Mass, Momentum and Energy Balances in Engineering Analysis
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Lecture - 02
Preliminaries

Welcome back. In this particular lecture, we shall be learning some Preliminaries and some concepts to do the balance of the mass or the energy and the momentum.

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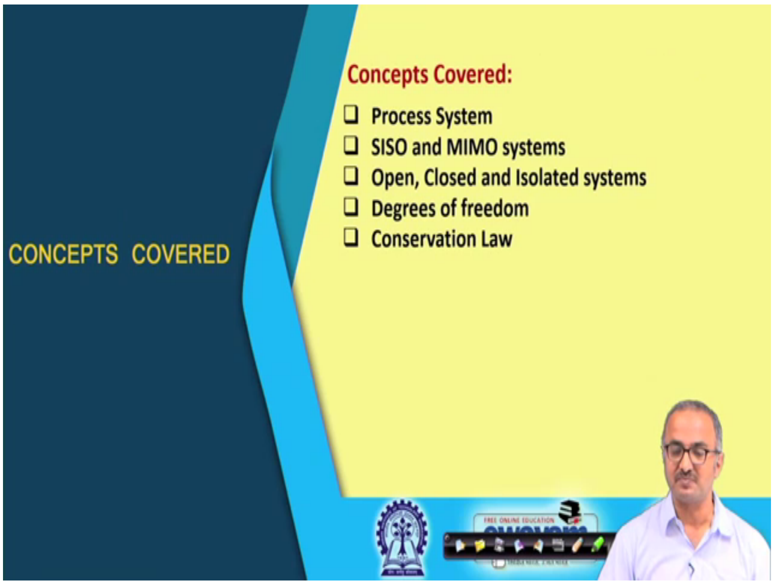

So, what we shall learn in this lecture are about the process system how do we classify the various types of process systems, because the classification is necessary to make the balances, we have to choose what kind of approach, we would adopt depending on the particular type of process system.

And then we shall see in the classification like the SISO and MIMO systems, open closed and isolated systems then degrees of freedom and the conservation laws. So, these are some of the preliminaries, we need to know before we go to the actual mass balances or the writing the balanced equations.

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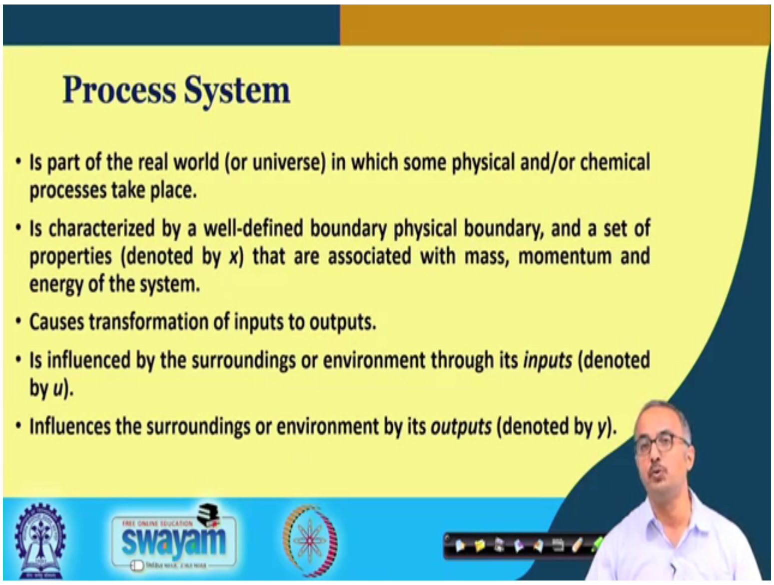

Now, you see that first whenever we talk of balances first you to identify, the system which we need to study or for which we need to make the balances and always we can identify the system properly, we cannot write the balanced equations. So, what first you to understand what we mean by a system; a system is a part of the real world or what we call the universe in which some physical or chemical processes take place.

Now, you can see that when we make this kind of a definition, it can encompass from very small to very large that means, we can talk of a small bacteria or amoeba and you can we can talk of the whole world or all other planet, everything we can consider. So, depending on what kind of system we are choosing, we shall be and what we want to have, what we want to know about the system depending on that we will make the balanced equations. So, it is very, very important to properly identify the process system.

And generally any process system is characterized by a few things like first, it is a physical boundary and it should be well-define boundary, because unless you have a well-defined boundary we cannot write the balanced equations. So, you have to make sure that you know the physical boundary of the system. And then each system is having some kind of a set of properties like for example, when we have a boiling water, the boiling water the characterized is that it is characterized by the temperature ok.

So, what the temperature is from that you can identify that whether the water is boiling or not, and on temperature plus the pressure all comes into picture, because the boiling temperature depends on the pressure. So, all these two things we can say that these two things are characterizing a boiling water. And other than these there are many other parameters, other properties, which are associated with the mass momentum and energy of the system. For example, density is associated with the mass, for viscosity is associated with the momentum, temperature is associated with the energy.

And any system is causing some transformation of inputs to some outputs that means, something goes inside the system and it undergoes some kind of processing and it gives rise to some kind of outputs. So, the system is basically a mechanism of transforming or converting the inputs to some outputs.

Naturally the working of a system is always influenced by how it the system is interacting with the surroundings. So, the environment or the surrounding plays a very, very important role in deciding the output of a system. So, here the inputs are going from the outside the system that means, some surroundings into the system that we call inputs. And generally these are designated by u. And then the there as it the system also influences the surroundings by ejecting something from the system that is the output of the system and that is represented generally by y. And there are some signals these signals are either the inputs or the outputs of the system.

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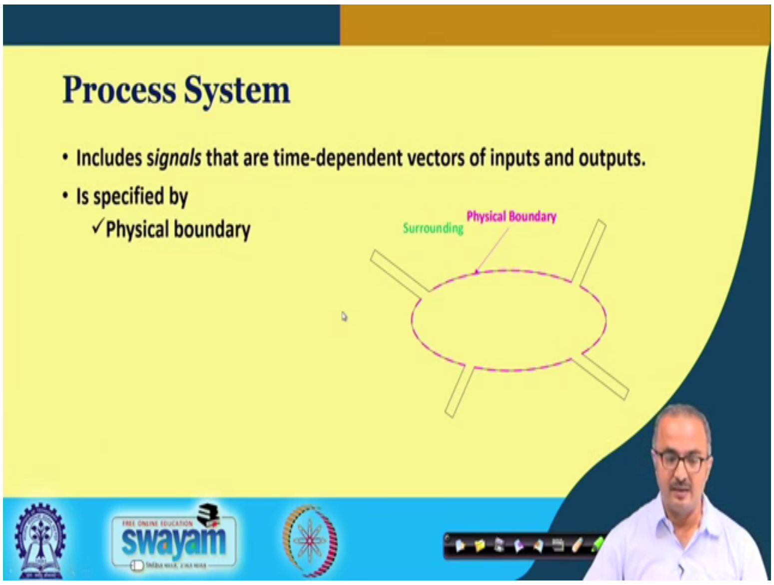

So, whenever in nutshell we can say that whenever we want to characterize or designated system, we need a few things. First thing is a physical boundary as you can see that we demarcate a particular boundary. And as soon as we demarcate a boundary, the surroundings will be coming automatically that means within this boundary we have the system and outside this boundary, we have the surroundings.

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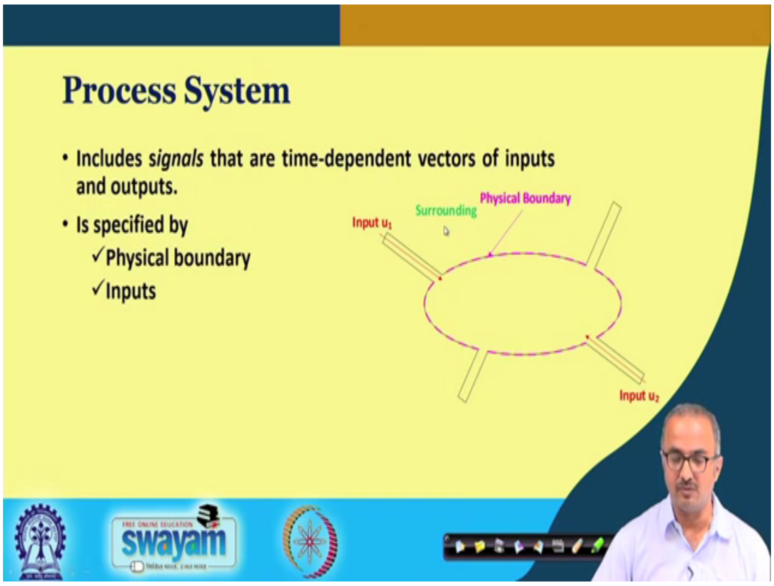

And next we have some inputs that means, there can be more than one input ports. So, we can see that there are various types of inputs like u 1 and u 2, two inputs are shown in this particular figure. And then we have the outputs which are given by y 1 and y 2. And lastly we have some process that is taking place within this system boundary. So, all these things needs to be prespecified to identify a particular system. So, whenever you are starting to analyze any process, you follow this method to first for identification of the particular system.

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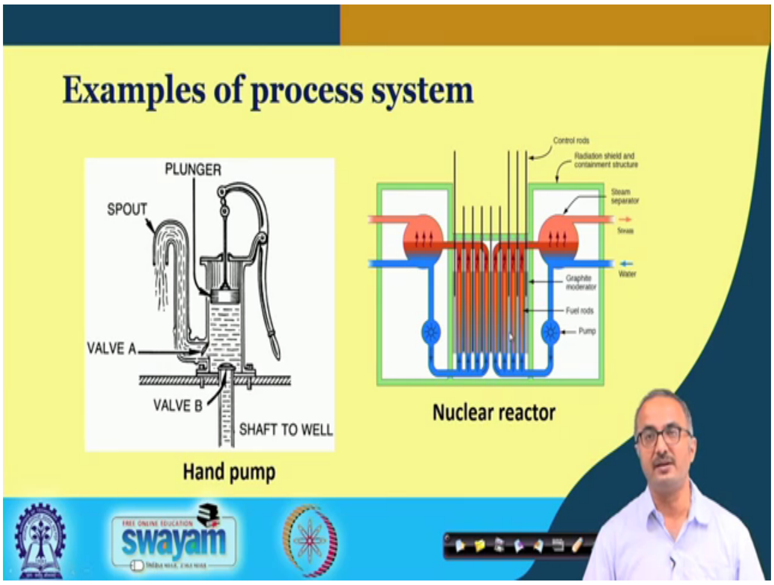

Now, let us see some examples from our day-to-day life and something from the industrial applications. So, this particular system you see that here I have shown a hand pump. Then this is a very, very regular thing which we find in the villages. So, here you see that we have seen this is that we pump to get the water from this hand pump. And what we are doing basically there is a plunger, which is pressurizing. And there is a valve which is opening and closing. And there is a shaft, which is going inside the earth and from there the water is being drawn up there is again a valve over here and then the water is going through this valve, and it is coming out through the spout. So, this is a very usual system.

And if you correlate this particular system with our definitions, you can see say there is an input and there is an output. And from here we are giving some kind of thrust so that is a so surrounding is giving some kind of a, a some kind of pressure to the system to give the output from some input ok. And in this particular case, you can see that if we assume the temperature not to change much ok. And then we can see that when you write want to write the balanced equations you may consider the mass balance that is how much mass is coming up and how much mass is going out of the system. And whether there is any kind of accumulation of mass inside this pump or not, all these things can be very well determined if you write the mass balance equation.

Now, we come to another industrial application that is in the nuclear reactor, and perhaps you know that in the nuclear reactor where these neutrons are coming. And they are we use some graphite rod to moderate the or slow down the neutrons. So, here you see that we also put some radiation shield, and there is some kind of a mechanism to cool down the whole system by putting water. Water gets cooled. And here we find that it is getting evaporated and steam is getting generated.

So, here you see that to analyze this system, we can either consider this particular system or we can consider this particular system. So, a particular system can have various subsystems in it. And this is one example that we can see that overall system consists of various types of subsystems. And these subsystems are interacting amongst themselves to determine the overall performance of the actual system. So, in all these cases, we can write the mass momentum and energy balances for analysis.

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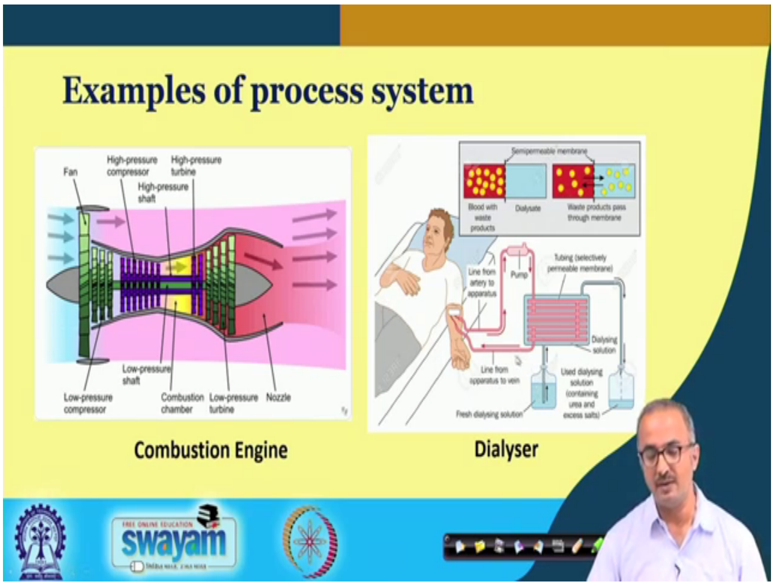

Next we come to a combustion engine. This also you see many times that in this combustion chamber what is happening basically that we are having some kind of a fuel and some kind of an oxidizer, which is getting combusted at some point in the combustion engine. And it is generating some high pressure gas and this gas is being ejected out and this ejection causes a backward thrust. So, it is basically the Newton's third law of motion, and by this the particular vehicle is able to move.

So, this is a very common example here we are finding that when we are seeing combustion that means a particular fuel is getting transformed, it is getting oxidized to give out some other components like carbon dioxide and water ok. So, in this case, we find that there is a transformation and again, we can write some kind of mass balance, energy balance, because energy, because whenever something is getting combusted, some energy is generated thermal energy. And that thermal energy is causing this kind of energy balance to the system.

So, we can write the momentum balance energy balance and momentum balance just to know that how much pressure will be given by the ejecting gas. So, all these three will come together to tell us that how the particular system will be moving. Next we come to dialyzer about which I just told you that in the dialyzer, what we are doing that we are taking the blood out from the particular person. And it is getting basically purified, because our own system may be our kidney is not working in our of the lungs (Refer Time 10:29). So, we are taking this thing out and we are putting it through this artificial, we are trying to purify the blood and we are sending back the purified blood to the system. And here there are using some other dialyzing solutions to help in this to maintain the particular a balance of the various types of minerals like sodium, potassium.

So, this is and in this case if you look from the balance point of view, you have to figure out that how much impurity is coming out, how the impurity is getting separated, and during the separation if there is any kind of energy exchange all these processes need to be considered to design, and analyze this kind of a system.

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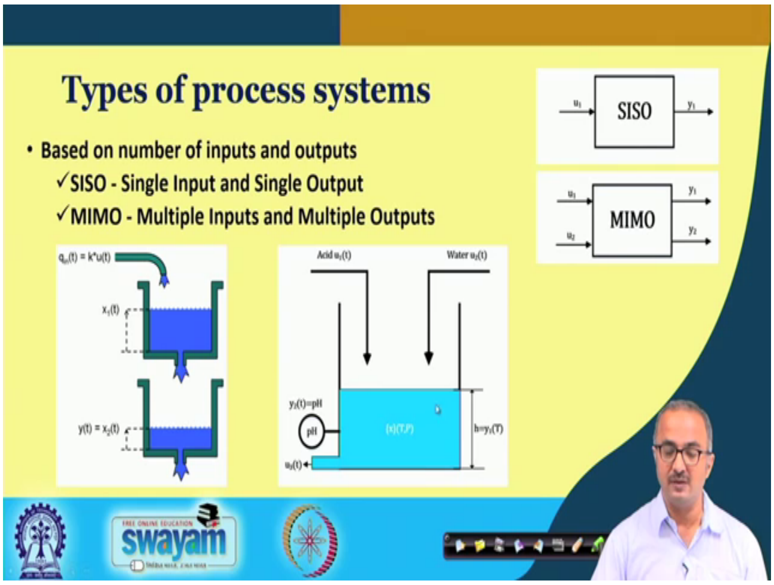

Now, we come to different types of systems. And these types are classifications are based on different bases. So, one basis of the systems are on the number of inputs and outputs. Now, first is the SISO system that is Single Input and Single Output. Now in this case what is happening there is a, this is a system ok. And here we find there is only one input going to a system and it is producing only one output and one example can be given by this particular figure, you can see here that here some kind flow is happening and this flow is going through the two tanks this is a first tank and this is the second tank in the both the tanks there is there are two levels of the liquid one is x 1 and one is x 2. So, this x and x 1, x 2 they are representing the state of the system.

And if we want to control this particular height of the second tank that that I take as the that state I take as the output that is the y. So, that is why we are showing that y is equal to x that is the state of one system is also its output ok. And here we find that there is a injection of the particular liquid. So, by having the proper balance of this input rate and the output rate, we can maintain the certain level within this particular tank ok. So, here you see that there is single input and this is single output so this is a SISO system.

Next is a MIMO system in this case we have Multiple Inputs and Multiple Outputs and it is represented by this particular diagram. Here we have this system and here we have the two inputs u 1 and u 2 and we are having two outputs y 1 and y 2. Such systems also you may find in your day to day life like one example I give you that here in this particular system, we are mixing an acid with water to maintain the ph of a certain mixture that means, we are basically diluting the acid.

And you see that in this thing these two acid and water are coming into a particular tank. And here we are also trying to maintain the level of the tank. So, here we have this acid and the water and the output all these three can be taken to be the inputs ok. And this here maintaining there is a particular ph that is the output and the temperature and pressure of this particular mixture is taken to the state variables. So, by adjusting any of these like the acid input or the output of the system or the water input all these things may any of this may be taken to adjust the level and the ph of the mixture in the tank so these becomes a the example of a MIMO system.

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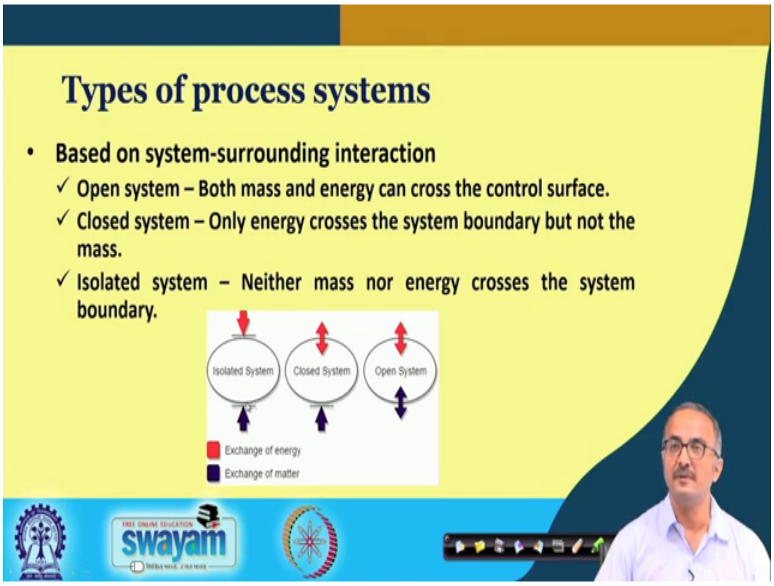

Now, we come to another basis of classification and that is based on the how the system is interacting with its surroundings. So, in the first we have the open system open means whenever we talk of these interactions, we talk in terms of the mass and energy ok. So, when we talk of open system it means that across the system boundary both mass and energy can flow either from the system to the surroundings or from surroundings to the systems so is in this is an open your system.

And then we have a closed system it means that it this closed system means that it allows, the exchange of the energy between the system and the surroundings, but it does not allow the exchange of the mass between the system and the surroundings. And lastly we have an isolated system in this neither the mass nor the energy can cross the boundary of the system. And this kind of things you encounter many a times in your day to day life first let us see schematically that if this red color shows the energy exchange and the blue color shows the matter exchange. And you can see for isolated system these none of these are permissible this is the barrier. So, this barrier shows that none of these are permissible for the isolated system.

In case of closed system you can see that mass is not permitted, but the energy can be exchanged between the system in our surroundings and lastly, you can see there is no barrier either to the mass or to the energy this is for the open system. So, this is schematic representation of the open system closed system and the isolated system.

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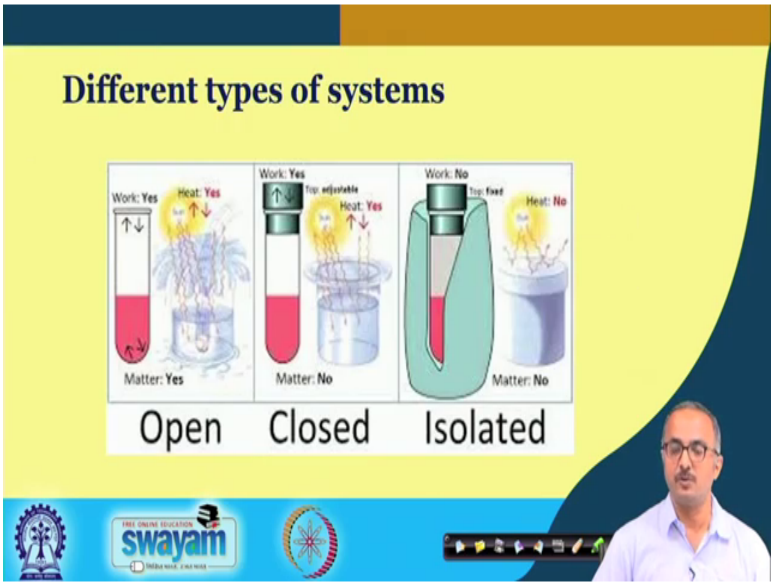

And now let us see from our day to day life and one example that here you see that we have taken this open system. Here what we are seeing that there is some kind of a vessel in which we are having some kind of mass and if we are keeping the there is no lead, that means, the it is open to the atmosphere then suppose there is we are heating it, then what will happen that there is a exchange of the heat from the surrounding to the system. And due to this heating, we find that the liquid may get vaporized and it goes to the surroundings, that means, both the energy and the mass are getting exchanged between the system and surroundings.

So, this is an open system. on the other hand what we can also do is this that we can put a lid on the particular vessel once, you put the lid what we will find that even if there is some evaporation, the mass cannot go out of the system provided we make it to the proof. So, in this case, but we can still say that the energy can again still pass through the lid and it happens many a times at our home also like the pressure cooker that we are heating it the water is evaporating, but it is not going unless otherwise it is reaching some particular value ok. We and then what we find the, that nozzle of the pressure cooker it opens up to release the pressure excess pressure, but otherwise the water gets evaporated and remains within the pressure cooker. So, this becomes an example of a closed system and as soon as it opens up then it becomes an open system ok. So, it is intermittent to the closed and intermittent to the open system.

And the third one is isolated system this is one example that the flask you can talk about that in the flask what happens we are putting some kind of a liquid and we warned that temperature of liquid should remain constant and that is possible only when we insulate the particular flask, and if the insulation goes then, we find energy exchange starts happening. So, we cannot maintain the temperature inside. So, this flask is an example of an isolated system.

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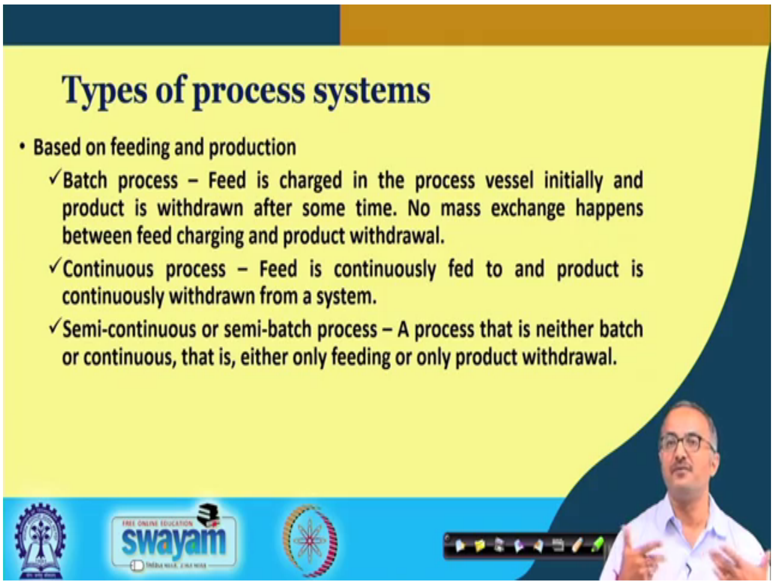

Another classification is based on the feeding and the production of the in the particular system. Now, feeding and production you can see from this example that we have batch process batch process means, what that I have a system and we put some kind of raw material say or some or some kind of materials inside the system and then we no more supply anything. And neither we are withdrawing any kind of product from the system and what we now do that for some time we just allow some process to take place within the system and after that time then we start withdrawing. So, during this period when after filling up with some material, we are allowing this system to undergo some kind of processing. So, that the feed gets converted to some desired product and, but during that time we are not withdrawing any product. So, this becomes a batch process ok.

And then we have a continuous process in the continuous process, what we find that this is a continuous flow of that means from the surroundings to the system; that means, continuous input and at the same time we are also withdrawing some output. So, this becomes a continuous system and then third classification is semi batch or semi continuous process in this case it is neither a continuous process nor a batch process; that means, what that either we have only input without withdrawing any output or we have only output without any kind of input. So, in this case we call it semi continuous or semi batch, it is something like half filled or half empty glass. So, you can call it in a semi batch or semi continuous.

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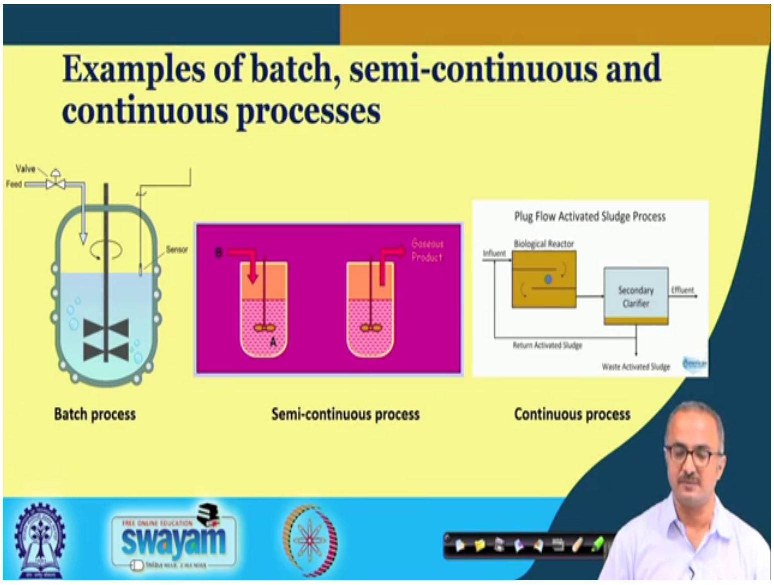

And let us see the examples of this. Like here we have shown you a batch process. In this case we see that we are stirring some material this is a very means day to say life, you can see that suppose you are trying to dissolve sugar in milk ok. In a sugar tumbler then what you see that you just dissolve it and here we are you are not really taking out or putting in anything. So, this mixing of the sugar in water or sugar in milk becomes an example of batch process.

Another is a semi continuous process here what we see some component b is coming and some component a is getting generated ok, but we are not withdrawing a ok. So, it is semi batch and again after some time what we will do that we start withdrawing the product, but now there is no input. So, it becomes an example of the semi continuous or semi batch process this is also we seen our day to day life that when we are cooking in the like kitchen sometimes we are pouring some water and keep studding the particular food item. So, here we are just simply giving something in the thing in the vessel, where we are cooking not only water, we can also put some spices or we can put some other ingredients ok, but we are not withdrawing until unless the process is finished.

And once the cooking is done then we are now withdrawing without any kind of input. So, this becomes a semi continuous or semi batch process. And once we have inputted something and we are not withdrawing also and we are keeping the vessel on the fire for some time to get the food ready during that period you can say this is a batch process. And lastly we have the continuous process in this case, we find that there is a continuously some input is going and something is coming out continuously for example, it is happens in the water filter that there is a water going through the filters from the tap and at the outlet, we are also withdrawing the water. So, this becomes an example of a continuous process.

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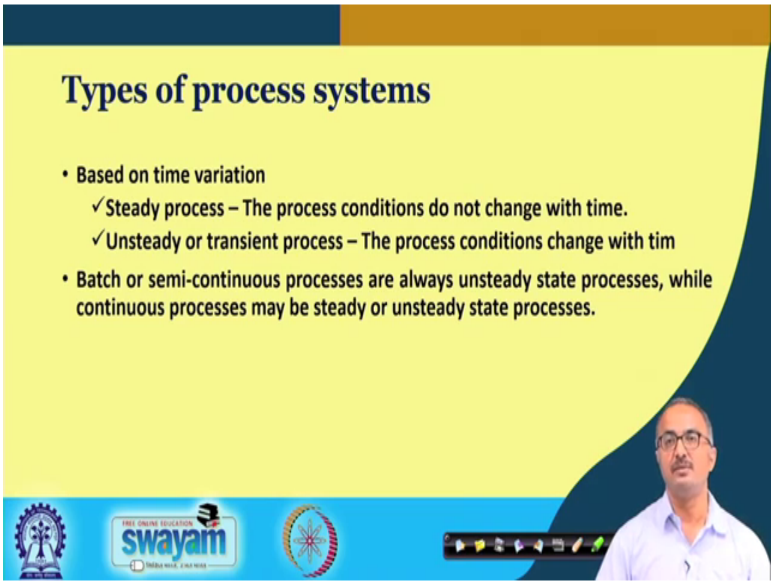

And again we classify the processes based on the time variation. Now, if some process the process variables are not changing with time then we call it a steady state process and if the process variables are changing with time, we call it a steady state process. Please mind it that steady state does not mean that the particular variables cannot change special; that means, with the space it may change there may be some variation within the space, but those variations will remain constant with time ok. So, that is the steady state process

And generally what we find for the batch and the semi batch processes they are unsteady state, because during this process they are continuously changing, the process variables changing and when the variable is approaching the desired value only then we start withdrawing it ok. So, during this semi batch or batch process the whole process is analyzed as in unsteady state process or what we call the transient process. On the other hand continuous process may be or may not be steady it initially there will be transient and ultimately the continuous process may reach a steady state.

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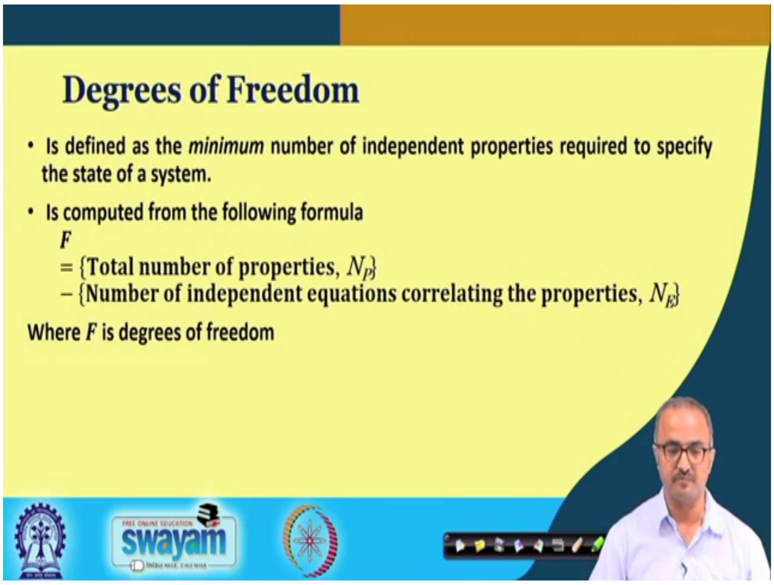

Next we come to a very important concept that is degrees of freedom, because degrees of freedom has to be known to characterize a process and you see that to characterize a process there can be many, many variables, but, but all the variables need not be specified. So, in the thermodynamic system we define the degrees of freedom as the minimum number of independent properties to characterize or specify the particular system.

Now, if we denote by F the degrees of freedom we calculate it like this that we first count the total number of properties involved in the particular system. And then we also write all the correlations all the equations which correlates these properties. So, if I subtract the total number of independent equations correlating, the properties from the total number of properties then we get the degrees of freedom and if we represent the number of properties with N P, and number of independent equations with any then we have this N P minus any as a degrees of freedom.

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And here we see that the properties may be extensive or intensive. Extensive means it will depend on the mass of the system and intensive means it is independent of the system. So, here we see that if N P is equal to N E, that means, we have the number of properties same as number of equations then we get an unique solution and we call it a well defined problem determine problem. Now, if the number of properties is more than number of equations then we call it under specified, because now we cannot uniquely find out the values of all the properties, because we do not have sufficient number of equations.

And in this case, we find the degrees of freedom will be more than 0. And if we have N P that is the number of properties less than number of equations, that means, we are over specifying there could be multiple solutions. So, in this case the degrees of freedom will be less than 0 and we call it over specified system.

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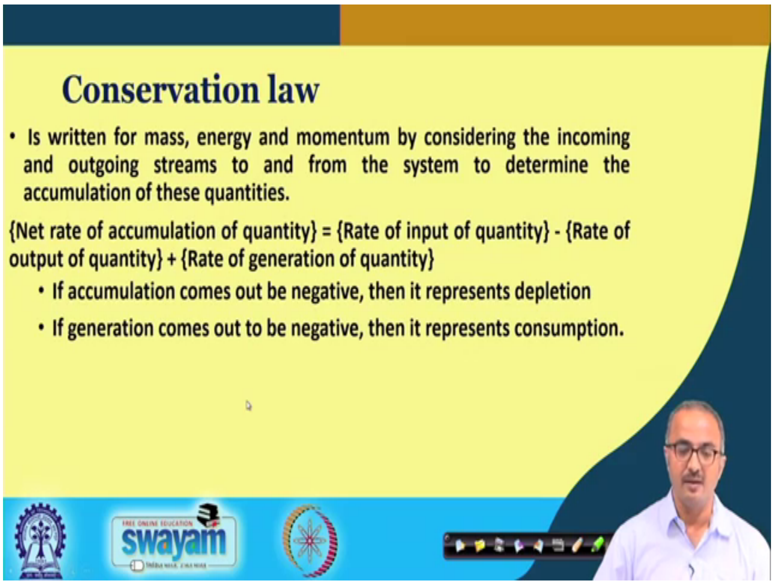

Now, once we learnt about the different systems and the properties and degrees of freedom, now we are ready to look into the balanced equation. And in this case, we go with the conservation law. And the conservation law is about that net rate of accumulation of a quantity within a system is equal to the rate of input of the quantity minus rate of output of the quantity plus rate of the generation of the quantity ok.

So, now to know this how much is accumulated in the system, we need to know the input the output and the rate of generation. Now, you see that depending on the type of the system, we find that different types of the mathematical expressions will be used, but every time these will be conforming to this particular equation for the conservation law. One thing you must understand that accumulation may be negative its negative accumulation means it is depleting for example, water is getting accumulated in a particular vessel. So, this is positive and, but if the water can depleted then it is negative accumulation.

Similarly, generation is positive, that means, some species getting generated, but if the species consumed then it will be negative generation, that means, a consumption. So, the accumulation and generation may be positive or may be negative.

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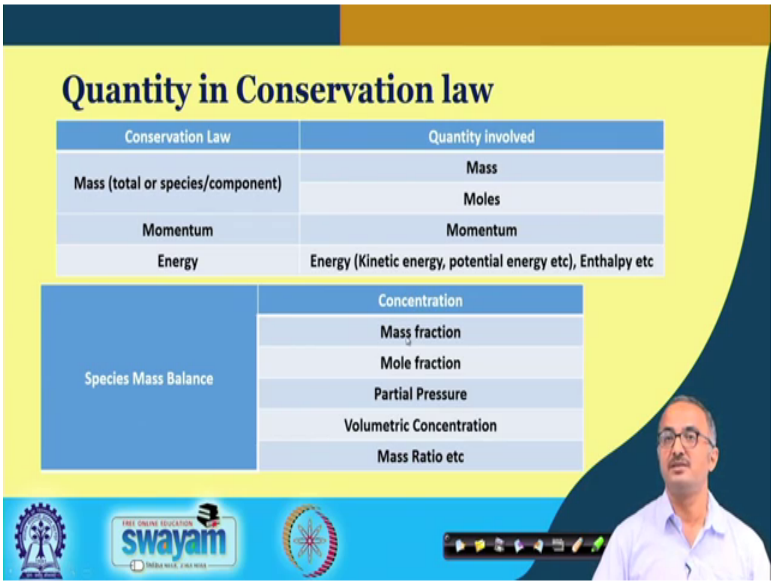

And these are the various quantities which are there in the conservation equations like the mass for the mass balance. And mass balance can be on the species all over the whole system. May be a momentum then we are momentum is a quantity involved in the velocity. And we have energy we have different types of energy, and the enthalpy. And lastly in the mass balance when we talk of species mass balance, we have we are representing various types of concentrations like mass fraction, mole fraction, partial pressure, volumetric concentration, mass ratio, all these things we shall be studying in detail in our future lectures.

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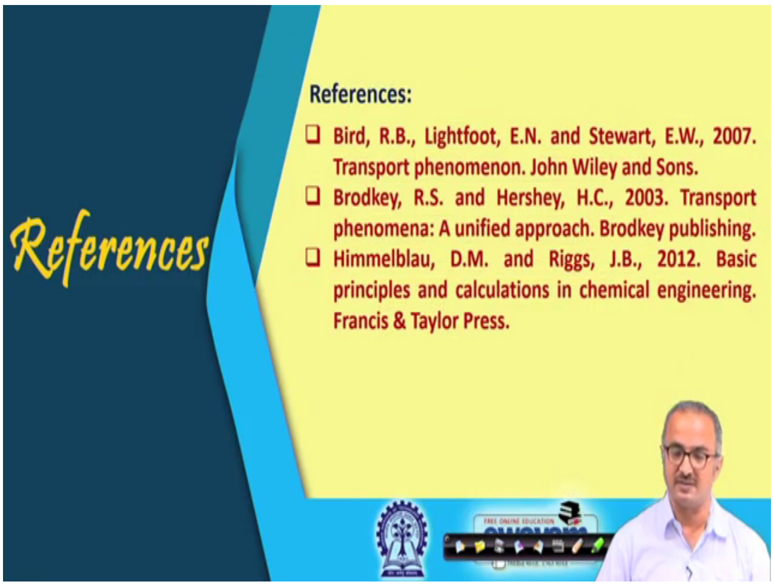

So, these are the various references from which you can know more about the concepts I have told you today.

Thank you.