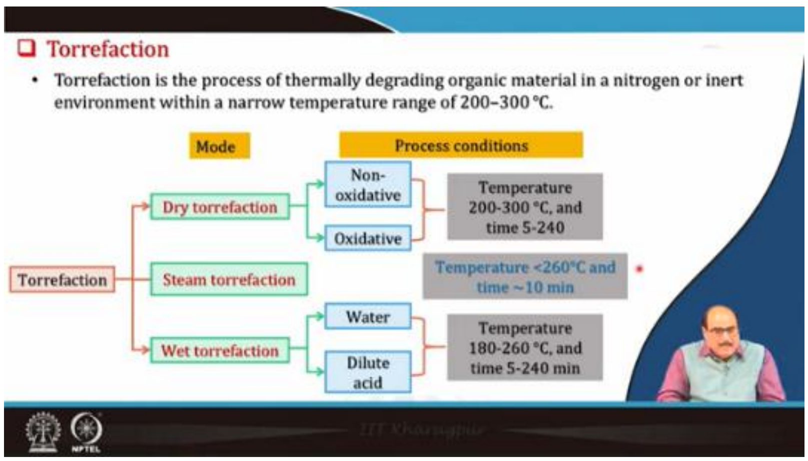
Here is a setup for the hydrothermal carbonisation process, as shown in the figure. It is performed in a closed reactor that is the reactor you can see here, and at a temperature of around 180 to 280 degrees Celsius under 2 to 6 megapascal pressure for 5 to 240 minutes, depending on the type of biomass. And a feedstock with 75 to 90 per cent moisture content is considered ideal here for this process. So, hydrothermal carbonisation comprises three processes mainly dehydration, decarboxylation and decarbonization. So, here is what you get: the hydrothermal carbonisation process for hydrothermal carbonisation, which is biomass. It is given to the batch reactor at 180 to 200 degrees Celsius, where high moisture is present. gases get removed and the other material is treated for maybe 1 to 72 hours, 20 to 25 bar pressure, you get the slurry. And then this slurry is filtered to get the liquid that is biooil, and after drying, you get the HTC coal.



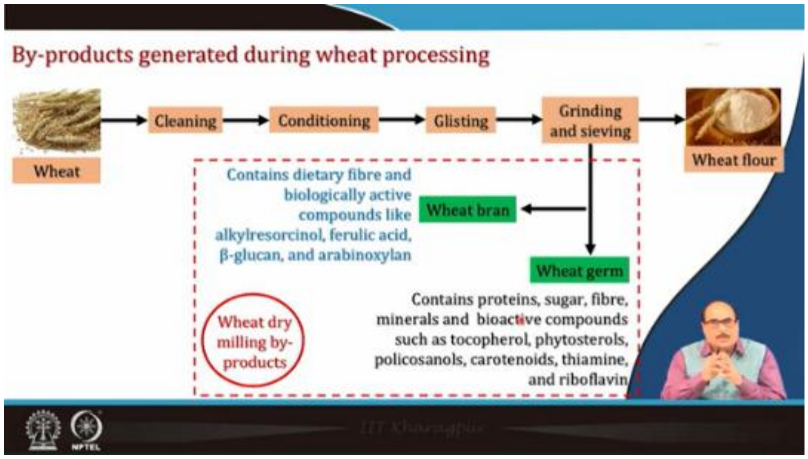
Then let us talk about hydrothermal liquefaction. It is a process that converts biomass into liquid biofuel by processing in a hot, pressurised water environment for a sufficient time to break down the solid biopolymer structure to mainly liquid components. It converts the solid biopolymeric material into a liquid one, and the typical processing conditions are 300 to 400 degrees Celsius temperature at 4 to 22 megapascals Operating pressure, as has been shown here. Like this, the sewage sludge or food waste, etc., can be used for hydrothermal liquefaction. That is, the various gases, etc., are used, and then this is a hydrotreating. And finally, at the destination, you get the hydrocarbon. The end product typically contains 10 to 73 per cent bio-oil, 8 to 20 per cent gases, and 0.2 to 0.5 per cent char. The bio-oil produced contains less oxygen than the bio-oil generated by pyrolysis. However, to improve bio-oil quality and yield, various catalysts, including alkali or acid catalysts such as potassium carbonate, hydrogen, sulfuric acid, nickel, titanium dioxide, etc., are used.



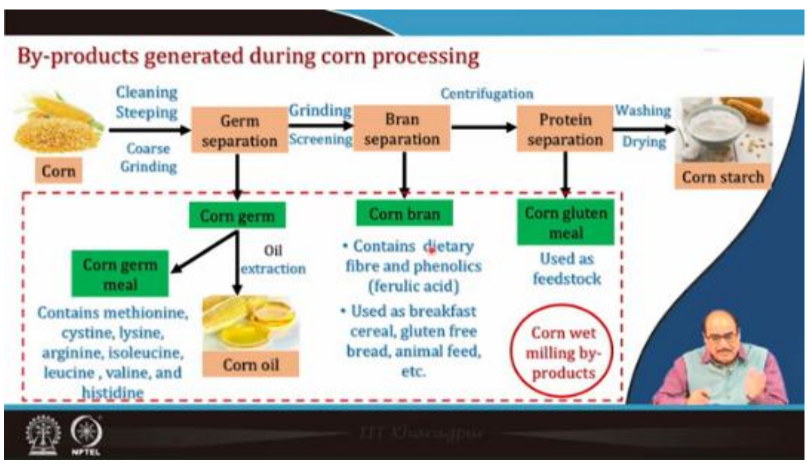
So, the process flow diagram for the hydrothermal liquefaction, you see here, biomass for hydrothermal liquefaction, is put into the reactor, after which it is centrifuged, and it gives the aqueous phase. And the aqueous phase, along with it, goes to the solvent treatments, etcetera. Inorganic residue you get in water, and the organic fraction is evaporated, and it is concentrated; moisture evaporated and concentrated, one gets the recovered solvent here, and the concentrate is the bio-crude, and through this process, after centrifugation, that is, the aqueous phase is given this treatment. The solid phase is a solid bio-crude, which is again given to the solvent treatment, solvent wash and filtration, and then you get bio-crude or the solid residue, which is used afterwards. After solvent wash and filtration, the solid residue can be used as landfill or fertiliser. This bio-crude can be further processed and upgraded to get good-quality bio-oil.



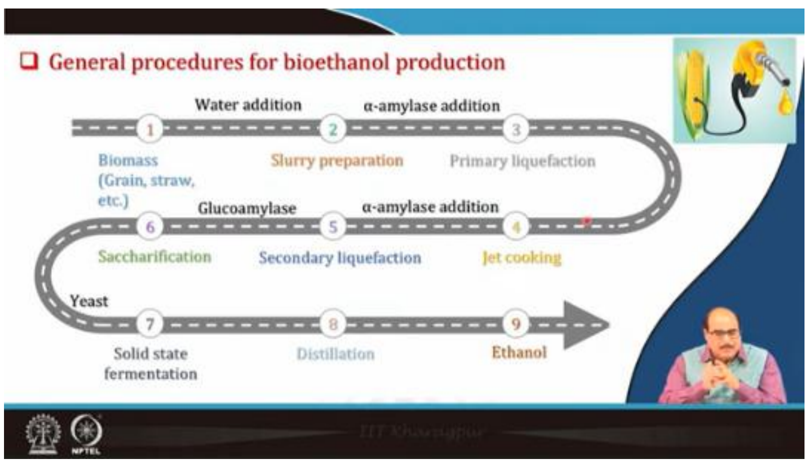
Then, torrefaction. Torrefaction is the process of thermally degrading organic materials in a nitrogen or inert environment, within a narrow temperature range of 200 to 300 degrees Celsius. This torrefaction may be of three types: dry torrefaction, steam torrefaction, and wet torrefaction. Dry torrefaction may be non-oxidative or oxidative. Non-oxidative torrefaction typically occurs at temperatures of 200 to 300 degrees Celsius for 5 to 240 seconds. Whereas, steam torrefaction occurs at a temperature of 260 degrees Celsius for approximately 10 minutes. Wet torrefaction may involve water or dilute acid, at a temperature of 180 to 260 degrees Celsius for 5 to 240 minutes. The process flow diagram for torrefaction may include biomass, which is dried and then torrefied through a combustion reaction, and that can be compacted and you get torrefied biomass, and this has various applications in various industries.



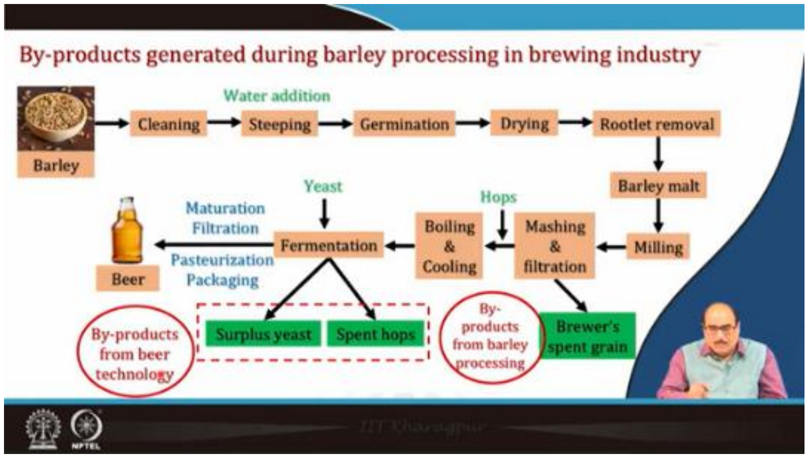
Wheat bran contains very valuable products like dietary fiber and biologically active compounds. Like alkylresorcinol, ferulic acid, beta-glucan, and arabinoxylan. Whereas, the wheat germ contains proteins, sugar, fiber, minerals, and bioactive compounds. Such as tocopherol, phytosterol, policosanols, carotenoids, thiamine, riboflavin, and so on. So, these are the various wheat dry milling byproducts, and all these products. Wheat bran can be collected, germ can be collected, and then there are various processes. That is, technologies are available which can be used to extract these products from the wheat bran and use them for various purposes.



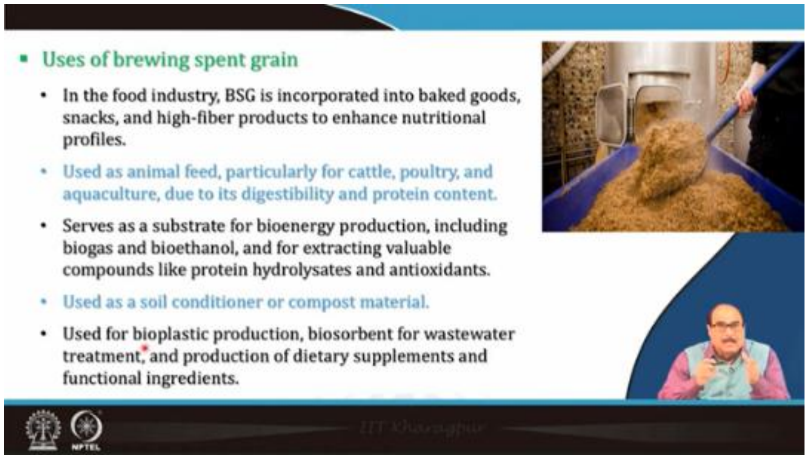
Similarly, if you look at the corn processing, the byproducts are generated during the process. Maybe from the corn, it is used for the preparation of corn starch. So, the first thing is that it is an operation that is subjected to cleaning, stripping and coarse grinding, you want to get the germ suppression. So, this germ corn is a byproduct of the corn milling industry. and which can be used for oil extraction we will get corn oil or even the germ meal after extraction of the meal the oil meal which is obtained it contains methylene, cysteine, lysine, arginine, isoleucine, leucine, valine and histidine there is various essential amino acids etcetera you see it contains good amount of the. So, that corn germ meal can be used for various food purposes, etc. Corn oil has a lot of medicinal value and even for food purposes it can be used. Then that after the separation of the germ the remaining cotyledons of the corn, they are ground and screened you get one get the branch suppressor that is the with the help of suitable screening method. Bran is separated to get corn bran and the bran bran and their byproducts. It contains dietary fiber and phenolic that is ferulic acid and it is used as a breakfast cereal gluten free bread animal feed etcetera. Then after separation of the bran it is centrifuged and then subjected to a specific process for protein separation etcetera and then you get corn gluten meal which is used as a feedstock And this material solid mass is washed and dried one get corn starch. So, from the corn you get various product corn starch and the byproducts are germ, bran and gluten meal. So, these are the wet milling byproducts of the corn and there even processes are available technology is available this can be used for various industrial purposes.



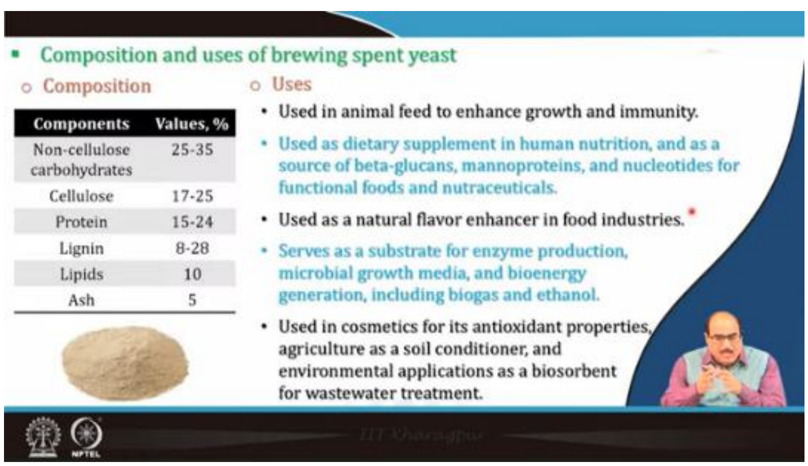
So, here, we talk about bioethanol production general procedure for bioethanol production and corn is one very important raw material which is used globally for the bioethanol production. So, biomass it can be mainly the corn is taken or even sometime grain straw etcetera also can be taken. It is hydrothermal treatment is given, then slurry is made after the slurry is prepared then it in it alpha amylase addition is done which results into the that is the basically the primary liquefaction process by the alpha amylase. So, this alpha amylase it breaks the starch. into and then it is subjected to jet cooking and again alpha amylase addition whether secondary liquefaction take place. And then after this process, glucoamylase is added, which causes a result into the saccharification. That is, after glucoamylase is added, that is the saccharification means. Yeast is added in the saccharification process, and you get results into the solid-state fermentation. Finally, distillation, and you get the ethanol bioethanol. So, from corn or other materials using this process and this is at each and every parameter well-defined now; technology is available. I cannot go into all those details, but these are the steps which are used in the ethanol production from corn biomass or other materials.



So, now let us briefly talk about products generated during the barley brewing process in the brewing industry. In the brewing industry, when beer is produced, barley is a major raw material. So, the operations involved in it are cleaning, then steeping, that is, water is added into the barley, after that, germination, drying, and rootlet removal, then you get the barley malt. So, from barley, using this system, it is converted into barley malt, and then it is milled subjected to mashing and filtration, where hops are added, the boiling and cleaning, then yeast is added, fermentation is allowed to occur then maturation filtration and pasteurization packaging these are the treatments and one will get beer. So, in the process there are three major step that is where after mashing and filtration you get the wort that is the liquid material and you get the brewers spent grain that is the residual material after filtration the residual material here it is one major byproduct from the barley processing you can say, that is the solid biomass you get. Then the fermentation. after it is you get the surplus yeast as well as spent hops, hops which is added here for giving the flavor etcetera to the brewers. So, this flavor is extracted and then hops material also. So, spent hops, spent surplus yeast and then brewers spent grain. These are you can say the major byproducts from the fermentation.

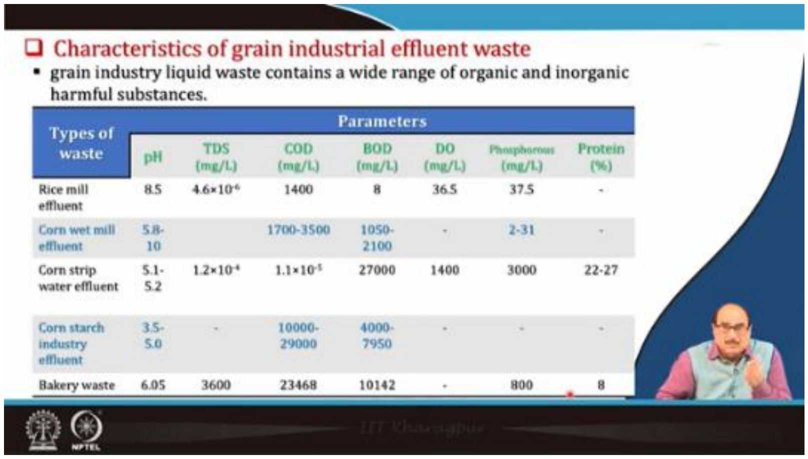


So, these how can they utilize the brewing spent grain that is after the process which is obtained, it is a basically it can be used incorporated into baked goods, snacks, high fiber products to enhance nutritional value because again it is a very valuable It contains lot of nutrients in it. It is also used as animal feed particularly for cattle, poultry meat, aquaculture due to its digestibility and protein content. It serves as a substrate for bioenergy production, including biogas and bioethanol. It can be used for extracting valuable compounds like protein, hydrolyzate, and antioxidants. It is used as a soil conditioner or compost material. It can be used as a bioplastic material for bioplastic production, bio-absorbent for wastewater treatment, and production of dietary supplements and functional ingredients. So, it has a lot of applications and usage; the only thing one needs is a suitable collection mechanism, and this can be used.



Then, the spent yeast which you get—if you look at the component—it has a non-cellulosic material of about 25 to 30 percent. And cellulose, 17 to 25 percent; it also has a good amount of protein, lignin, lipids, and ash. So, this can further be used in animal feed to enhance growth and immunity. It can be used as a dietary supplement in human nutrition and as a source of beta-glucans, mannoproteins, and nucleotides for functional foods and nutraceuticals. It can be used as a natural flavor enhancer in the food industry. It serves as a substrate for enzyme production, for microbial growth media, and bioenergy generation, including biogas and ethanol production. It is used in the cosmetic industry for its antioxidant properties, in agriculture as a soil conditioner, in environment applications as a biocharment for waste water treatments etcetera. Even the breathing spent hops, they are used as a natural antioxidant or flavoring agent due to their bitter compounds and antimicrobial properties. It serves as a nutrient rich organic fertilizer, it serves as an ingredient in livestock feed to improve gut health and immunity.

Even the pharmaceutical and cosmetic industries utilize brewing sprint hops for its anti-inflammatory, antimicrobial and potential anti-cancer properties in various formulations. It is used as a bioenergy used for bioenergy production through biogas generation etcetera. Even it can be used as a substrate for extracting valuable compounds like xanthohumol or for nutraceutical applications and so on. So, all these have lot of all right. Similarly, that is even is the characteristics of the grain industrial effluent waste if you look at that is the type of the grain industry waste liquid waste contains a wide range of organic and inorganic substances even sometime it may be harmful substances.

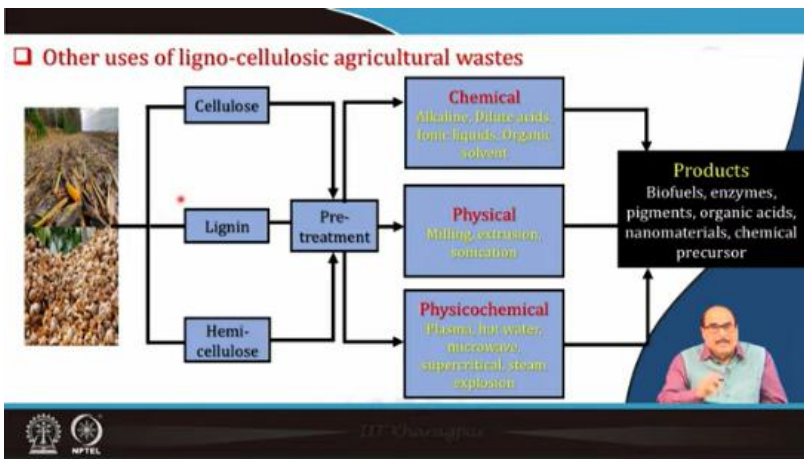


Characteristics of grain industrial effluent waste

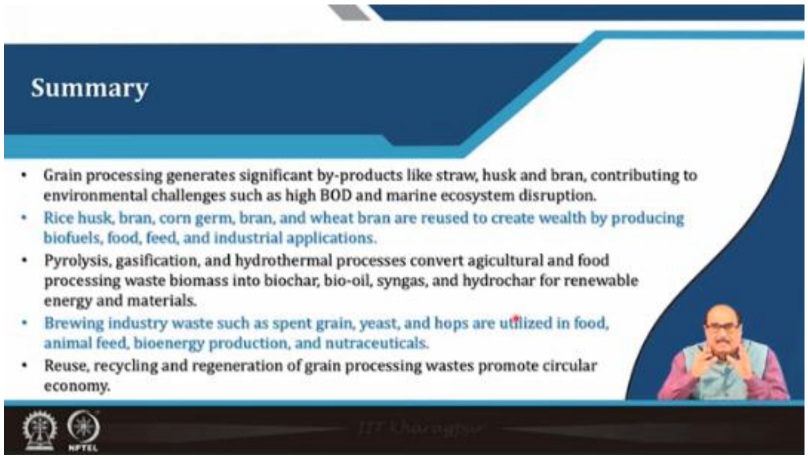
- grain industry liquid waste contains a wide range of organic and inorganic harmful substances.

Types of waste	Parameters						
	pH	TDS (mg/L)	COD (mg/L)	BOD (mg/L)	DO (mg/L)	Phosphorous (mg/L)	Protein (%)
Rice mill effluent	8.5	4.6×10^{-6}	1400	8	36.5	37.5	-
Corn wet mill effluent	5.8-10		1700-3500	1050-2100	-	2-31	-
Corn strip water effluent	5.1-5.2	1.2×10^{4}	1.1×10^{5}	27000	1400	3000	22-27
Corn starch industry effluent	3.5-5.0	-	10000-29000	4000-7950	-	-	-
Bakery waste	6.05	3600	23468	10142	-	800	8

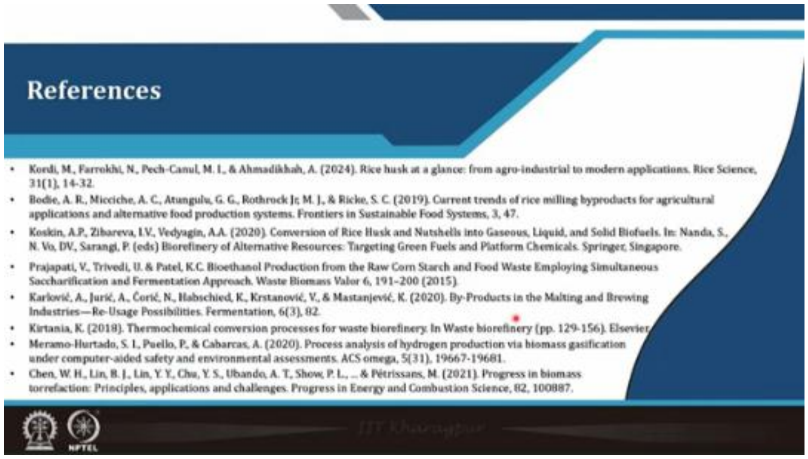
So, one has to be careful. like rice mill effluent it has a that is the pH, TDS, COD value all these we have given. Similarly, corn wet mill effluent or corn steep water effluent, corn starch effluent, bakery waste, etcetera. So, they have these—these are the parameters I have tried to give you. The purpose here is to make you aware that these effluents may contain various undesirable substances. So, one should properly collect these effluents, but again, they have a lot of valuable products. They can be—they should be subjected to proper effluent treatment, and then can be channelized again for various beneficial use purposes.



The other uses for lignocellulosic agricultural waste like cellulose, lignin, and hemicellulose which are produced as a byproduct or as waste product. So, they can be given suitable pretreatment, alright. It may be chemical treatment, it may be alkaline, dilute acid, etcetera, or physical treatment like milling, extrusion, sonication, or physicochemical treatment like plasma treatment, hot water, microwave, supercritical, or steam explosion, etcetera. And they can produce various byproducts, various useful products like biofuels, enzymes, pigments, organic acids, nanomaterials, or various chemical precursors can be used. So, I just tried to give you an overview, although the subject is very wide and it is difficult to completely narrate or structure. But I have given you a general overview that is what grain processing is in general—all the grain, whether it is cereal, and they generate a lot of byproducts, and all these byproducts like husk, bran, germ oil—that is the wheat bran and other things—they can be used for creating wealth by producing various valuable products like biofuel, food, feed, and industrial applications.



Pyrolysis, gasification, hydrothermal—another process can be used. So, even these products can be used. So, they have two advantages: they can create wealth, and at the same time, they will keep our environment clean—like environmental pollution it will not be polluted, which is otherwise in general, a problem—like if the effluent, as I told you, if the effluents are properly treated then this environmental pollution, etcetera—this biomass, etcetera—if they can be channelized. So, every industry is in the circular economic concept now, which is emerging—it is coming. That is, they have a proper mechanism so that these waste products or byproducts generated should be properly collected. And this would be channelised to various technological processes to extract and produce various bioavailable or valuable products for different uses. They can be used as an ingredient or even as a product for various purposes.



So, with this, these were the references used in this lecture. I thank you very much for your patience. Thank you.