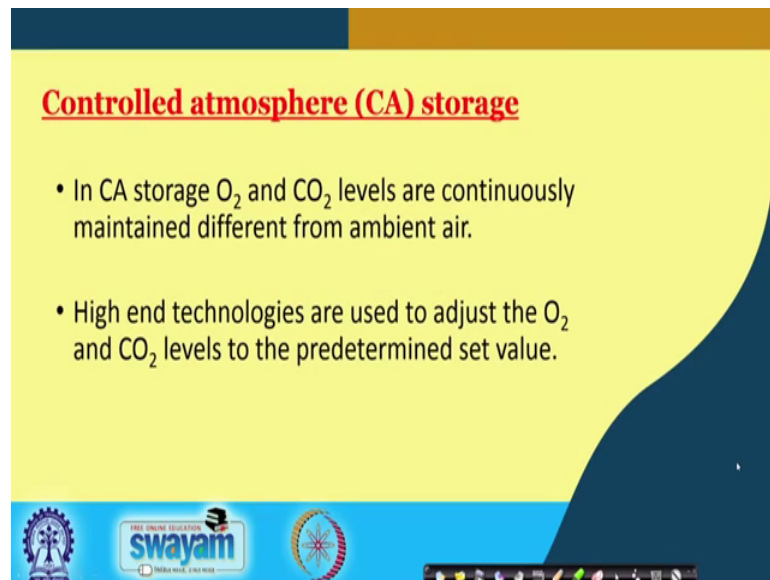


Novel Technologies for Food Processing and Shelf Life Extension
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Lecture - 44
Multiproduct CA/MA Storage Unit

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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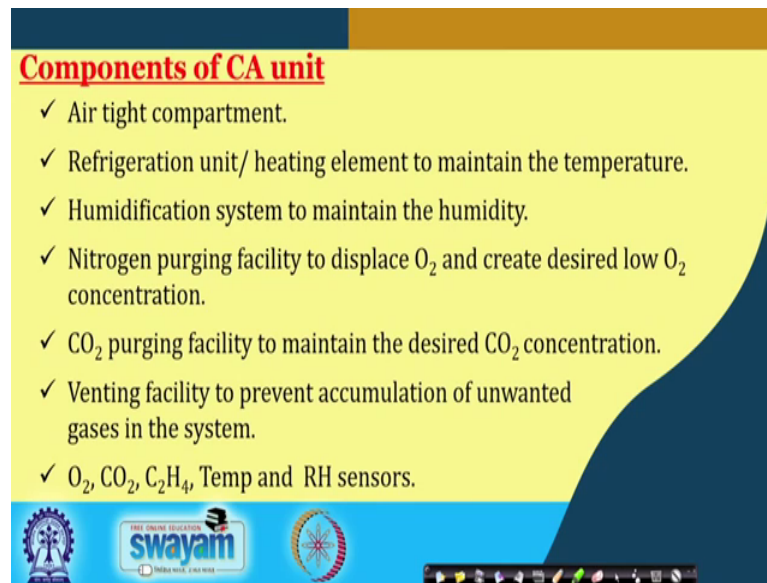
Controlled atmosphere (CA) storage

- In CA storage O_2 and CO_2 levels are continuously maintained different from ambient air.
- High end technologies are used to adjust the O_2 and CO_2 levels to the predetermined set value.

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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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Components of CA unit

- ✓ Air tight compartment.
- ✓ Refrigeration unit/ heating element to maintain the temperature.
- ✓ Humidification system to maintain the humidity.
- ✓ Nitrogen purging facility to displace O_2 and create desired low O_2 concentration.
- ✓ CO_2 purging facility to maintain the desired CO_2 concentration.
- ✓ Venting facility to prevent accumulation of unwanted gases in the system.
- ✓ O_2 , CO_2 , C_2H_4 , Temp and RH sensors.

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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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Two types of CA chambers are commonly used

- ✓ Palliflex unit
- ✓ Air-tight compartment

Advantage
Different gas conditions can be set per pallet in the same chamber.

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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Palliflex unit contains

- A special plastic pallet
- A plastic cover for gas-tight sealing
- Bottles of nitrogen (N_2) for O_2 reduction
- Bottles of CO_2
- Gas inlet and outlet hoses
- A fully automatic measuring and regulation system with a built-in O_2/CO_2 meter.

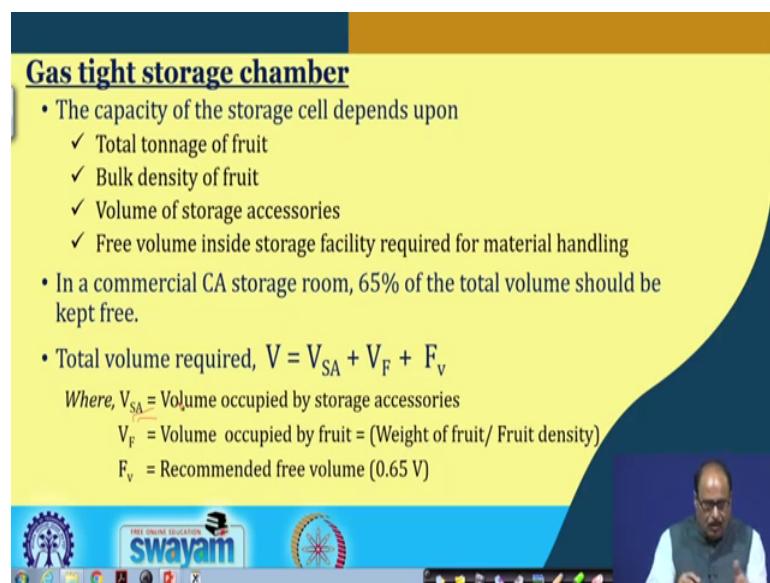
Advantage
Different gas conditions can be set per pallet in the same chamber.

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 of 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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Gas tight storage chamber

- The capacity of the storage cell depends upon
 - ✓ Total tonnage of fruit
 - ✓ Bulk density of fruit
 - ✓ Volume of storage accessories
 - ✓ Free volume inside storage facility required for material handling
- In a commercial CA storage room, 65% of the total volume should be kept free.
- Total volume required, $V = V_{SA} + V_F + F_V$
Where, V_{SA} = Volume occupied by storage accessories
 V_F = Volume occupied by fruit = (Weight of fruit/ Fruit density)
 F_V = Recommended free volume (0.65 V)

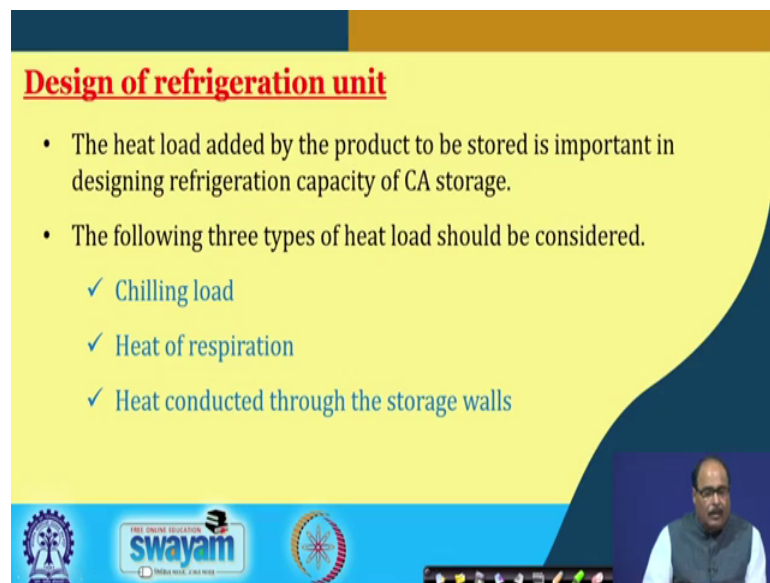
The other system with the gas tight storage chamber; the capacity of the storage chamber will depend upon the tonnage of the fruit that is what is the quantity of the fruit should which is a required to be kept or quantity of the other food materials required to be kept, bulk density of the food, volume 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 of 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 unit 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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Design of refrigeration unit

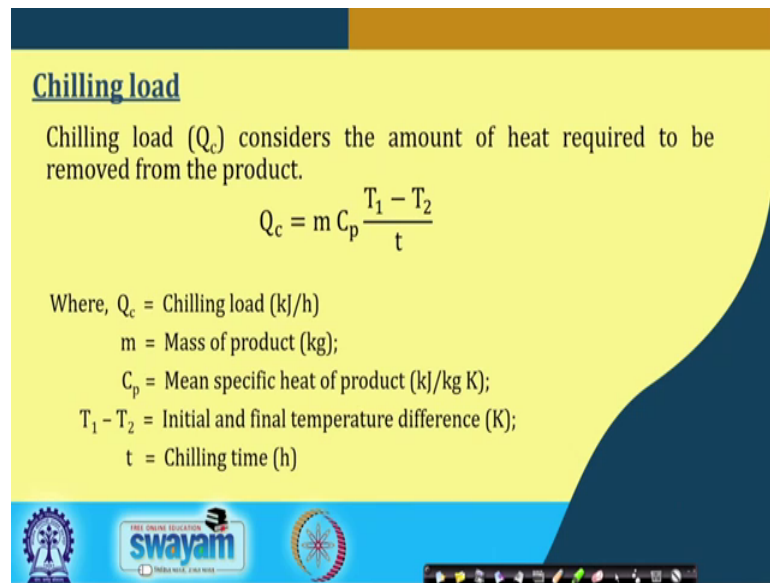
- The heat load added by the product to be stored is important in designing refrigeration capacity of CA storage.
- The following three types of heat load should be considered.
 - ✓ Chilling load
 - ✓ Heat of respiration
 - ✓ Heat conducted through the storage walls

The slide features a yellow background with a dark blue curved shape on the right side. At the bottom, there are logos for 'swayam' and 'INDIAN INSTITUTE OF TECHNOLOGY KANPUR', along with a small video inset of a man in a white shirt and dark vest.

Now, let us discuss one by one what are the various aspect like heating system, CO₂ generating system, O₂ 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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Chilling load

Chilling load (Q_c) considers the amount of heat required to be removed from the product.

$$Q_c = m C_p \frac{T_1 - T_2}{t}$$

Where, Q_c = Chilling load (kJ/h)
 m = Mass of product (kg);
 C_p = Mean specific heat of product (kJ/kg K);
 $T_1 - T_2$ = Initial and final temperature difference (K);
 t = Chilling time (h)

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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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Heat of respiration

- Biological products generate heat even when they are stored in cold atmosphere due to heat of respiration by living tissue and heat of reaction of chemical components of food materials.
- The amount of heat generated by food materials is

$$Q_R = \frac{m h_g}{t}$$

Where, Q_R = Heat of respiration (kJ/h)
 m = Mass of food (kg)
 h_g = Heat generated by food (kJ/kg h)
 t = Time (h)

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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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Heat conducted through storage walls

- The steady state heat flow by conduction from the walls and ceiling is calculated based on Fourier's law of heat transfer

$$Q = U \times A \times \Delta T$$
$$\frac{1}{U} = \frac{1}{h_o} + \frac{d_{s_{in}}}{K_{in}} + \frac{d_{s_w}}{K_w} + \frac{1}{h_i}$$

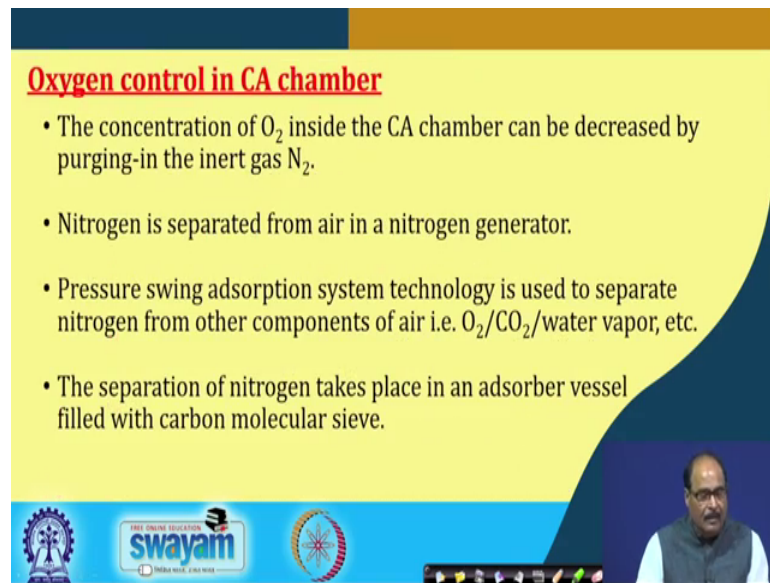
Where, A is the area perpendicular to the direction of heat transfer,
 ΔT is temperature difference between inside and outside the chamber,
 U is the overall heat transfer coefficient. It is calculated based on insulation and wall thickness (Δx),
 K_w and K_{in} are the thermal conductivity of wall and insulation
[Usually polyurethane foam (PUF) or polyisocyanurate (PIR) are used as insulating materials].
 h_o and h_i are outside and inside convective heat transfer coefficients.



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, ΔT 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 $\frac{1}{U}$ is $\frac{1}{h_o}$ plus $\frac{d_{in}}{K_{in}}$ plus $\frac{d_w}{K_w}$ plus $\frac{1}{h_i}$, where K_w and K_{in} are the thermal conductivities of the wall and insulation materials; h_o and h_i 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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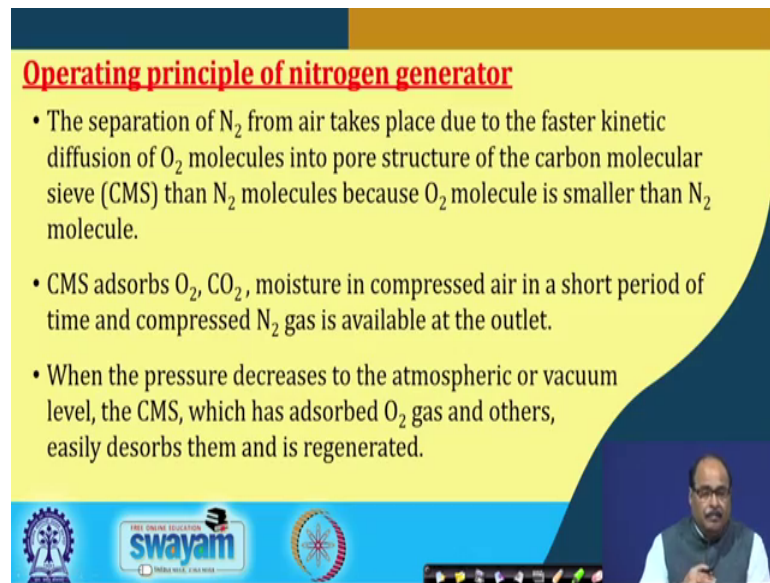
Oxygen control in CA chamber

- The concentration of O_2 inside the CA chamber can be decreased by purging-in the inert gas N_2 .
- Nitrogen is separated from air in a nitrogen generator.
- Pressure swing adsorption system technology is used to separate nitrogen from other components of air i.e. O_2/CO_2 /water vapor, etc.
- The separation of nitrogen takes place in an adsorber vessel filled with carbon molecular sieve.

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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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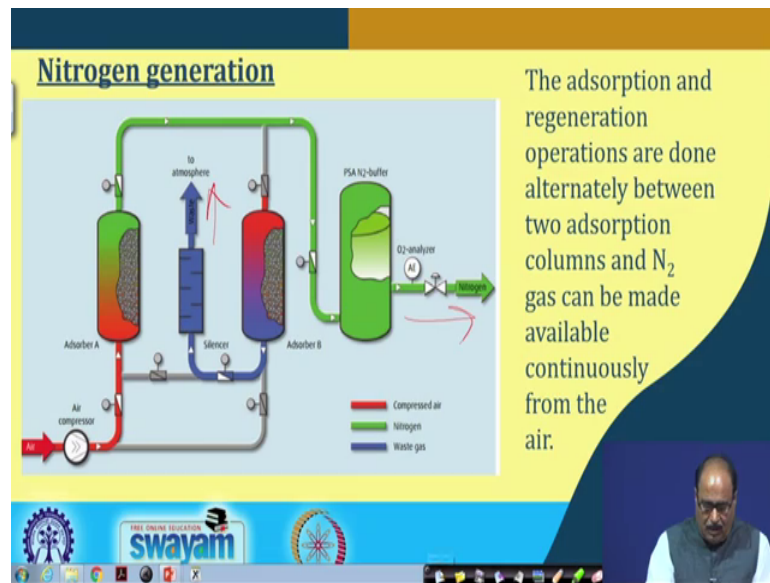
Operating principle of nitrogen generator

- The separation of N_2 from air takes place due to the faster kinetic diffusion of O_2 molecules into pore structure of the carbon molecular sieve (CMS) than N_2 molecules because O_2 molecule is smaller than N_2 molecule.
- CMS adsorbs O_2 , CO_2 , moisture in compressed air in a short period of time and compressed N_2 gas is available at the outlet.
- When the pressure decreases to the atmospheric or vacuum level, the CMS, which has adsorbed O_2 gas and others, easily desorbs them and is regenerated.

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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.

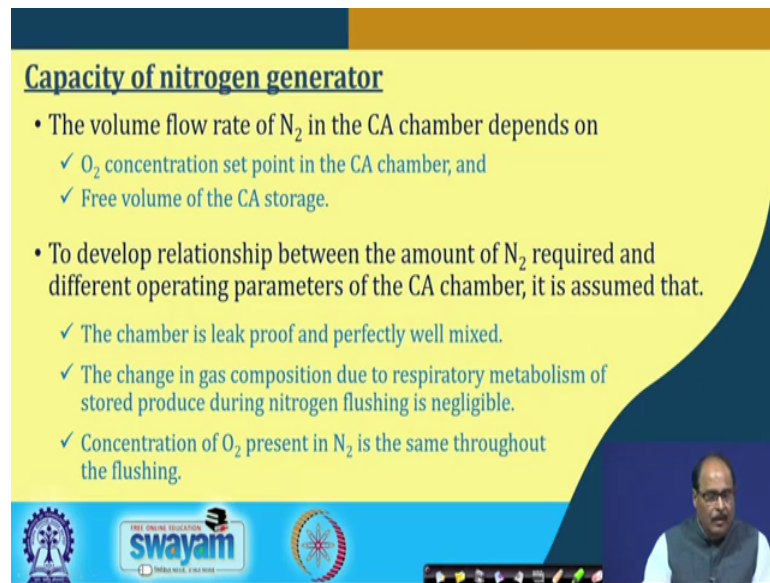
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So, you can see here in this figure that is the nitrogen generator in the picture that is this green (Refer Time: 14:36) is known as the nitrogen gas, how the air is compressed air, red color is enters there are two adsorbers alright. So, how this 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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Capacity of nitrogen generator

- The volume flow rate of N_2 in the CA chamber depends on
 - ✓ O_2 concentration set point in the CA chamber, and
 - ✓ Free volume of the CA storage.
- To develop relationship between the amount of N_2 required and different operating parameters of the CA chamber, it is assumed that.
 - ✓ The chamber is leak proof and perfectly well mixed.
 - ✓ The change in gas composition due to respiratory metabolism of stored produce during nitrogen flushing is negligible.
 - ✓ Concentration of O_2 present in N_2 is the same throughout the flushing.

The slide also features the Swamyam logo and a small video feed of a presenter in the bottom right corner.

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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Determination of capacity of nitrogen generator

A mass balance between the inflow and outflow of O₂ in the CA chamber was made as follows:

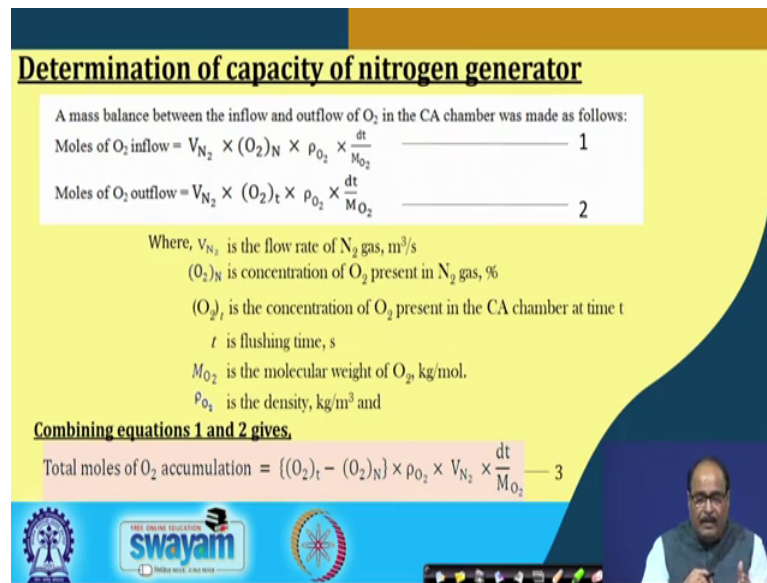
Moles of O₂ inflow = $V_{N_2} \times (O_2)_N \times \rho_{O_2} \times \frac{dt}{M_{O_2}}$ ————— 1

Moles of O₂ outflow = $V_{N_2} \times (O_2)_t \times \rho_{O_2} \times \frac{dt}{M_{O_2}}$ ————— 2

Where, V_{N_2} is the flow rate of N₂ gas, m³/s
(O₂)_N is concentration of O₂ present in N₂ gas, %
(O₂)_t is the concentration of O₂ present in the CA chamber at time t
 t is flushing time, s
 M_{O_2} is the molecular weight of O₂, kg/mol.
 ρ_{O_2} is the density, kg/m³ and

Combining equations 1 and 2 gives,

Total moles of O₂ accumulation = $\{(O_2)_t - (O_2)_N\} \times \rho_{O_2} \times V_{N_2} \times \frac{dt}{M_{O_2}}$ — 3



So, with these assumptions, one can determine the capacity of the nitrogen generator by calculating moles of O₂ 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 O₂ 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 O₂ t minus O₂ n multiplied by rho O₂ multiplied by V n 2 multiplied by d t by M O₂.


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Estimating volume flow rate of N₂ in the CA chamber

Total moles of O₂ accumulated in the CA chamber during flushing time t =

$$-V_f \times d(O_2)_t \times \frac{P_{O_2}}{M_{O_2}} \quad \text{--- 4}$$

Combining equations 3 and 4 gives the total volume flow rate of nitrogen (V_{N₂}) in the CA chamber.


$$V_{N_2} = \frac{V_f}{t} \times \ln \frac{(O_2)_a - (O_2)_N}{(O_2)_t - (O_2)_N}$$


So, the equation 3 you get. From equation 3 total moles of O₂ accumulation can be. So, this total moles of O₂ 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_{N₂} is equal to V_f by t ln O₂ a minus O₂ n divided by O₂ 2 minus O₂ 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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Humidity control

- The moisture loss of stored product inside the CA chamber reduces if the RH levels are kept above 90%.
- A humidification system maintains RH up to desired level.
- The RH in the storage facility can be controlled by the fine water spray or steam.



Disc atomizer



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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Determination of capacity of humidifier

Final humidity inside the CA chamber is determined based on the principle of mass and energy balance.

Let, the flow rate, humidity ratio and enthalpy of the

- ✓ Initial air stream in the CA chamber be m_1, h_1, H_1
- ✓ Saturated air stream from the humidifier be m_2, h_2, H_2
- ✓ Finally desired air stream in the CA chamber be m_3, h_3, H_3

The mass balance is done by balancing the air flow rate.

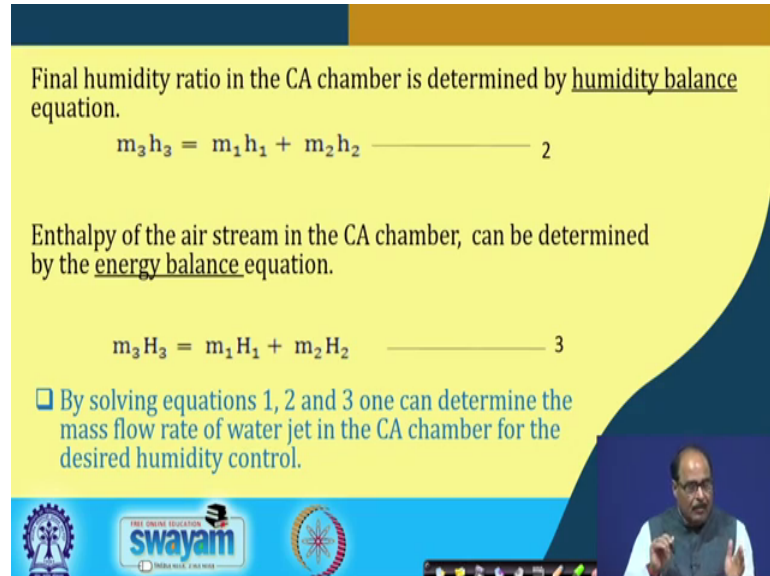
$$m_3 = m_1 + m_2 \text{ ————— } 1$$

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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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Final humidity ratio in the CA chamber is determined by humidity balance equation.

$$m_3 h_3 = m_1 h_1 + m_2 h_2 \quad \text{-----} \quad 2$$

Enthalpy of the air stream in the CA chamber, can be determined by the energy balance equation.

$$m_3 H_3 = m_1 H_1 + m_2 H_2 \quad \text{-----} \quad 3$$

□ By solving equations 1, 2 and 3 one can determine the mass flow rate of water jet in the CA chamber for the desired humidity control.

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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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CO₂ control in CA facility

- Air contains 0.03 % CO₂
- Target value of CO₂ set in CA chamber is usually greater than that present in air; it varies with product. For example, 5 % CO₂ is required for CA storage of guava.

Rate of CO₂ accumulation in the CA chamber due to product respiration

$$\text{CO}_2 \text{ accumulated (cc/h)} = (\text{Mass of stored product}) \times (\text{Rate of CO}_2 \text{ production per kg product})$$

Rate of CO₂ flow in the CA chamber from cylinder

$$\text{CO}_2 \text{ required (cc/h)} = \frac{(\text{Target value of CO}_2 \text{ set, \%} - 0.03)}{(100 \times \text{Free volume inside CA chamber})}$$

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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 CO₂ 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 CO₂ 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 CO₂ accumulation in the CA chamber due to the product respiration because when the material respire it gives CO₂. So, the CO₂ accumulation is can be calculated. So, it will be CO₂ accumulated will be equal to mass of the stored product multiplied by rate of CO₂ production per kg product that is a rate that is per kg per hour.

Then similarly rate of CO₂ inflow in the CA chamber from the cylinder can be calculated from the CO₂ that is that is what the CO₂ required if the target level of CO₂ set percentage minus 0.03 divided by 100 into free volume inside the CA chamber.

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- If $CO_2 \text{ required} > CO_2 \text{ accumulated}$
Then CO_2 gas is purged in the CA from CO_2 cylinders.
- If $CO_2 \text{ accumulated} > CO_2 \text{ required}$
Then the CO_2 level inside the CA is maintained by using CO_2 scrubbers.
- Air from the storage area is removed by the CO_2 scrubber, and the CO_2 purified air is then fed back in.
- The CO_2 scrubber has a cycle of two activities
Absorption - Removal of the CO_2 by using an active carbon filter.
Regeneration - Cleaning of the active carbon filter.

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 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_2 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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Ethylene control

Ethylene gas may be added to the CA chamber to induce ripening.

Required flow rate of ethylene in the CA chamber

$$= \frac{(\text{Amount of } C_2H_4 \text{ to be maintained in the CA chamber, \%})}{100} \times \text{Free volume inside CA chamber}$$

- ✓ Ethylene decomposers remove it from cold stores based on catalytic combustion.
- ✓ The C_2H_4 decomposer uses O_2 to combust ethylene to form CO_2 and water.
- ✓ This enables C_2H_4 to be kept at the required (ppm or ppb) levels.

Logos: Swamyam, IIT Bombay, IIT Madras, IIT Kharagpur, IIT Gandhinagar, IIT Roorkee, IIT Varanasi, IIT Patna, IIT Jodhpur, IIT Guwahati, IIT Mandla, IIT Raipur, IIT Durgam, IIT Palakkad, IIT Tirupur, IIT Thiruvananthapuram, IIT Hyderabad, IIT Gandhinagar, IIT Roorkee, IIT Varanasi, IIT Patna, IIT Jodhpur, IIT Guwahati, IIT Mandla, IIT Raipur, IIT Durgam, IIT Palakkad, IIT Tirupur, IIT Thiruvananthapuram, IIT Hyderabad.

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.

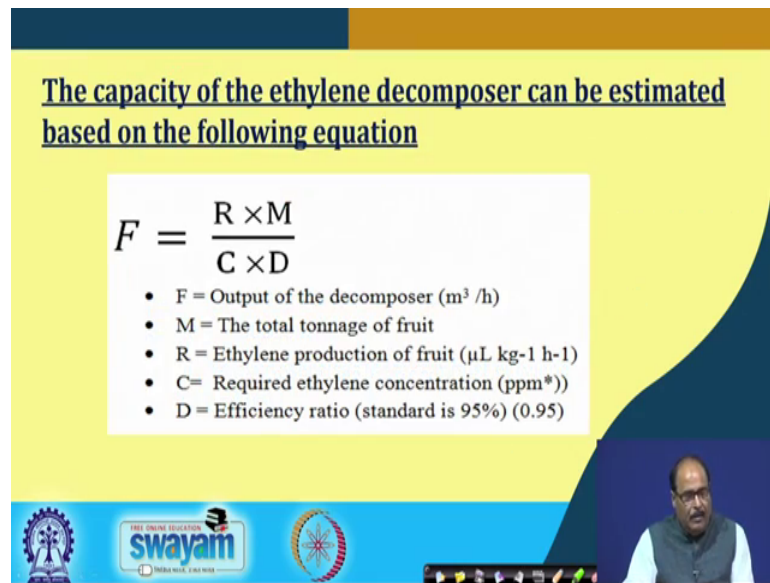
So, the required flow rate of ethylene in the CA chamber can be calculated by equation that is the amount of ethylene to be maintained in the CA chamber that is the percent divided by 100 multiplied by free volume inside the CA chamber. Ethylene decomposers they are they can be used. These decomposers 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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The capacity of the ethylene decomposer can be estimated based on the following equation

$$F = \frac{R \times M}{C \times D}$$

- F = Output of the decomposer (m³ /h)
- M = The total tonnage of fruit
- R = Ethylene production of fruit (μL kg-1 h-1)
- C= Required ethylene concentration (ppm*)
- D = Efficiency ratio (standard is 95%) (0.95)



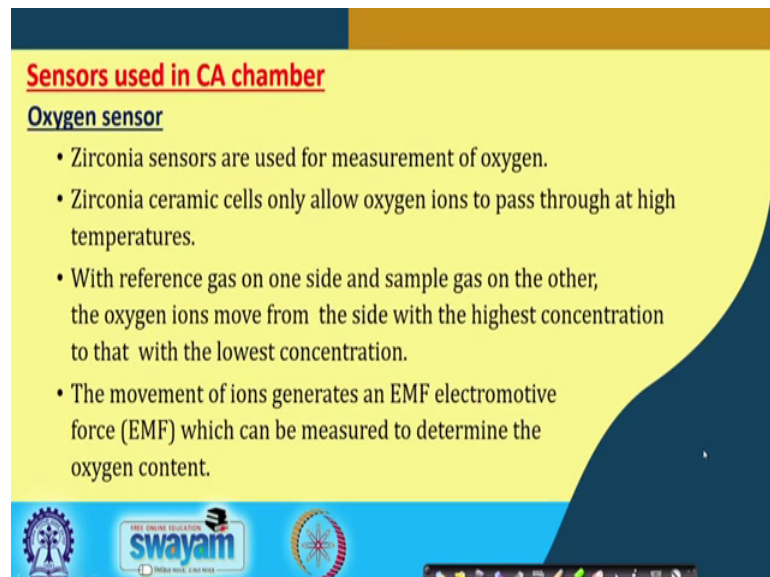
So, the capacity of the ethylene decomposer can be estimated from the equation $F = \frac{R \times M}{C \times D}$. F is the output of the decomposer, M is the total tonnage in the fruit; R is the ethylene production of fruit; C is the required ethylene concentration, and D is the efficiency ratio which is 95 percent efficiency ratio is taken in general.

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Sensors used in CA chamber

Oxygen sensor

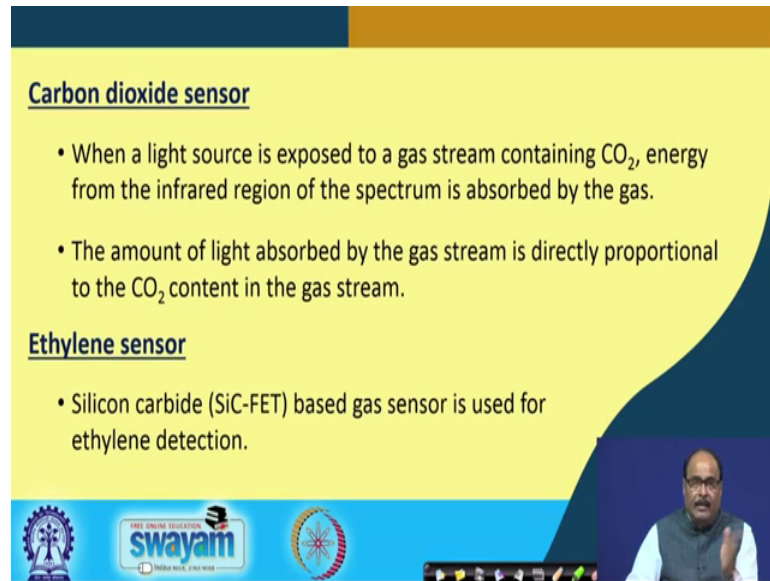
- Zirconia sensors are used for measurement of oxygen.
- Zirconia ceramic cells only allow oxygen ions to pass through at high temperatures.
- With reference gas on one side and sample gas on the other, the oxygen ions move from the side with the highest concentration to that with the lowest concentration.
- The movement of ions generates an EMF electromotive force (EMF) which can be measured to determine the oxygen content.



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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Carbon dioxide sensor

- When a light source is exposed to a gas stream containing CO₂, energy from the infrared region of the spectrum is absorbed by the gas.
- The amount of light absorbed by the gas stream is directly proportional to the CO₂ content in the gas stream.

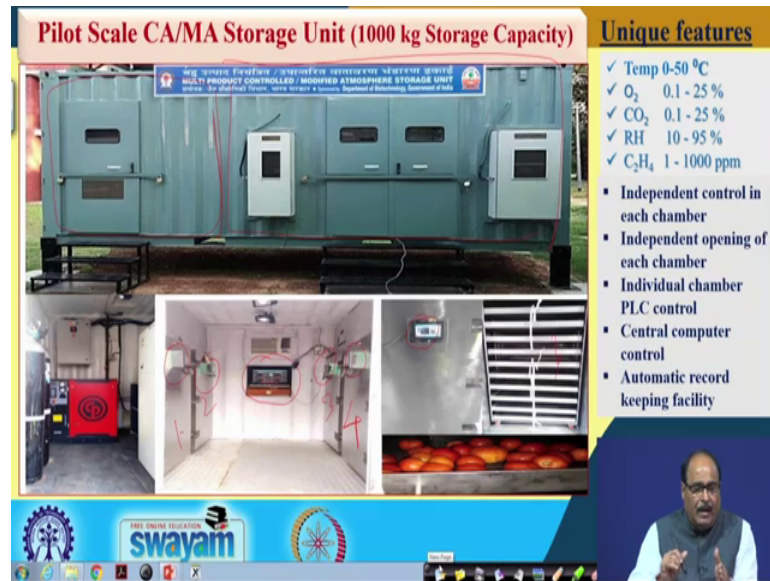
Ethylene sensor

- Silicon carbide (SiC-FET) based gas sensor is used for ethylene detection.

The slide footer includes the 'swayam' logo and a small video inset of a man in a white shirt and dark vest speaking.

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 CO₂ 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 trolley, and the trolley 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, CO₂ 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, CO₂ 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.