Novel Technologies for Food Processing and Shelf Life Extension
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Lecture - 44
Multiproduct CA/MA Storage Unit

Hello everybody, today in this lecture we will study about the Multi Product Controlled Atmosphere or as Modified Atmosphere Storage Unit. Basically in this part of the lecture, we will discuss about various aspects of design of a controlled atmosphere storage facility.

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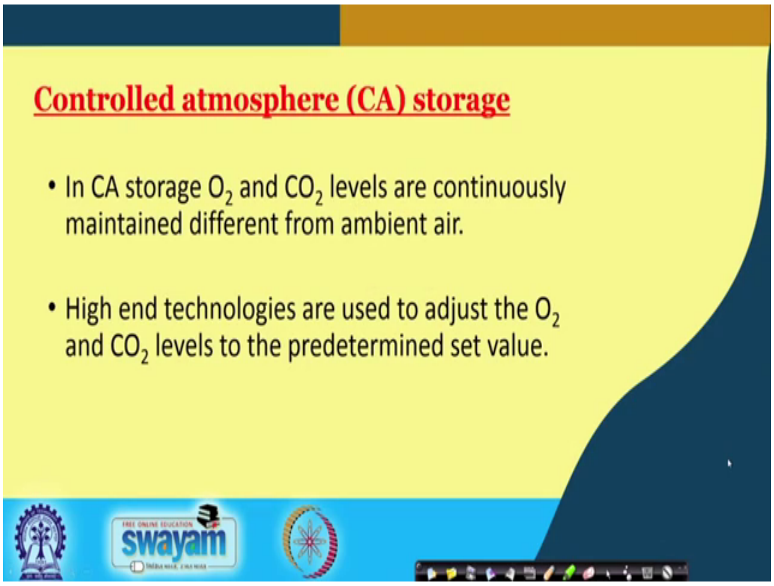

In the earlier classes, we have seen that the controlled atmosphere storage includes oxygen and carbon dioxide levels which are continuously maintained different from those normally available in ambient air. So, may be by suitable means the O 2 and CO 2 levels are maintained. Generally high end technologies are used to adjust the oxygen and carbon dioxide levels to the predetermined set value. Predetermined set value means that is the particular concentration of oxygen or particular concentration of carbon dioxide that is required for maximum shelf life of a commodity.

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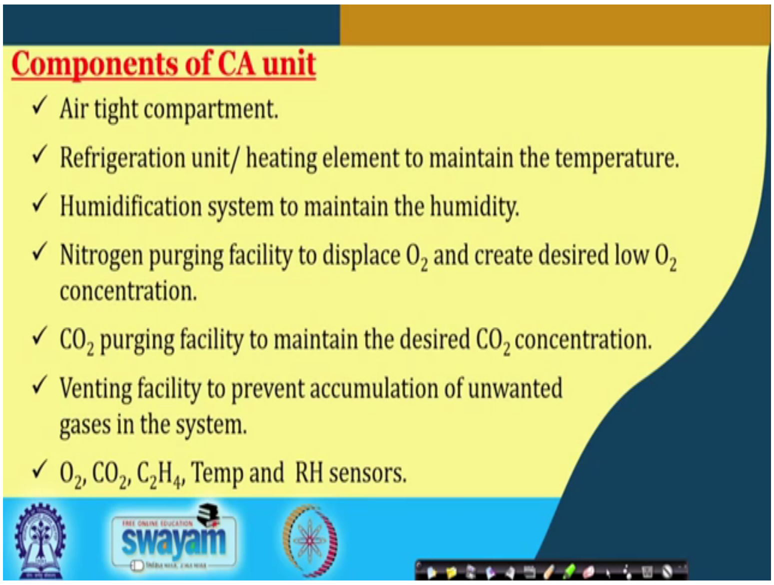

So, a facility for the controlled atmosphere storage accordingly should include the required instrumentation and other support units which are required, which are needed for manipulating the environmental conditions as well as maintaining the environmental conditions. So, obviously, it should have one air tight compartment chamber, then refrigeration unit or heating element to maintain the desired temperature. It should have a humidification system to maintain relative humidity.

It should be provided with nitrogen purging facility to displace oxygen and create desired levels of oxygen concentrations. The system or facility should be provided with carbon dioxide purging facilities to maintain the desired carbon dioxide concentration in the storage environment. And the facility should be provided with all venting accessories etcetera to prevent accumulation of unwanted gases in the system. That is and the O 2, CO 2, ethylene, temperature, relative humidity sensors, etcetera that is very important component of the storage facility that is to sense these and indicate the levels of these gases in the facility.

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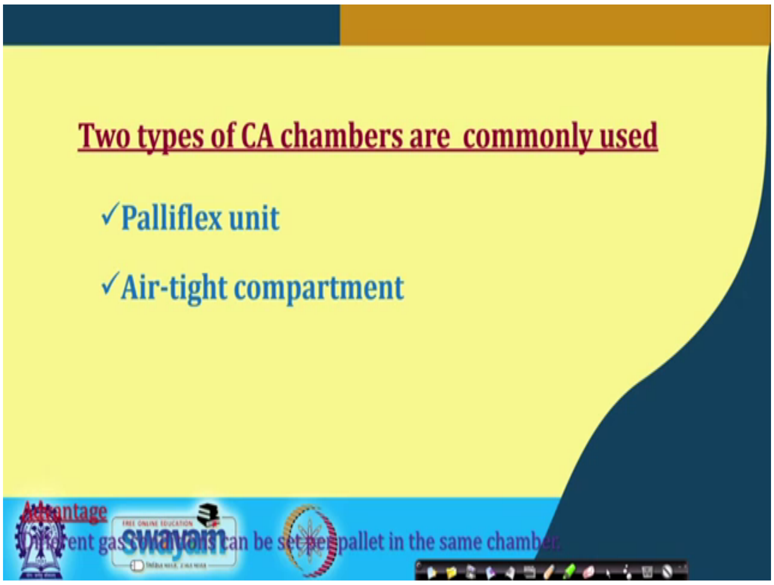

So, there are generally two types of controlled atmosphere chambers; one contains palliflex unit, the other is the air tight compartment.

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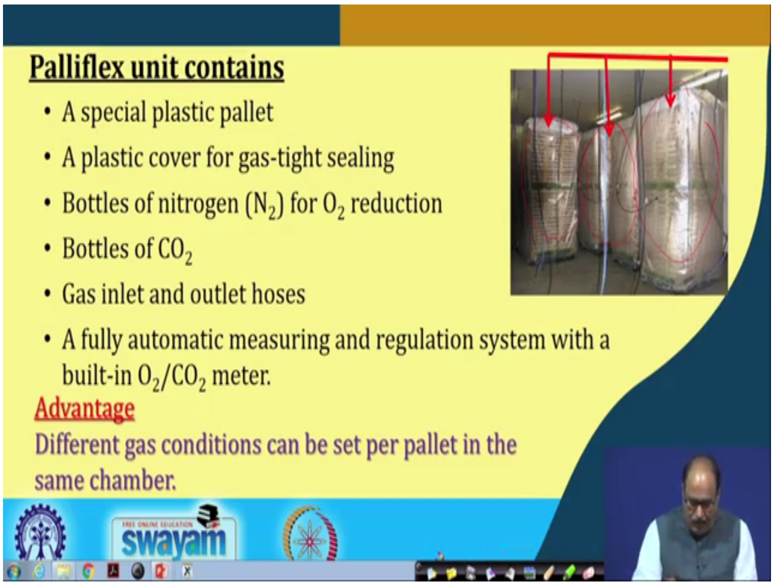

In the palliflex unit as you can see in this figure that is there is a special plastic pallet, these a plastic cover for gas tight sealing, bottles of nitrogen for oxygen reductions that provided the bottles of carbon dioxide, the gas inlet and outlet hoses. And a fully automatic measuring and regulation system with a built-in oxygen or carbon dioxide meter. So, you can see that different palliflex units that is these are there. So, the atmosphere inside this plastic pallet sector is maintained.

So, the major advantage or this palliflex unit consists of that different gas conditions can be set as per the requirement that is in the different pallets, different conditions can be maintained, and all these pallets they can be kept in the same chamber. So, it provides little flexibility of even storing different commodities requiring different conditions in the same chamber.

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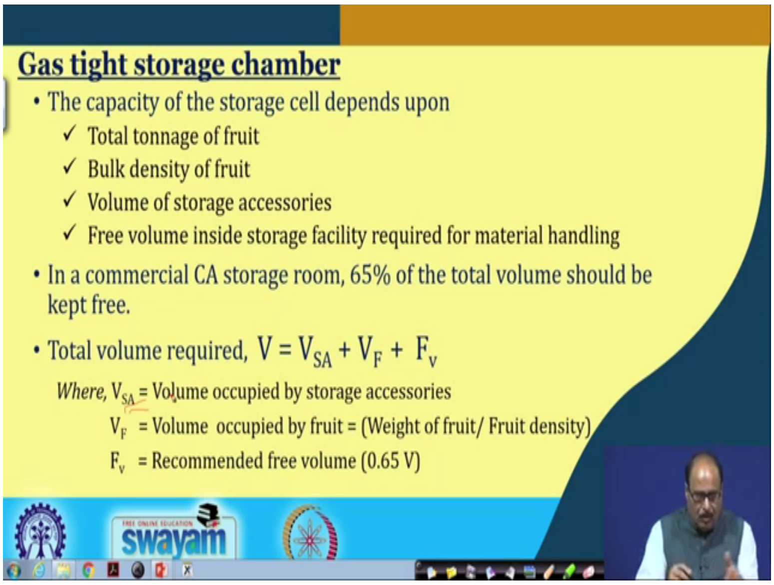

The other system with the gas tight storage chamber; the capacity of the storage chamber will depend upon the tonnage of the fruit that is what is the quantity of the fruit should which is a required to be kept or quantity of the other food materials required to be kept, bulk density of the food, volume of the storage accessories, and free volume inside storage facility which is required for material handling.

As per the regulatory requirement in a commercial controlled atmosphere storage unit 65 percent of the total volume should be kept free, that is for the material movement and for other purposes. So, total volume or the storage room required can be calculated from this equation that is V is equal to V SA plus V F plus F V where V SA is the volume occupied by the storage accessories that is the nitrogen generator, carbon dioxide cylinder accessories, sensors etcetera. And the V F is the volume occupied by fruit or in general if you want to say volume occupied by the fruit, there is to be kept in the storage unity storage unit.

And this can be obviously, determined by the weight of the fruit divided by its density. And F V is the free volume that is required as I told you that it is the 65 percent of the total space. So, it is basically 0.65 V. So, accordingly the V can be calculated that is total volume required in the storage unit can be calculated.

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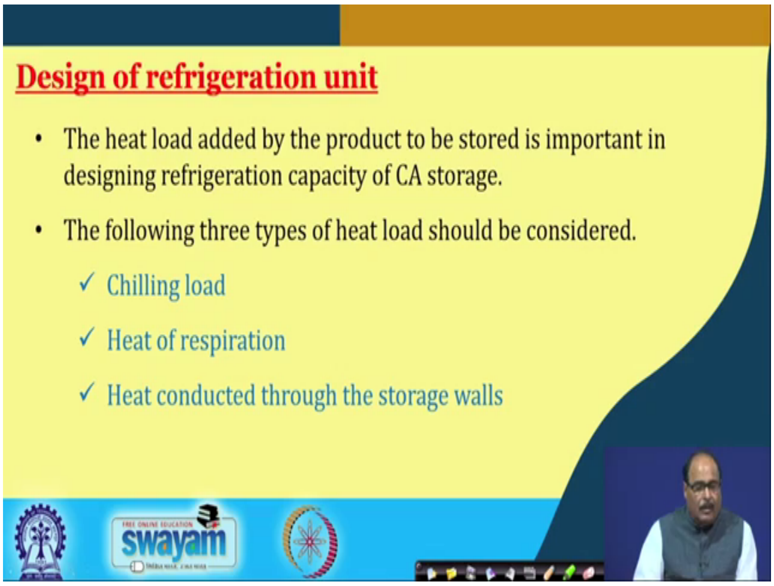

Now, let us discuss one by one what are the various aspect like heating system, CO 2 generating system, O 2 generating system, what are the various factor which are included in their design and in the load calculation etcetera so first of all the design of a refrigeration unit. So, the heat load added by the product to the storage is an important consideration that is it is one important factor for the calculation of the refrigeration capacity of controlled atmosphere storage system.

So, there are three types of heat load which should be considered. Number 1 chilling load, then heat of respiration, and heat conducted through the storage wall. So, all these three; consideration or all these three loads finally will decide the total load that is required in the storage facility.

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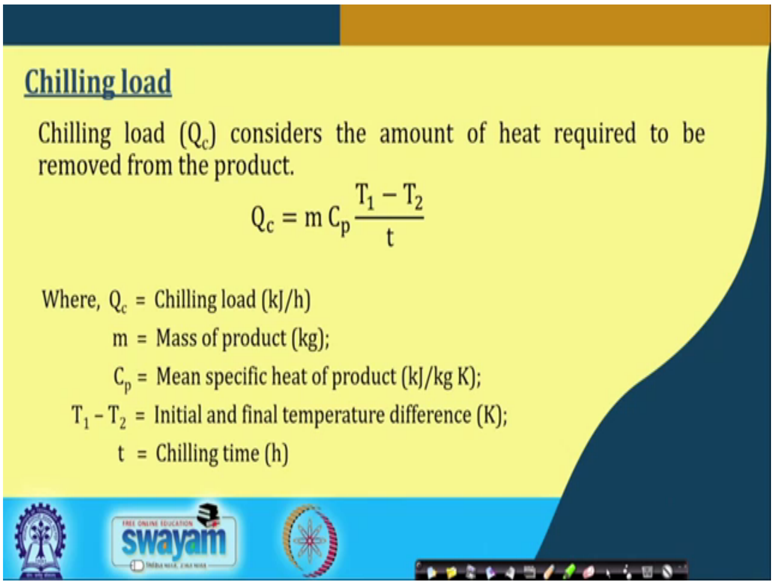

So, the chilling load that is Q c, it considers the amount of heat required to be removed from the product that is the product enters in the storage facility as a comparatively higher temperature. So, in order to bring it to the required level that is required temperature suppose a material handles at 30 degree Celsius and in the storage facility the temperature is required to be maintained at 5 degree Celsius; so, whatever the heat is required to be removed to bring the material from 32 5 degree Celsius that is called chilling load.

The Q c can be calculated by the equation that is the m C p T 1 minus T 2 by t, where m is the mass of the product, C p is the mean specific heat of the product, T 1 minus T 2 is the initial and final temperature as I told you that from 30 to 5, then 30 minus 5 that is. So, it is T 1 minus T 2 is the temperature difference and of course the t is the chilling time. So, from this one can calculate the chilling load Q c.

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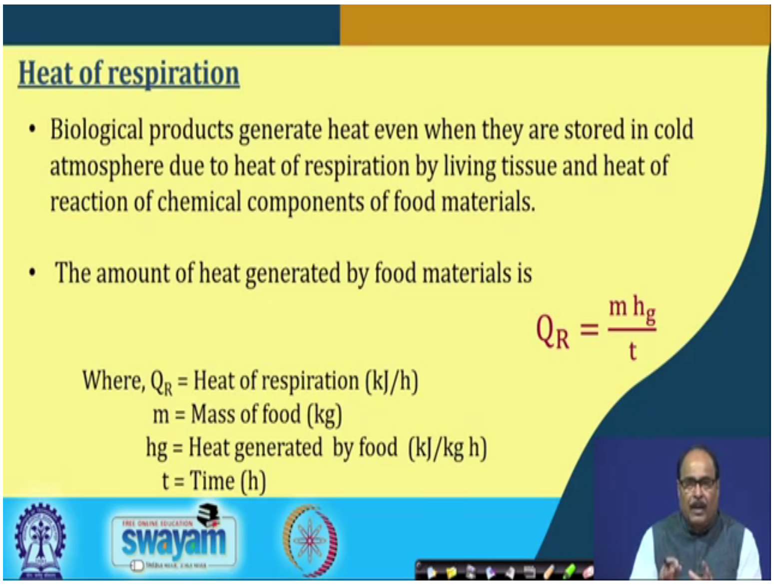

The heat of respiration as you all know you have seen in the earlier classes that all the biological materials, and they are put in the storage facility even inside this room, they generate heat all right, when they are stored even if they are stored in cold atmosphere. So they generate heat due to heat of respiration all right. And also there are certain chemical reactions which undergo inside the material. So, the chemical reactions also produce heat.

So, the amount of heat generated by the food material that is Q R may be equal to m h g by t, where m is the mass of the food, t is the time and h g is the heat generated by the food that is k j per kg hour, kilo joule per kg hour. So, from this one can find out what is the heat generated by the food or heat of respiration or total height of the chemical reactions etcetera.

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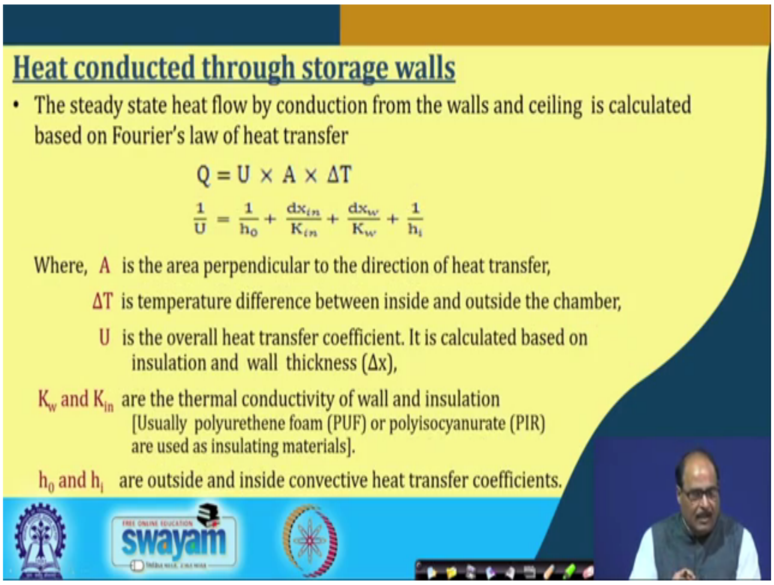

Then third component, heat conducted through the storage walls. And here the steady state heat flow by conduction from the walls and ceiling is calculated based upon the Fourier’s law of heat transfer which state that Q total heat transferred is equal to U A delta T, where A is the area perpendicular to the direction of heat transfer, delta T is the temperature difference between inside and outside temperature, U is the overall heat transfer coefficient.

And it is calculated based on insulation and wall thickness that 1 by U is 1 by h 0 plus d x i n by K i n plus d x w by K w plus 1 by h i, where K w and K i n are the thermal conductivities of the wall and insulation materials; h 0 and h 1 they are normally outside and inside convective heat transfer coefficients. So, from these values or these considerations, one can find out how much will be the total heat that will be conducted through the storage walls.

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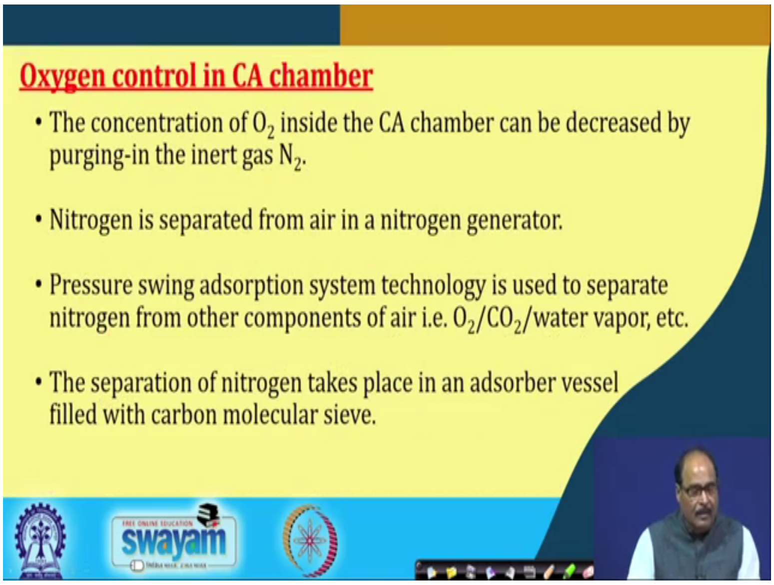

So, from these three finally the load heating load or cooling load of the refrigeration unit can be calculated. Now, second aspect is the oxygen control in the controlled atmosphere chamber. The concentration of oxygen inside the CA chamber can be decreased by purging-in the inert gas nitrogen, because here normally we are taking by some artificial means we try to create the conditions. So, nitrogen is separated from air in the nitrogen generator. Pressure swing adsorption system technology is generally used to separate nitrogen from other components of air that is O 2, CO 2 or water vapor etcetera. And the separation of nitrogen takes place in an adsorber vessel which is filled with carbon molecular sieve.

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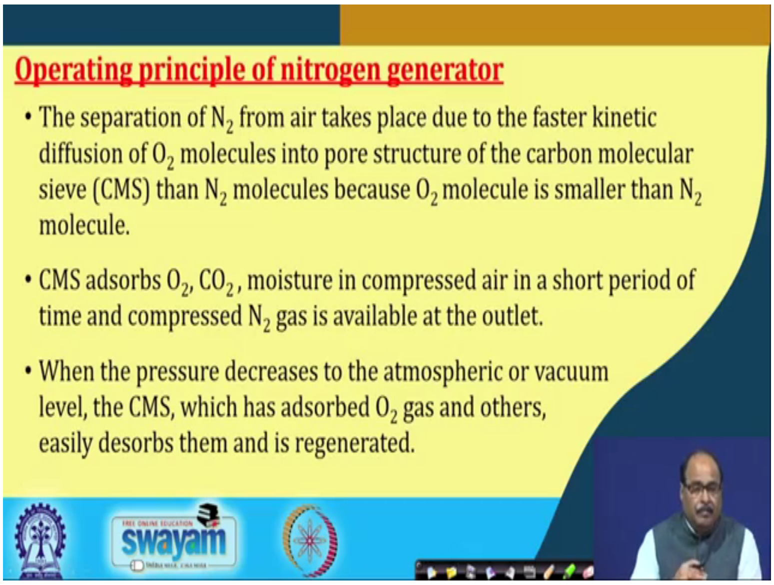

So, the operating principles of the nitrogen generator includes that the separation of nitrogen from air takes place due to the faster kinetic diffusion of oxygen molecules into the pore structure of the carbon molecule sieve that is normally called as CMS than the nitrogen molecules, because the oxygen molecule is smaller than the nitrogen molecule. CMS adsorbs oxygen, carbon dioxide, moisture in compressed air in a short period of time and compressed nitrogen gas is available at the outlet. When the pressure decreases to the atmospheric or vacuum level, the CMS, which has adsorbed oxygen gas and other, easily desorbs them and is regenerated. So, in the process that is the CMS gas regenerated, and the nitrogen production is continued.

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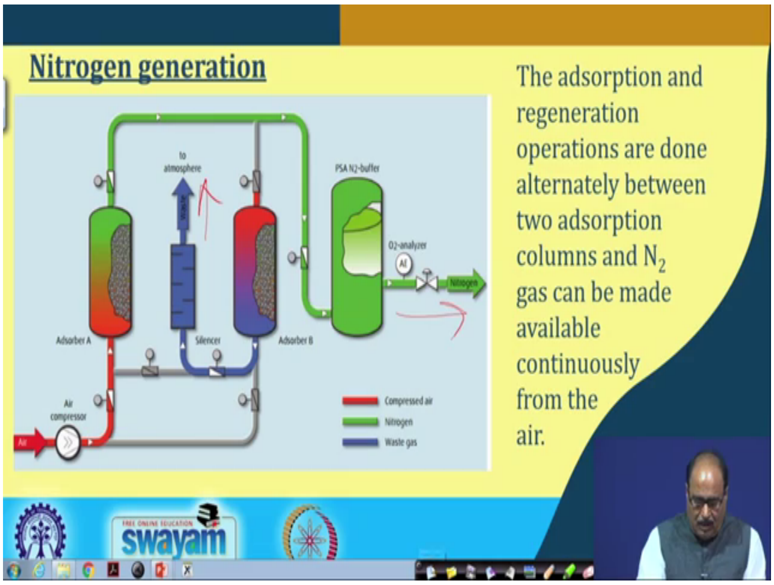

So, you can see here in this figure that is the nitrogen generator in the picture that is this green (Refer Time: 14:36) is known as the nitrogen gas, how the air is compressed air, red color is enters there are two adsorbers alright. So, how this nitrogen is separated from these adsorber system, that is adsorber and regeneration operations are done alternatively between two adsorption columns. And nitrogen gas is made available continuously from the air, and it is it is dispersed.

So, consider nitrogen gas is going, whereas the air is coming here. It goes through these two. And the waste gases etcetera they are allowed to escape to the atmosphere. So, in this process that is the nitrogen generators they work.

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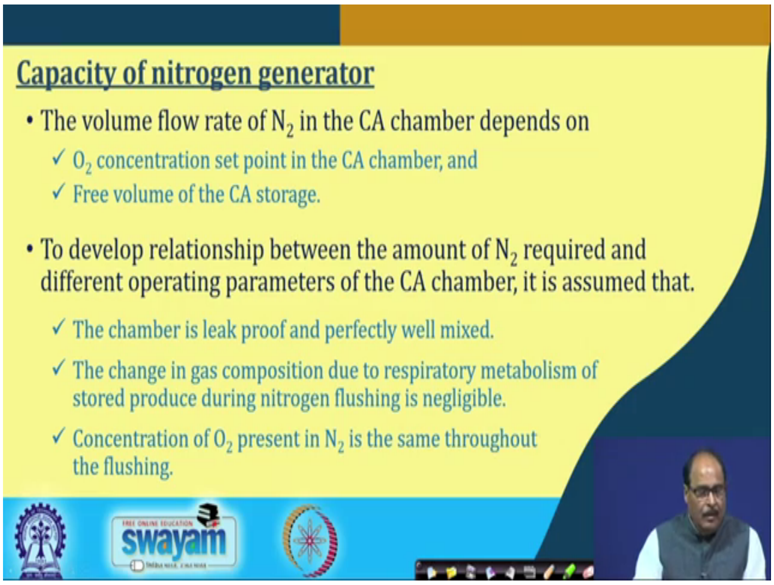

So, important factor is that how to calculate, how to decide the capacity of the nitrogen generator. So, the volume flow rate of nitrogen in the controlled atmosphere chamber depends upon oxygen concentration set point in the CA chamber and free volume of the CA chamber. So, to develop relationship between the amount of nitrogen required and different operating parameters of the CA chamber generally it is assumed that number one the chamber is leak proof and perfectly well mixed ok. The second assumption is the change in gas composition due to respiratory metabolism of stored product during nitrogen flushing is negligible. And third assumption is that concentration of O 2 present in nitrogen is the same throughout the flushing.

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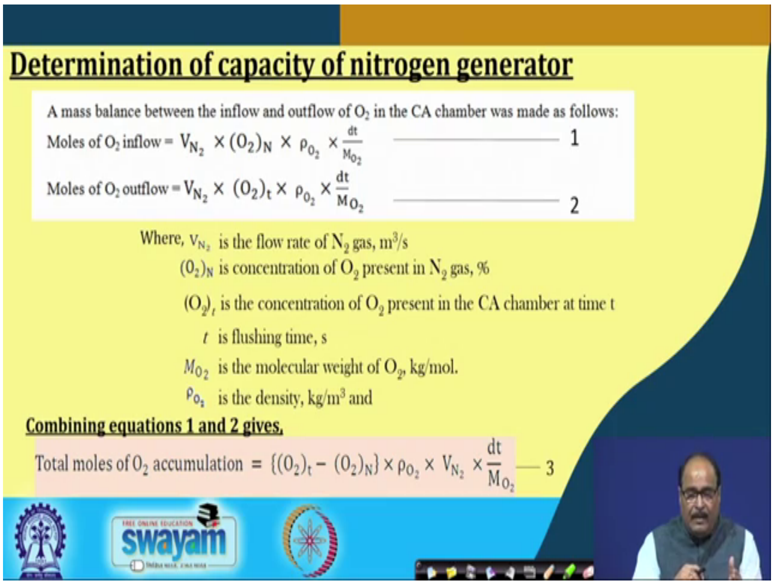

So, with these assumptions, one can determine the capacity of the nitrogen generator by calculating moles of O 2 that is oxygen inflow, and moles of oxygen outflow that is for the calculation of moles of oxygen inflow and outflow which are shown here in equations 1 and 2. That is the flow rate of the nitrogen that is concentration of oxygen present in nitrogen, concentration of oxygen present in CA chamber at time t, t is the flushing time molecular weight of oxygen and density of the oxygen these are taken into consideration.

For on these data, the inflow and outflow of O 2 in the CA chamber is calculated. And from these data, if we combine equation 1 and equation 2, you can get the find out one can calculate what is the total moles of oxygen accumulation that is total moles of oxygen accumulation is equal to O 2 t minus O 2 n multiplied by rho O 2 multiplied by V n 2 multiplied by d t by M O 2.

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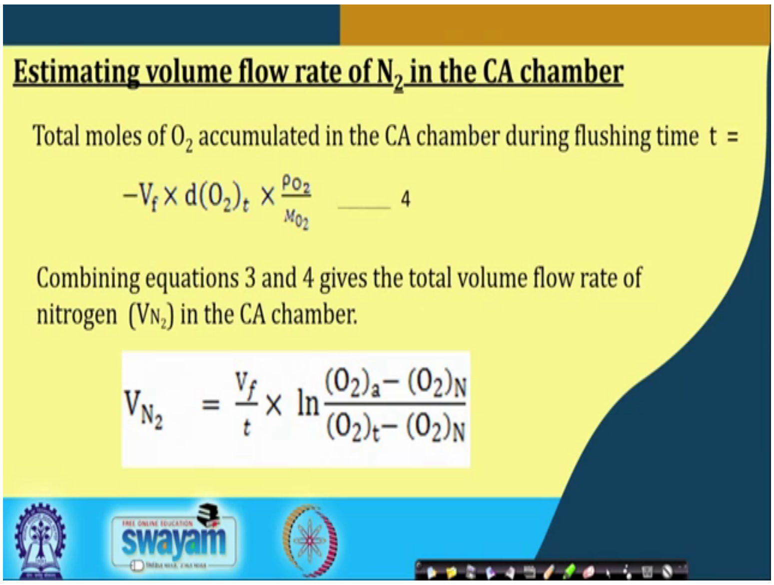

So, the equation 3 you get. From equation 3 total moles of O 2 accumulation can be. So, this total moles of O 2 accumulation in the CA chamber during flushing time t can be then calculated using equation 4. And one can combine by combining the equation 3 and equation 4, the total volume flow rate of the nitrogen in the controlled atmospheric chamber can be found out that is given by the equation V N 2 is equal to V f by t ln O 2 a minus O 2 n divided by O 2 2 minus O 2 n. So, from this, one can calculate what is the total volume flow rate of the nitrogen inside the controlled CA chamber.

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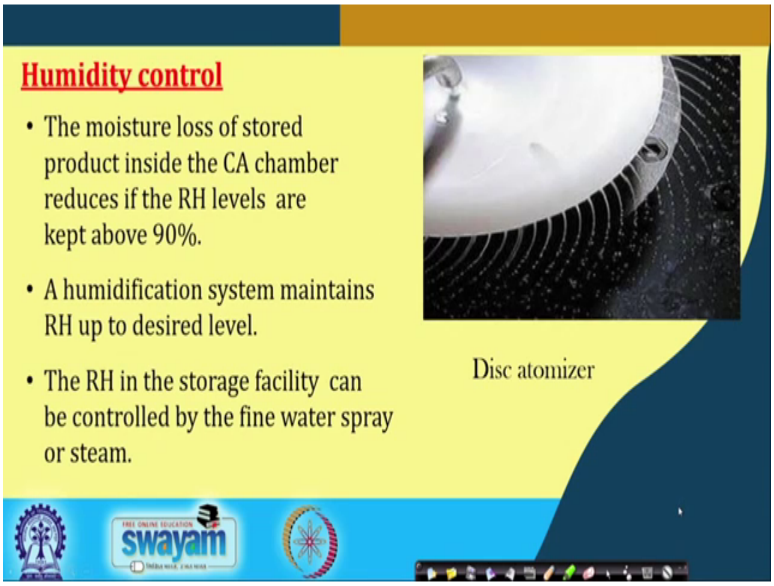

Then the next aspect is the humidity control that is the moisture loss of the stored product inside the CA chamber. If it is reduced below 90 percent, then there is a no significant weight loss. So, normally it is advisable that to make a constant weight of the material, the relative humidity alright should be above 90 percent. So, for this purpose, most of the CA units might require be provided with a suitable relative humidity or relative humidity maintaining system or humidification system right.

So, RH in the storage facility can be controlled by providing with the (Refer Time: 19:38), there are some water and then by having appropriate atomization system generally disc atomizer which you can see here, which sprinkles fine droplets of the water in the system and the humidity. So, either by water spray or by steam spray, the humidity that is depending upon whether you want more humidity in the system, you want less humidity in the system accordingly water spray or steam spray can be done.

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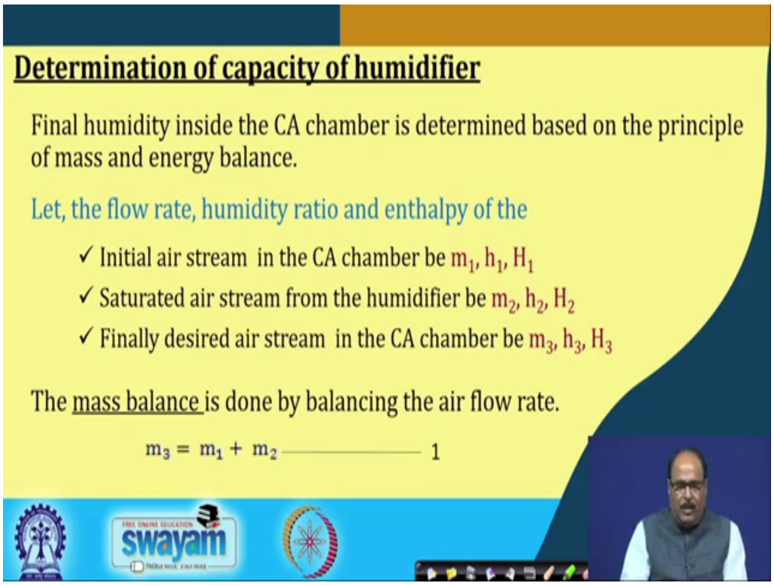

So, regarding the for the calculation of the capacity of the humidifier right, there is the inside the storage chamber, what should be the final humidity, it can be determined on the based of the energy balance as well as mass balance. So, if we assume that the flow rate, the humidity ratio and enthalpy ratio of the initial air stream in the CA chamber, saturated air stream from the humidifier and the desired air stream in the CA chamber. If these be m 1, h 1, H 1, and m 2, h 2, H 2, and m 3, h 3, H 3 respectively, then the mass balance can be done by balancing the air flow rate in the system, that is m 3 is equal to m

1 plus m 2; m 1 is the mass of the air stream in the CA chamber; m 3 is the mass of the finally desired air stream inside the CA chamber.

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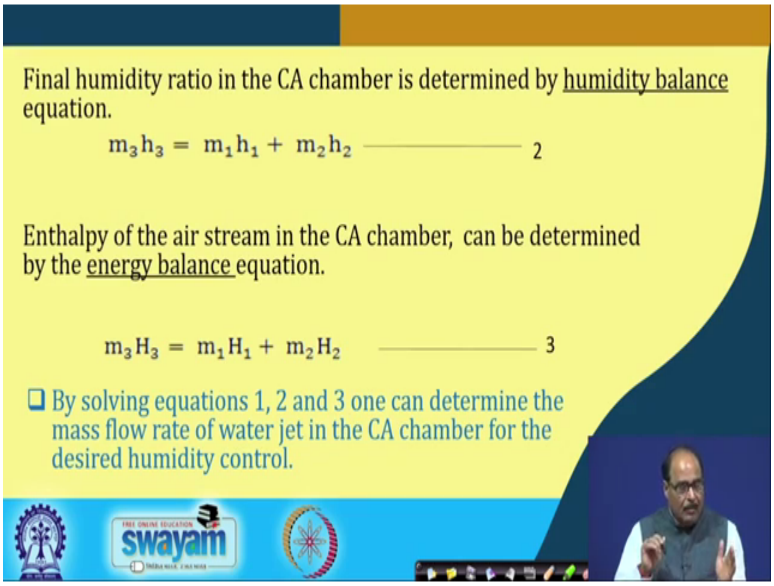

Similarly, the final humidity ratio in the CA chamber is determined by humidity balance equation m 3 H 3 is equal to m 1 H 1 plus m 2 H 2. The enthalpy of the air stream in the CA chamber can be determined by the energy balance equation that is m 3 H 3 is equal to m 1 H 1 plus m 2 H 2. And by solving these three equations that is the energy balance equations, humidity balance equation and mass balance equation, equation 1, 2 and 3, one can determine the mass flow rate of water jet in the CA chamber for the required or for the desired humidity control.

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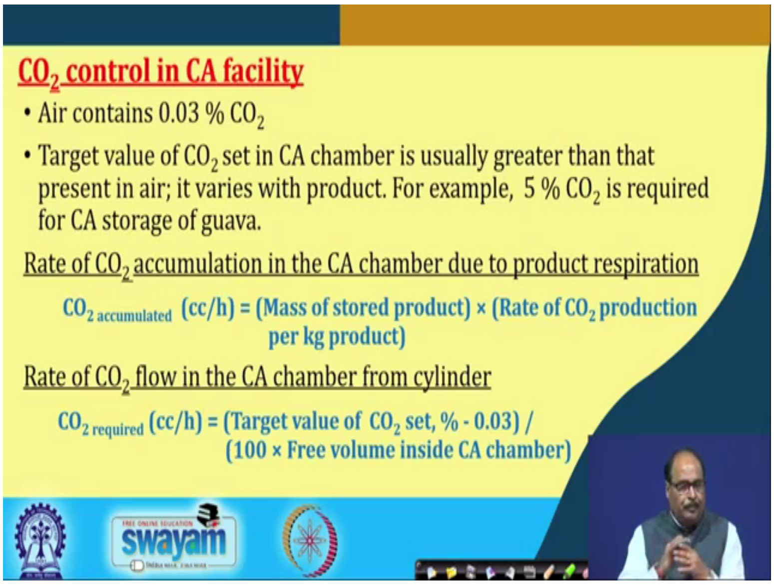

Then for the carbon dioxide control in the CA facility, I hope you all know that the air contains about 0.3 percent carbon dioxide. The target value of CO 2 which is set in the CA chamber is usually greater than that which is present in the air that is it is higher than the normal carbon dioxide concentration. And this required CO 2 level to be maintained, it depends upon product to product.

For example, for guava that is for the CA storage of guava normally 5 percent carbon dioxide in the storage atmosphere is maintained. Similarly, for banana, it may be different; for apple, it may be different. So, the rate of CO 2 accumulation in the CA chamber due to the product respiration because when the material respires it gives CO 2. So, the CO 2 accumulation is can be calculated. So, it will be CO 2 accumulated will be equal to mass of the stored product multiplied by rate of CO 2 production per kg product that is a rate that is per kg per hour.

Then similarly rate of CO 2 inflow in the CA chamber from the cylinder can be calculated from the CO 2 that is that is what the CO 2 required if the target level of CO 2 set percentage minus 0.03 divided by 100 into free volume inside the CA chamber.

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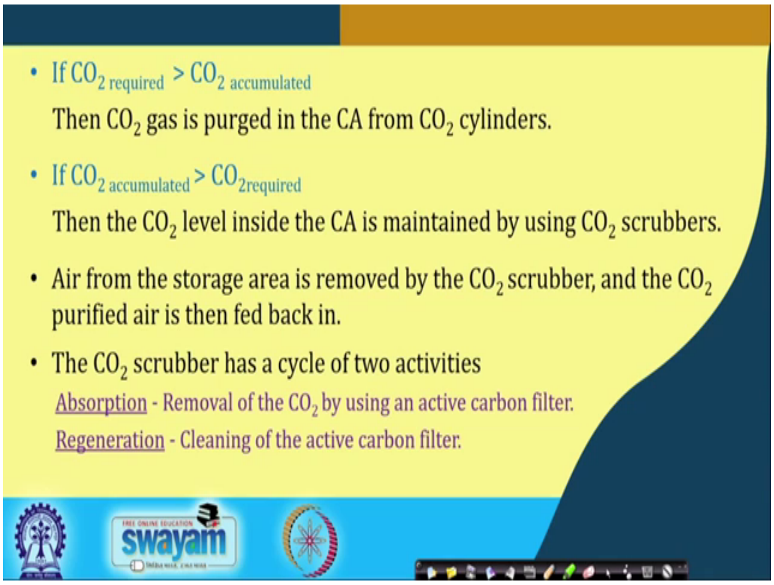

So, using these equations, one can calculate what is the CO 2 accumulated, what is the CO 2 required. And if CO 2 required is more than CO 2 accumulated, the carbon dioxide gas should be purged in the CA atmosphere from CO 2 cylinders which are provided in the storage facility. In case, if CO 2 required is less than the CO 2 accumulated, or in other words if CO 2 accumulated is more than the CO 2 required, then the CO 2 level inside this storage facility is maintained by using CO 2 scrubbers.

And we have what are different types of CO 2 scrubbers etcetera that is we have studied we have seen in the earlier class that is it the may worked on adsorption system or regeneration system, so that is important that is whether. So, both type of arrangement one should have that is CO for arrangement for removal of CO 2, arrangement for addition of CO 2, and as the case may be it should be accordingly maintained.

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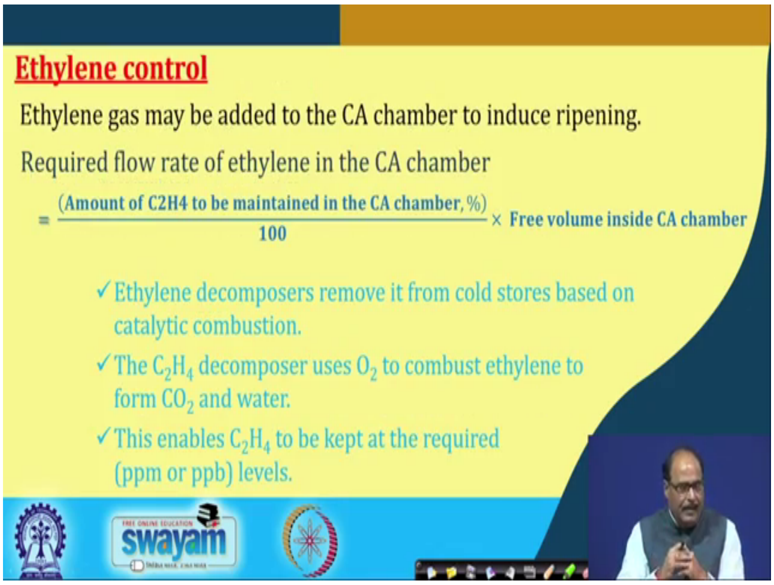

Then finally, the ethylene control because many a times it might be required to reduce the rate of ripening or to hasten the rate of ripening. So, accordingly the ethylene concentration of the ethylene gas inside the storage facility might be increased or concentration of ethylene gas inside the storage facility might be removed by having ethylene absorbers or giving ethylene gas cylinder connection etcetera as the case may be depending whether one wants to increase the rate of ripening or one want to decrease the rate of ripening.

So, the required flow rate of ethylene in the CA chamber can be calculated by equation that is the amount of ethylene to be maintained in the CA chamber that is the percent divided by 100 multiplied by free volume inside the CA chamber. Ethylene decomposers they are they can be used. These decomposers remove ethylene from the cold stores based on the catalytic combustion. The ethylene decomposers uses oxygen to combust ethylene to form carbon dioxide and water. And this enables ethylene to be kept at the required level whether it is ppb level or ppm level can be.

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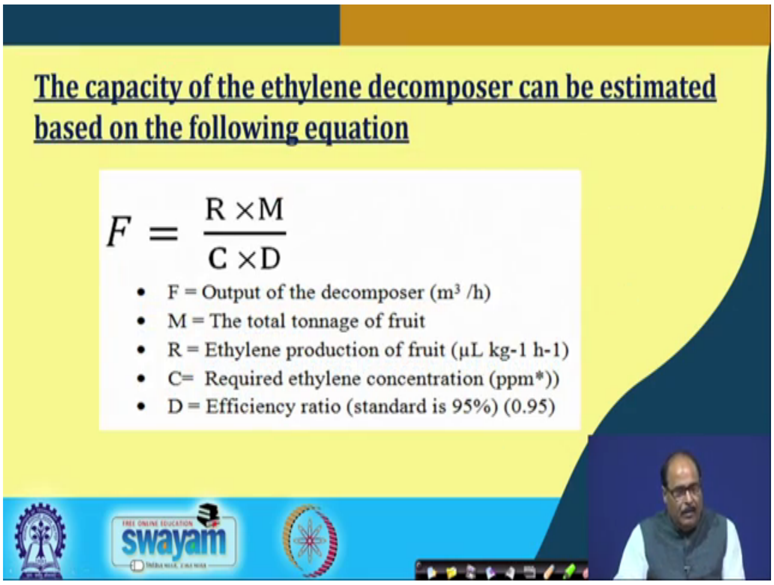

So, the capacity of the ethylene decomposer can be estimated from the equation F is equal to R M by C D. F is the output of the decomposer, M is the total tonnage in the fruit; R is the ethylene production of fruit; C is the required ethylene concentration, and D is the efficiency ratio which is 95 percent efficiency ratio is taken in general.

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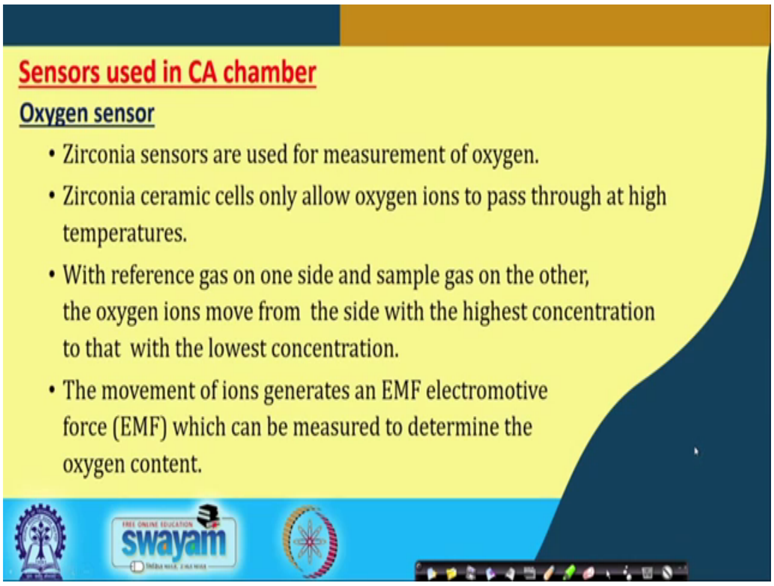

So, now the other important thing the sensors that is the system should be provided with the oxygen sensors, humidity sensor, ethylene sensors for sensing the oxygen concentration and indicating it, It is normally zirconia sensors are used for measurement of oxygens. Zirconia ceramic cells only allow oxygen ions to pass through at high temperature. With reference gas on one side and sample gas on the other, the oxygen ions move from the side with the higher concentration to that with the lowest concentration. The movement of ions generates an electromotive force which can be measured or which is measured to determine the oxygen content.

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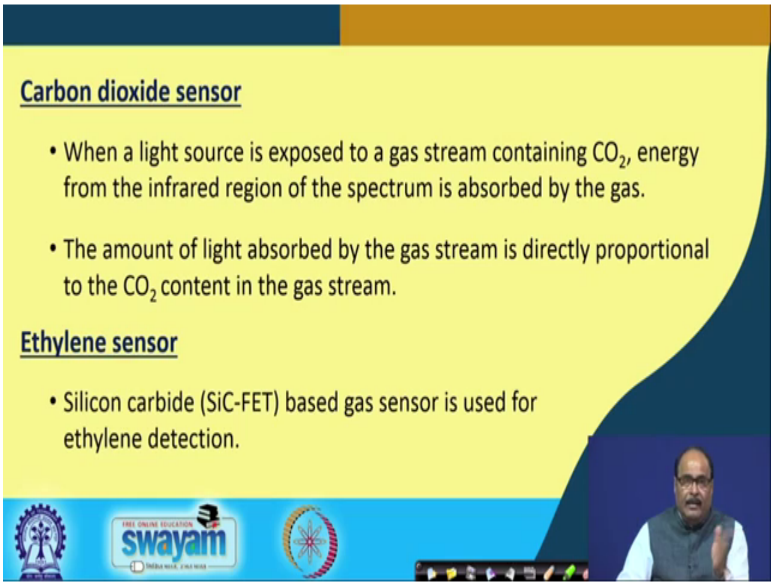

And then it indicated using different that is appropriate indicators. Similarly carbon dioxide sensor, when a light source is exposed to a gas stream containing carbon dioxide, energy from the infrared region of the spectrum is absorbed by the gas. And the amount of the light absorbed by the gas stream is directly proportional to the CO 2 content in the gas. Ethylene sensors are normally silicon carbide based gas sensors ok, which are used for the detection of ethylene.

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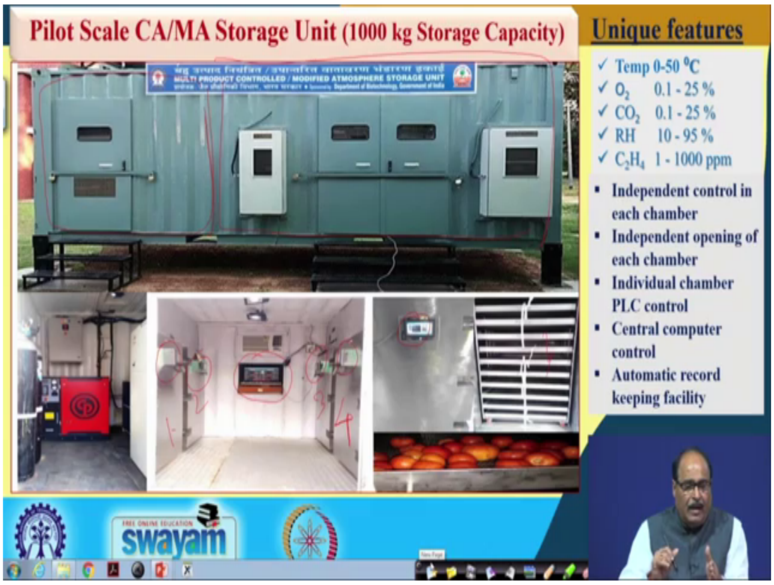

So, now all these components by taking into consideration, we in the agricultural and food engineering department at IIT Kharagpur have got one controlled and modified atmosphere storage unit made. And this is installed that is for this controlled and modified atmosphere unit multi-product control and modified atmosphere unit has the capacity to store 1000 kg of the fruit.

You can say the top it is the picture; and in the bottom there is lower part of the slide, it contain that is inside of the storage facility. That is this is a container, it can be just by putting an engine can be a movable storage facility, it can be made taken from there to for the collection of the materials alright. So, in one-third of the facility that is which you can see here inside that is all the instrumentation that is used, where nitrogen generator ethylene cylinder, carbon dioxide cylinders, etcetera are there in the top of the system. We have also provided with the water tank and electrical connections etcetera.

So, the one-third contains instrumentation. The second two-third of the system normally it is provided with the chambers. So, you say that inside there are four chamber basically 1, 2, 3 and 4 chambers. And all these four chambers that is in individual chambers they can keep 250 kg of individual fruits. So, these chambers they can be opened and closed individually or also they can be open and closed by a centralized system. They all the data that is respiration data and other data etcetera which can through that this can be is directly transfer to the computer, and we can even study that is how the respiration and other behaviour is taking place, how respiration etcetera weight loss and all those things taking place during the storage (Refer Time: 30:54)

That is here you see the inner view of one chamber that is in the chamber, there are trolleys different trolleys are provided, these trolleys. If one wants that is the material can be kept on the trace, and the trace we put on the trolleys, and trolleys can be trolley loaded with the materials can be put. Or if one wants to put these fruits or vegetable, another material into box etcetera, all these whole trolley system can be taken out, and bagged food or fruits vegetable in packets etcetera they can be put here.

Another that is individual chamber as you can see here the it is indicators are there that is individual chambers are provided with the indicators. And all these chambers that is the temperature from 0 to 50 degree Celsius, oxygen from 0.1 to 25 percent, CO 2 from 0.1 to 25 percent, relative humidity 10 to 95 percent, and ethylene from 1 to 1000 ppm. So, in all these chambers that is any combination and permutations of these that is the gases oxygen, CO 2 and ethylene, and temperature and relative humidity can be maintained that is the in different chambers different combination of these can be maintained in all the four chambers same combinations can be maintained right.

Depending upon whether you want to store that is the same material in all the chambers can be done or different material. In chamber 1, we can have tomato; in chamber 2, one can have apple; in chamber 3, one can have other fruit or other food material and accordingly the conditions can. So, the gaseous composition, temperature, relative humidity, etcetera that can be controlled as per the desired level, whether you want to facilitate the ripening of the fruit, whether one wants to delay the ripening of the food to increase the shelf life.

So, accordingly what is required thing, accordingly the conditions can be kept and even it has been provided with the automatic record keeping facility the system. So, this is your our multi product CA and MA storage unit which is fabricated and installed in our department. So, with this I thank you very much for your patience hearing.

Thank you.