Applied Thermodynamics for Marine Systems

Prof. P. K. Das

Department of Mechanical Engineering

Indian Institute of Technology, Kharagpur

Lecture - 19

Psychometrics

Good afternoon. We have started our discussion on vapour compression refrigeration cycle which is the most common and most widely used refrigeration cycle. Though there are other types of cycles, their applications are limited and for special purposes those other cycles are used. So, mainly we will have vapour compression cycles and we will concentrate on that. Now, I will just recapitulate quickly, what we have done so far.

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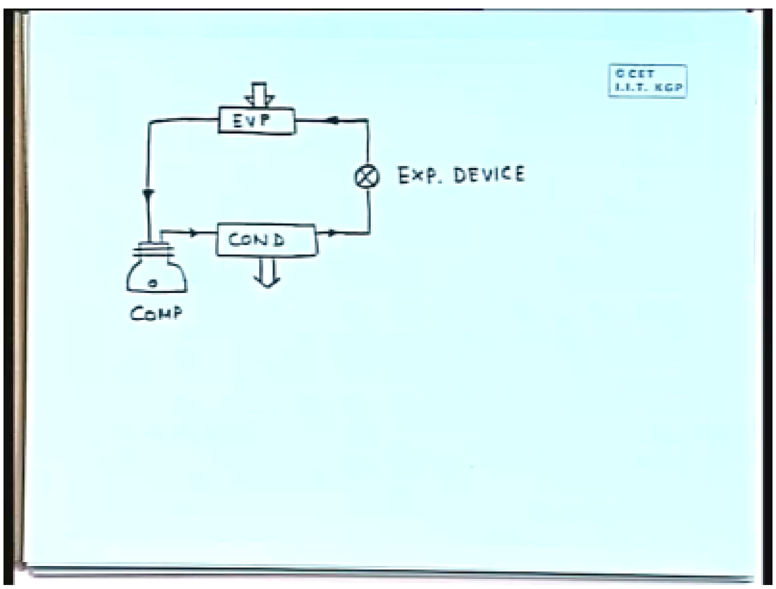

In a vapour compression refrigeration cycle, we will have a compressor. This is the compressor which will be driven by some external agency like electric motor. Then after the compressor, the compressed vapour, which is basically refrigerant in the form of vapour, will go to the condenser. In the condenser it will reject heat. So, this is the condenser, this is compressor. It will reject heat and then, there is an expansion device. This is the expansion device. After that it will go to the evaporator. The evaporator is the component where the cooling effect is produced, so it will absorb heat.

What happens after the expansion device is that the pressure of the refrigerant falls and it is at a low temperature and it is also in the liquid condition. In the evaporator, it will evaporate and it will absorb heat. So it will produce a cooling effect; at the same time it will get transformed into a vapour state. But, this refrigerant vapour is at a low pressure. So to continue the cycle it has to go back again to the compressor to be compressed and then go to the condenser. This is the way the cycle will be executed. There are number of variations of this basic cycle.

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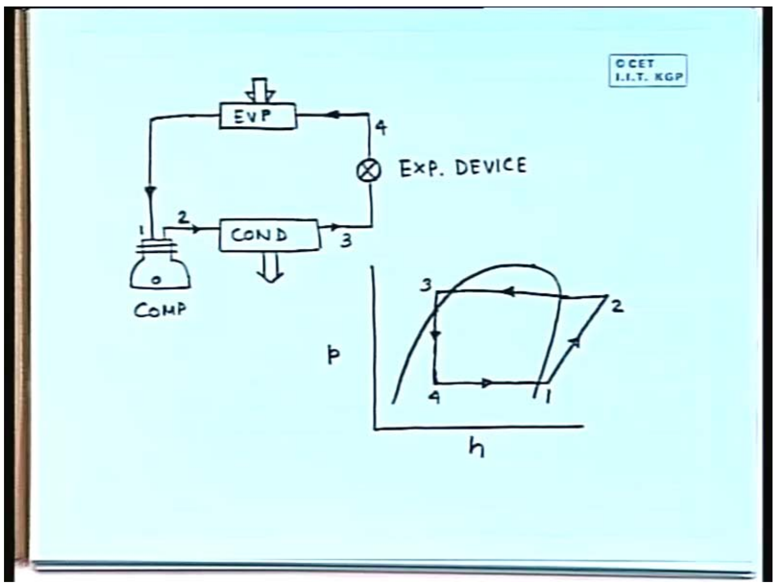

I like to once again make a sketch of the thermodynamic diagram of the cycle. It is better explained with the help of a ph diagram. So which way we get p and which way we get h? This side is pressure and this side is enthalpy. This is the two phase dome in the ph plane and somewhere you have got the critical point; this is the expansion process. We have started with the compression process. This is 1, that means it is at the entry of the compressor; then this is 2, that is at the exit of the compressor. Then it goes all the way to the saturated liquid condition and in the most probable case, it is also sub-cooled slightly. Then, we will have some Joule Thomson expansion process which is irreversible and we can express it with the help of a dotted line. But, in most of the cases it is shown by a firm line because we assume that it is along this constant enthalpy path. So, 1, 2, 3 and 4 and here also we will have 1, 2 then 3; then after expansion this is 4. So, basic cycle and basic thermodynamic cycle diagram has been shown here. This is more or less the ideal diagram of the cycle without assuming any sort of irreversibility. This 3 to 4, this process is an irreversible process. But, apart from that, we have not considered any other losses anywhere.

In actual practice, we will have number of deviations from the ideal cycle. So, we can have a small discussion regarding the deviations. What sort of deviations will we have? The ideal cycle, if somebody wants to discuss it, it should start just at the saturated vapour condition. That means the compression process should start at the saturated vapour condition. But, in actual practice there is a little bit of superheating. After the evaporator, the vapour has to come through the valve and it has to go to the compressor through the valve passages pores etc., which are at relatively higher temperature. So, these passages will not only induce certain amount of pressure drop but will also induce certain amount of super heat.

If we assume that the vapour is entering at saturated condition, even if it enters the valve port at saturated condition as it picks up certain amount of thermal energy it will get superheated. Here, it has not been shown but there will be some amount of additional pressure drop and some amount of super heating. Then, 1 to 2 is a compression process. In ideal cases, we assume this compression process to be isentropic. But we will not have isentropic compression processes in any of the compressors which we can design or manufacture; it will deviate from the isentropic compression process. There are number of reasons for the irreversibilities. But the main reasons are: 1) we assume isentropic process means reversible adiabatic process but the process is not adiabatic; there will be some amount of heat transfer. During compression the vapour will be at high pressure and it will also gain temperature that means its temperature will also rise. At that time, there will be heat transfer and there will be frictional losses. So, the gas, when it flows through the compressor whether it is a positive displacement compressor or a rotary compressor, in every case there will be friction. So, we will not have reversible adiabatic process in the compressor.

If somebody wants to go for a detailed calculation of the compression process, it will not be advisable to take the compression process as an adiabatic compression process. One can take appropriate polytrophic compression for the gas inside the compressor. Then, after that the gas will come out. Again, when it is coming out, it has to go through the valve passages, the pipe line and then it has to go to the condenser. Here also, that means at the exit of the compressor, it will have some additional pressure drop. Because the valve passages are restricted small passages, there we will have additional pressure drop. It will come out at a high temperature after compression. When it passes through the pipeline connecting the compressor and the condenser there will be some amount of heat transfer. Generally, this is d super heating. So, we will have some amount of d super heating and then it goes to the condenser. The condensation process, we assume it to be a constant pressure process. However small it may be, there will be some amount of pressure drop because it has to pass through narrow passages, narrow tubes, etc. So there will be certain amount of pressure drop.

In ideal case, one may think that the condensation is just stopping when the refrigerant has reached the saturated liquid condition. But, in actual practice it may not be possible; there will be certain amount of sub cooling. The sub-cooled liquid will then go through this expansion process. Initially when the liquid is entering the expansion device it may be in the sub-cooled condition but then Joule Thomson expansion will take place and it will come out as a two phase mixture. Again, in the expansion device the process is very complex. Whatever expansion device it may be, it may be a thermostatic expansion valve or capillary tube the process is very complex because here we can have the flow of a two phase mixture or we will have a flow of two phase mixture. Continuously, there will be more and more production of vapour phase. You can see that this is starting from almost saturated liquid but as it goes in the downward direction, as its pressure reduces, then more and more vapour generates. This is some kind of a flushing process. We will have more and more generation of vapour.

The process is more complex and lot of irreversibilities are involved with it. But, even then one assumes that here enthalpy remains a constant during this process and one can make some sort of a design of the expansion device. Then, ultimately when it reaches the evaporated pressure, we will have the evaporation. Again, in the evaporation process we will have a pressure drop however small it may be. Though we are assuming it is a constant pressure process it will not be so. We will have certain amount of pressure drop. So these are the deviation between the ideal vapour compression cycle and the actual vapour compression cycle.

Now, certain features of this deviations are desirable from a practical point of view, particularly, this superheating of the refrigerant vapour after the evaporation process or before its entry to the compressor. It is quite desirable because we do not want to send any liquid refrigerant into the compressor. That is why sometimes in larger establishments means, in larger refrigeration units you will have a device which helps the superheating of the vapour after it comes out of the evaporator. Basically one can have one additional heat exchanger. Are you aware of it? Sometimes this is called suction line heat exchanger. There is a heat exchange between this and this line. One can have one additional heat exchanger; after the condenser and before the compressor there can be one heat exchanger.

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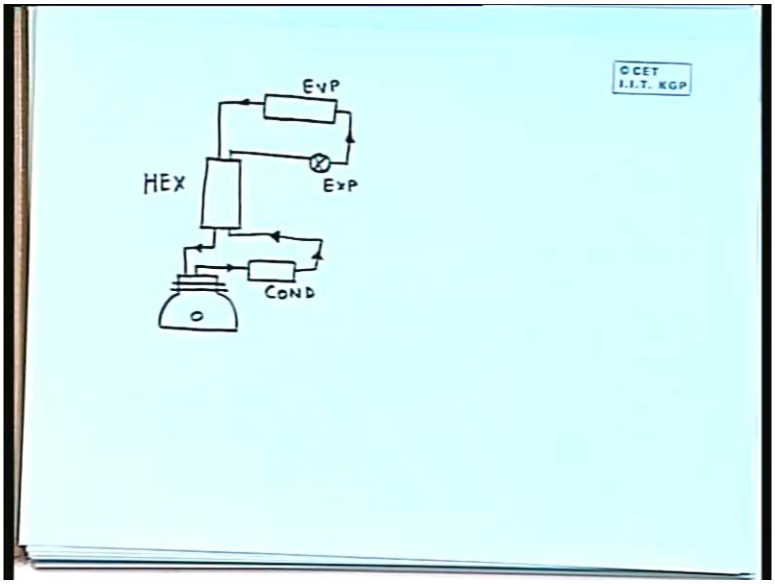

If we try to draw that it will be something like this. We will have condenser. Then, there is one heat exchanger, there is an expansion device and then it is going to the evaporator. This is the evaporator and after the evaporator it comes to the same heat exchanger; it goes here. This is your condenser, this is the expansion device, this is the evaporator and then we will have heat exchanger. So, after the evaporator it is going to the heat exchanger. After condenser when the refrigerant is coming out still it is having a slightly higher temperature. So this heat can be utilized by the refrigerant which comes out of the evaporator so that it guarantees that the refrigerant will enter the compressor in the superheated condition. This is not there in a small system. But in large refrigeration systems we will have this type of arrangement. So this is for the basic refrigeration principle and basic refrigeration system.

One can have large number of variation of this, particularly when we want to create low temperature. So, what one can do? One can use two refrigeration cycles in cascade. I will not go into details of it. I will just make some sort of a verbal description of it. One can have two refrigeration cycles in cascade. That means the heat absorbed by the evaporator of one cycle; or the heat will be absorbed by the evaporator of one cycle from the condenser of another cycle. By this we can create a much lower temperature. That is possible. Then, one can have a multi pressure system or one can have multi evaporator system. These are different variations of the basic refrigeration cycle and depending on our requirement one can have these types of variations. Sometimes we want to have the variation to have a higher COP or sometimes we want to have these variations to have a lower temperature. Depending on these demands we will have the variation in the basic refrigeration cycle. But, most of the refrigeration cycles that I have mentioned earlier work on the vapour compression principle, where the Joule Thompson expansion is the basis for the production of cooling effect. Now, there are other types of cycles also and as I have told it is vapour compression cycle that one can use. Other types of refrigerants like gas can be used as a refrigerant. Those are gas refrigeration cycles and they have special usages for marine systems; those are not very relevant, so we will not discuss them.

Let me have a small discussion regarding refrigerants. To have a desired cooling effect at a given low temperature, it is very crucial to select the proper type of refrigerant. Most commonly used refrigerant till a few years ago, even now in number of large systems, is chlorofluorocarbon. We will have different chemicals in this group; mainly they are chlorofluorocarbons. These refrigerants actually give lot of advantages. Till date they were being used. Now also we have this type of refrigerants in big systems, in domestic systems and also in some of the old domestic systems, but it is being phased out because they have produced some depletion in the ozone layer. Now, we have what we call eco-friendly refrigerants. People are trying; few years ago chlorofluorocarbon was the only name but now we can see lot of other new refrigerants which are generally termed as eco-friendly refrigerants. We still have to see which one is the best. People are trying different refrigerants. Commercial systems are there with different refrigerants but we have to still find out which one will be the best performer. Probably after a few years, just as R-12 or R-22 has become very popular, similar type of thing we will get. But now, it is in the experimental stage and so we are trying certain refrigerants. They have got some merits but at the same time they have got certain demerits. We have to watch and see. Now, only one thing I like to mention. As the chlorofluorocarbons are quite common they can be expressed with a common formula.

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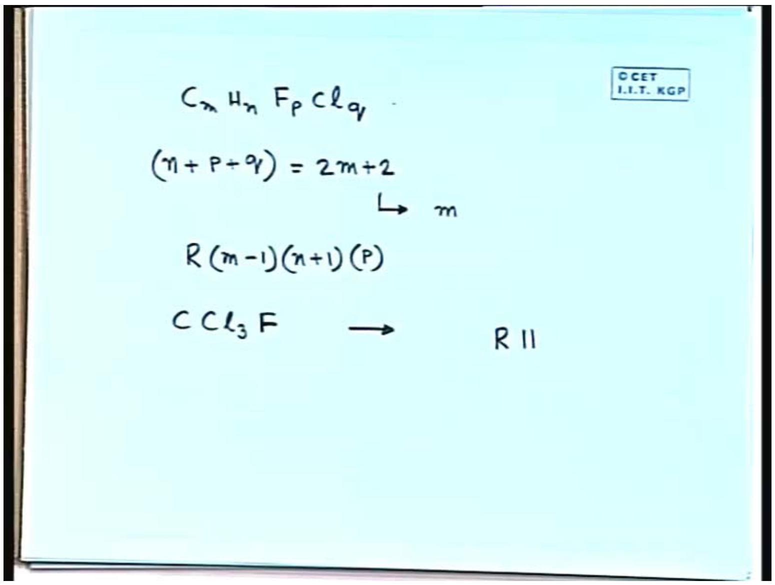

$C_mH_nF_pCl_q$: this could be the general formula of a refrigerant which is most commonly used. This is carbon, then hydrogen, then fluorine, then chlorine and these are the number of molecules which are in this particular component. If we have this formula n plus p plus q is equal to 2m plus 2, then, from here one can calculate the value of m. These are known quantities m, n, f and q. So, from there one can have the name of the refrigerant as R m minus 1 n plus 1 and p. This is the name of the refrigerant. So, generally the refrigerant name is expressed as R and then there are three numbers; sometimes two numbers and sometimes three numbers. So, these three numbers come from this particular formula. We can take one example like CCl_3F. Can you tell me what will be the name in terms of R? This will be R11. Let us not waste time, you can see it; this will be R11. Similarly, we can get the name of other refrigerants or generally commercial name or most commonly used name is this. From here, we can find out the chemical formula. That is why I have given this.

It is needless to elaborate the discussion but we know that the refrigerant should have certain properties so that one material will be selected as refrigerant. Depending on the application we will find that we have got a very wide range of refrigerants. Some of the permanent gases like sulphur dioxide and carbon dioxide, even carbon dioxide nowadays is again being tried. Long back, people used to have carbon dioxide as refrigerant. With the discovery of different chlorofluorocarbons this has been abolished or abandoned but now again carbon dioxide is gaining importance. So carbon dioxide, sulphur dioxide, ammonia, etc. are used as refrigerants. Even water can be used as refrigerant, air can be used as a refrigerant; but they have got different ranges of operation. So, there should be some properties for these refrigerants. What are the properties that are important for a refrigerant to perform well? Which are their properties one should look for?

Well, specific heat is one thing, but before that one has to see the pressure-temperature relationship for boiling and condensation. Let us say evaporator. What we want in an evaporator is that an evaporator should extract heat. But let us say I extract heat at a low temperature; the evaporator should extract heat or the refrigerant should be such that it will extract heat in the evaporator at a low temperature. Let us say to create that low temperature we have to have excessively low pressure. Then what will be the disadvantage? The varying pressure difference will be required. That is one thing. We have to maintain very high vacuum and we have to handle very large volume. If it is having excessively high pressure, then what will happen? All the section has to be made very thick. So these are the problems. The critical point should be high enough for a refrigerant. There are other things. It should be compatible with the metal. Generally, the refrigerants are closed system. They should remain there inside this closed system for years together without having any sort of chemical deterioration or reaction with the metal. They should be cheap; they should not be toxic because if there is any leakage etc., and over and above nowadays this environmental issue has come that they should be environment friendly. So that is how the refrigerants were selected.

Before the environment issue, before people became aware of this ozone depletion, we were very happy with this chlorofluorocarbon groups but nowadays we have to try something else. That is all. What we will do is we will take up problems on this basic refrigeration cycle and if time permits I like to take up some vapour absorption refrigeration also. I do not know how far it is important in the case of marine system. In marine system do you have vapour absorption? If you do not have it, then I will not discuss it. We will mainly concentrate on problems on vapour compression cycle and we will spend some more time on air conditional system.

Regarding the system details, I think it is needless to discuss more. We do not have much variation in marine systems whatever I have seen from different books. Basically there will be these four components and in some bigger system we will have the internal heat exchanger. These are the things we will have and there those refrigeration systems are large. So we will have thermostatic expansion valve there. Mainly the evaporator and condensers are shell and tube heat exchangers and compressors are reciprocating compressors or in certain cases, they are centrifugal compressors or screw compressors. This is the basic configuration of any marine refrigeration system. Otherwise, there is no such speciality and we will take up some problem to see the numerics. What we like to do is, now we go for the application of refrigeration. Refrigeration has got different applications. One of the main applications of refrigeration is air conditioning.

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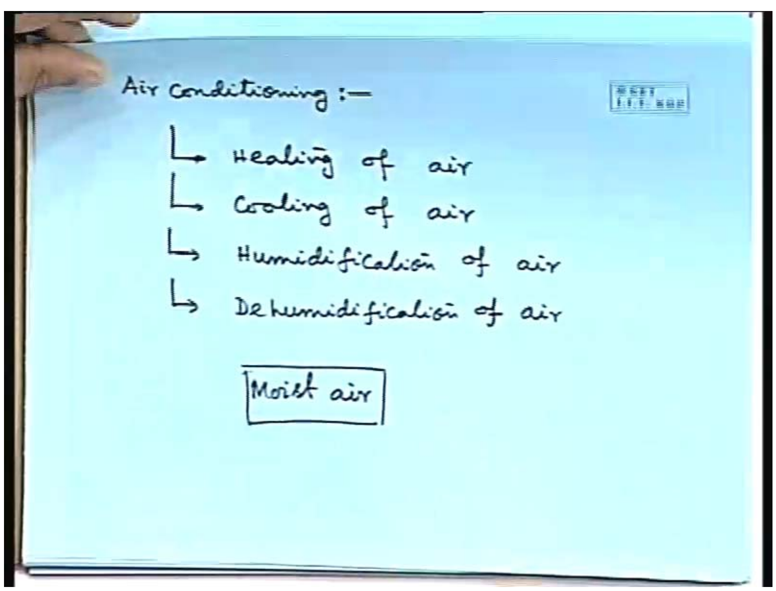

Air conditioning, as the name suggests, it is the conditioning of air. It is not merely cooling of air but conditioning of air. We will come into this aspect afterwards but why refrigeration and air conditioning, these two words are uttered almost in one way is because they are very closely related and a main function or a main activity in air conditioning is cooling the air and that is not an easy job. We will discuss it also afterwards and we will see that cooling of any object is rather difficult proposition compared to heating it. One can easily have some heat source either from firing fuel or burning fuel or by electrical heating and heating can be done. But for cooling or to extract heat one should have some elaborate arrangement and we can see that one arrangement could be refrigeration or vapour compression refrigeration. But, as in air conditioning we have to deal with the conditioning of air which generally deals with these functions: heating of air, then cooling of air, humidification of air and dehumidification of air. Before going to the systems and processes of air conditioning we have to study the properties of air or particularly properties of moist air.

In air conditioning these are the four basic functions generally we do. There are other functions also. Heating of air, cooling of air, humidification of air and dehumidification of air; in most of the cases, we will see that we have to do this operation simultaneously, means probably we have to heat and humidify the air, cool and dehumidify the air. So we have to have these operations simultaneously. Humidification and dehumidification means that we have to control the amount of water vapour or moisture in the air. Sometimes we have to extract certain amount of moisture from the air or sometimes we have to add certain more moisture to the air. Basically, the medium of air conditioning by which we will create the comfort condition, that is, moist air. We will study the property of moist air.

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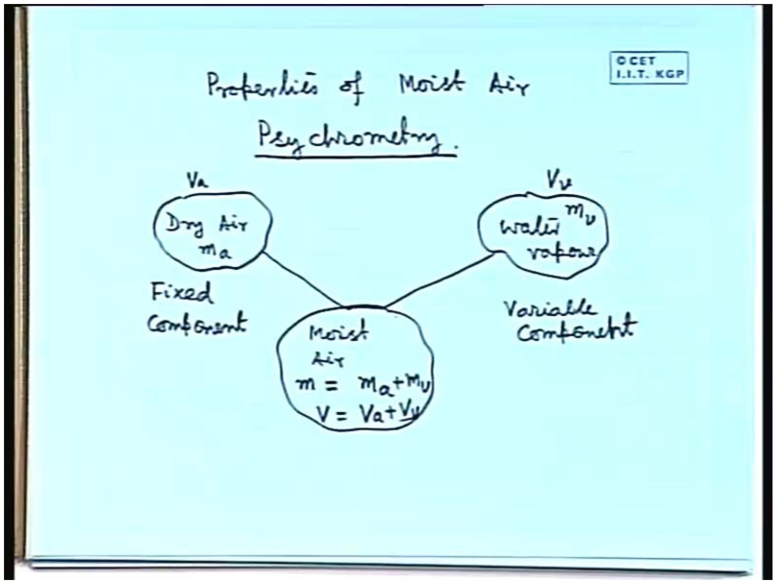

Moist air has got a special name, Psychrometry. We have got a special name for this branch of science, we call it psychrometry. In this, basically we deal with a gaseous substance. This gaseous substance is made up of two things: dry air and water vapour. If we combine these two we will have moist air. Let us say dry air has a mass of m_a and water vapour has a mass of m_v; so moist air will have a mass m which is equal to m_a plus m_v. Let us say, this is having a volume V_a and this is having a volume V_V. So it will have a volume V is equal to V_a plus V_V. What is important is that water vapour as well as dry air, both are in gaseous state and at low pressure both behave like ideal gas.

Our air conditioning application pressure range is slightly above or below atmospheric pressure but not exactly atmospheric pressure. Sometimes, it will be slightly above or below atmospheric pressure. We can see that our pressure range is low pressure range only and at that condition both dry air and water vapour they behave like ideal gas. Basically, moist air we can take it as a mixture of two ideal gases and that is how our analysis will be based on. We will have the analysis based on a mixture of ideal gases. Only one thing one has to remember. In this analysis what we will do is this dry air we will call fixed component. Let us take a sample of moist air. In that, there is a certain amount of dry air and a certain amount of moisture or water vapour is there. The mass of the dry air will not change. So, we will take it as the fixed component whereas, the mass of the water vapour we can have more water evaporated into that sample or certain amount of water vapour precipitated or got condensed. So we will have this as variable component; this is the fixed component and this is the variable component.

I have made a demarcation like this. What is the advantage? All the properties, we will try to express in terms of the fixed component. In other applications or earlier what we have done is, we have sometimes expressed properties per unit mass. Here, we will express it per unit mass of the dry air; not the total mass but per unit mass of the dry air. The scenario is clear in front of our eyes that we have sample of moist air which will constitute certain amount of dry air and certain amount of moist air or water vapour. The dry air content will remain fixed but the moisture content may vary. This mixture will obey the law of ideal gas mixture so it will obey Dalton's Law of Partial Pressure and other laws. First we will try to define certain properties of moist air.

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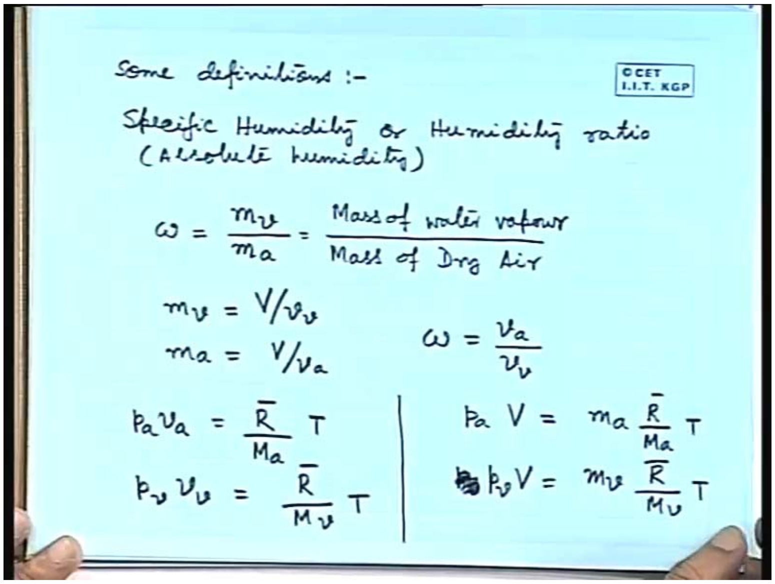

Specify humidity or humidity ratios; in certain books, this is also called the absolute humidity, though the specific humidity is the more common name or more commonly used name. Conventionally this is expressed by a symbol w and it is m_v, mass of water vapour divided by m_a, mass of dry air. This is your specific humidity or humidity ratio. Then, m_v one can write as V by v_v, where v_v is the specific volume and V is the total volume. One can write m_a is equal to V by v_a; so, we can write omega or small w is v_a by v_v. Then again, one can write p_a v_a is equal to R by M_a T, where R is the universal gas constant, p_a is the partial pressure of dry air and v_a is the specific volume of dry air. One can again write p_v v_v is equal to R by M_v T, for a particular sample of moist air. Then one can write p_a into V is equal to m_a R by M_a T and p_v V is equal to m_v R by M_v T. What are these M_A and M_V? These are molecular weight of the dry air and water vapour. Again, here you see dry air is a mixture of different gases but as a whole we are taking this to be as an ideal gas. Dry air basically is not a single component. There are a number of constituents but we are taking it as an ideal gas and water vapour is another ideal gas.

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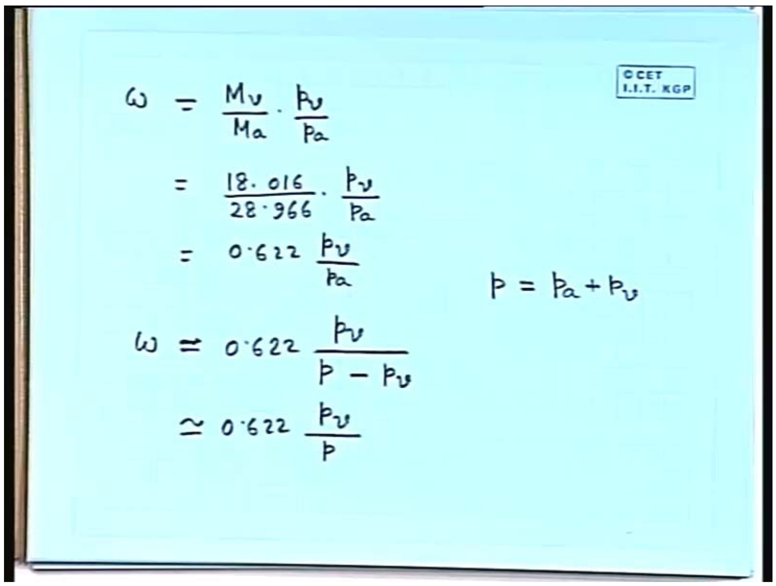

Then, we can write omega is M_v by M_a and p_v by p_a and then we can write putting these values 18.016, this is the molecular weight of water and then, we can have 28.966, 29 actually or approximately, this is the molecular weight of air. So, we will have 0.622 p_v by p_a. We have got the specific humidity in terms of partial pressure of water vapour and dry air. We can have slight modification in this equation or simplification in this equation. We can write it like 0.622 p_v, partial pressure of water vapour. Instead of p_a, we can write p, the pressure of the mixture minus p_v because from the law of partial pressure we know p is equal to p_a plus p_v. So that is what I have used here. Generally, the amount of water vapour is very small in a mixture, so its partial pressure will also be small. Now, we can use this symbol 0.622 p_v by p. So by some simple measurements we can determine the specific humidity or humidity ratio.

What do we have to do? Suppose, now in this room, we want to know what the specific humidity or humidity ratio is. We have to know the pressure, we have to know the vapour pressure and we have to know the total pressure that can be measured with the help of barometer or something like that. We have to know the vapour pressure and using this p_v and p, using this formula we can determine what the absolute humidity or specific humidity is. Generally, what happens is we have got a chart. Depending on temperature, what is the vapour pressure that can be obtained and from there also one can calculate what the specific humidity is.

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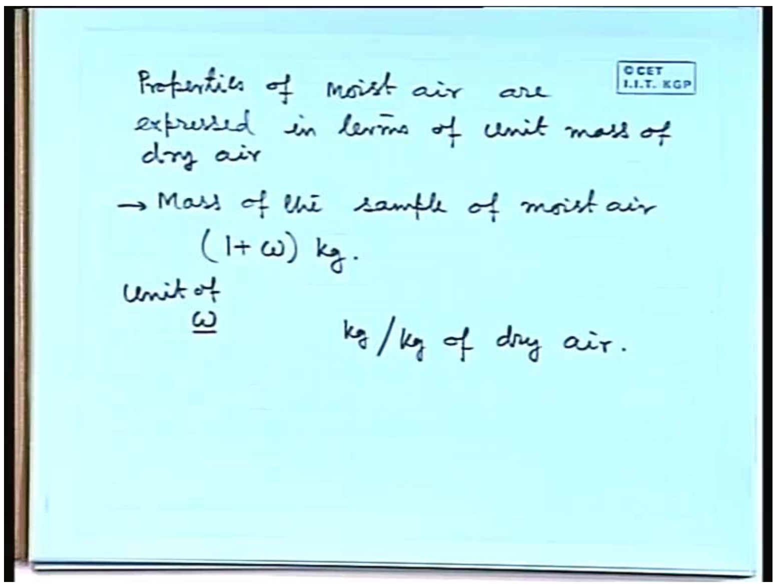

So, basically in this connection, I like to tell one thing. As I have said, properties of moist air are expressed in terms of unit mass of dry air. What do we do? For the sample if we want to express the properties, then it is basically for 1 kg of dry air. Then, what will be the weight of the sample? Weight of the sample will be mass of the sample of moist air will be 1 plus this much kg. What is w or omega? w or omega is the mass of water vapour for 1 kg of dry air. So, what will be the unit of omega? Now, if we express it in kg per kg of dry air then the number becomes very small. So sometimes it is expressed in grams per kg of dry air; grams of water vapour per kg of dry air. This is kg per kg of dry air. Let us stop here, take a small break and then again we will start.