Basics of Mechanical Engineering-3

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

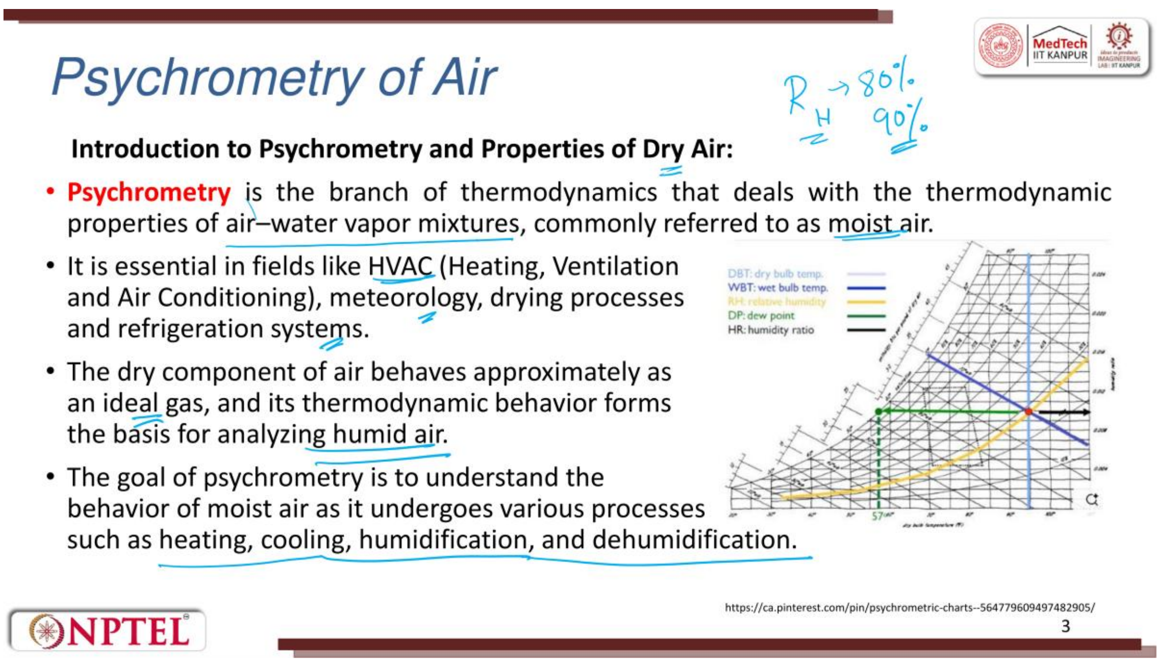
Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

Week 04

Lecture 19: Psychrometry of Air

Welcome to the next lecture of this course, Psychometry of Air. Introduction to psychometry and properties of dry air. Dry air has no water molecules in it.



Psychometry is the branch of thermodynamics that deals with thermodynamic properties such as air-water mixtures, commonly referred to as moist air. Air-water-vapor mixture.

For example, we talk in terms of relative humidity. Today, the relative humidity is very high—80%, 90%. In North India, June, July, August, or July and August, you will have very high relative humidity. That means there is a lot of water in the air. When there is a lot of water in the air, what happens is you will feel sticky because the water from your body will try to come out.

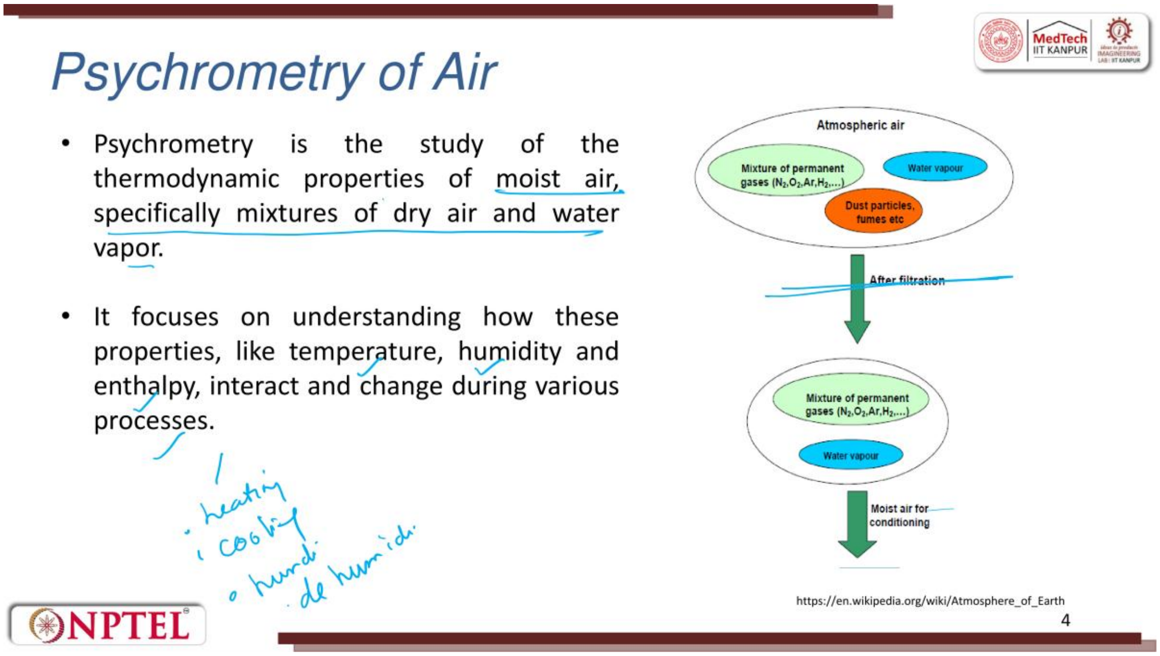
The external environment also has a lot of water. So the water cannot escape your body through the drying process. So it sticks there. When we talk about relative humidity, we always try to derive the property from the air-water-vapor mixture. This property of the air-water-vapor mixture is very important when used in the field of HVAC.

HVAC is used in all malls. Wherever you have air conditioning, we always call this system HVAC—heating, ventilation, and air conditioning. When you go to any mall, you see inside the mall there is always cool air, a cool breeze, or you find a comfortable temperature there. It is because of this HVAC system. So this property of psychrometry is very important in the field of HVAC. Then meteorology, drying processes, and refrigeration systems.

The dry component of air behaves approximately as an ideal gas. And its thermodynamic behavior forms the basis for the analysis of humid air. So there are two things I mentioned: air and water vapor. So when the air is completely dry, what happens is the rest left is water vapor. So when the air is dry, it is approximated as an ideal gas.

The goal of psychrometry is to understand the behavior of moist air as it undergoes various processes such as heating, cooling, humidification, and dehumidification. Humidification is when you try to pump moisture into the atmosphere. You increase it. When do we do this? In a dry atmosphere, or when you are trying to sleep on a cold winter day. What happens is you put a heater on and then you sleep. When you do so, the room air becomes very dry.

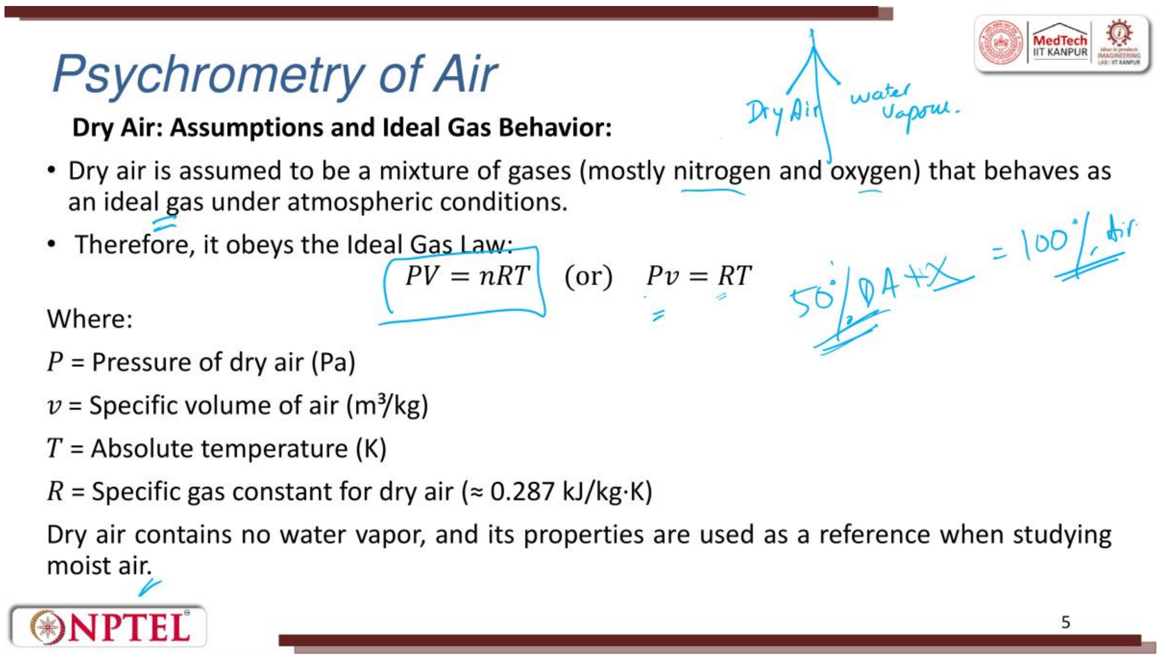
So that is why in a corner of the room, we try to fill some water and keep it. So the water adds water vapor into the atmosphere or into the room. So that is called humidification. Dehumidification is when I try to extract water vapor from the air. So that is dehumidification. So we use this in the air conditioning system. So the psychrometric chart is very important to understand moist air behavior.



So, psychrometrics is the study of the thermodynamic properties of moist air, specifically a mixture of dry air and water vapor. So, if you see here, atmospheric air is a mixture of permanent gases: nitrogen, oxygen, argon, hydrogen, etc., etc. You will also have water vapor inside, as well as dust particles and fumes.

These are all part of atmospheric air. So after you put a filter, what happens is the dust is removed, and only this enters the system. That is why, if you see in our air conditioners—whether it is a split AC or a window AC—the filter frequently requires cleaning because it removes dust particles. And the rest enters the system. So, what we do then is try to remove the moist air, or take the moist air for conditioning into the system.

So, it focuses on understanding how these properties like temperature, humidity, and enthalpy interact with the change of various processes. What are the processes? Heating, cooling, then you can say humidifying and dehumidifying. This is what happens inside the room. So now, friends, you see how important this psychrometry of air is.



Dry air, as I told you. So there are two components. One is dry air. Then another one is water vapor. Two components, right?

So now, if I can try to make one understand properly. So, whatever the balance is, it will be water vapor. So, for example, it can be like 50 percent of dry air plus dash is equal to 100 percent of water air. So now, if I know one property thoroughly, then I know the end value. I can just subtract it and get this x. So again and again, we are trying to emphasize: let me understand this dry air more. So dry air is assumed to be a mixture of gases, mostly nitrogen and oxygen, that behaves like an ideal gas under atmospheric conditions.

So it obeys the ideal gas what are the properties it is PV = nRT which is an ideal gas law or Pv = RT. So what we did is we converted this V divided by n, so it became small v, where P is the pressure, V is the specific volume, R is the specific gas constant, and T is the temperature. So, dry air contains no water vapor, and its properties are used as a reference when studying moisture. Just for a simple calculation, we understand more and more about dry air. Dry air = ideal gas. Ideal gas = PV = nRT.

Psychrometry of Air

Specific Heat of Dry Air:

- The specific heat capacity at constant pressure (cp) and constant volume (cv) for dry air are:

$$c_p \approx 1.005\ kJ/kgK, cv \approx 0.718\ kJ/kgK$$

- This gives a ratio of specific heats:

$$\gamma = \frac{c_p}{c_v} \approx 1.4$$

- These values are essential for calculating energy changes when dry air is heated or compressed.

Now, specific heat of dry air. The specific heat capacity at constant pressure (Cp) and constant volume (Cv) for dry air can be found to be this. So, Cp takes a value of 1.005 kilojoule per kgK, and Cv takes kilojoule per kg·K—specific pressure and specific volume. So, when we try to take a ratio between Cp and Cv, we always get a gamma value of 1.4.

That is why, in adiabatic processes, we always take gamma as 1.4, right? So, in this ideal gas, this is what it is. Friends, you do not have to memorize these units; whatever the magnitude, you do not have to worry about. In the examination, I will give you what is Cp, what is Cv. These values are essential for calculating energy change when dry air is heated or compressed.

Psychrometry of Air

Enthalpy and Internal Energy of Dry Air:

- For ideal gases, the specific internal energy and enthalpy of dry air depend only on temperature:

$$u = cvT \quad , h = c_p T$$

- Changes in enthalpy and internal energy:

$$\Delta u = cv(T_2 - T_1), \Delta h = cp(T_2 - T_1)$$

- These formulas are crucial in heating or cooling calculations.

Enthalpy and internal energy of dry air. For an ideal gas, I know the specific internal energy and enthalpy of dry air, which depends on temperature. So u equals constant volume temperature, and h equals constant pressure temperature. So the changes in enthalpy and internal energy: enthalpy is h, internal energy is u. Changes in internal energy—du; change in enthalpy—dh. This can be figured out by this formula: cv is T2 - T1 or cp is T2 - T1. So these formulas are crucial in heating or cooling calculations.

Psychrometry of Air

Density of Dry Air:

Using the ideal gas equation:

$$\rho = PRT$$

Where:

ρ= Density of dry air (kg/m³)

At standard conditions (1 atm, 25°C):

$$P = 101.325\ kPa\ , T = 298\ K$$

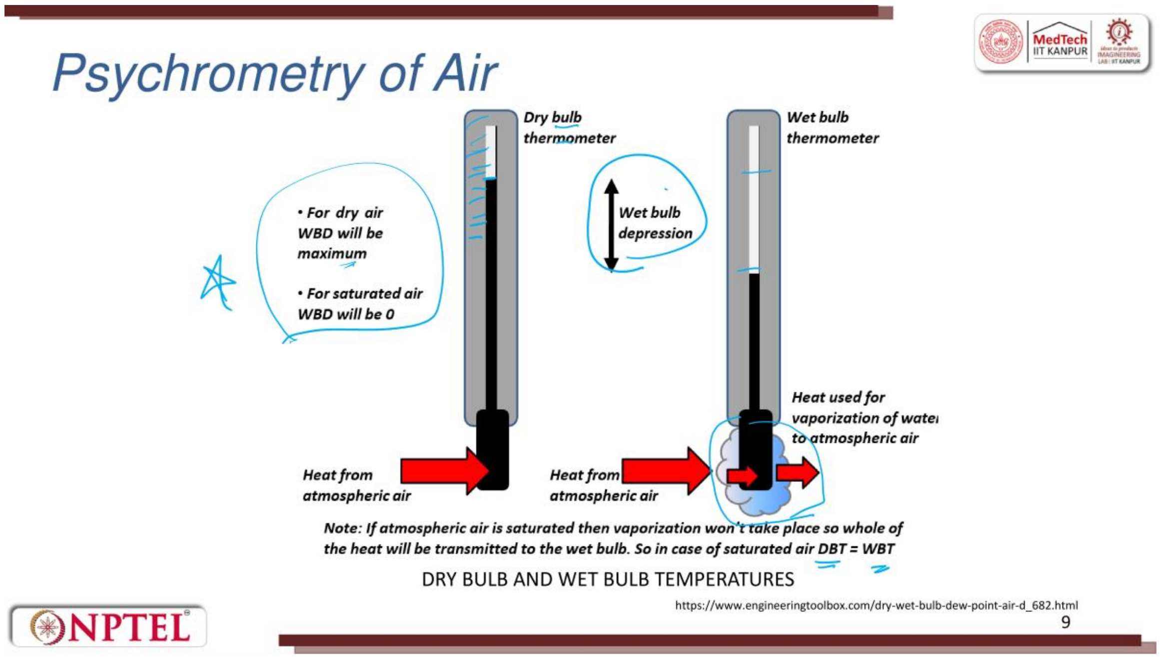
$\Rightarrow \rho = 101.3250.287 \times 298 \approx 1.18\ \ kg/m^3$

$\rho = m/v$.

The density of air is the ρ component. What is density? Mass by volume, right? Using the ideal gas equation, $\rho = PRT$, where rho is the density of air. At standard condition (1 atmosphere), the ρ= Density of dry air (kg/m³). This is what I wrote: mass per volume. So till now, what did we see, friends?

I will just rebrush. We saw dry air in a psychrometric chart because, in a psychrometric chart, you will have two things. One is air; the other one is vapor. So we are trying to understand air. For dry air, we try to convert this dry air into an ideal gas.

We saw the ideal gas equation, then the specific heat of dry air, gamma we defined, and then we saw the change in enthalpy and internal energy for dry air. Finally, we also saw the density.



Now, when we try to see dry bulb and wet bulb experiments, these are the experiments, or dry bulb and wet bulb temperatures we use. So, a dry bulb thermometer. So, there are two thermometers.

One is called a dry bulb. The other one is called a wet bulb thermometer. So, here, what we do is we put a normal thermometer, right? And it is called a dry bulb thermometer. We pass hot air or air from the heat in the atmosphere.

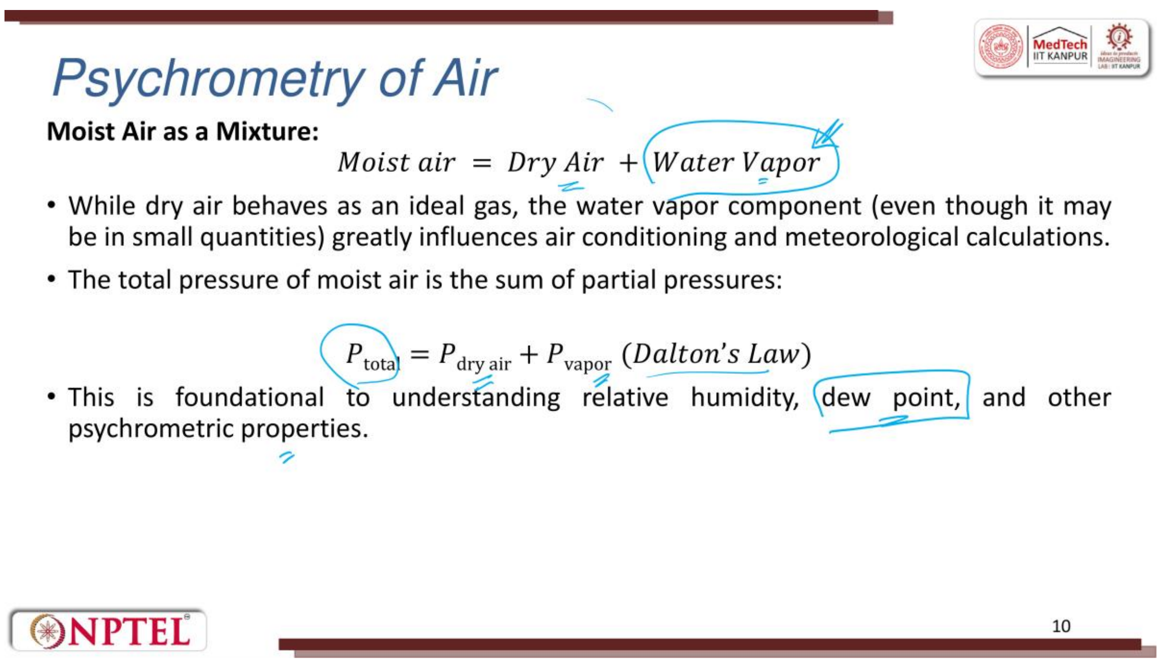
For example, take a normal thermometer, put it in your mouth; if you have a raised temperature, there is mercury there, and this mercury keeps rising. And here you have graduations; you can try to figure out what the value is. So, this is for dry. Right, now let us go for wet. The only difference between dry and wet is, here also you blow heat here, but in wet, what we do is we cover it with a wet cloth.

So, when we cover it up with a wet cloth, the heat that falls on it is used to evaporate the water content in the cloth or whatever you cover it with. So, the heat used for vaporization of water into atmospheric air is done here. So, here what we do is, this is the dry bulb temperature. So, the dry bulb temperature comes up to here. The wet bulb temperature comes up to here.

So, this difference is called the wet bulb depression: dry bulb. Wet bulb. Dry bulb thermometer. Wet bulb thermometer. The difference is, You try to cover it up with a wet cloth. Note. If atmospheric air is saturated. Then vaporization wouldn't take place. Because you try to pass heat.

Here it is a wet cloth. Now, it is there, in the atmosphere already enough of water is there. Then the vaporization cannot happen. That's what we say. If atmospheric air is saturated.

Then vaporization wouldn't take place, so whole of the heat will be transferred to the wet bulb. So in the case of saturated air, the dry bulb temperature is equal to wet bulb temperature. For dry air, the wet bulb will be maximum. For saturated air, the wet bulb will be 0. So this is important. For dry air, wet bulb will be maximum. For saturated air, the wet bulb will be zero.



So the moist air as a mixture. Moist air is nothing but dry air plus water vapour. While dry air behaves like an ideal gas, the water vapour content greatly influences the air conditioning and the meteorological calculations.

The water vapour. The total pressure of the moist air is the sum of total is nothing but a sum of dry plus vapour. Partial pressure which is according to Dalton's law we try to get it. $Ptotal = Pdry\ air + Pvapor$. So this is the foundational to understand relative humidity dew point and other psychometric properties. I have now introduced a new terminology called as dew point relative humidity is what we get see every day which is getting reported.

Psychrometry of Air

RH 60 T=30°C T=40°C T=48°C

- In psychrometry, **humidity** describes the amount of water vapor present in air.
- Since air can hold varying amounts of moisture depending on temperature and pressure, several terms and definitions are used to quantify this vapor content accurately.
- These parameters are essential for understanding human comfort, designing HVAC systems, drying materials, and conducting meteorological studies.

- **The key humidity terms include absolute humidity, specific humidity, relative humidity and humidity ratio—each describing the moisture content from a different perspective.**
- **Let us understand about these and more of such terms ahead:**

T=25°C RH→90
T=30°C RH→90

Psychrometry of Air

?

https://www.britannica.com/science/fog

In psychrometry, humidity describes the amount of water vapor present in air. Since air can hold varying amount of moisture, depending on the temperature and pressure, several terms and definitions are used to quantify the vapor content accurately. So, moisture depending on the temperature. So, this is very important in air holding. So, what does it mean is you can have RH 60 (relative humidity 60) for a temperature of 30 degree

Celsius, for a temperature of 40 degree Celsius, or for a temperature of 48 degree Celsius, no problem, relative humidity constant.

Or you can say as and when the temperature goes high, the relative humidity goes low. Or you can try to have the temperature is 25 degrees with RH as 90. Then you can have T is equal to 30 degree where RH is still 90 you can have. Possible. So, that is what they say.

Since air can hold varying amounts of mixture, so 90, 60. Depending on the temperature and this temperature, in turn, affects pressure. Several terms and definitions are used to quantify this vapor content accurately. So these parameters are essential for understanding human comfort, designing HVAC systems, drying materials, and conducting meteorological studies. Drying material is, for example, solar drying you do. Room temperature drying you do.

When you try to take a cloth, you wash it, you put it in the sun, you hang it on a string, it gets dried within an hour, right? The temperature is very high, the air does not have any water content, vaporization is quick. Try to do it on a rainy day when the temperature is still 30 degrees Celsius. You wash and put the same cloth on a string. You can see that it takes a long time to dry because there is water content in the atmosphere.

Second, let us look at drying vegetables. See, when my grandmother was there, she used to make papad, and this papad used to be made at room temperature, then she would go to the terrace and leave it for drying. And this process would happen only on a sunny day or in summer. Or you take a potato, you slice it, then you bake it, and then you make chips, you dry them in the air. So now the question is, how will it dry? What will be the time taken for drying?

So, this looks to be a little crude. Now, let us move towards the fast-moving segment industry. You buy potato chips. Now, the chips, whatever you buy, cannot get burnt more. They cannot be burnt less.

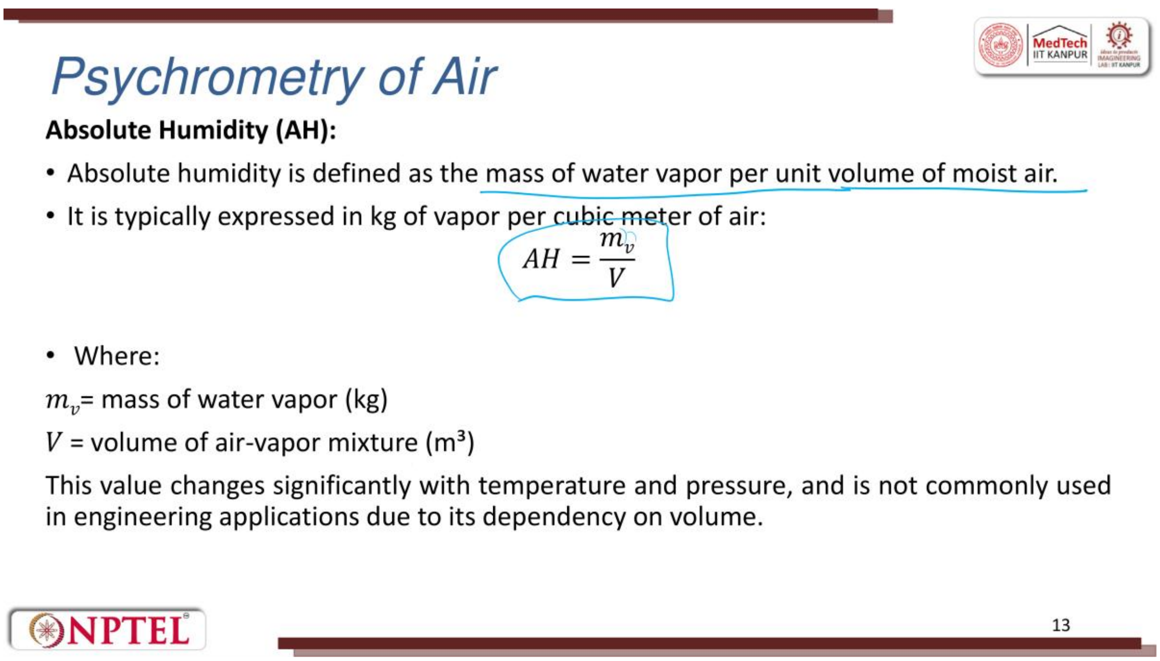
And the chip has to warp faster. And it has to make a shape. It is not expected to be flat. And then, on top of a chip, you have serrations. Now you see, it is the surface area increase.

Now you put it in oil where the temperature is high. The chips become crispy and try to take a shape. So now there are industries that work on drying material. How do I play with pressure, temperature, and time to get the drying done very fast or the cooking done very fast? So this is very, very important.

Domino's Pizza uses this. If you go to Kentucky Fried Chicken, they use this. They try to understand the psychometry of air. They understand this. That's why what they do is their machine is always made in such a way that it does not get disturbed because of environmental factors.

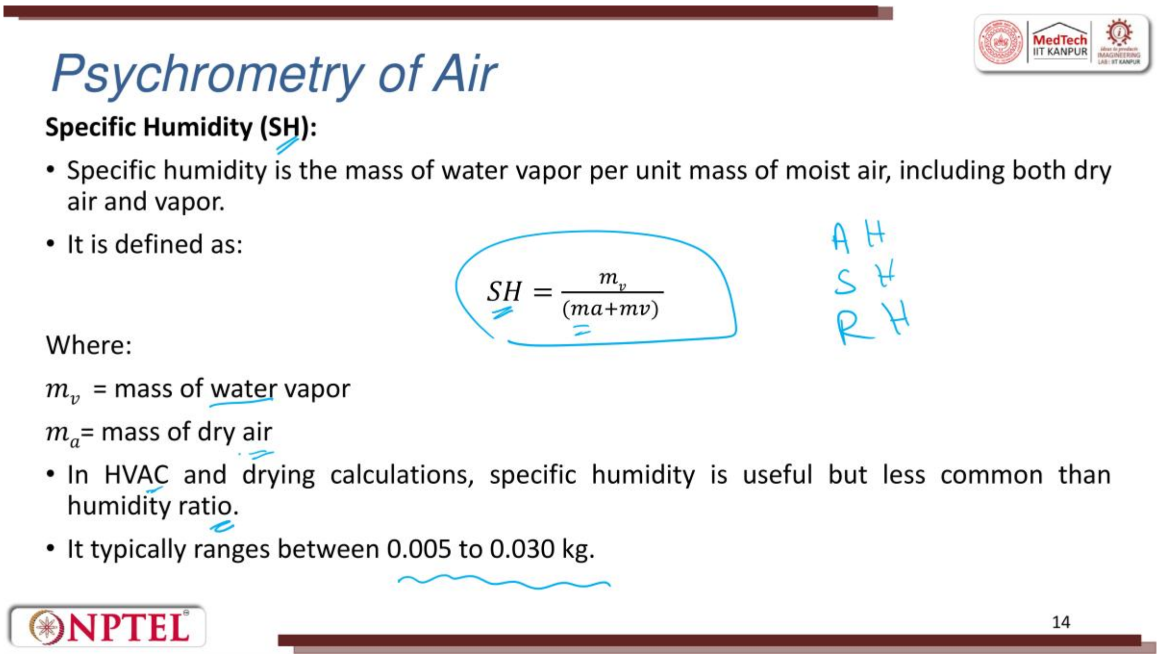
The environmental factors are RH and T, right? So, it is very important. The key humidity terms include absolute humidity, specific humidity, relative humidity, and humidity ratio. Each describes the moisture content from a different perspective. Let us first understand more about these. Fog occurs when air is saturated.

I leave this question to you. Why? Think about it and try to find out an answer. This is a question for you. Think and then solve. This answer is in the previous slides that we discussed.



Absolute humidity, which is called AH. Absolute humidity is defined as the mass of water vapor per unit volume of moist air. It is typically expressed in kg of vapor per cubic meter of air. This is the formula.

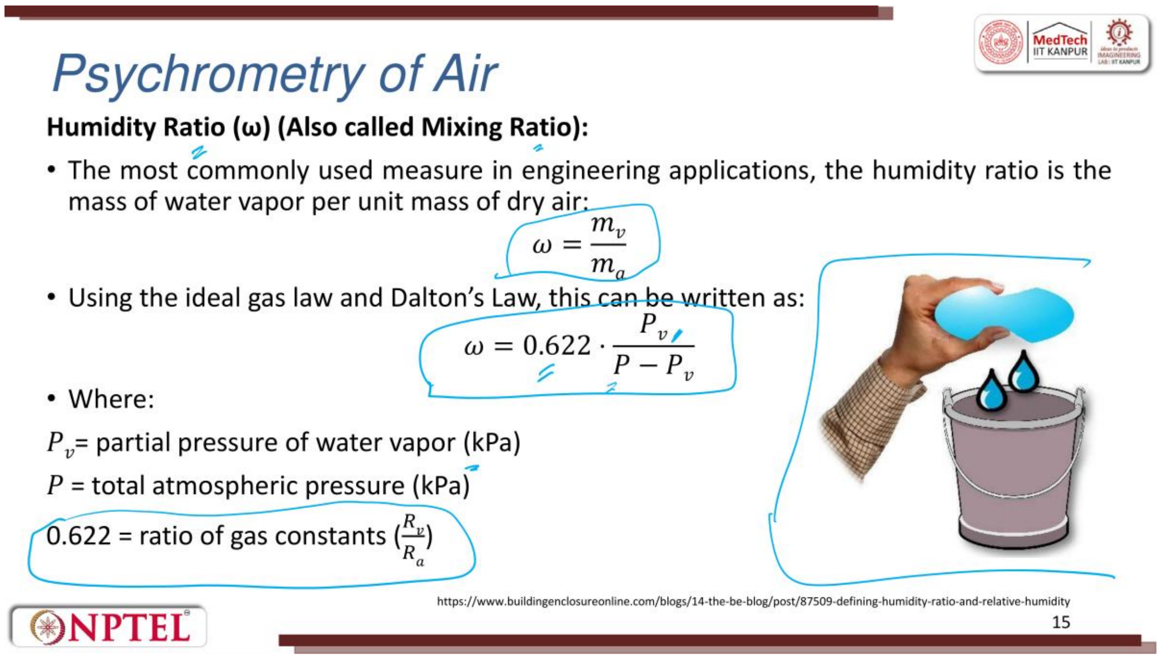
It is typically expressed in $AH = \frac{mv}{V}$, where mv is the mass of water vapor, and V is the volume of the air-vapor mixture. So, we try to calculate AH. Absolute humidity is defined as the mass of water vapor per unit volume of air.



Specific humidity—there are several terminologies: AH, SH, RH. SH is specific humidity. Specific humidity is the mass of water vapor per unit mass of moist air, which includes both dry air and vapor.

So, it can be expressed as, $SH = \frac{mv}{(ma+mv)}$.

mv is the mass of water vapor, ma is the mass of dry air, and ma plus Mv is the mass of the moist air. So, this is called specific humidity. In HVAC, in ACs, and in dry calculations, specific humidity is useful but less common than humidity ratio, but it is less common than this. Typically, SH ranges from 0.005 to 0.030 kg.



Next, the humidity ratio. The humidity ratio is also called the mixing ratio. The most commonly used measure in engineering applications is the humidity ratio, which is the mass of water vapor per unit mass of dry air, known as the mixing ratio. Using the ideal gas law and Dalton's law, this can be written in this form, where the humidity ratio is $\omega = 0.622 \cdot \frac{Pv}{P-Pv}$.

What is Pv? Pv is the partial pressure of water vapor, and P is the total atmospheric pressure. The constant 0.622 is the ratio of the gas constant, which we derive from the ideal gas and Dalton's equation. So, the humidity ratio or mixing ratio is a very important parameter. Friends, see this example here.

Now, you will try to understand what this is and then see its relevance to the mixing ratio. There is a sponge; somebody is pressing it, and water drops fall.

Psychrometry of Air

Relative Humidity (ϕ)

- Relative humidity expresses the degree of saturation of air with moisture and is the most commonly reported humidity metric in weather forecasts and indoor air quality assessments.
- It is defined as:

$$\phi = \frac{P_v}{P_{sat(T)}} \times 100 \quad \%$$

RH

- Where:

P_v = actual partial pressure of water vapor

$P_{sat(T)}$ = saturation vapor pressure at air temperature T

- Relative humidity ranges from 0% (completely dry air) to 100% (saturated air).
- High relative humidity means air is close to saturation and cannot absorb much more moisture, which affects comfort and drying rates.

NPTEL

Lastly, humidity is the relative humidity. Relative humidity is expressed as the degree of saturation of air with moisture and is the most commonly reported humidity metric in weather forecasts and indoor air quality measurements. RH is relative humidity.

So, we saw what absolute humidity is, we saw specific humidity, then we saw the humidity ratio or mixing ratio, and lastly, relative humidity. This is most commonly used because it describes the degree of saturation of air. So, relative humidity

$$\phi = \frac{Pv}{Psat(T)} \times 100 \quad \%$$

PV is the partial pressure, which we have already written here. PV is the partial pressure of water vapor. Here also, it is the same. PV is the actual partial pressure of water vapor. P saturation is the saturation vapor pressure at a temperature T. Then RH can range from 0 to 100%. Extremely dry air on a very hot summer or in desert region. Hot, where there is no possibility of vapor, you can have it as 0 degrees.

But the other way around, 100 degrees is June, July, in August. So that's why we always say in North India, July, August, because what happens, the rain is also there, the temperature is there, the air is stagnant, air cannot move. So in North India, what happened? You have Himalayas, which is stopping the air movement. So the air gets completely hit and then saturated.

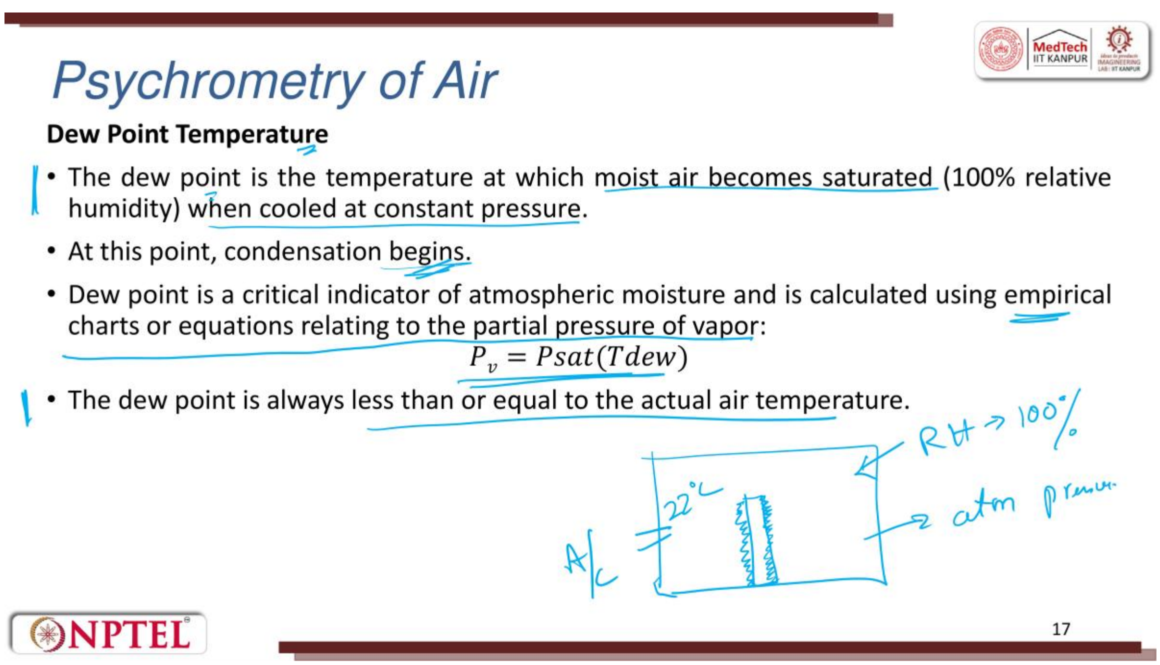
So, Delhi, Kanpur, you go down to Bihar, then you go down to Chandigarh, Punjab. So, everywhere, what happens? There is a stop of air. So, there is no air movement. So, whatever the air was, it is still existing air.

So, that has a lot of water content because it is raining, and the river also evaporates because of the temperature, which also gets into the atmosphere. So, the RH can go up to 100 percent. So, that is called completely saturated air. You can have dry air, or you can have saturated air. Now, what happens is, when we try to plan an HVAC system or an AC, we try to see the relative humidity and plan it accordingly.

So, friends, a question comes to you. Why are we not planning to have RH also set in the AC? AC, what do you do? You always set the temperature. 18 degrees, 24 degrees, 26 degrees.

You set the temperature and then you sleep. So, depending on the RH, why don't we also change the RH setting of the system and then you start sleeping? So, then you will have better control, won't you? But there is no option. Please think about it—why is there no option?

High relative humidity means the air is close to saturation and cannot absorb much more moisture, which affects comfort and drying rate.



So, the next definition in this is dew point temperature. Dew point temperature is the temperature at which moist air becomes saturated. When cooled at constant pressure. Dew point.

Dew point is the temperature at which moist air becomes 100% saturated. When cooled at constant pressure. At this point, condensation begins. So, I will give you a situation where exactly this happens. You have a closed room.

Right. In a closed room, the RH is 100 percent. This room is at atmospheric pressure. Now, in this room, if you try to use an AC that maintains a temperature of 22 degrees Celsius. And if there is a glass plate or a glass window, you can see water precipitation.

So, when precipitation happens, it is nothing but condensation beginning. Now, that is what the dew point is. The dew point is the temperature at which moist air becomes saturated when cooled at constant pressure. The dew point is a critical indicator of atmospheric moisture and is calculated using empirical charts and equations relating to partial pressure. $Pv = Psat(Tdew)$.

The dew point is always less than or equal to the actual air temperature. Keep this in mind—a very important point. The dew point is always less than or equal to the actual air temperature.

Psychrometry of Air

Degree of saturation (μ):

- The degree of saturation, denoted by the Greek letter μ, quantifies how close the air-vapor mixture is to being fully saturated with water vapor at a given temperature and pressure.
- It is defined as the ratio of the actual humidity ratio W—which is the mass of water vapor per unit mass of dry air—to the humidity ratio at saturation Ws , which represents the maximum amount of water vapor the air can hold under the same temperature and pressure conditions.
- This ratio is dimensionless and always less than or equal to one, with a value of one indicating a fully saturated mixture.

NPTEL

Psychrometry of Air

- The equation shown expresses this relationship mathematically:

$$\mu = \frac{W}{W_s} |_{t,P} = \frac{p_v}{p_s} [\frac{1-\frac{p_s}{p_t}}{1-\frac{p_v}{p_t}}] = \phi [\frac{1-\frac{p_s}{p_t}}{1-\frac{p_v}{p_t}}]$$

- Here, pv is the partial pressure of water vapor in the air, ps is the saturation pressure of water vapor at the given temperature, and pt is the total pressure of the air-vapor mixture.
- The symbol ϕdenotes the relative humidity, which is related but not identical to the degree of saturation.

NPTEL

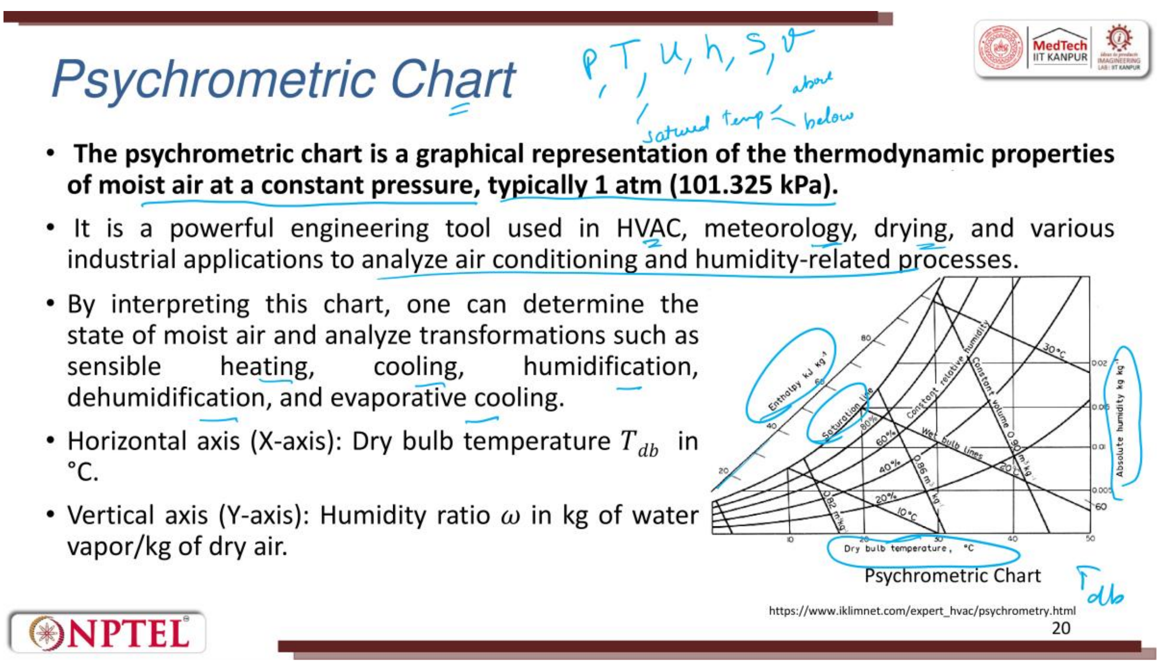
The next discussion will be on the degree of saturation. So we saw the degree of saturation here also—the degree of saturation of air in RH.

So, the degree of saturation is defined by mu. Degree of saturation, which is denoted by the Greek letter mu, quantifies how close the air-vapor mixture is to being fully saturated with water vapor at a given temperature and pressure. How close the air-vapor mixture is to being fully saturated with water vapor at a given temperature and pressure. It is defined as the ratio of the actual humidity ratio W, which is the mass of water vapor per unit mass of dry air, to the humidity ratio at saturation Ws. So, W is defined as the mass of water vapor per unit mass of dry air to the humidity ratio at saturation Ws, which represents the maximum amount of water vapor the air can hold under the same temperature and pressure conditions.

This is a unitless parameter; it is a ratio. So, it is a unitless parameter and always takes a value less than or equal to 1, with a value of 1 indicating it is fully saturated; it takes a value between 0 to 1. So, it says less than or equal to 1, right? A value of 1 indicates it is fully saturated. So, the equation for this can be mathematically expressed in this form. This is extrapolated from what we have seen previously.

$$\mu = \frac{W}{W_s} |_{t,P} = \frac{pv}{ps} [\frac{1-\frac{ps}{pt}}{1-\frac{pv}{pt}}] = \phi\ [\frac{1-\frac{ps}{pt}}{1-\frac{pv}{pt}}]$$

So, here pv is the partial pressure of water vapor, ps is the saturation pressure of water vapor at a given temperature, and pt is the total pressure of the air-vapor mixture.

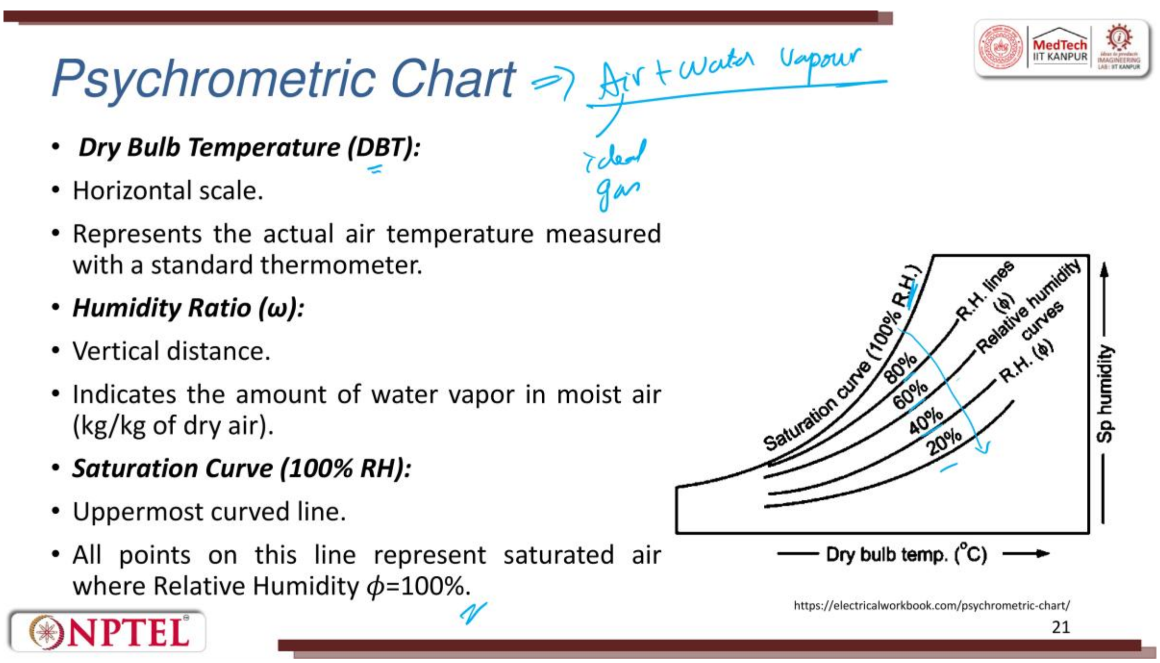


Now, let us try to look into the Psychrometric Chart. The psychrometric chart is a graphical representation of thermodynamic properties of moist air at constant pressure, typically at 1 atmosphere. So, you have this chart.

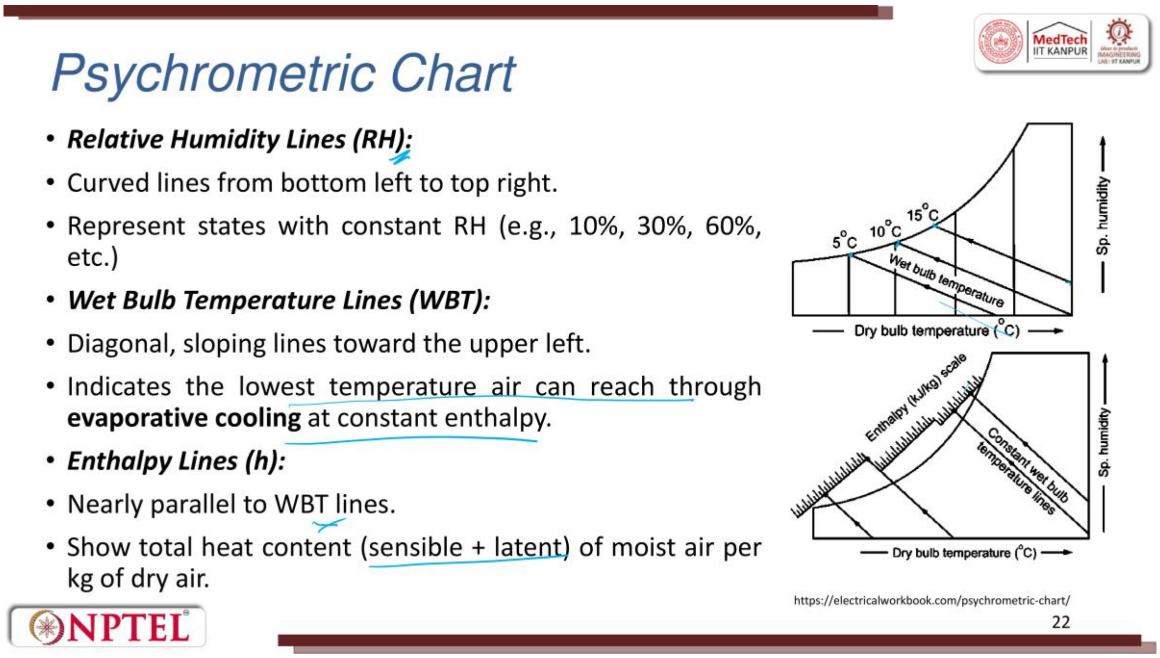
So, here you have enthalpy. So, you have absolute humidity here, and then you have the bulb temperature given here. So, these are two things: the saturation line. So, then you have this enthalpy bulb temperature, which is normal room temperature, and absolute humidity, which is this. It is a powerful engineering tool used in HVAC, meteorology, drying, and various industrial applications to analyze air conditioning and humidity-related processes.

By interpreting this chart, one can determine the state of moist air and analyze transformations such as sensible heating, cooling, humidification, dehumidification, and evaporative cooling. So, that is why this chart is very, very important. This chart is very simple. It talks about known parameters P and T, which are measurable. And then it tries to talk about internal energy, enthalpy, and entropy.

To some extent, you can try to get it. And then what happens is it has a specific volume. This is all there. Right. So now you have what the saturated temperature is. You have above and below. So, that is what is put here. So, once you know this, then you can try to plan a system where you can enjoy staying inside a room.



So, the horizontal axis is dry bulb temperature (DBT), dry bulb temperature in Celsius. The vertical axis is humidity ratio (omega) in kg of water vapor to this. So, then you have dry bulb—this is dry bulb temperature on the horizontal axis. On the vertical axis, you will have humidity, and then you will have saturation curves. So, this saturation curve talks about 100 percent, 80 percent, 60, 40, 20.

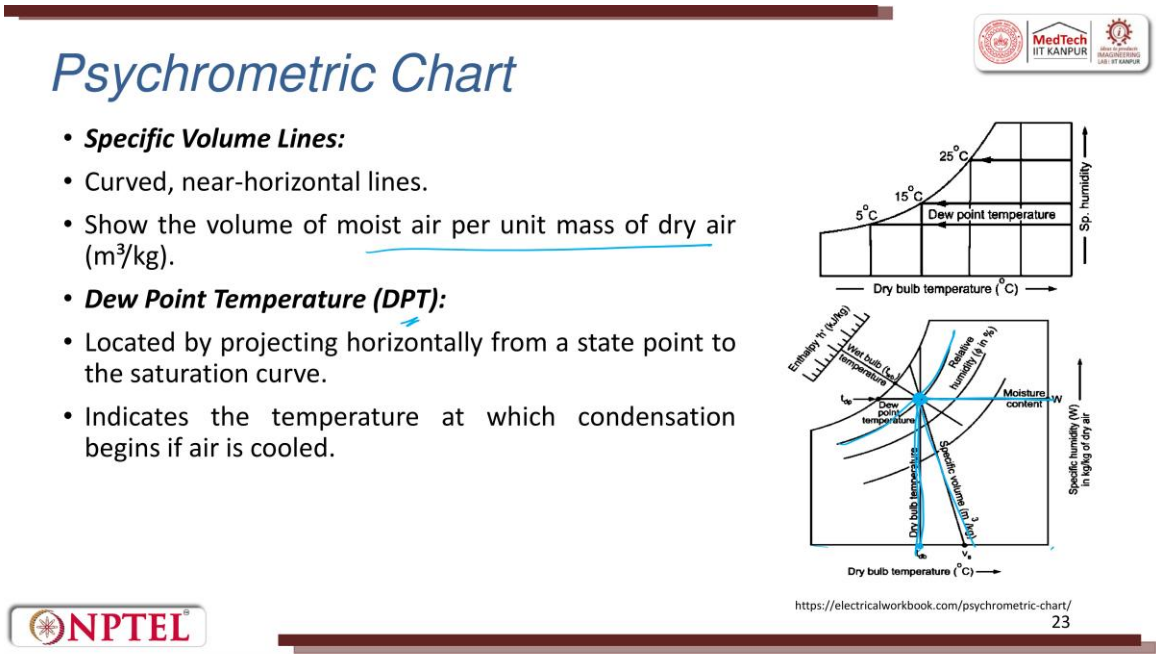


And you can try to find out the relative humidity line (phi), the relative humidity curve, and then you have the relative humidity line you can try to have. These are saturated curves: 100, 60, 40, 20. You can have x and y axes given. So, the horizontal axis is dry, and the vertical axis is specific humidity. So, it represents the actual air temperature measured with a standard thermometer, which is there. Dry bulb, you remember. Humidity ratio indicates the amount of water vapor in moist air. Then the saturation curve up to 100% is there.

All points on the line represents the saturated air under relative humidity phi equal to 100. So, the RH relative humidity line RH the curved lines from bottom left to top right. So, here we try to have 10 percent, 30 percent, 60 percent. So, it is constant relative. So, you can try to have this right.

The next is wet bulb temperature line (WBT) which is diagonal slope towards the left indicates the lowest temperature air can reach through evaporative cooling at a constant enthalpy. Then you have enthalpy lines, which is nearly parallel to the WBT, wet bulb temperature. It shows the total heat content sensible and latent of moist air per unit kg of dry air. So, it is given in this. So, you can see here enthalpy is given here.

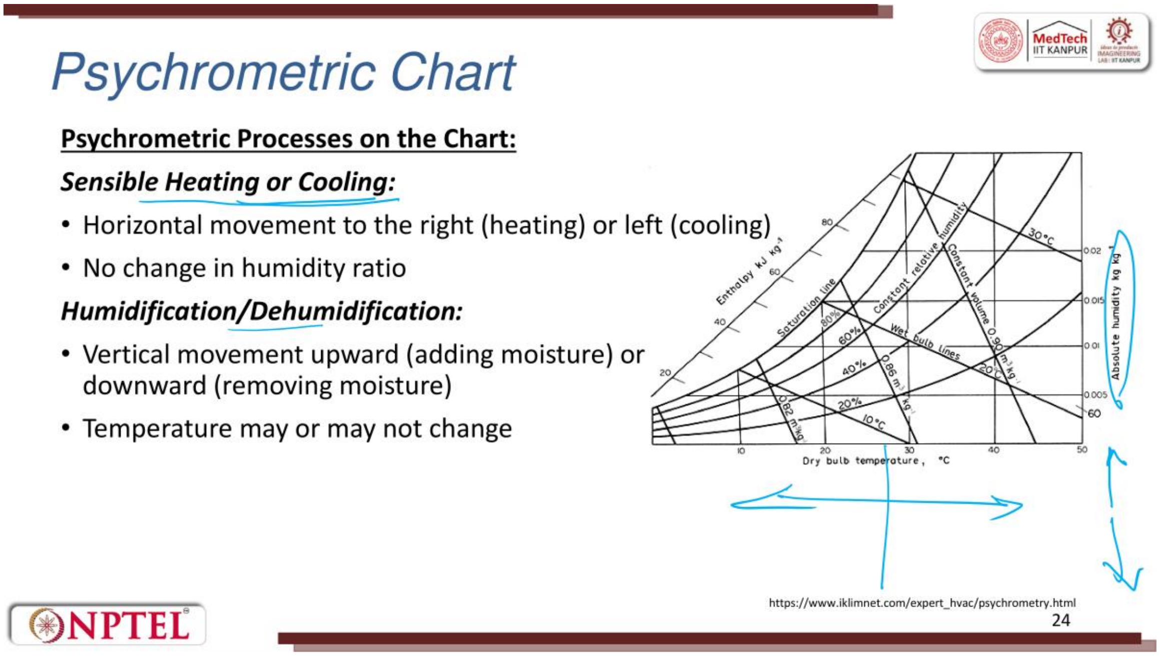
Constant wet bulb temperature lines are here. These are wet bulb lines. So, specific humidity; you try to draw with 15 degrees, 10 degrees Celsius, 5 degrees Celsius and this is the dry bulb temperature.



So, the specific volume lines can be drawn. These lines are nearly horizontal, where you can see the dew point temperature: 5 degrees, 10 degrees, 15 degrees, and 25 degrees, showing the volume of moist air per unit mass of dry air. Try to calculate this.

Then, the dew point temperature is located by projecting horizontally from the state point to the saturation curve. So, this is the saturation curve. So, what you do is, from the state point, you project lines, right? So, it indicates the temperature at which condensation begins if the air is cooled. So, this is the specific volume you try to heat here.

The bulb temperature you try to heat here, then the moisture you try to heat here. So, now what you get is the dew point, okay? So, these are some of the outputs we try to get from the psychrometric chart: dry bulb temperature, humidity ratio, and saturation curves. So, the dry bulb temperature is given, the humidity ratio is given, and then you have the saturation curves. Then, from here, what we do is try to calculate the relative humidity lines, then the wet bulb temperature lines, then the enthalpy lines, which are very important. Then, we try to calculate the specific volume line, and finally, the dew point temperature.



For psychrometric processes on a chart, it is sensible heating and cooling. You can try to draw a horizontal movement to the right or to the left. Right is heating; left is cooling. So, you can try to have this, and no change in the humidity ratio will happen.

So, we will try to find out what sensible heating or cooling is. So, the ratio humidification or dew humidification in the vertical line movement upward adds moisture; downward removes moisture. So, you can try to have humidification and dehumidification. The temperature makes no change. So, this is humidity.

If you go up, if you go low, if you go this side: heating, cooling. So, that's also derived from this chart. See now, it is a combination you can do. If it is heating, you go this side; if it is cooling, you go this side.

Psychrometric Chart

Cooling with Dehumidification:

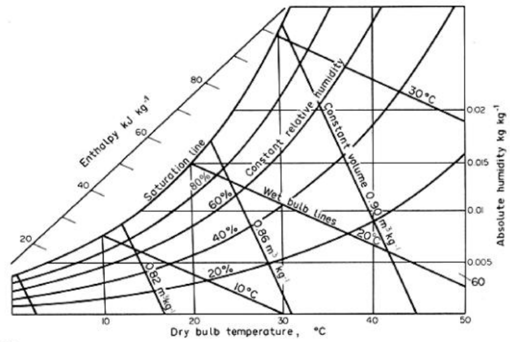
- Diagonal movement down to the left
- Temperature and humidity both decrease.
- Often passes through saturation line (condensation begins)

Heating with Humidification:

- Diagonal movement up to the right
- Both temperature and humidity increase

Evaporative Cooling (Adiabatic Saturation):

- Movement along a constant WBT or enthalpy line
- Temperature decreases, humidity increases, enthalpy remains constant



https://www.iklimnet.com/expert_hvac/psychrometry.html

Now, you want to draw with only heating or with cooling, so that is what is told here. So, cooling with dehumidification is a diagonal movement down to the left.

The temperature and the humidity both decrease, often passing through a saturation line, which is where condensation begins. Heating with humidity, this is cooling with dew humidification. Heating with humidification moves diagonally to the right; both temperature and humidity increase. So, this creates evaporative cooling, which is otherwise called adiabatic saturation. Movement along the constant wet bulb temperature or enthalpy lines.

The temperature decreases, humidity increases, and enthalpy remains constant. So, with this, you can get all these data because we are trying. This is nothing but an air-water-vapor mixture. Now, I try to move this as an ideal gas; now I have this. So, with this, what do I do? I try to figure out every relationship. So, for that, what do I do? I go for this psychrometric chart.

So, this I will try to figure out. So, cooling with humidity, cooling with dehumidification, heating with humidity, and evaporative cooling.

Psychrometric Processes

- Psychrometric processes describe how moist air is conditioned or altered for specific applications like air conditioning, drying, or ventilation.
- Each process involves a change in one or more thermodynamic properties such as dry bulb temperature, humidity ratio, enthalpy, and relative humidity.
- These processes are conveniently visualized and analyzed using the psychrometric chart, which helps determine energy requirements and equipment design parameters.
- We explore the five major psychrometric processes: sensible heating, sensible cooling, humidification, dehumidification, and adiabatic saturation (evaporative cooling), each with its path on the chart and governing equations.

So, what are Psychrometric Processes? Psychrometric processes describe how moist air is conditioned. Moist air is conditioned or altered for specific applications like air conditioning, drying, or ventilation, right? In various processes we do.

Each process involves a change in one or more thermodynamic properties such as dry bulb temperature, humidity ratio, enthalpy, and relative humidity. Every process has these: dry bulb temperature, humidity ratio, enthalpy, and relative humidity. These processes are conveniently visualized and analyzed using psychrometric charts, which help determine energy requirements and equipment design we always try to do.

Psychrometric Processes

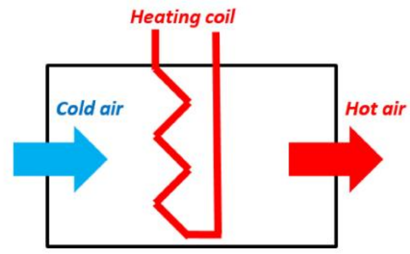
Sensible Heating:

- In sensible heating, the dry bulb temperature of air increases while the humidity ratio remains constant (no moisture is added or removed).
- This process is depicted as a horizontal line moving right on the psychrometric chart.
- Assumptions:

➢No moisture exchange

➢Pressure constant

➢Only sensible heat is added



SENSIBLE HEATING

Psychrometric Processes

$$Q_{sensible} = m_a \cdot c_{pa} \cdot (T2 - T1)$$

Where:

m_a : mass flow rate of dry air (kg/s)

c_{pa} : specific heat of dry air ≈ 1.005 kJ/kg·K

T_1,T_2: initial and final dry bulb temperatures

Applications: Space heating, heating ducts, pre-heaters in HVAC systems

We explore five major psychrometric processes: sensible heating, sensible cooling, humidification, dehumidification, and adiabatic saturation, which is nothing but evaporative cooling. With the path on the chart and the governing equations, we can try to design the process.

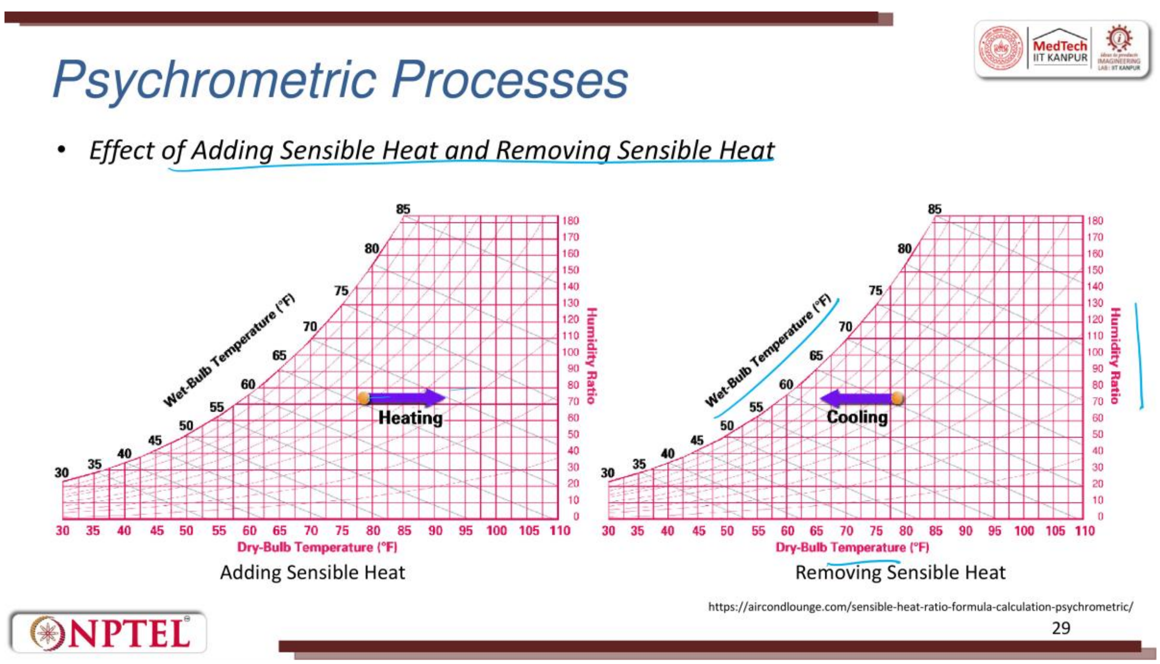
What is sensible heating, which we have seen, right? Sensible heating—we always talk about sensible heating. In sensible heating, the dry bulb temperature of the air increases while the humidity ratio remains constant. No moisture is added or removed. That is sensible heating.

The dry bulb temperature of air increases with the humidity ratio remaining constant. This process is depicted as a horizontal line moving right on the psychrometric chart. So, the assumption is no moisture exchange happens: cold air, heat coil, you get hot air. Pressure is constant. Only sensible heating is added, which is a heater used in winter days. In sensible heating, the dry bulb temperature of air increases while the humidity ratio remains constant on a cold winter day.

So, which is derived by this equation:

$$Q\, sensible = m\, a \cdot c\, pa \cdot (T\, 2 - T\, 1)$$

Mass flow rate is the air—cold air—which is coming up, and CPA is the specific heat of dry air. The temperature difference is used in space heating, heating ducts, and preheating in HVAC.



So, the effect of adding sensible heating and removing sensible heating. So, this is heating; this is cooling. So, you have wet bulb temperature, dry bulb temperature, relative humidity, and now you know all the extractions—whatever you want, you can do.

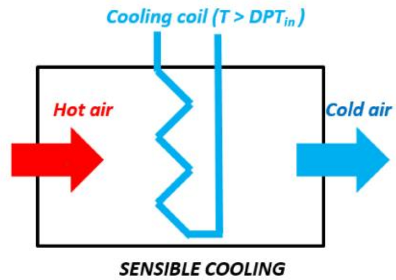
Psychrometric Processes

Sensible Cooling:

- This is the inverse of heating.
- Air temperature drops with no change in moisture content.
- The process follows a horizontal path to the left on the psychrometric chart.
- Equation:

$$Q_{cooling} = ma \cdot cpa \cdot (T_1 - T_2)$$

- Applications: Air coolers, ventilation systems, precooling before dehumidification



https://armstronginternational.com/products-landing/humidification-solutions/

Sensible cooling is when you pass hot air and you get cold air. So, this is the inverse of heating, right? The air temperature drops with no change in the moisture content. Here also, it is the same. No moisture is added or removed.

So, here it is cooling. The process follows a horizontal path to the left of the psychrometric chart. So, the equation is given as the same

$$Qcooling = ma \cdot cpa \cdot (T1 - T2)$$

Applications are air coolers, ventilation systems, and dehumidification.

Psychrometric Processes

Cooling with Dehumidification (Typical in Air Conditioning):

- Here, moist air is cooled below its dew point, causing water vapor to condense.
- Both dry bulb temperature and humidity ratio decrease.
- This path is a downward-sloping line to the left, often ending on the saturation curve.
- Latent heat removed during condensation adds to the cooling load.
- Total cooling load:

$$Q_{total} = ma \cdot (h_1 - h_2)$$

- Where

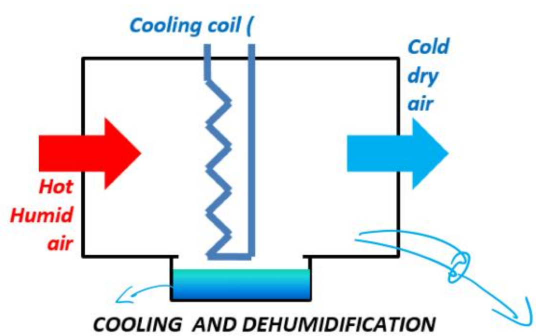
h: specific enthalpy of moist air (kJ/kg dry air)

Condensate mass: $$m_{condensate} = ma \cdot (\omega_1 - \omega_2)$$

- Applications: Air conditioners, industrial air dryers

Psychrometric Processes

Cooling with Dehumidification (Typical in Air Conditioning):



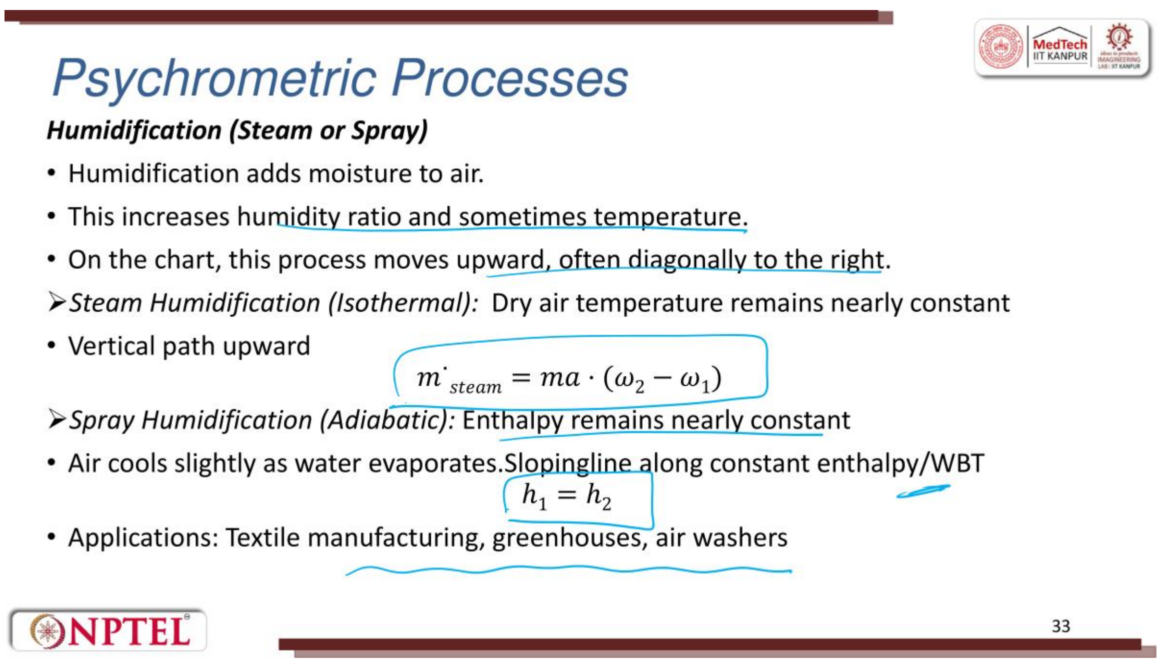
https://armstronginternational.com/products-landing/humidification-solutions/

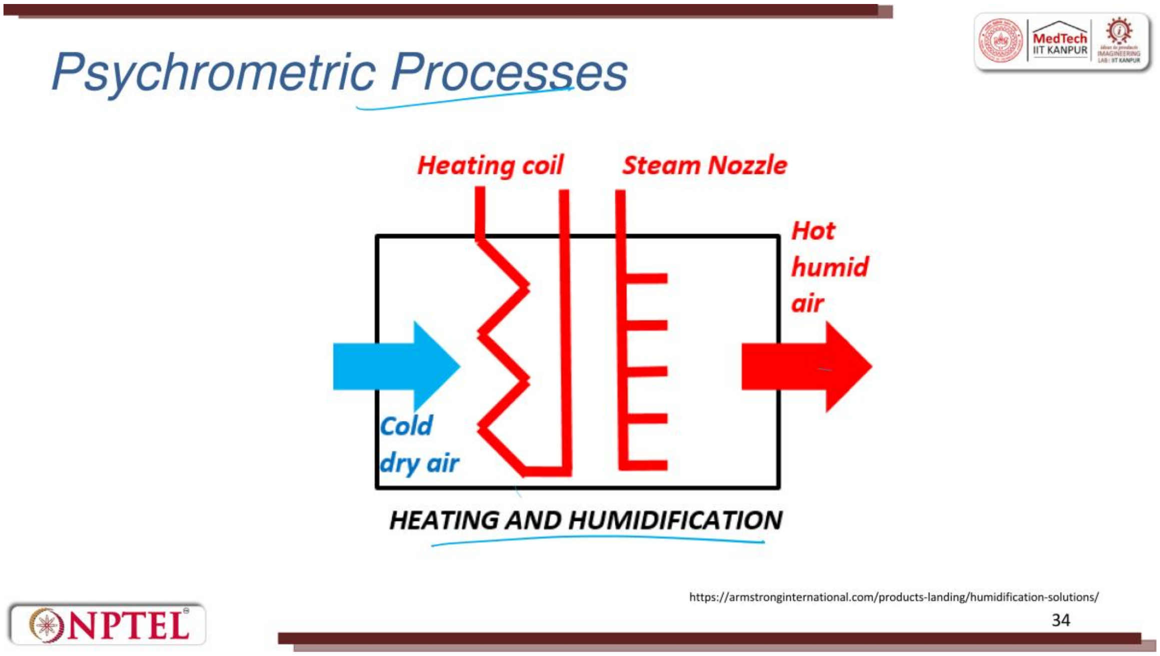
Cooling with dehumidification typically occurs in air conditioning. So, dehumidification means water content has to be removed. Here, moist air is cooled below its dew point, causing water vapor to condense.

Both dry bulb temperature and humidity ratio decrease. This path is a downward-sloping line to the left, often ending at the saturation curve, which is the saturation curve, ending at the saturation curve. Latent heat removed during condensation adds to the cooling load.

So this is calculated this way. So that is why in your AC when hot humid air from outside is coming, it cools, and then you will have always a dehumidifier. That is why you see water coming out of your air conditioner. On a rainy season day, you can always see all the ACs will have a duct through which the water comes out because of cooling with dehumidification. Humidification, steaming process, or spraying process adds moisture to the air.

This I said on a winter day where a heater is used. The increasing humidity ratio and sometimes temperature. On this chart, this process moves upward, often diagonal to the right.



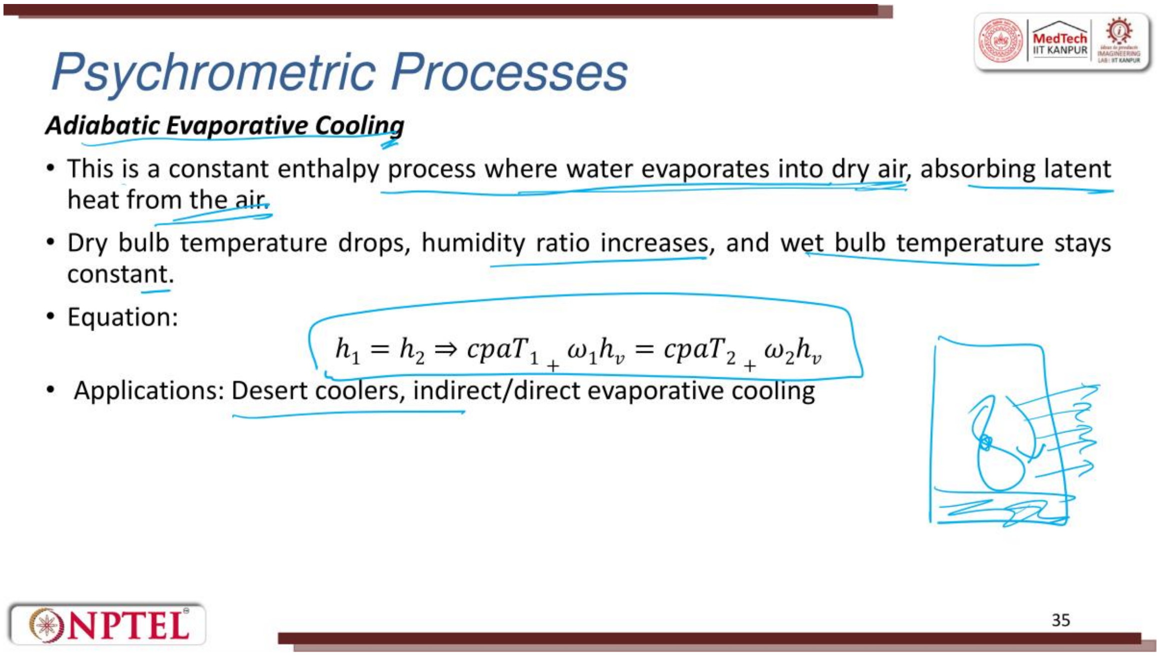


So this is how you try to calculate the steam humidification which is

$$\dot{m}_{steam} = m_a \cdot (\omega 2 - \omega 1)$$

So, the spray humidification enthalpy remains nearly constant. The air cools slightly as water evaporates, sloping line towards WT, which is h1 = h2.

Application: It is used in greenhouses, air washers, and textile manufacturing, steam or spraying. So we use steam cleaning for utensils, so that is called as air washers, right? Textile manufacturing also uses this. So, here what we do is, we will have cold air passed, you will have a heating coil, then what we have is steam nozzles, then we have hot humid air passed into. This is heating and humidification, which is cooling and dehumidification. This is humidification, heating, and humidification.



The last part is adiabatic cooling. So, in adiabatic evaporative cooling, it is a constant enthalpy process where water evaporates into the dry air, absorbing latent heat from the air. The equation is

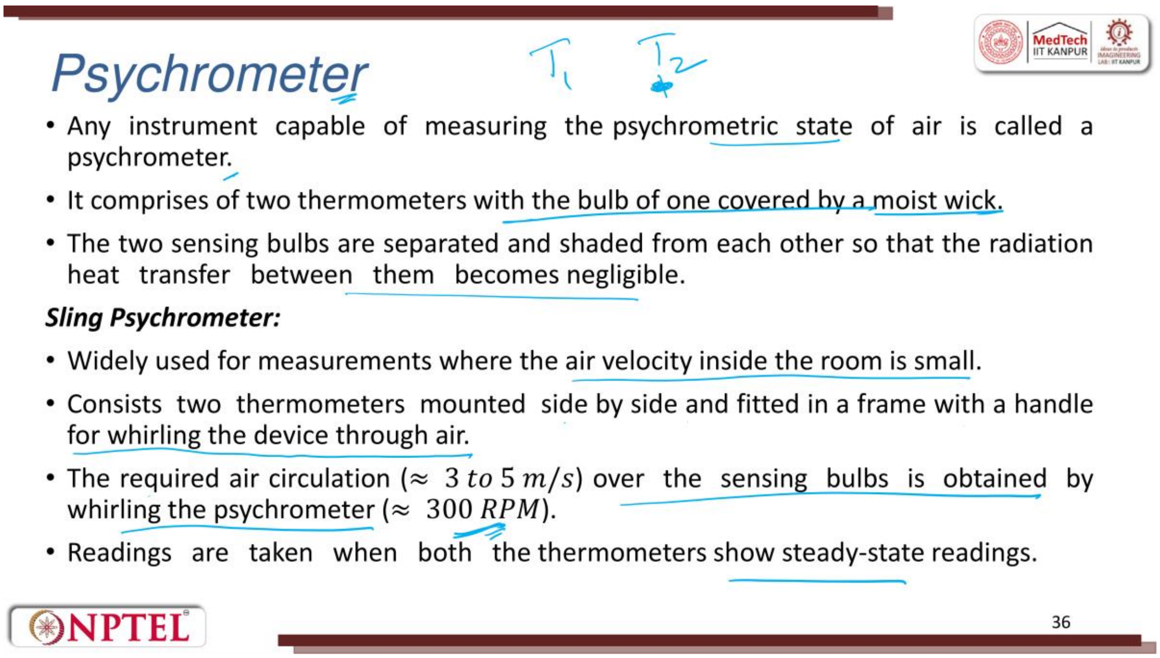
$$h1 = h2 \Rightarrow cpaT1 + \omega 1hv = cpaT2 + \omega 2hv$$

It is a constant enthalpy process where water evaporates into dry air. So, this is in a desert cooler, where we always have this adiabatic evaporative cooling. So, what we do in desert cooling is, you have a fan that rotates at a very high speed, then we have a water-filled cooler. So, now when the fan rotates, the air is dry; this fan tries to evaporate water, and this evaporated water through the fan is pushed into the dry space. So, then you have an increase in water vapor in the system. So, it is a constant enthalpy process where evaporation into dry air is happening.

So, the dry bulb temperature drops, the humidity ratio increases, the wet bulb temperature stays constant, and the equation is given like this. So, this is a function in a desert cooler. So, I have given you all the examples. Desert cooler. How does it work?

Then I have given you an air washer. How does it work? Then I have given you an air conditioner. How does it work? Then I have also given you an air cooler.

How does it work? So now you can understand all these things. Sensible cooling, cooling with dehumidification, cooling with humidification, then drying with humidification, then evaporative humidification.

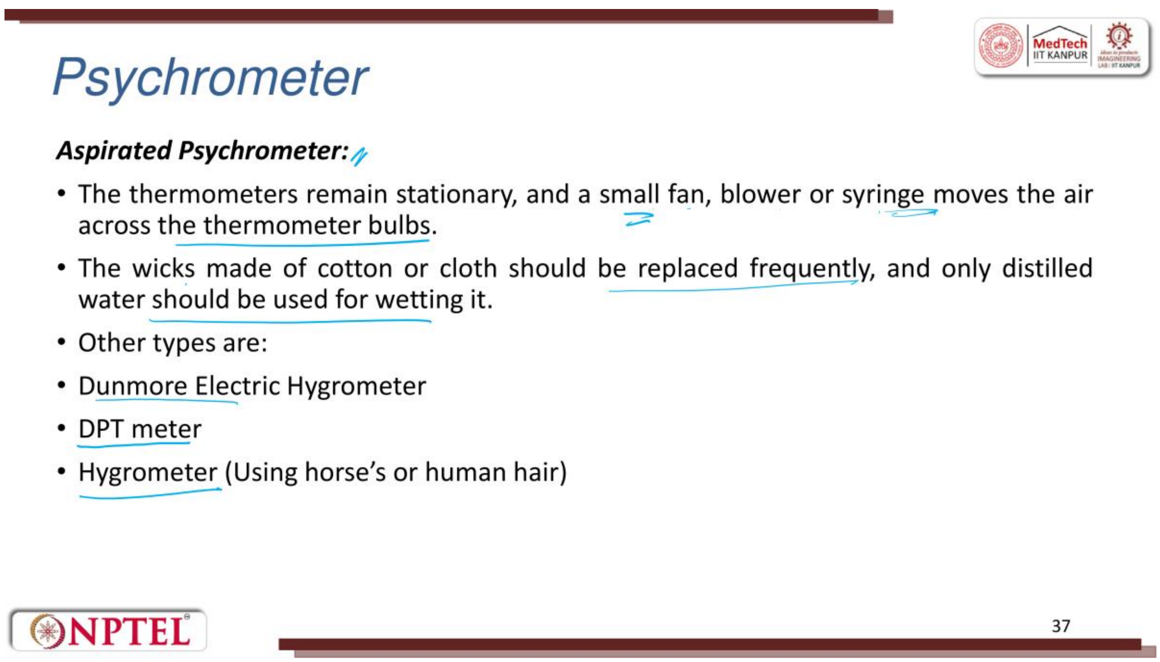


So, this psychrometer. Any instrument capable of measuring the psychrometric state of air is called a psychrometer. It comprises two thermometers with the bulb of one covered by a moist wick. For example, thermometer 1, thermometer 2, two thermometers with the bulb of one covered by a moist wick. So that is what we see, a wet bulb. The two sensing bulbs are separated and shaded from each other so that the radiation heat transfer between the two becomes negligible. A sling psychrometer is widely used for measurement where air velocity inside the room is very small.

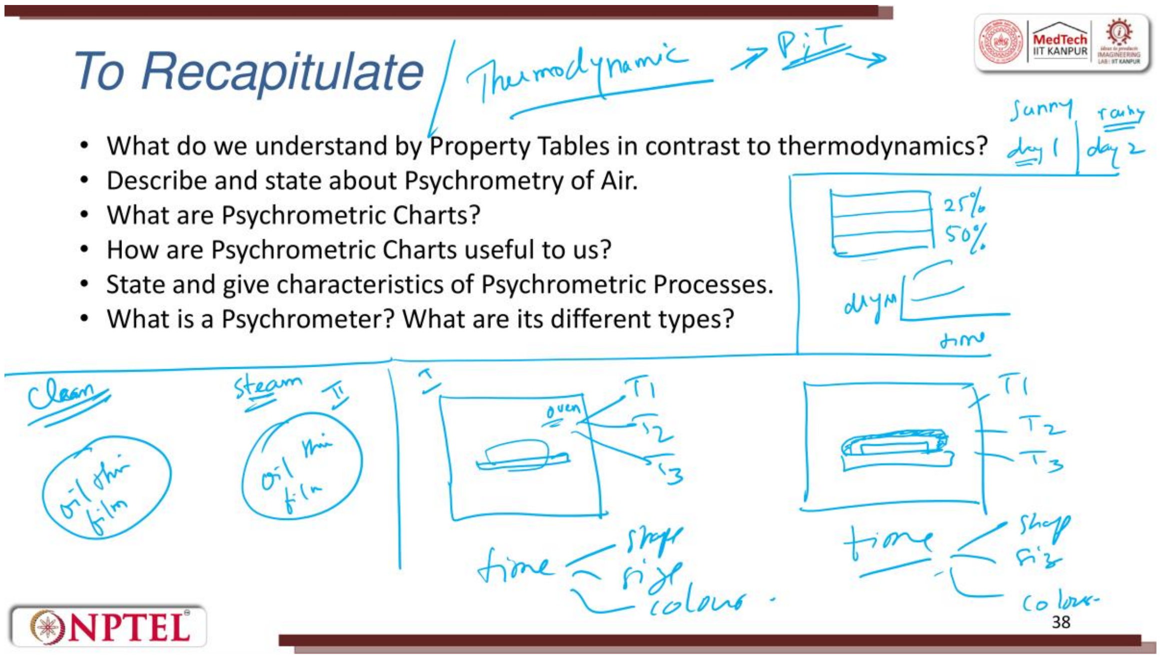
It consists of a thermometer mounted side by side and fitted in a frame with a handle for whirling the device through the air. Sling psychrometer, and this is another psychrometer chart. This requires the air circulation over a sensible bulb, which is obtained by whirling the psychrometer with this device. Readings are made when both thermometers show a steady-state reading. So, there is another one which is called an aspirated.

The thermometer remains stationary, and a small fan, blower, or syringe moves the air across the thermometer bulb. So, you see here three different types. So, first they talk about the psychrometer. This is used; it has a wet bulb and a dry bulb. So, in this, we have a sling type and then we have an aspirator type.

In a sling type, what we do is ensure the air velocity inside the room is constant or very small. So now you try to put both side by side and then with a handle, you whirl. The device through the air. So the whirling speed is 300 rpm. You measure the reading at a steady state.



Aspirated psychrometer. Here, you use a small fan to blow. A fan, blower, or syringe moves the air across the thermometer bulb. The wicks, made of cotton or cloth, should be replaced frequently, and distilled water should be used for wetting. This type is otherwise called a DPT meter, hygrometer, or Dumour electric hygrometer. This is nothing but an aspirated trichrometer.



So, in this chapter, we saw the property table and the states of psychrometry of air, then the psychrometric chart. How do you use the psychrometric chart and the characteristics of the psychrometric process? Then, finally, we saw what a psychrometer is and what the different types of psychrometers are. So, it is nothing but a wet bulb and a dry bulb.

So, friends, let us try to do some small experiments. So, try to take a small green leaf, keep it inside an oven, set the temperature to T1, then to T2, then to T3, where T1 is lower and T3 is higher. And see what happens to the shape, size, and color of the leaf. The leaf should be a little larger. So, keep a larger leaf in an oven and see what happens.

Next, try to do the same experiment with T1, T2, and T3, where you keep the leaf. The leaf should be covered by a cotton cloth. The same leaf covered by a cotton cloth. Now, record it with time; what is the change in shape, size, and color? Right? So here, with a cloth which is covering this.

And then, let us try to go to a cleaning station. Try to take a vessel that has an oil coating in it, a thin oil film. Try to remove this thin film only with cold water, then with steam, and wash it for the same time. Now, see what happens to these two cleanings and what is the effect of steam with respect to the output. This is the second experiment: experiment 1, experiment 2.

The last experiment is to take a handkerchief and try to have two different days. Day 1, which is a sunny day. Day 2, which is a rainy day. And try to partially, for example, up to here or up to here, or you can try to have 25% loading with water, 50% loading with water. Dry it on day 1, which is sunny, and dry it on day 2, which is rainy.

And try to plot the dryness with respect to how and when it dries, and how it dries for two things. And now, with all these experiments, you will try to understand the influence of thermodynamics in real-time use, where the measurable parameters are pressure and temperature. Now, at various conditions, we are supposed to see how it performs with different outputs. So, friends, when we do all these three experiments and go through this chapter once again, you will start appreciating why this is important. Now, these are all simple experiments.

Now, these experiments have to be integrated into a system where multiple processes happen. So, that gives you better clarity on this chapter.

References

1. Patrick Chasseing. 2023, Fundamentals of Fluid Mechanics: For Scientists and Engineers, Springer.
2. Younus A. Çengel, Michael A. Boles, Mehmet Kanoğlu, 2023, Thermodynamics: An Engineering Approach, McGraw Hill Education.
3. Frank M White, 2017, Fluid mechanics, McGraw Hill Education
4. R. Fletcher, 2000, Practical methods of optimization, Wiley
5. J.P. Holman, 2010, *Experimental Methods for Engineers*, McGraw Hill Education.
6. Adrian Bejan, 2016, *Advanced Engineering Thermodynamics*, Wiley.
7. Michael J. Moran, Howard N. Shapiro, 2014, *Fundamentals of Engineering Thermodynamics*, Wiley.

NPTEL 39

So, these are the references we have used for preparing the slides for this particular chapter.

Thank you very much.