Engineering Hydrology

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Lecture – 9

Atmospheric Water

Hello all, welcome you all to the second module of Engineering Hydrology. We know water is present in the atmosphere, on the ground surface and beneath the ground surface in different forms. So, the second module will be dealing with the water which is present in the atmosphere. So, atmospheric water, why it is very important?

It is important because two processes we can consider. That is one is the precipitation and the other one is evaporation. In both the cases atmospheric water is having close interaction with the surface water. As precipitation water is falling on the ground and from the oceans or seas or water bodies, water will be evaporated into the atmosphere in the vapor form.

So, study of this atmospheric water is very, very important because we are depending on rainfall or precipitation for our water requirements. How we are getting precipitation? From the water vapor which is present in the atmosphere. So, let us have a detailed understanding about atmospheric water in this module.

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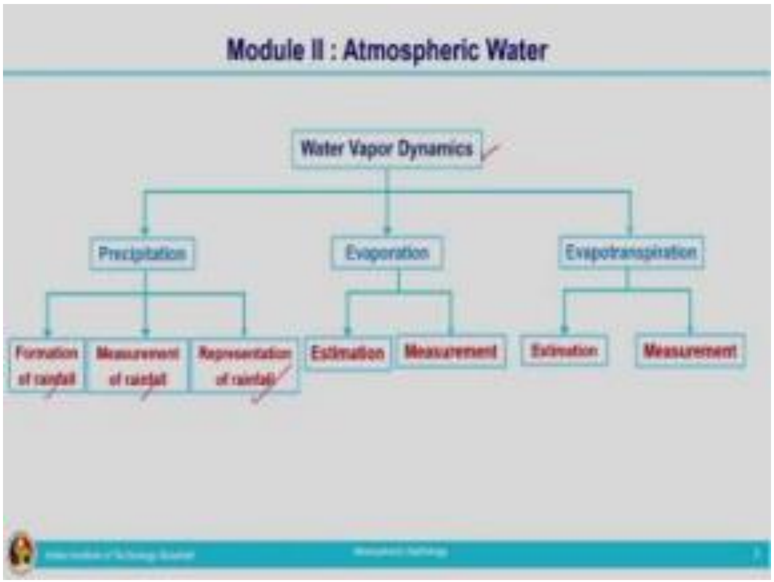

So, first of all, we need to understand water vapor dynamics. And it will be including precipitation, evaporation and evapotranspiration. When we are talking about precipitation, we need to have idea about formation of rainfall. Then comes the measurement of rainfall and representation of rainfall.

How rainfall is formed from the water vapor in the atmosphere, how we are getting the precipitation? Mainly we are focusing on rainfall. Precipitation includes different types of precipitation. Out of that we mainly depend on rainfall for our water requirements. So, we will be giving more emphasis to precipitation in the form of rainfall.

After seeing formation of rainfall we need to have idea, how can we measure this rainfall? Then we need to represent this rainfall in different forms. After that we will move on to evaporation. In the similar way, we will be having understanding about estimation and measurement of evaporation.

Then the next process which will be covering in this module that is atmospheric water module is the evapotranspiration, again, the estimation and measurement. So, once we get complete knowledge about precipitation, evaporation, evapotranspiration, we will get an idea how water can be, water vapor can be modelled in the atmosphere.

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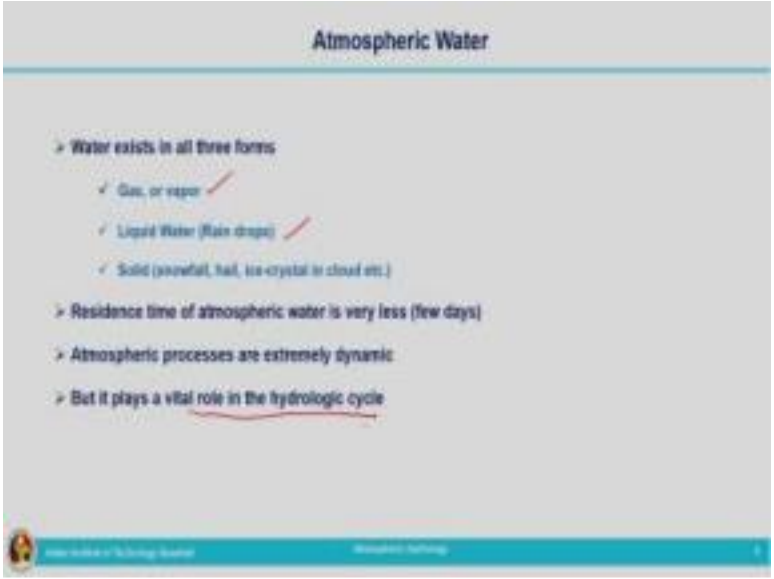

Atmospheric water also, we can have in the vapor form, in the liquid water form. We are having the water vapor present and we are having the water droplets present in the atmosphere and also when we are having snowfall, hail in such cases we are having the water in the solid form in atmosphere. So, if we are talking about atmospheric water, generally we will be looking at the water vapor but all the three phases of water is present in the atmosphere also.

And we have seen, the residence time of atmospheric water is very, very small. That is why the process itself is very dynamic and also makes the process very complex. Even though it is existing in the atmosphere for very small days, residence time is very small we cannot ignore that. That is an important factor which plays a vital role in the hydrologic cycle

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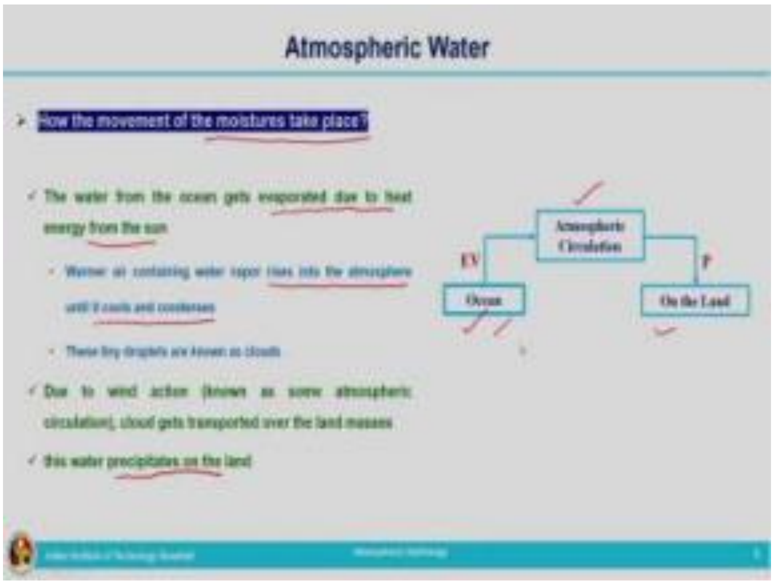

Now we need to study, how the movement of moisture is taking place in the atmosphere? We know hydrologic cycle is a continuous process in which the water is converted into the water vapor and then back to water. This process is continuously happening; it is an endless process, so how the movement of moisture is taking place?

We are having different water bodies. For example, we can take the case of ocean, seas or any other water body. The water in the water body will be absorbing heat energy from sunlight and it will be converted to the water vapor. Due to the process known as evaporation this water vapor will be formed and it will be moved towards the upward direction into the atmosphere. So, it is getting evaporated due to the heat energy from the sun. When it is absorbing heat energy, we will be having warmer air near to the water body which contains the water vapor and it rises into the atmosphere. It will be rising up to a level until it cools and condenses. Then clouds will be formed, these tiny water droplets will be forming clouds. How this water vapor that is warmer air which is containing the water vapor will be lifted up? There should be some action, right? Due to wind action, this warmer air will be lifted up that is what is known as atmospheric circulation. So, when the clouds are formed and due to the wind action, these clouds will be transported from one place to another place and when condensation takes place, water will be precipitating on the land.

So, we are having two main processes, evaporation and condensation, based on that we will be getting precipitation on the land. Again, from the land surface and the water body, water is getting evaporated into the atmosphere, this warmer air containing the moisture or the water vapor will be transported from one location to the another location by means of the wind action and as it moves up and up, it will become cool and cloud formation will be taking place and then cooling of these air masses will be producing the rainfall.

So, this process is continuously taking place. This way we are having two processes such as evaporation and precipitation which is transforming the water to water vapour and then condensation will be making the water vapor into precipitation.

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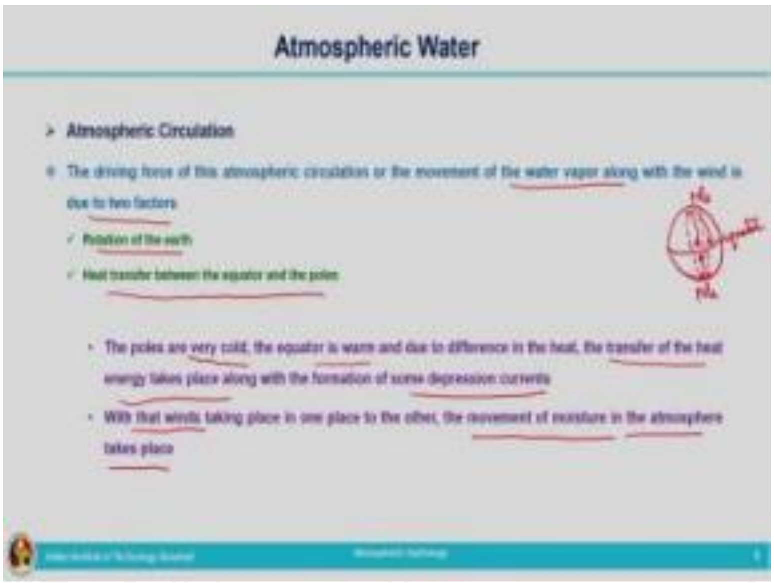

Now we need to have some understanding about atmospheric circulation. How this circulation or this wind action is acting on the warmer air masses? This circulation mechanism is having two main reasons. One is the rotation of the Earth; second one is the temperature difference between the pole and the equator.

Let me draw a figure. At the poles the temperature will be very low and at the equator we will be having warm air. Because of the difference in temperature between the equator and the poles, what will happen? The warmer air will be moving up into that atmosphere. So, the warmer air will be moving towards the pole and as it reaches a certain height, what will happen, it will become colder and it has a tendency to come down to lower atmosphere.

And again, the process will be continuing, it will be moving up and coming down. So, this way the temperature difference between the pole and the equator is causing the formation of this wind. Circulation is mainly due to the rotation of the Earth and the difference in temperature between the pole and the equator.

Because of the difference in temperature, there will be an energy transfer, heat energy transfer taking place between the poles and the equator. Similarly, in this way also warmer air will be moving towards the poles, colder air will be moving towards the lower atmosphere then it will be transported towards the equator. This process is continuously taking place. That is the main reason behind the atmospheric circulation.

The driving force of this atmospheric circulation or the movement of water vapor is due to two factors, what I have already mentioned; it is rotation of the Earth and heat transfer between the equator and the poles. The poles are very cold and equator is warm. Due to this temperature difference, difference in heat what will happen, transfer of heat energy will be taking place between the poles and the equator which will be forming the depression currents.

These depression currents are responsible for the movement of moisture in the atmosphere from one place to another, that is the depression current or the winds which are formed due to the temperature difference. So, the heat energy transfer between the poles and the equator is making the movement of moisture from one location to another location.

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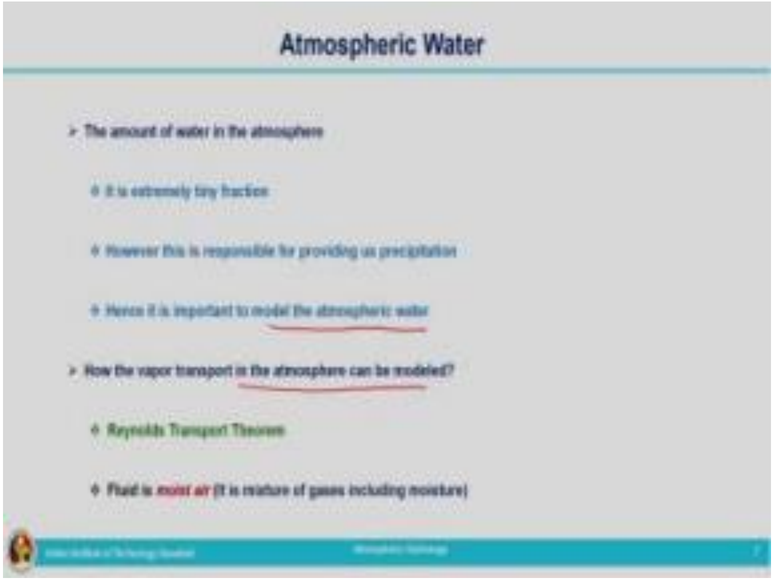

We need to understand the amount of water present in the atmosphere. We know it is a very small fraction of water which is present in the atmosphere. But this small fraction is responsible for precipitation which we are experiencing. So, we need to model the atmospheric water for studying the movement of this water vapor. After doing the modelling only we can understand different processes clearly.

How this water vapor transport in the atmosphere can be modelled? For that we have developed a mechanism in the previous lectures, that is nothing but Reynolds Transport Theorem. Reynolds Transport Theorem is the consistent mechanism which can be used for developing the mathematical equations which represents the movement of fluid or fluid flow.

So, Reynolds Transport Theorem will be utilized here also for developing the equations related to water vapor movement. Here what is the fluid which we are considering? It is the moist air. In the atmosphere we have seen water is present in the form of liquid, vapor, that is liquid droplets are present, vapor and also in the form of small ice also it is present. But mainly it is in the form of water vapor. So, the fluid which we are considering for the modelling of the atmospheric water is the moist air. It is a mixture of gases including moisture.

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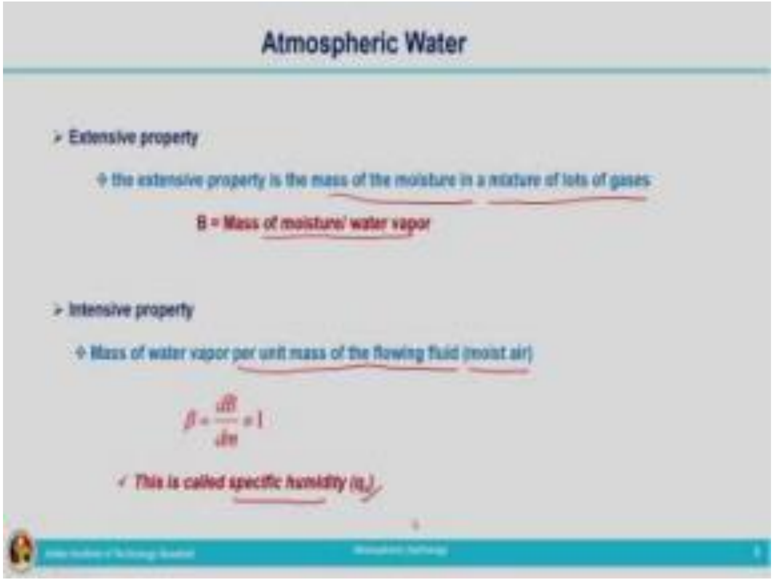

Now, if we are using the Reynolds Transport Theorem for modelling purpose, we need to define the extensive property and the intensive property. So, what will be the extensive property in this case, '*B*'. It is something related to quantification of the water vapor, how much quantity is present in the atmosphere. So, extensive property will be definitely the mass of the moisture present in the mixture of gases.

$$B = \text{mass of the moisture/water vapor}$$

You should understand the difference between moisture and moist air. In the atmosphere in addition to this moisture we are having so many gases present. That is moist air is the combination of different gases along with the moisture or the water vapor. So, our extensive property *B* is the mass of the moisture or water vapor. Now what will be the intensive property? We know the relationship between the extensive property and the intensive property,

$$\beta = {}^{dB}\!/_{dm}$$

That is mass of water vapor per unit mass of the flowing fluid. What is the flowing fluid? Flowing fluid is the moist air. So, here it will not be one, it is the ratio between the mass of the moisture to the unit mass of the moist air, both are not same.

But in the previous case, when we were deriving the mass conservation equation, β turned out to be 1 because dB/dm = 1 i.e. extensive property is also mass of the fluid, then flowing fluid is also the same. So, $dB/dm = dm/dm = 1$. But in this case, flowing fluid is not consisting of moisture alone, it is consisting of so many other gases.

So, we are having two terms, one is moisture and the other one is the moist air. So, intensive property is the mass of water vapor per unit mass of the flowing fluid. So,

$$\beta = {dB}/{dm} \neq 1$$

It is termed as specific humidity. That is the mass of water vapor per unit mass of the flowing fluid is nothing but the *specific humidity* which is represented by q_v.

We all are familiar with the term humidity, right? So, this is nothing but when we talk about the atmospheric water, intensive property is specific humidity that is the mass of the moisture divided by mass of the moist air.

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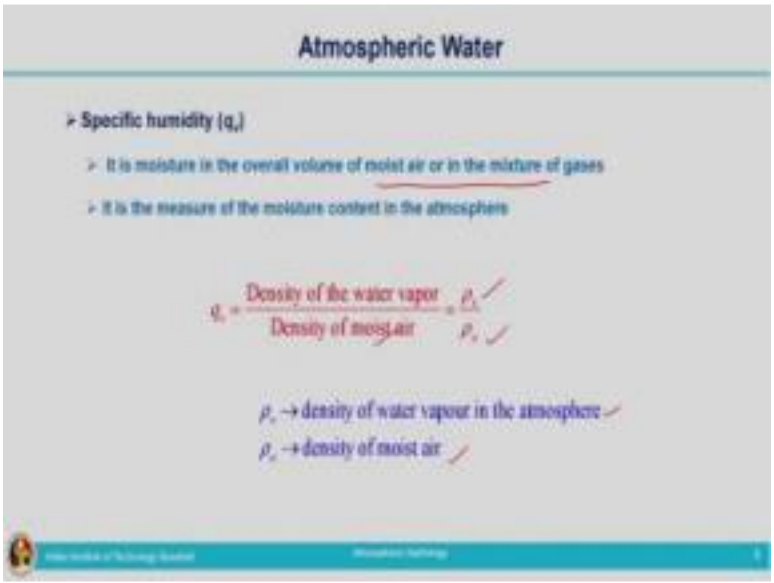

Now let us look into specific humidity. So, specific humidity is the measure of the moisture present in the moist air or in the mixture of gases. Now how can it be defined?

$$q_v = \frac{\text{Density of water vapour}}{\text{Density of moist air}} = \frac{\rho_v}{\rho_a}$$

ρ_a is the density of the air. Generally, we will be calling moist air as air, simply air. So, ρ_v is the density of water vapor in the atmosphere and ρ_a is the density of moist air.

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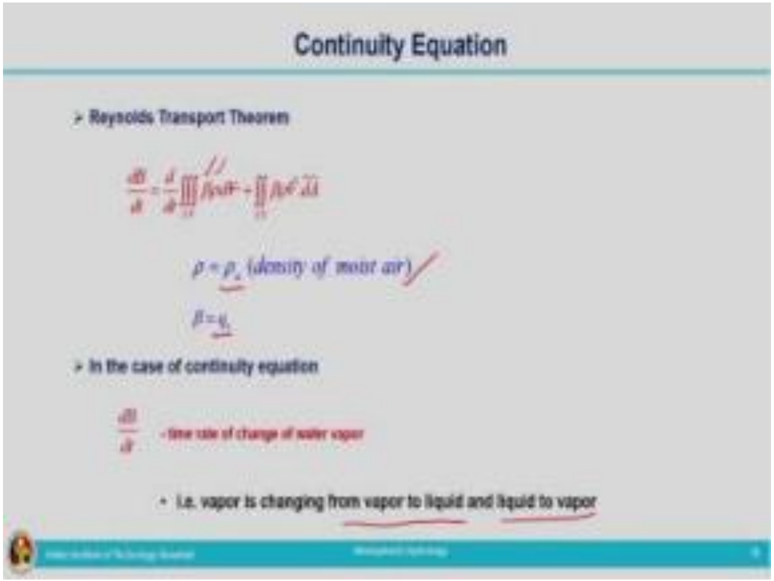

Now we are going to look at the Reynolds Transport Theorem, which is very much familiar to us.

$$\frac{dB}{dt} = \frac{d}{dt}\iiint_{CV} \beta\rho d\mathcal{V} + \iint_{CS} \beta\rho\vec{V}\cdot\overrightarrow{dA}$$

Now here we know β is the intensive property, ρ is the density of the flowing fluid, that is ρ is density of moist air. That is represented by ρ_a. β we have already seen it is nothing but our specific humidity q_v.

Now look at the left hand side of the Reynolds Transport Theorem, that is dB/dt is there. In earlier case what we were telling,

$$\frac{dB}{dt} = 0$$

There is no change in the mass taking place. But in this case you examine the problem, we are talking about the movement of moisture in the atmosphere. So, we know the process is taking place within the atmosphere is so dynamic, there are evaporation taking place, at the same time condensation also taking place. So, continuous transformation from one phase to another phases taking place in the atmosphere. So, in this case

$$dB/dt = \text{time rate of change of water vapor}$$

That is water vapor is changing from vapor to liquid and liquid to vapor. That is with respect to time there are changes taking place in the extensive property. What is the extensive property? Extensive property is the mass of the moisture. So, continuous transformation from vapor to liquid and liquid to vapor is taking place. So, $\frac{dB}{dt} \neq 0$

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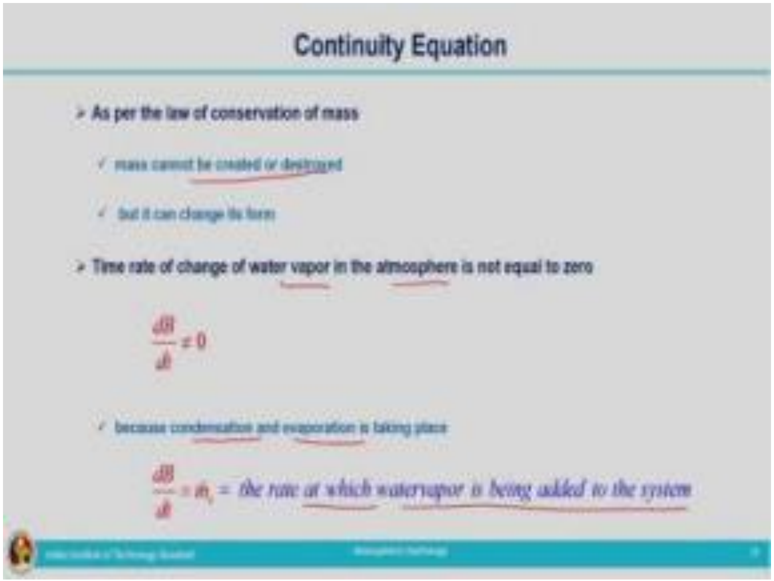

As per conservation of mass, mass cannot be created or destroyed but it can be transformed from one phase to another. It can change its form. So, time rate of change of water vapor in the atmosphere is not equal to zero. What is the reason behind it? We are having condensation and evaporation taking place in the atmosphere. So,

$$\frac{dB}{dt} = \dot{m}_v$$

That is time rate of change of extensive property, time rate of change of mass of water vapor present in the system which we are considering. That is left hand side of Reynolds Transport Theorem is something related to system. So, time rate of change of extensive property, here in this case it is the mass of the water vapor is equal to $\dot{m}_v$. It is not equal to zero because we are having continuous phase changes taking place.

$$\frac{dB}{dt} = \dot{m}_v = \text{the rate at which water vapor is being added to the system}$$

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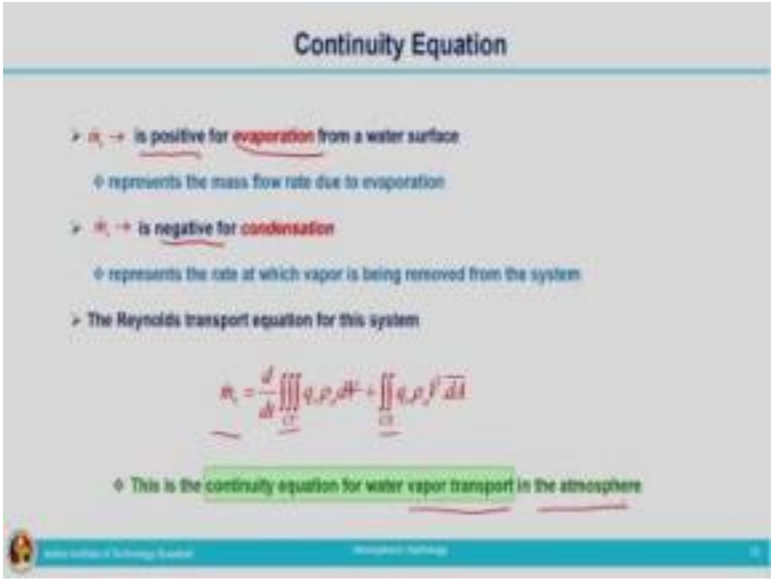

For example, in the case of evaporation, water vapor is added to the system. So, it will be positive and in the case of condensation, it will be negative, water vapor is converted to liquid form, that is, it has been removed from the atmosphere. So, it is converted from vapor to liquid. So, $\dot{m}_v$ will be considered as negative.

So, whenever these processes are coming, you are talking about water vapor added to the atmosphere then $\dot{m}_v$ or dB/dt will be positive. If water vapor is removed, there is a process called condensation is taking place means it will be negative, dB/dt will be negative. There is a reduction in the mass of the water vapor taking place in the atmosphere. Now in the Reynolds Transport Theorem, we are going to substitute

$$\dot{m}_v = \frac{d}{dt}\iiint_{CV} q_v \rho_a d\forall + \iint_{CS} q_v \rho_a \vec{V} \cdot \overrightarrow{dA}$$

So, this equation is very important because this is the well-known continuity equation for atmospheric water. Continuity equation for water vapor present in the atmosphere which represents the water vapor transport in the atmosphere.

So, this need to be thoroughly understood, it is not a very difficult expression. Once Reynolds Transport Theorem is clear to you, only thing is that we need to substitute for *B*, density of the flowing fluid and also β; extensive property, intensive property and density of flowing fluid.

Extensive property in the case of continuity equation, we are considering the mass of the fluid which we are considering. So, we have found that intensive property is not equal to 1 in this case, it is the ratio of the mass of the water vapor to the unit mass of the flowing fluid that has been designated as specific humidity.

So, β we got and density of flowing fluid is density of the moist air that is ρ_a. Then the third part is the left-hand side of Reynolds Transport Theorem *dB/db*. In this case, there are phase changes taking place, that is vapor to liquid and liquid to vapor continuous phase changes taking place, so we cannot take it as equal to zero, certain value should be substituted for that. Here we are assuming it to be $\dot{m}_v$,

$$\frac{dB}{dt} = \dot{m}_v$$

This $\dot{m}_v$ will be positive or negative depending on evaporation or condensation. So, we have derived the continuity equation for water vapor transport in the atmosphere. Here I am stopping today's lecture. The reference related to this particular matter which we have covered in this lecture are given here. Thank you all, have a nice day.