Municipal Solid Waste Management
Prof. Ajay Kalamdhad
Department of Civil Engineering
Indian Institute of Technology - Guwahati

Lecture - 24
Definition and Phases of Composting

So hello students, so today we are going to start next module, biological transformation already in the previous module we talked about chemical transformation, where we mostly talked about incineration process or you can say the combustion process detailed about that along with few case studies. Now, we will continue the biological transformation and there will first we start with the composting process. That is anaerobic decomposition process and the next module we will continue the biological transformation that will especially on to the anaerobic digestion.

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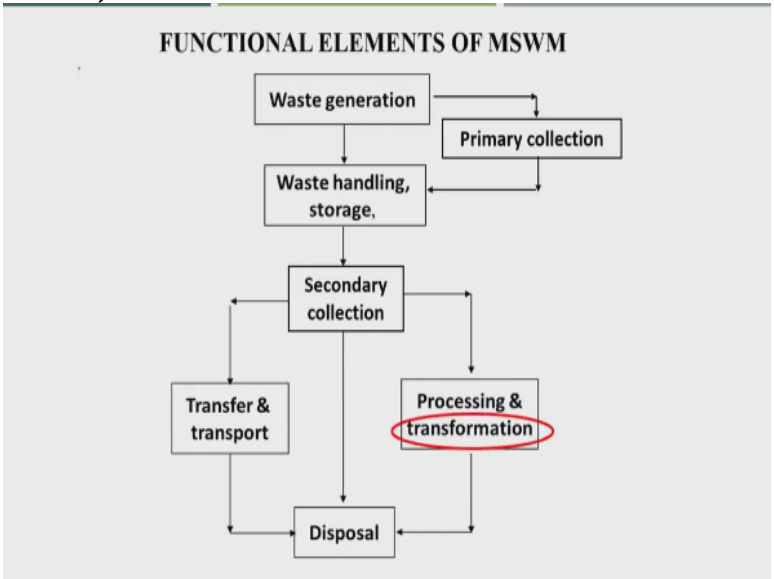

So, also this is a functional element, and we are still on the functional element transformation. Now, this lecture we will talk about, first the definition and phases of composting. See why I kept the special lecture on definition because, when you ask anyone what is the composting process, everyone will say, it is a decomposition of organic matter that is called is not composting process, but it is not, I think something is a true into that, but it is not exactly the only the decomposition of organic waste. So, I will give one proper definition which I got from one textbook.

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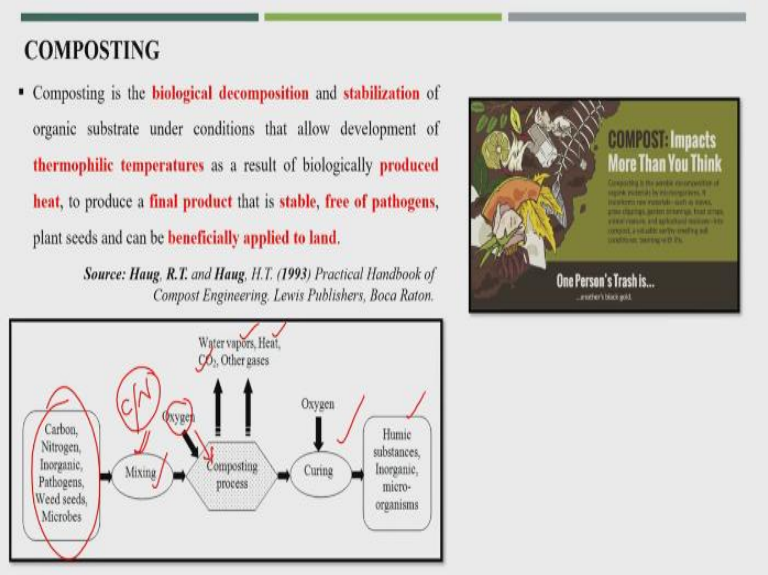

The definition that is given is, Composting is a biological decomposition, see remember it is a biological decomposition. So many times you heard such kind of word like mechanical composting plant, I really never understood why they are calling is a composting plant is not mechanical composting process, it is a purely biological decomposition process.

So, mechanical why they are saying because there will be some kind of mechanical equipment for the filtering of the compost because of that only they are calling it but it is not mechanical composting process, it is a biological composting process. So, it is a biological decomposition and stabilization of organic substance, this is also very important word stabilization should be stable. I will go I think once I think we will continue this lecture.

I will talk about what do you mean by stable, when you call it is stable, I think just for the half a minute, I will explain what is the stable means, I think stability is very important stability or maturity is very important that you can easily calculate by the how much amount of oxygen is getting up taken by the bacteria, are with the microbes and how much carbon dioxide is getting produced while in the degradation proceeds.

So, need to be a very stable, if it is not stable, unnecessary it will create problem once you add that same compost on the soil under the condition that allow development of thermophilic temperature. This is also one of the very important word thermophilic temperatures and what do

you mean by thermophilic? Thermophilic means the temperature is more than 45°C, mesophilic is less than 45°C.

This is very important word I think you should remember that when you visit any compost plant ask those people how much amount of temperature or how much degree temperature you are getting in the composting plant if they have any kind of composting method there you ask the question that how much temperature they are getting while in the degradation process. So, because of that some energy will be produced and that energy we can easily calculate or can find temperature as a result of biologically produced heat, that heat we can measure or to produce the final product that is stable which I already talked about is stable free of pathogen. See it is also very important that stable and free of pathogen, see any waste you use whether it is a kitchen waste after the degradation process there will be a lot of pathogens could be possible.

And if you are using specially the sewage sludge for the composting process even the agriculture waste also if you use there also you will find a lot of pathogens and these pathogens will get reduced by thermophilic temperature which I am going to discuss further and that is why if you have visit any compost plant if you want to take the compost in your hand just see that just ask the question how much is the thermophilic temperature you got it if they are not able to answer do not take the compost in your hand otherwise maybe there will be a lot of pathogens could be possible.

And also the plant seeds there should not be plant seeds, in the final compost and many times see some of the locations you will find, this is the compost it is first put it in some one particular area you will see some of the plants are growing into that means we will see that how basically the compost that the seeds are growing into that means that is not the properly composted, it should be free from the plant seeds.

That a seed has to be completely degraded, during the composting process and can be beneficially applied to land this is also one of the very important point that it should be beneficial to the land then only we can say it is a proper composting process. So, how it will be benefit to the land by having proper nutrients and that what major nutrients are required for the soil NPK

nitrogen, phosphorus and potassium? This is the major nutrients are required for the soil as in fertilizer.

So, this is the flowchart you can see by that we can understand that by these carbon nitrogen, this is the organic matter. So, organic matter first the proper mixing is required, I will share that what do you mean by these mixing? This mixing is nothing but proper carbon and nitrogen ratio. This is very important for the degradation process for that you need proper mixing, not only mixing but even the size is very important for the degradation process, that size also the we will be required one special kind of trader to reduce the size of the particular organic material.

And this is the compost followed by composting process where the water vapors, heat, carbon dioxide and maybe I think some amount of nitrogen also could be possible to come out from that those gases and will be required oxygen for the degradation process and finally, will be also required curing process, curing is nothing but it is a another I think most of the methods do not require, curing process. But I think if you can keep it for another 30 days.

So the final degradation could be possible that and finally we will get the compost which will having the humic substances and along with them some microbes in the final compost. This is the complete understanding of the composting process.

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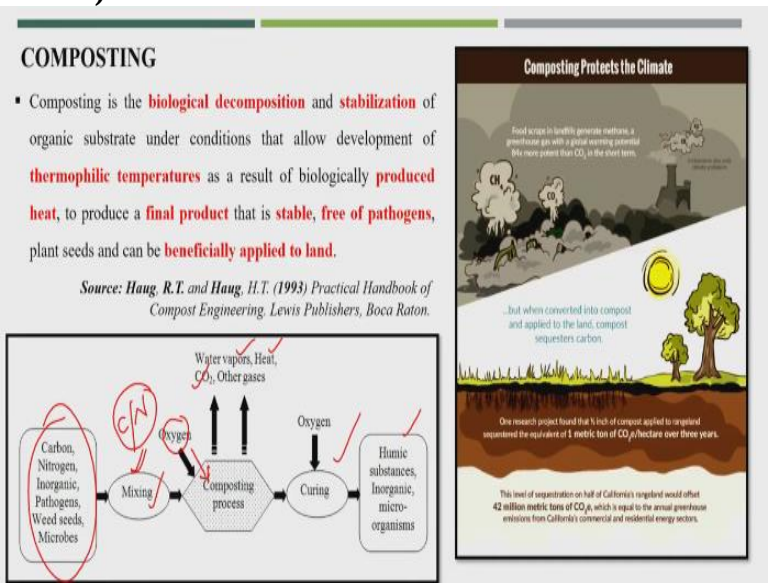

And here also you can see that how important is the composting process for the climate change. See already I discussed about the wet waste and is a major problem which is unscientific, and is getting disposed into the dump sites or landfill areas and these organic wastes because it has to be degraded. So, whether you do compost or whether you do not have any kind of treatment process, it will get degraded and because of that, leachate will also get produced and a lot of gases will get produced unnecessarily.

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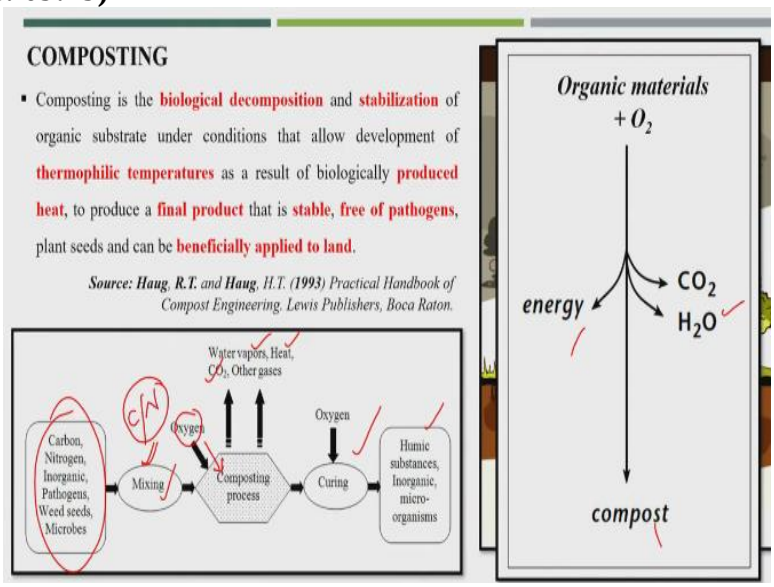

So, this is another flow you can see that by adding organic material plus oxygen, we will get fuel, gases, energy and finally compost. See one more point I want to share here when somebody will say that there are 2 types of composting process maybe some of the textbook also you can find there are 2 types of composting process one is aerobic composting, other is anaerobic composting. No there would not be any anaerobic composting process. See always remember that when you say composting process is aerobic degradation process, aerobic process.

And that is why we are always seeing the flow also I put oxygen, oxygen is always required, to have the proper aerobic condition process.

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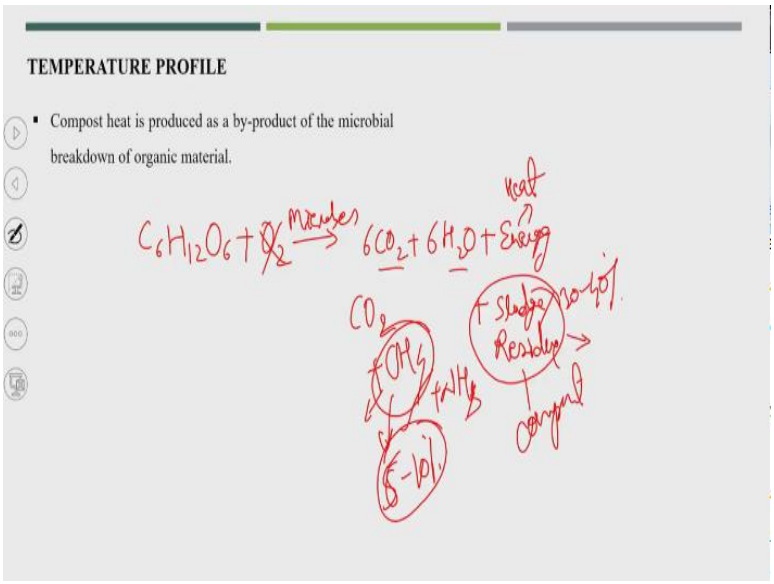

So now we will talk about temperature profile. So, compost heat is produced by the byproducts of microbial breakdown of the organic material. These also you can easily understand I think, it is difficult to have proper chemical formula of organic waste, but by simple one formula, we can understand how the heat is getting produced like $C_6H_{12}O_6$. Once it will react with oxygen with some microbes it will produce 6 amounts of carbon dioxide and 6 amounts of H_2O plus some kind of energy and finally, we will get some sludge as residue.

Now, this is a simple degradation of glucose, so, glucose once it reacts with oxygen with microbes, it will produce carbon dioxide and H_2, this energy can be measured by heat and this residue is our compost finally. So, similar kind of degradation or similar kind of reaction takes place in the composting process. Now, in anaerobic conditions, obviously carbon dioxide will be produced along with methane, producing odorous gases.

And the quantity of these residue now in the aerobic process, it will be around 30 to 40% and for the anaerobic condition that will be only 5% to 10%. So, what is the benefit of having anaerobic degradation process, there is no benefit of anaerobic condition and because there are unnecessary odorous gasses that are produced, even nitrogen gas will come out, along with nitrogen oxides will also be produced in form of ammonia NH_4 in the anaerobic process, NH_3 gas.

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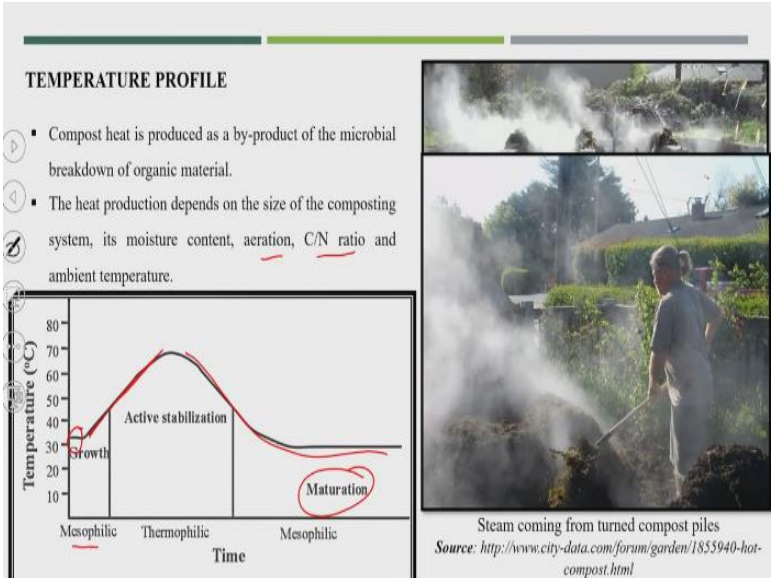

So, the second point is the heat production depending on the size of composting system, it is moisture content, aeration, CN ratio and ambient temperature. This is one of the important points for degradation process, it is the size of the composting system, maybe size is not that important one, but the moisture content, because why moisture content is important because for microbial degradation, the microbes requires oxygen that can be around 60 to 70% moisture content is always required for the degradation aeration.

Obviously aeration will be required for the growth of the microbes, carbon to nitrogen ratio, because now here the carbon is required for the degradation process and nitrogen is required for have the more microbes for the degradation process and finally ambient temperature that is also important that you know that in the ambient temperature like temperature 30°C to 35°C the degradation could be very fast, that is why the production of microbes also will very well and so, proper degradation also can be possible.

So, this is normally the temperature profile in case of composting process. So, it will start from mesophilic conditions initially, when seen here, they initially microbes will start to be there, they will be stabilized in the initial conditions so there would not be much change in the temperature and followed by, it will be like this kind of log curve will come up where temperature will increase and then finally, once the degradation will get over, mostly the sugar concentration or easily degradable organic materials will get degraded.

And then finally, it will get reduced and finally it comes through the maturation process that is the curing process which I showed in last slide, and finally, that is why this entire system, we can easily share in 3 parts, first the mesophilic temperature thermophilic temperature and finally again mesophilic temperature. So, you can see here that this kind of steams, normally this steam is producing because of thermophilic temperature; it is a hot composting method you see here while the turning of entire material, this turning is required for aeration process.

Because the entire material should be under aerobic condition. So, because of that also lots of vapors will be coming out.

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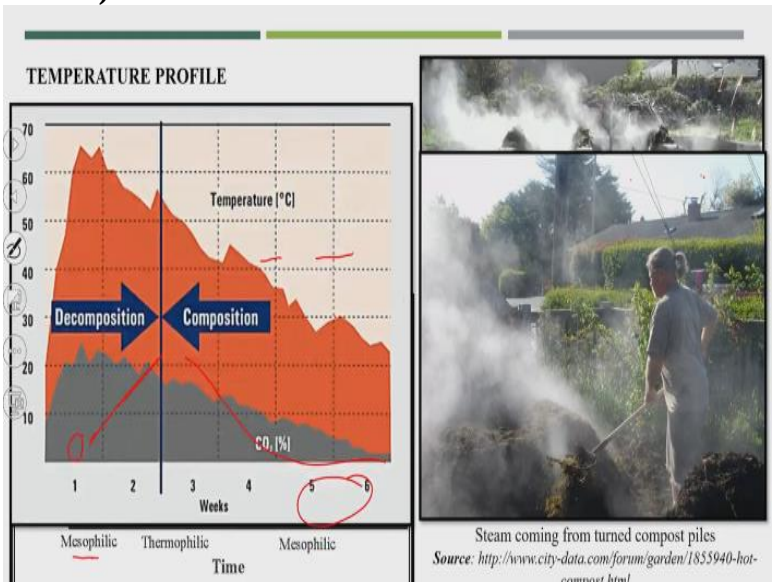

And now here finally, the temperature profile will be initially, decomposition and finally, it will be the completion of entire material. By that way we can understand.

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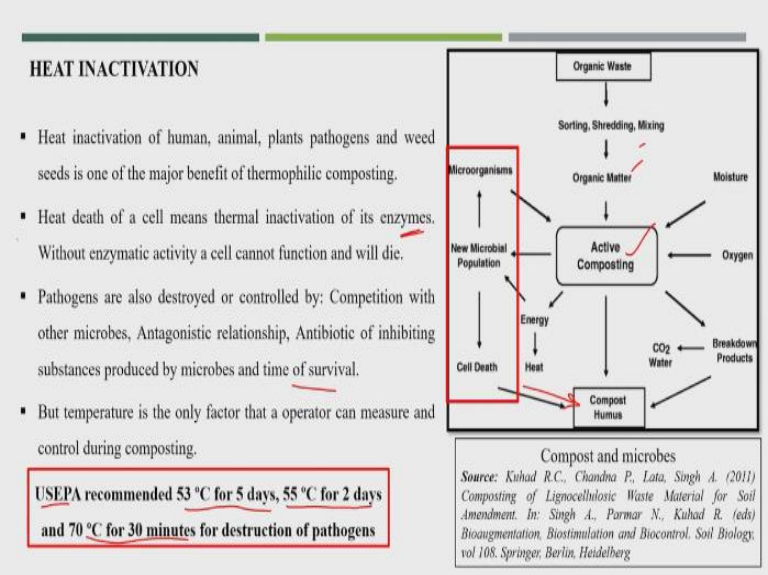

Now, I think we will talk more on the temperature. So, in that one the heat inactivation, so, why it is very important? So, heat inactivation of human, animal, plant, pathogens and weed seed is one of the major benefits of thermophilic temperature which I was talking about in the definition, why it is very important to see what pathogens are there whether it is human pathogens, if you are using the seawage sludge there is a lot of equal it will be there and a lot of pathogens could be possible.

And if you are using the animal waste like even cow dung also which will have the other kind of pathogens that will get inactivate because of thermophilic temperature heat death of a cell means thermal inactivation of its enzyme without enzyme activity or cell cannot function and will die. So, every by microbes or bacteria specially will have enzyme, so, if the enzyme is getting proper death because of heat and without enzyme, any cell or any microbes cannot live.

it cannot function and finally, it will die. Pathogens are also destroyed on control by competition with other microbes, and there are other benefits also like antibiotic innovations can be possible and even time of survival, this is also a very important one. So I think it is not only the heat inactivation, but also there are few more points where these pathogens can be death in the composting process.

But temperature is the only factor that can operate and can be measured and controlled during temperature, other parameters is difficult to manage in the composting process, but the

temperature is with us how best, we can make, how best, we can degrade the organic matter? So that thermophilic temperature can be possible to get produced. So in the USEPA is the US Environmental Protection Agency, I think this is one of the major agencies which talk about a lot of rules and regulation.

So they recommended that 53°C for 5 days, 55°C for 2 days and 70°C for 30 minutes is for destruction of pathogens. See now here you remember that how important is the thermophilic temperature and why I propose that if you visit any composting plant and you ask the question how much the thermophilic temperature is possible to be produced in that particular composting plant, why is it very important? So, here this is our major one.

So, organic waste is already shredded. Finally, the active composting and this is the microbe's new microbial population and finally by cell death, they say and finally we will get compost and by that we can understand the entire composting process and for that we also require moisture oxygen and some other process.

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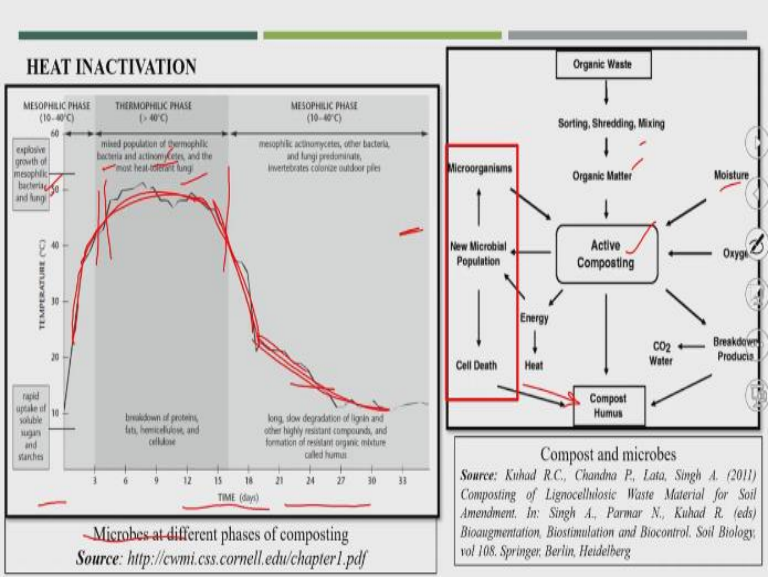

Microbes at different phases of composting
Source: http://cwmi.css.cornell.edu/chapter1.pdf

Compost and microbes
Source: Kuhad R.C., Chandna P., Lata, Singh A. (2011) Composting of Lignocellulosic Waste Material for Soil Amendment. In: Singh A., Parmar N., Kuhad R. (eds) Bioaugmentation, Biostimulation and Biocontrol. Soil Biology, vol 108. Springer, Berlin, Heidelberg

Now here this graph is showing that the thermophilic same the 3 different phases of the composting process mesophilic phase, thermophilic phase and finally again mesophilic phase. Now here you see that mesophilic phase tends to 40°C or 45°C, they are majorly the mesophilic bacteria and major one which are working here for the degradation process. Now until here after

that this is the thermophilic temperature, these particular were mixed population of thermophilic bacteria actinomycetes and most heat tolerant fungi.

So, majorly 3 microbes are working, which I am going to talk in next slides the bacteria, this is one microbe, actinomycetes another microbe and fungi is another one. So, normally in this particular area the major degradation by the bacteria and once the temperature is getting reduced, here the actinomycetes will start working, the second one and finally here the fungus will start working, this is particularly visible by that temperature profile, we can understand and we can see that we have the particular microbes are degrading the organic matter.

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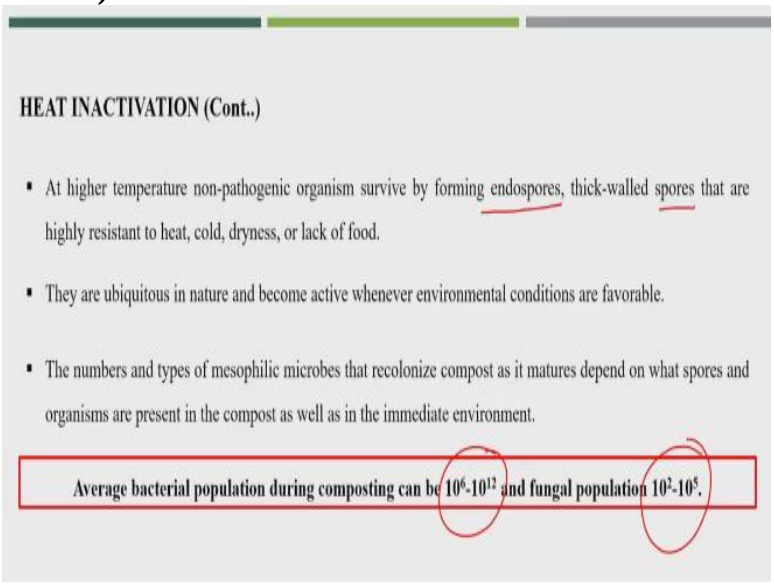

Now, again few more points onto the heat activations in high temperature non pathogenic organisms survive by forming endospores or thick walled spores that are highly resistant to heat, cold, dryness or lack of food. See, now these questions could be possible sir at this very high temperature like suppose the one particular composting plant is receiving or getting 70°C temperature in the degradation process. So, pathogens will die.

So, what about the other microbes, which are beneficial and which are required for the degradation process, see what it is written here the non pathogenic bacteria are those bacteria will form the endospores or we normally call as spore forming bacteria they will put one spores properly and this is highly resistant to heat cold dryness. So, they will be non active or they will be passive in a particular area temperature for one temperature will reduce.

Those spore forming bacteria which is in the passive condition which will get active condition the same microbes will work for the further degradation process. So, there would not be a negative point or there would not be any problem for the non pathogenic bacteria. So number and types of mesophilic microbes that recolonize compost as it matures depends on what spores and organisms are present in the compost as well in the immediate environment after thermophilic temperature.

So, every bacterial population during the composting can possibly exist between 10^6 to 10^{12} for fungal populations and 10^4 to 10^5 by different researchers have been found out and also if you are interested you can read more paper on that, people have done a lot of research, what kind of bacteria, what kind of fungus but how their populations are changing during the composting process. So, you can read further.

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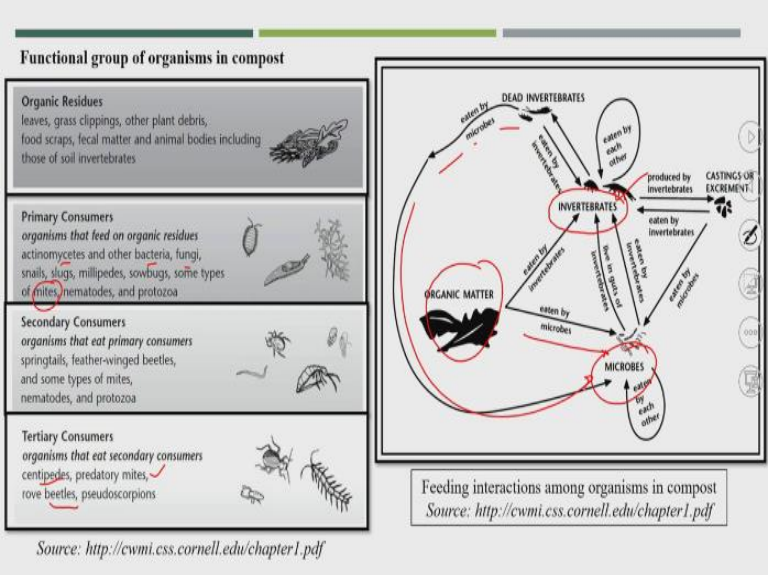

Now the functional group of organisms in compost: So, how the functional groups are changing in the composting process, first now, that any organic residue it can be leaves, grass clipping, any plant debris, food scraps, any fecal matter in sewage sludge, also actinomycetes and fungus these are the major microbes but also along with that there can be a snails, millipedes, snow bucks also can be there and also some type of mites can also be possibly there, you can easily find that white small, small mites also can be possible.

Now, after that primary consumers will degrade, then the secondary consumers will come up that secondary consumers can be springtails or some other some kind of mites also even, nematodes and protozoa that can also be possible to be produced in the composting process and tertiary consumers followed by secondary consumers can also be possible to be produced like centipedes or these other kind of row beetles also can be possible or some kind of mites also can be possible to be produced.

So, these are the major organisms during the degradation of organic matter in the composting process. So, here, this here are my thoughts, these microbes I think these the organic matter are degraded by microbes and there will be some kind of inverebrates also that is also that I will talk in the next slide along with the microbes, there will be microbes the smaller size invertebrates you can easily find by the sea in the composting process, and these again, these microbes, the death of microbes or dead microbes will be eaten by the invertebrates again once they will die, again it will be eaten by the microbes only in the composting process.

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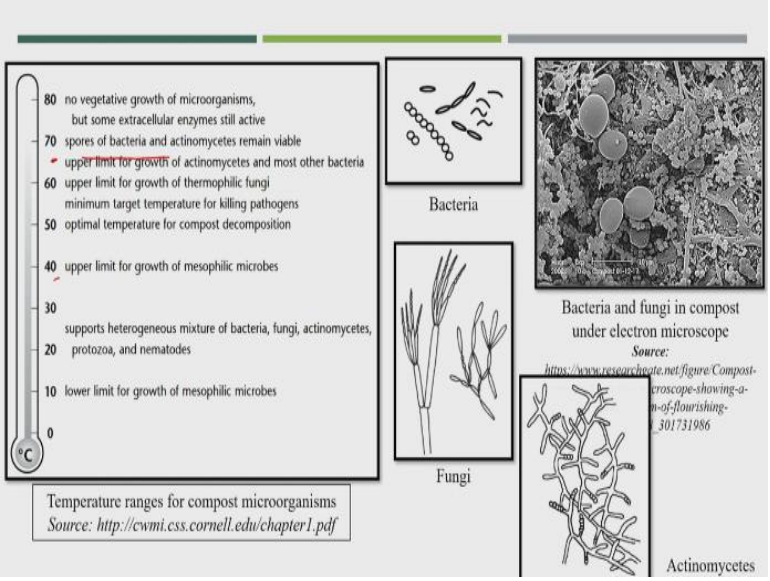

Temperature ranges for compost microorganisms
Source: http://cwmi.css.cornell.edu/chapter1.pdf

So, here you can see the temperature, how the growth of the different temperature changes the growth of microorganism. So, you see here in the 10°C, the lower growth of mesophilic microbe. So, 10° C ambient temperature is difficult to get proper degradation process once the temperature will rise like 30, 40°C upper limit of like you see here 40 is the upper limit of growth of mesophilic microbes, that is possible at this temperature.

And if you go here by 70°C which I was talking about spore of bacteria actinomycetes remain viable to the upper limit of growth of actinomycetes and more other bacteria and it 80°C, no negative growth of micro organism but some exosyndrom enzyme still get activated, that is the reason we require this high temperature. So, what are the different microbes when will the major microbes in the composting process start acting in the process, first in the bacteria, fungus. So, these are the, I think you can see in the photo some bacteria and fungus and finally actinomycetes.

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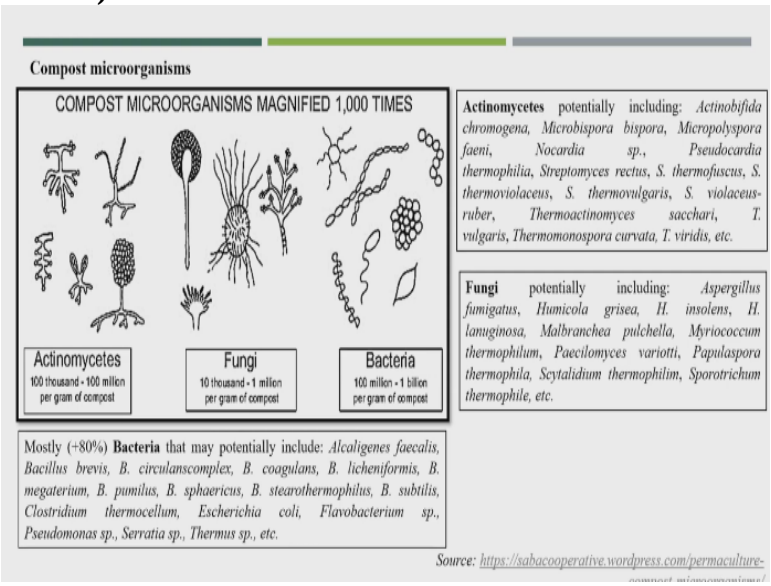

So, again you can see here what were the even along with the what could be the number or the actinomycete 100000 to 100 millions per gram of compost the fungus 10,000 to 1 million per gram of compost, in bacteria it is the maximum the 100 million to 1 billion per gram of compost. So, there will be a different kind of microbes are working in the composting process. So, see initially also I explained that calling some place as a composting plant as a mechanical compost plant is very difficult to accept that because they purely depend upon the microbes.

And mostly the bacteria you can see what I did I collected a lot of papers and from that papers I think many people have worked for isolation of different, different bacteria, different fungus, different actinomycetes into the composting process. So, these are the few names of the bacteria mostly the 80% of task of the degradation is by bacteria. Also major bacteria are the; you can see here the bacillus kind of bacteria are working for the degradation process. These are the few

actinomycetes the difference actinomycete and these are few fungus or fungi are working in the composting process.

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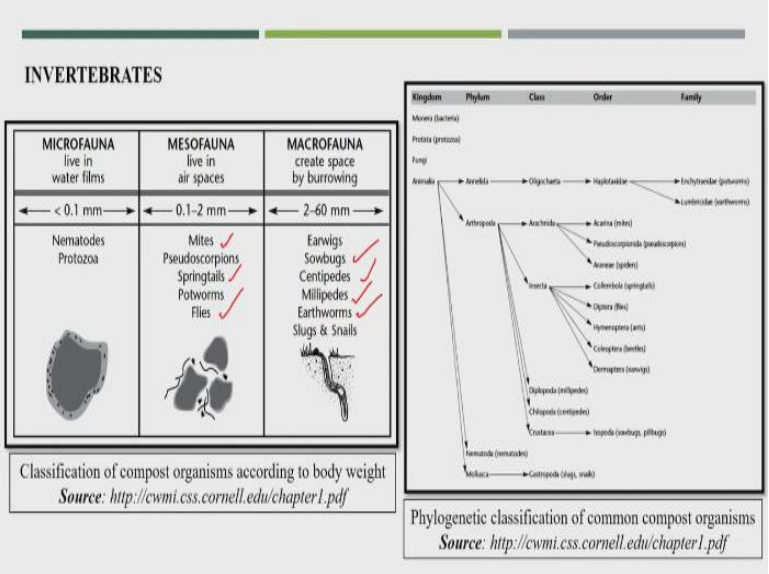

Classification of compost organisms according to body weight
***Source**: http://cwmi.css.cornell.edu/chapter1.pdf*

Phylogenetic classification of common compost organisms
***Source**: http://cwmi.css.cornell.edu/chapter1.pdf*

And now here this slide is specially for invertebrates where you can see that there will be a different kind of invertebrates you can see by their size, if you see that size is less than 0.1mm and these live in water filled in the composting method, very small one followed by that was the micro fauna and meso fauna that live in the air space, that could be a mites' springtails even the flies also possible to grow in the composting process.

And finally, the macrofauna that create a space by borrowing into the organic matter or burrowing into the compost material that could we see there will be some kind of earthworm also could be possible to produce centipedes, sow bugs, millipedes also could possible to grow into the composting process. But I think these kinds of invertebrate in the smaller size, it would not possible to produce very easily.

If you have a large composting plant and the composting time is more than 2 months, 60 days, 90 days then it is possible to produce these kinds of invertebrates. This is also good, how these kind of invertebrates so that proper degradation could be possible. These are the few more there are the different kingdoms of the invertebrates if you are interested you can read more onto these.

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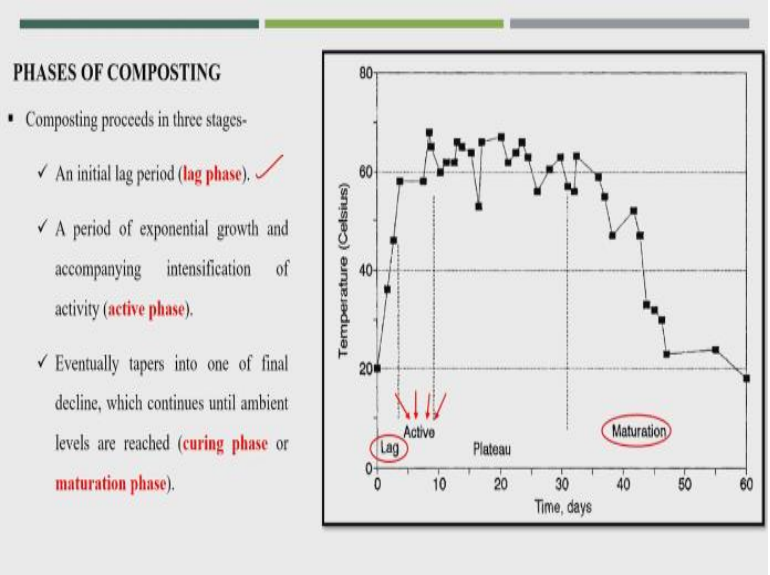

Now the phases of composting: So, already in temperature flowchart we saw that there will be 3 different phases mesophilic phase, thermophilic phase and finally maturation phase that is we can say again mesophilic phase or here I put it 3 different pages, the first is the lag phase where temperature is there would not be any change into the temperature and if there is more temperature like a period of exponential growth and accompanying intensification of the activity that normally we call as the active phase.

And finally, curing phase or maturation phase where eventually the tapers into one of the final decline which continues until the ambient levels have reached, ambient temperature will reach in the composting mass. So, here this is the lag phase and this is the active phase and finally maturation phase.

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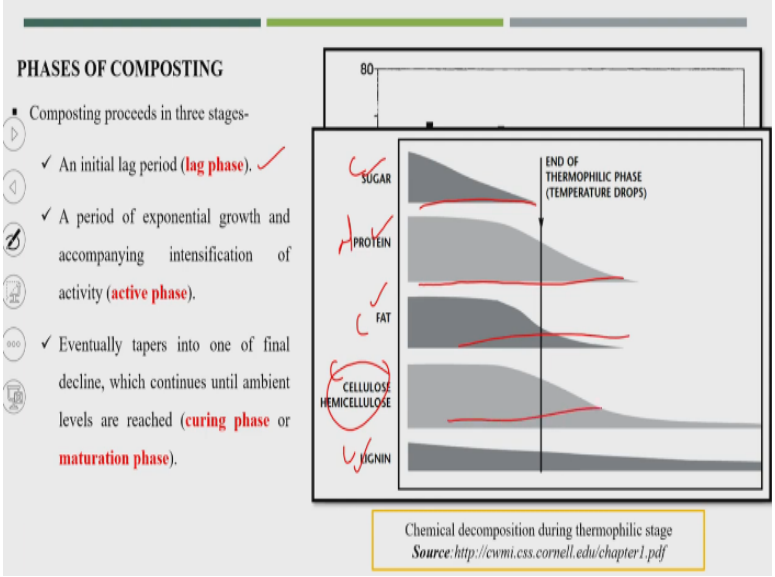

Or here you can see that see when we say the organic matter we are talking about the organic fractions of the municipal waste that is kitchen waste or that is normally is organic in nature. So, when you say organic in nature, what could be the different components could be possible there. So, it will have either sugar, protein, fat and cellulose and hemicelluloses and finally, lignin and this is the sugar the carbon form sugar, fat, this is the carbon protein is nitrogen form that is why I said decided that no carbon and nitrogen is important to manage here.

Now here see you see that by the temperature flow. So, if the temperature is lower, so initially sugar will get degrade. Then protein will get degrade, then fat, then cellulose and hemicelluloses and lignin in the last, but it is very difficult, these especially the cellulose hemicelluloses and lignin part of organic fracture is very difficult for the degradation process. So, if you are planning to how the degradation or composting of agriculture residue need to see that how much amount of cellulose or hemicelluloses or lignin percentage is there.

Or suppose if you are planning to have the composting of water weeds, like water hyacinth, or hydrilla verticillata. These are also another kind of weeds, polluted weeds, you are finding normally in the reserve wires are in water. So, they will have the more amount of hemicelluloses and lignin percentage that are very difficult to degrade, but if you are planning for proper mixing up of carbon and nitrogen, is possible and proper size, proper moisture content.

Proper aeration if possible to be maintained in the composting process there will be a possibility of degradation of the hemicellulose and lignin also within the small period of 20 days or within 30 days' period composting process.

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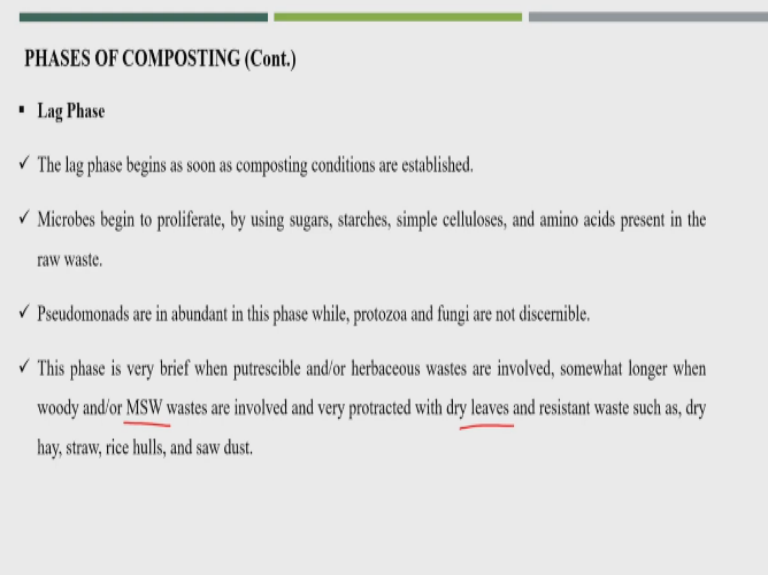

So, first is the lag phase, the lag phase begins as soon as composting conditions are established. The microbes begin to proliferate by using sugar starch and simple cellulose and amino acids present in the raw waste and Pseudomonas are in the abundance in this phase, while protozoa and fungi are not possible to grow in this particular condition. These phases are very brief and the time is very small here, very brief when putrescible and other kind of waste are involved.

Otherwise, somewhat longer when woody or MSW waste means I think there is more hemicelluloses and lignin, then that phase can be longer also can be possible which I think dry leaves this also content, large amount of lignin percentage in that.

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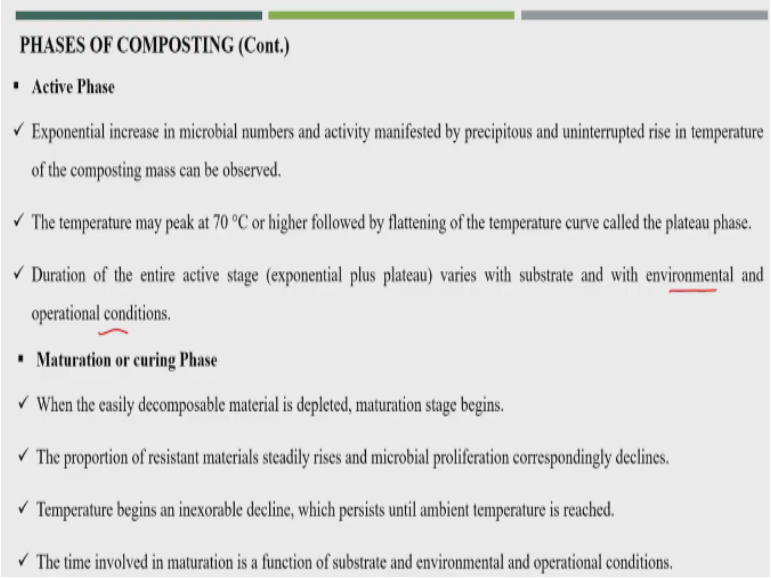

Now next phase is the active phase that is the second phase. So, there is an exponential increase in the microbe's number and activity manifested by precipitous and uninterrupted rise in the temperature of the compost can be observed. So, it is a continuous increase exponentially increase of the temperature here, the temperature may peak at 70°C or higher followed by flattening of the temperature curve called the plateau phase.

So, I think where the particular point the higher temperature and there I think that particular temperature could be maintained for maybe 2 days, 3 days or 4 days depend upon the type of organic material that will get stable at this temperature and the duration of entire active stage the exponential plus plateau varies with substrated with environmental and operational condition, I think every time if you see that always is writing by environmental and operational condition.

So, many times it is believed that because always we were seeing that composting can be possible only on proper ambient condition. So, what could be the proper ambient condition means no rain and temperature at 25°C or 30°C, but always in the entire year that is not possible to have because earlier before we were not more know how about the composting process, we believe in those time the composting would not be possible into the rainy season.

Even in the wet when the ambient temperature is 10°C in December, January none of the composting plant used to be run in those particular periods. But now, because we had come up

with new composting methods and new technology has been come up which I am going to talk about in this module, where these local ambient conditions also that would not be more problematic for the composting process.

And finally, the maturation or curing phase, when the easily decomposable material is depleted maturation stage begins and the proportion of resistant microbes steadily rises and microorganisms corresponding to decline in maturation there would not be availability of food for the microbes. So obviously, their population also will get reduced temperature begins and decline which persists until ambient temperature is reached. The time involved in the maturation is a function of substrate and the environmental and operation again, that particular point here that is also important based on the local conditions.

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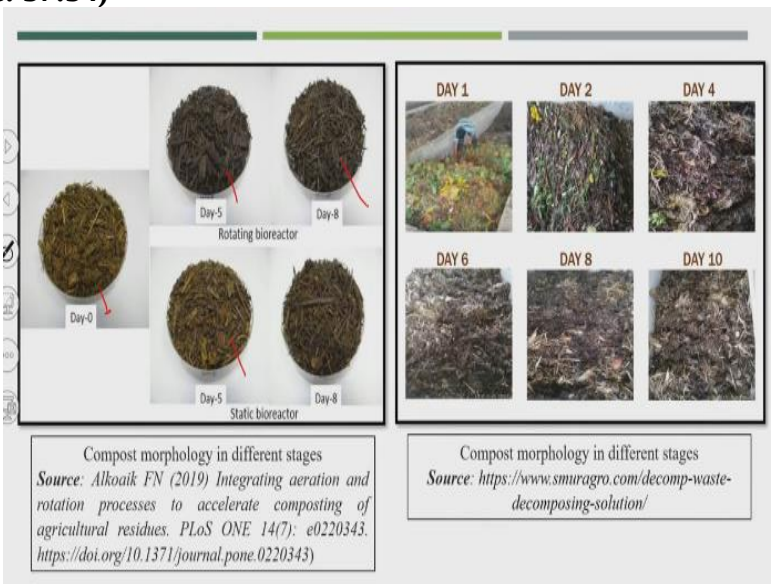

Compost morphology in different stages
***Source**: Alkoaik FN (2019) Integrating aeration and rotation processes to accelerate composting of agricultural residues. PLoS ONE 14(7): e0220343. https://doi.org/10.1371/journal.pone.0220343)*

Compost morphology in different stages
***Source**: https://www.smuragro.com/decomp-waste-decomposing-solution/*

So you can see here I think it is 0 day, I think maybe you will see here the 0 day what the color you can see what is the color in the 0 day and color in 5 days is initially it is become brown, this is converting into black in 8 days. So, that by that way you can understand the there are degradations. So, normally the wet waste is green in color, mostly that green color will convert into initially into brown color and finally at the black color that is showing the degradation process right here also you can see that these words the green color.

And finally at 10^{th} day, it is completely black color we are showing proper degradation process. So today, we understand that I think on this particular lecture, initially what I was thinking that

you people will understand properly the particular definition what exactly is the composting process and without thermophilic temperature and without knowing the microbes, I think it is very difficult to understand the composting process, even when you talk about the anaerobic degradation process also there are also these kind of things are very important.

Because the biological degradation process, so many times see, I think we are constructing very big, composting plants without knowing that whether we are allowing the segregated substrate or segregated material in the compost plant, entire wastes are mixed, we are putting for the composting process, knowing that the plastic would not degrade, metals would not degrade, glass would not degrade but still because we do not have segregation.

So entire waste we are putting into the composting plant and finally the entire degraded material is well shredded by big trommel, of which I am going to share few photographs here, so I will show why India has not successfully running the compost plants and these composting plants were started long back in 1970's, 75 but still we do not have such kind of particular units where we can say this is successfully running for 10 years, 15 years one particular composting plant.

And you know that there are lot of benefits of composts because already we are getting a lot of the negative points on the usage of chemical fertilizer for agricultural area and obviously these kind of composts is always a alternate of these chemical fertilizer. So I think we need to know more onto the composting process, so once you know, what are the microbes and what are the phases of composting then you will be able to understand the types of composting process based on the phases and thermophilic temperature. So that is all for today, and we will meet next on different type of composting processes, thank you.