Chemical Process Safety
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Lecture 28
Designs to Prevent Fire & Explosion: Inerting & Purging

Welcome to the new lecture that is the design to prevent fire and explosions, so up till now in the different modules we have studied different type of fires and explosion, we have classified them, we have find out that what are the causes for those fires whether it is a positive sense or in a negative sense. Now, since we all agree upon that these fires and explosion are extremely destructive in nature, so we must design the system through which we can prevent the hazard of fire and explosion.

So, in these this particular chapter we will discuss all the aspect that how we can prevent the fire and explosion though theoretically we know we all agree upon that if you remove any arm of a fire triangle then definitely we can extinguish the fire, but sometimes it is not at all feasible. So how we can design the system in such a way that we can prevent the hazard of fire and explosion? So, in this particular chapter we will discuss this type of things in different modules.

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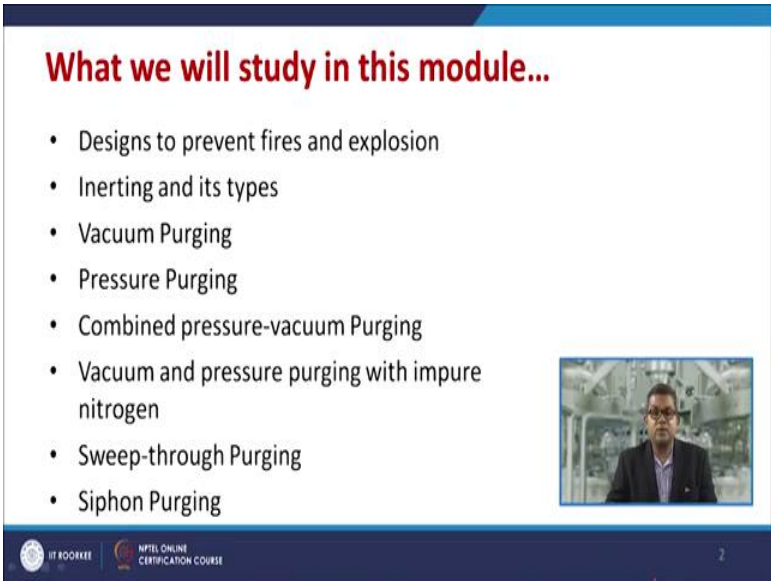

So, in this particular module we are going to study the design to prevent the fire explosion systems, how we can design it, different type of inerting, vacuum purging, pressure purging, combined pressure and vacuum purging, vacuum and pressure purging with impure nitrogen, sweep through purging and siphon purging.

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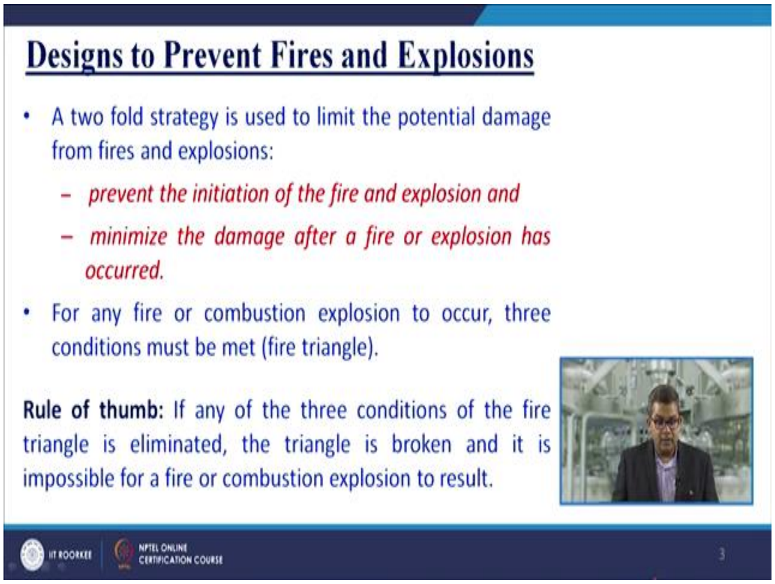

Now, first of all let us have a discussion about how to prevent the fire and explosion. Usually a twofold strategy is used to limit the potential damage from fires and explosion. One is the prevent the initiation of fire and explosion obviously this is one of the foremost requirement and the second is that minimize the damage after a fire or explosion has occurred. For any fire or combustion explosion to occur, three conditions must be met.

Please recall the fire triangle that fuel, source of ignition and supply of Oxygen and after this to sustain the fire net chemical reaction that obviously in terms of combustion. So, if we wish to make the system safer and if we cannot avoid the generation of fire, then we must to design the system accordingly.

The rule of thumb says if any of three condition of fire triangle is eliminated the triangle is broken and it is impossible for a fire or combustion and explosion to result or to sustain. So, this is the theoretical aspect, so while designing the prevention methodology for fire and explosion we must keep this thing in our mind.

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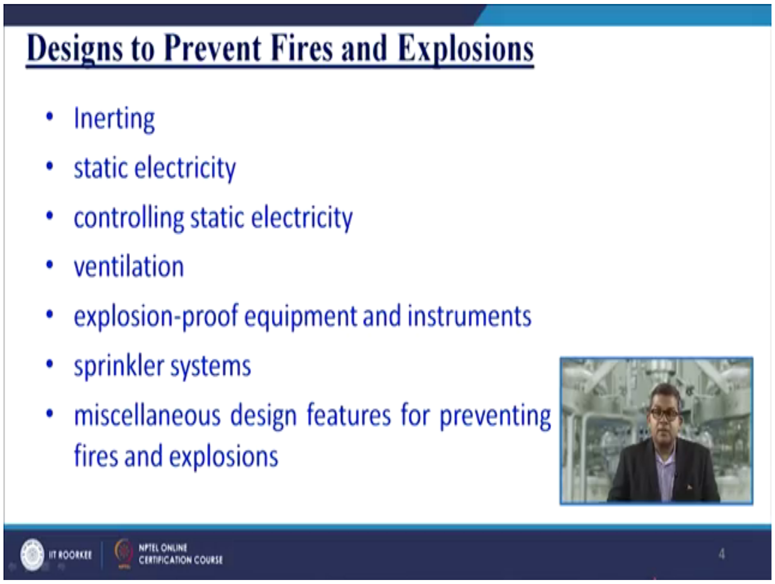

Now, question arises that how we can design the system? So there are seven broad spectrums through which we can go ahead with designing aspect. Inerting, static electricity, controlling static electricity, ventilation, explosion-proof equipment and instruments, sprinkler system and miscellaneous design features for preventing the reference. So we will discuss all the aspect in due course of time in various models.

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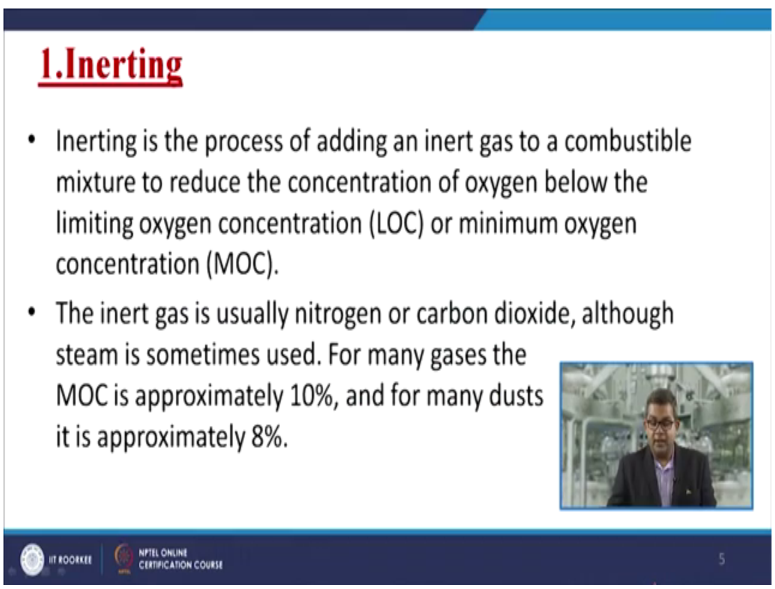

So, let us have first thing that is Inerting. Inerting is a process of adding an inert gas to a combustible mixture to reduce the concentration of oxygen below the limiting oxygen concentration or minimum oxygen concentration. So that the required stoichiometric demand is depleted, and flammable mixture or inflammable mixture does not catch fire. The inert gas is usually Nitrogen or Carbon dioxide, although steam is sometimes used, but not in a common fashion. For many gases the MOC is approximately 10 percent and for many dusts it is approximately 8 percent.

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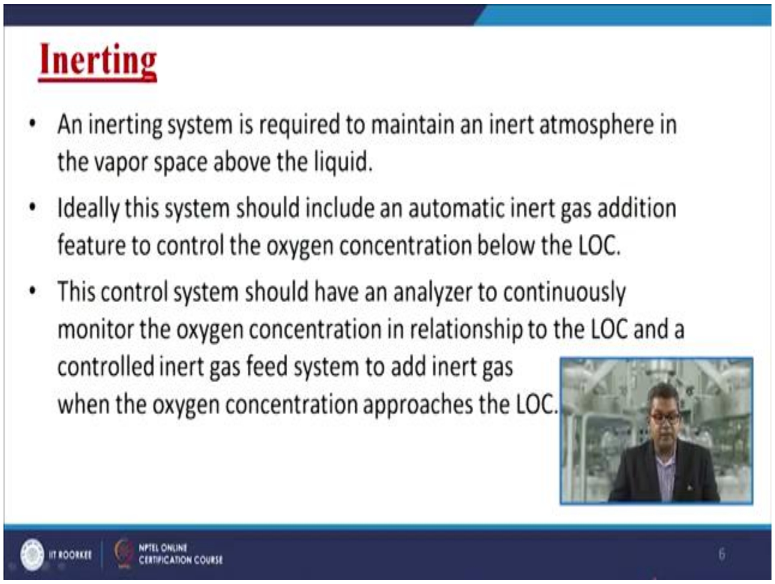

An inerting system is required to maintain an inert atmosphere in the vapor space above the liquid. Suppose, I am working here in a pool of say hexane and just because of its vapor pressure certain quantity of vapors has been generated and just above the pool of liquid surface. So, by virtue of my system design I am not in a position to cordon off oxygen or supply of air. Then inerting is a useful way (to inert) to minimize the impact of fire hazard.

We can introduce certain inert gases so that the minimum oxygen concentration or limiting oxygen concentration is depleted. So ideally this type of system should include an automatic inert gas addition feature to control the oxygen concentration below the limiting oxygen concentration.

Now this control system should have an analyzer to continuously monitor the oxygen concentration in relationship to the LOC and controlled inert gas feed system to add inert gas when the oxygen concentration approaches the limiting oxygen concentration. So that as soon as it approaches to LOC then it should activate and introduce the inert, so that the whatever oxygen is there it should come down (to the level) below the level of limiting oxygen concentration.

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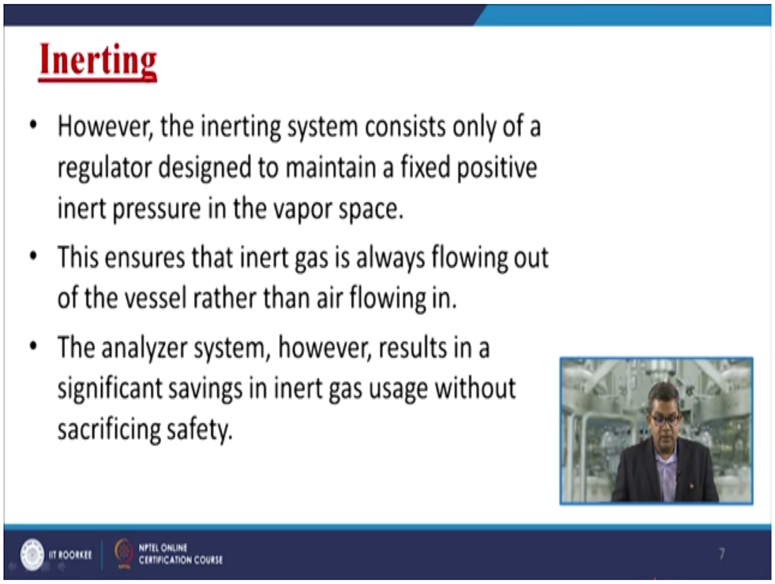

However, the inerting system consists only a (regular) regulator design to maintain a fixed positive inert pressure in the vapor space. Now, this ensures that inert gas is always flowing out of the vessel rather than air flowing in. So that the impact of air be minimized. The analyzer system however, results in a significant saving in inert uses without sacrificing safety. Now, thing is that whenever you are introducing inert gas then definitely certain quantum of money is involved because ultimately you are going to procure Nitrogen or Argon whatever inert gas is being used and you must have a pumping system through which you can introduce the inert gas to the system.

So, if you are having a proper analyzer system then definitely you need not to bother the continuous supply of inert gas to the system because ultimately whenever there is a heat system then if you are having the unnecessary inert gas over there then it will attract its certain heat value. So that is why you may have a significant saving if you adopt the analyzer system over there.

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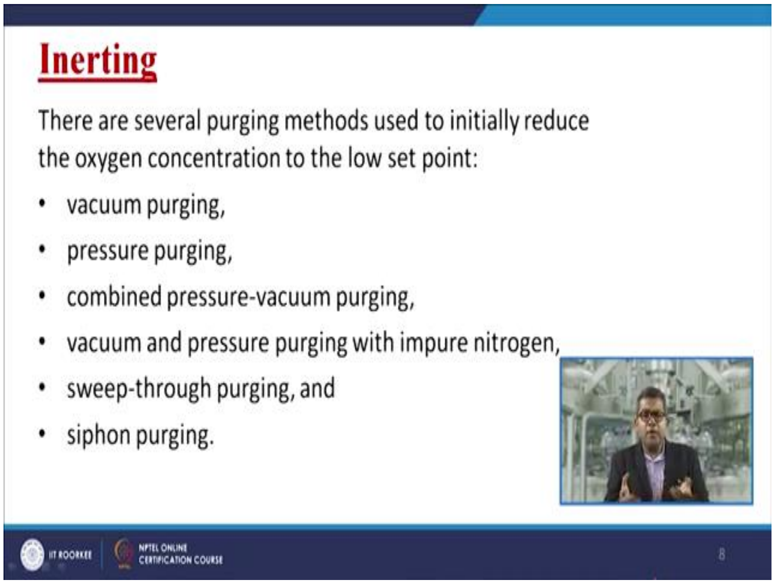

Now, how we can perform the inerting? This is the big question. So there are several purging methodology, purging is one of the ways through which you can introduce the (inerting matter material) inerting system. So, there are several purging methods used to initially reduce the oxygen concentration to the low set point. There are 6 different ways through which you can perform these purging operation, vacuum purging, pressure purging, combine vacuum and pressure purging, vacuum and pressure purging with impure nitrogen, Sweep through purging and siphon purging.

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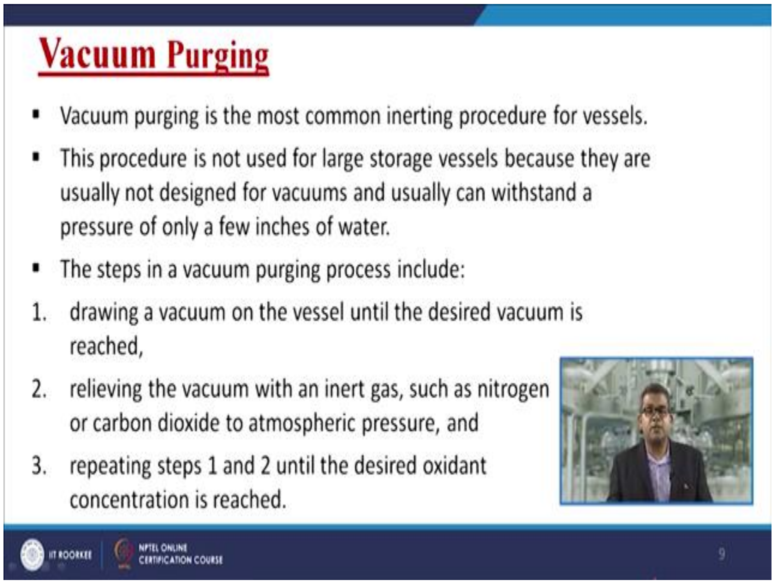

So, let have first let us have a look of vacuum purging. Now, vacuum purging is one of the most common inerting procedure for vessels. It is quite simple only thing is that it is highly energy intensive. Now, this process procedure is not used for large storage vessels because they are usually not designed for vacuum and usually can withstand a pressure for only a few inches of water. So if you are willing to adopt this protocol for a large hall or a large vessel then obviously you can create the vacuum inside, but it will be a costly affair. So, it is usually applicable for a small vessel, small pressure vessel, etc.

Now, there are three steps involved in vacuum purging. One is drawing a vacuum on the vessel until the desired vacuum is reached. You need to calculate a priori that how much vacuum is desired to have inerting in the particular system. Relieve the vacuum with an inert gas such as Nitrogen or a Carbon dioxide to atmospheric pressure and then if you have not achieved the desired result, so by analyzing the LOC or minimum oxygen concentration, then you need to repeat the step number 1 and 2 until the desired oxidant concentration is reached.

So, first thing is that suppose you are having the vessel you need to draw the vacuum and once it is achieved then you can introduce because of the pressure difference you can easily introduce the inert gas inside and if it is not then definitely again you need to repeat the vacuum system to this vessel and then again you need to introduce the things accordingly till you achieve the minimum oxygen concentration.

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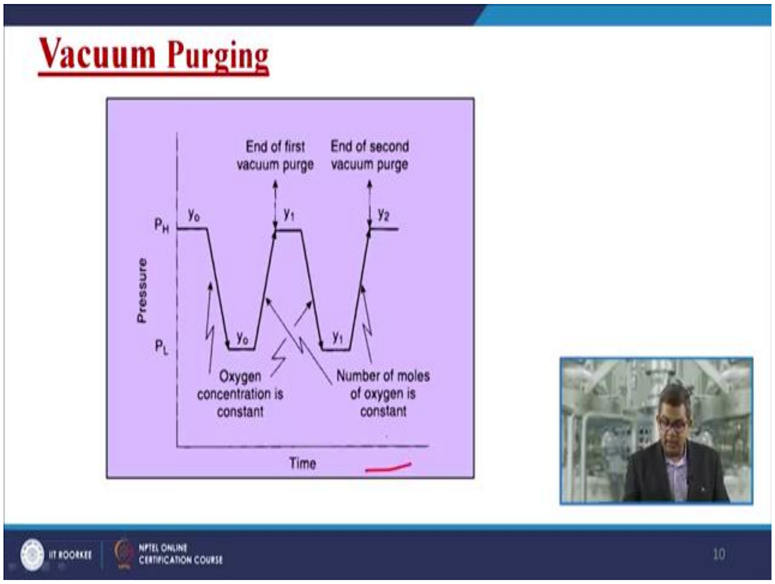

We can understand this particular aspect with this small plot here at the x-axis we are having the time domain and at y-axis the pressure domain.

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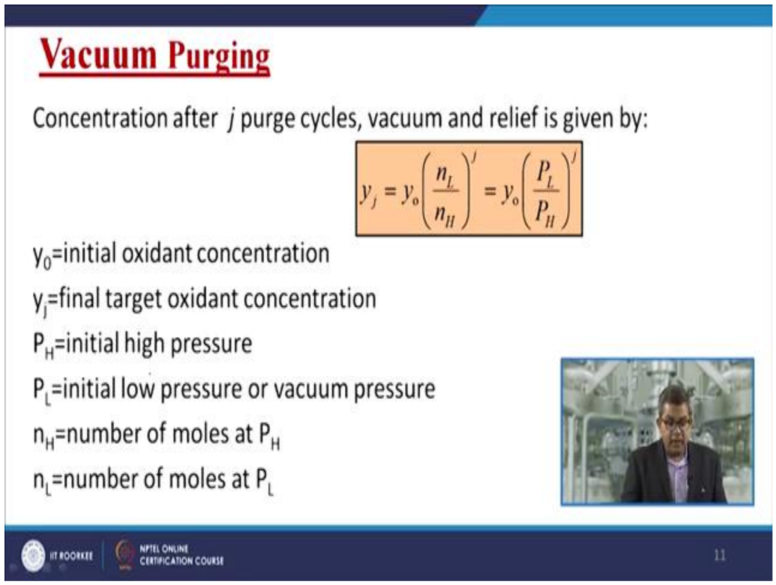

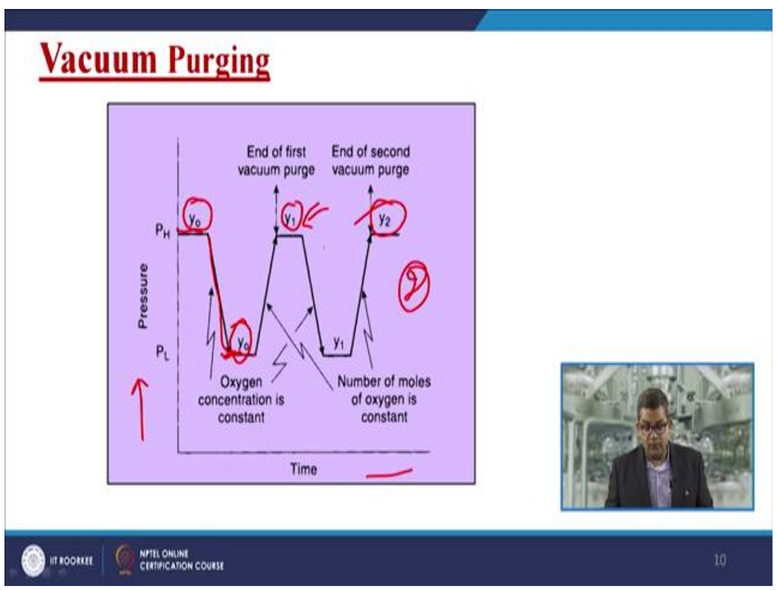

Now here the P_H is the initial high pressure this one and P_L is the initial low pressure or desired vacuum pressure. Y_0 is initial oxidant concentration and Y_1 is the final target oxidant concentration, so first thing is that you are having certain quantity of oxygen in a system specially suppose you are willing to have an introduction of inert gas to a vessel. Then initially you are having Y_0 concentration of Oxygen.

Then you reduce the pressure until it reaches to P_L that is the lower pressure limit, here you maintain the pressure and you introduce the desired oxygen concentration. Suppose you have achieved the desired Oxygen concentration by introducing the inert material and then you raise the pressure so that it can acquire the desired pressure to maintain the reaction mechanism.

So, here you have a Y_1 that is the final oxygen concentration and suppose if you are unable to have this LOC requirement then you need to repeat this system for again and again. So, here in this particular plot the things are repeated for twice so until it reaches the final desired concentration of oxidant.

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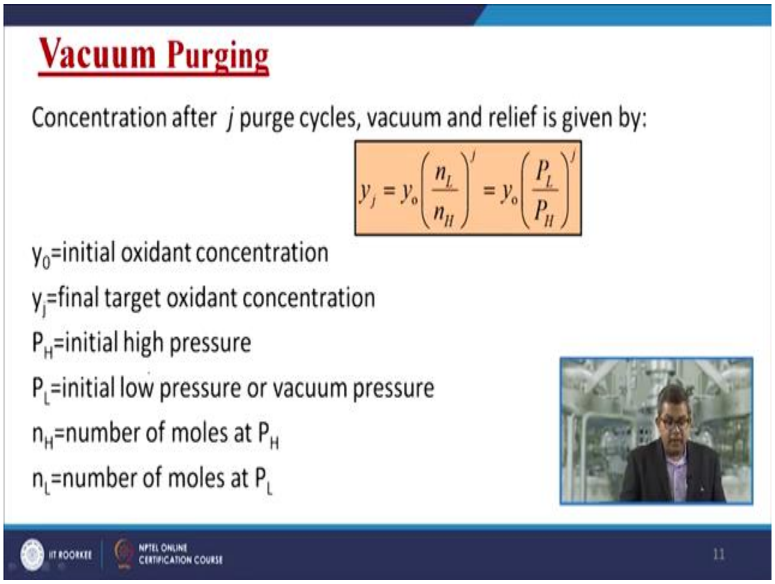

Now this is, you can calculate this through small mathematical formula that is concentration after J purge cycles suppose in the previous case we have to studied 2 purge cycles, concentration after J purge cycles vacuum and relief is given by:

$$y_j = y_0 \left(\frac{n_L}{n_H}\right)^j = y_0 \left(\frac{P_L}{P_H}\right)^j$$

So, you can easily calculate that what will be the final target oxidant concentration under the system in question.

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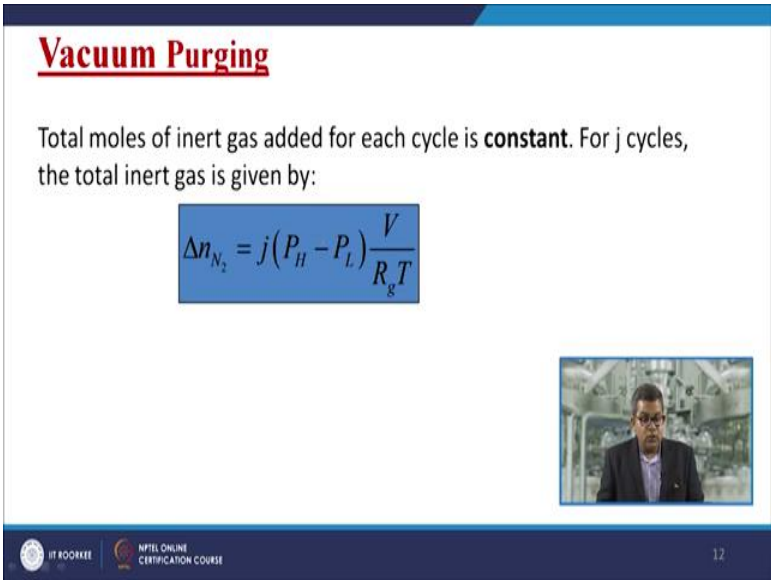

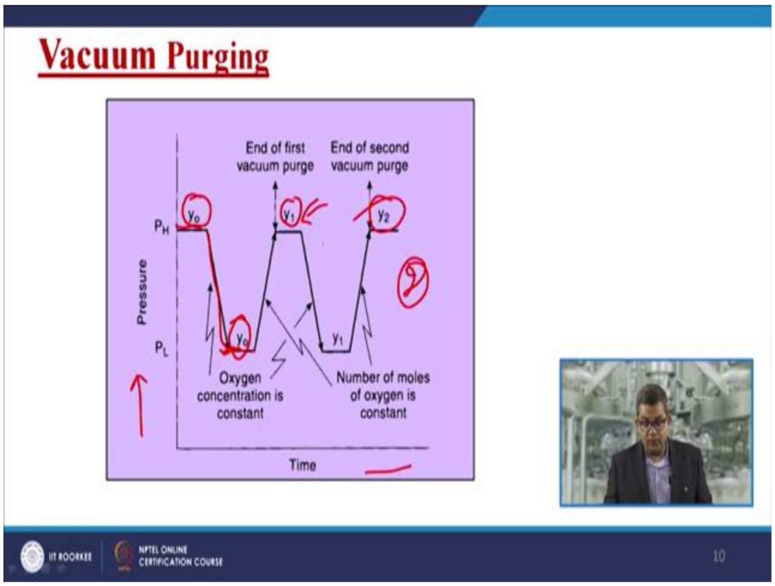

So, the total moles of inert gas added for each cycle is constant and you can have a look through this previous figure, this figure.

So, for j cycle the total inert gas is given by:

$$\Delta n_{S_1} = j(P_H - P_L)\frac{V}{R_g T}$$

Δn represent the change in number of moles of Nitrogen, Nitrogen in this case is introduced as the as an inert gas. T is the temperature of the system, R_g is the universal gas constant and V is the volume. So, by this way you can calculate that how many cycles are required, how many moles are needed to, how many moles of inert is needed to inert the system, the pressure system, pressure vessel system inside the reactor.

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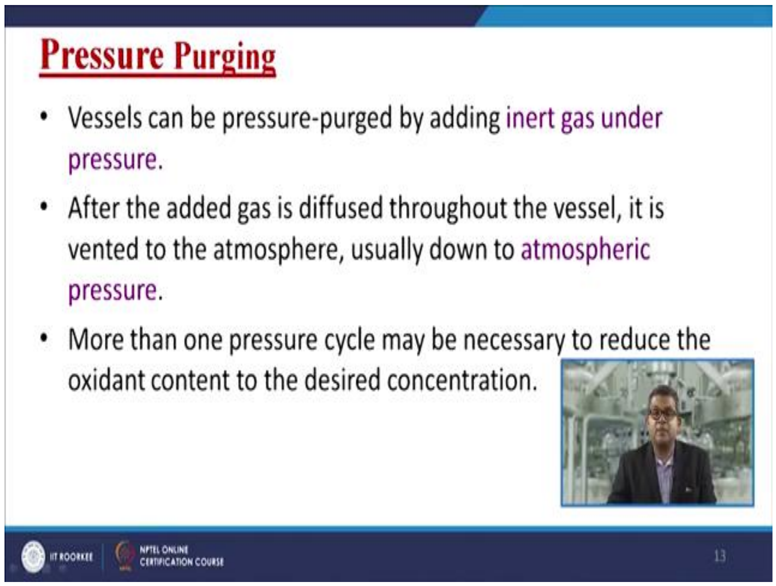

Now let us have look of pressure purging. Now, vessel can be pressure purged by addition of inert gas under pressure. Sometimes it performs action like sweep through purging so after the added gas is diffused throughout the vessel, it is vented to the atmosphere usually down to atmospheric pressure. So, more than one pressure cycle may be necessary to reduce the oxygen content to the desired concentration.

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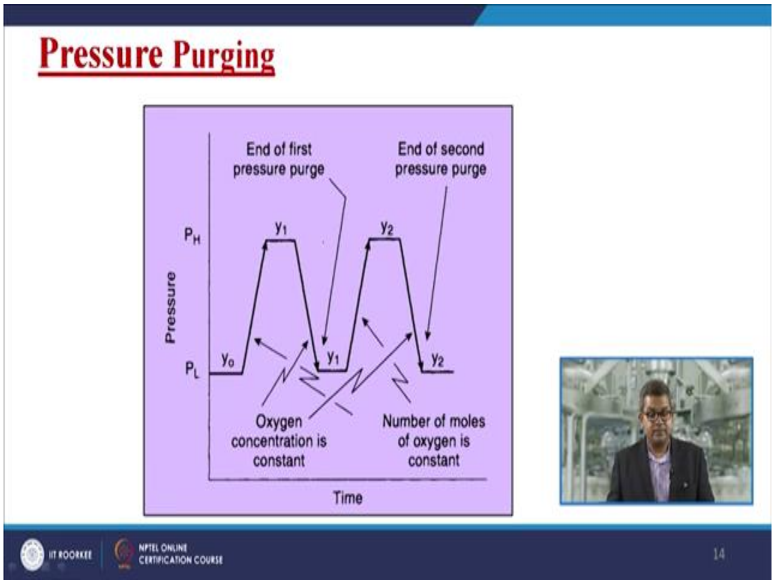

Now here again we are having small plot. Here we are having a high pressure and a low-pressure zone. Y_0 is the initial concentration of oxidant so we increase the pressure of the system and then we introduce the inert gas to it so that it maintains that Y_1 that is the concentration of oxidant in the vessel and then we lower down it again then we have the same type same concentration and then again we raise the pressure to P_H and then again reintroduce the inert system and maintain the Y_2 concentration of the oxidant and then by this way we can have the Y_2 that is the number of moles of oxygen in the system. And usually in all systems we used to keep the number of moles of oxygen constant, throughout constant. So, in this way we are having the two pressure purge cycles.

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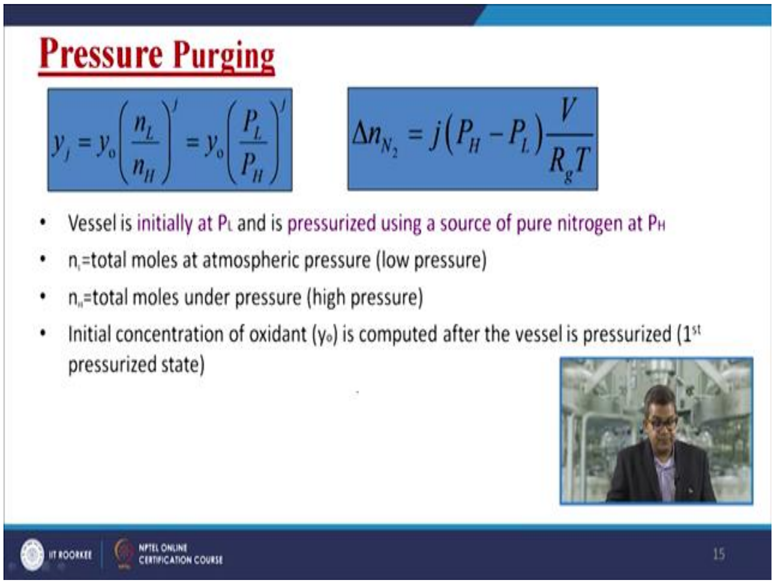

Again, we are having the mathematical representation for calculating the number of moles after j cycle.

$$y_j = y_0 \left(\frac{n_L}{n_H}\right)^j = y_0 \left(\frac{P_L}{P_H}\right)^j$$

$$\Delta n_{n_2} = j(P_H - P_L)\frac{V}{R_g T}$$

So, vessel is initially it is P_L and pressurized using the source of pure Nitrogen at P_H, n_L is the total numbers of moles at atmospheric pressure at low pressure, then n_H the total number of moles under pressure that is high pressure. So, by this way you can calculate the number of moles needed in terms of inert gas to make the pressure inerting.

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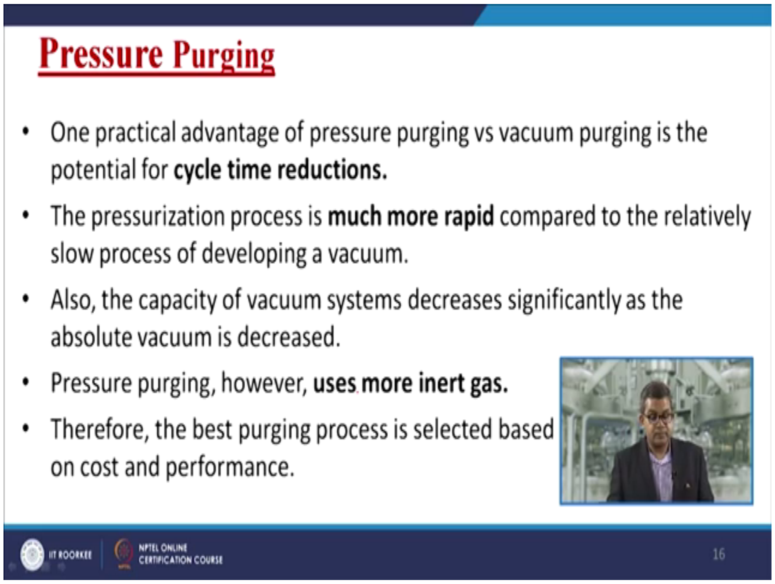

Now, there are so many advantages and disadvantages associated with pressure purging. Now, one practical advantage of pressure purging versus vacuum purging is that potential of cycle time reduction. Now, the pressurization process is much more rapid compared to the relatively slow process of developing a vacuum. Also, the capacity of vacuum system decreases significantly as absolute vacuum is decreased. Pressure purging however, uses more inert gas compared to the vacuum one, so the best purging process is selected usually based on the cost and performance.

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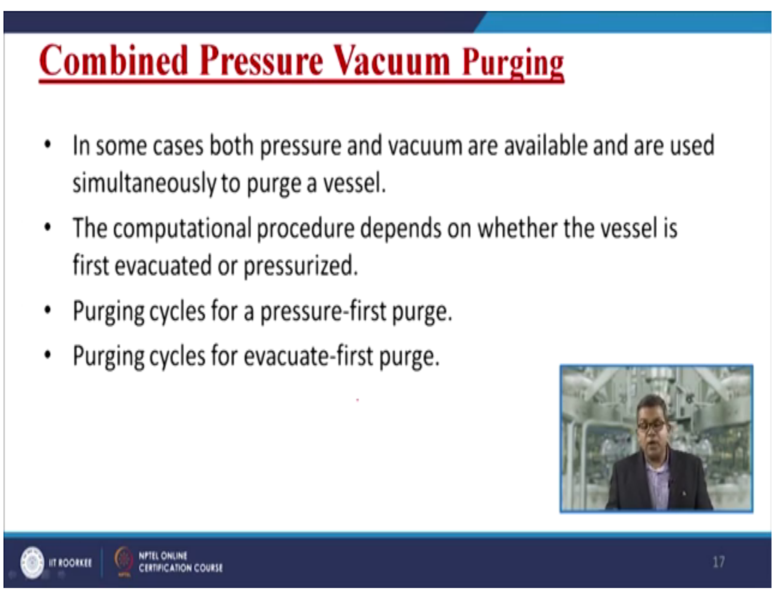

So, if you are willing to inert the hydrocarbon piping system then definitely the pressure purging is most advantageous because it will be very difficult to have a vacuum purging for a pipeline having a distance of say 1000 kilometer or 500 kilometer it will be very difficult. So, in some cases both pressure and vacuum purging are available and are used simultaneously to purge a vessel.

In that particular case, we need to go ahead with the combined pressure vacuum purging system because sometimes it is a need of time. So, the computational procedure depends on whether the vessel is first evacuated or pressurized. Now, purging cycle for pressure is the first purge then purging cycle two for evacuate that is the first purge.

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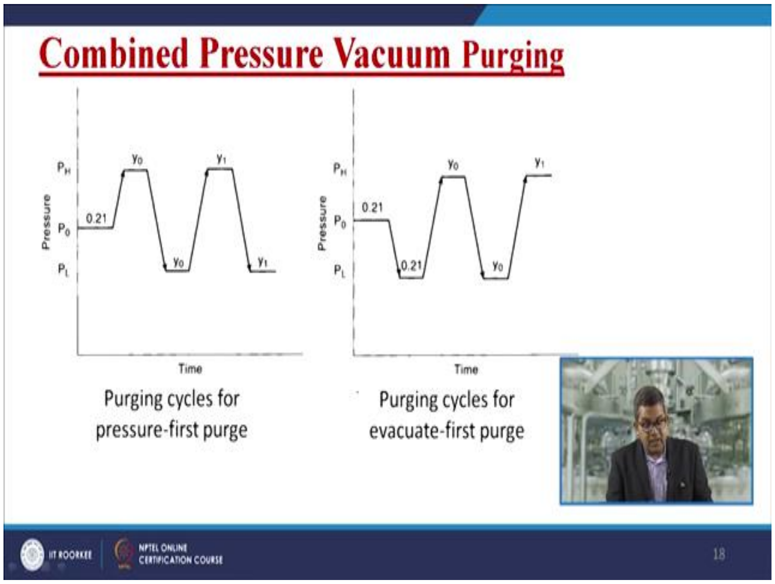

So, this is the comparative diagram here we are having the pressure first purging and here we are having the vacuum first purging. Here we are having the initial pressure rate say P_0 then it raised up to P_H then into introduction of certain quantity of inert material, inert gas and then the pressure lowered down to P_L and then it is a repeated cycle. The same thing here we are lowering down the pressure to have certain concentration of oxygen and then it is raised then again, the cycle is repeated to maintain the appropriate level of oxidant within the system.

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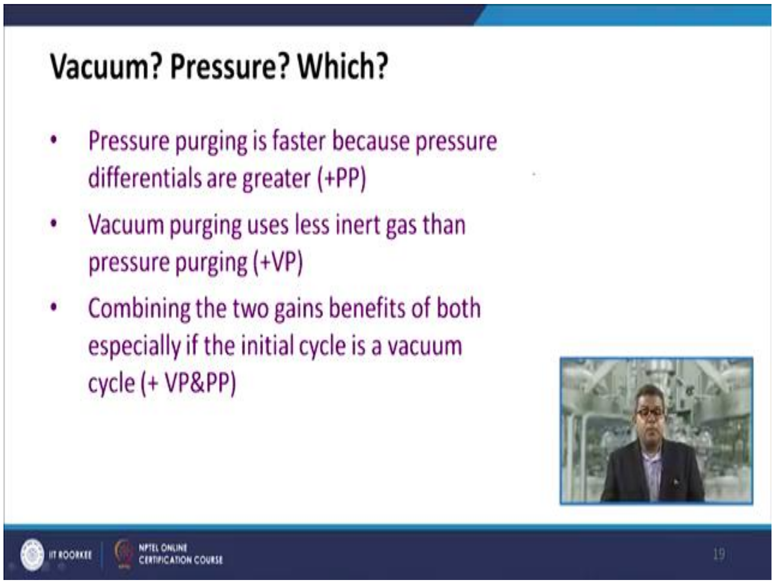

Now, question arises that vacuum whether we have to choose the vacuum or pressure and which one? Now, pressure purging is faster because pressure differentials are greater. So obviously if we analyze the things in terms of cost, in terms of ease of operation, pressure purging is bit faster. Vacuum purging uses less inert gas than the pressure purging so if you are not having a consideration of cost of inert gas then definitely you can go ahead with the pressure purging and if it is the consideration then you have you may think the option of vacuum purging. So, combination of these two gain benefits of both especially if initial cycle is vacuum cycle. So that you can utilize the aspect of pressure differential.

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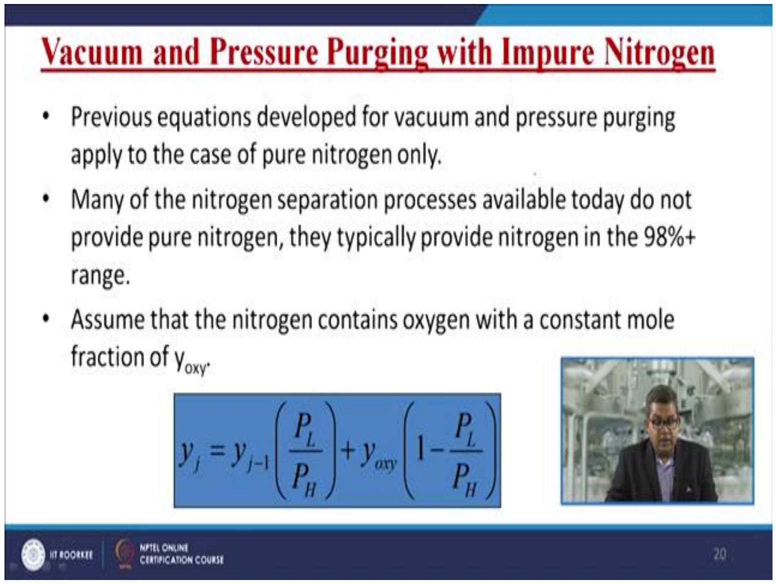

Sometimes we may have to use the vacuum and a pressure purging with impure Nitrogen. So, previous equation which we have discussed, developed for the vacuum and pressure purging apply to the case of pure nitrogen only. Many of the Nitrogen separation processes available today do not provide pure Nitrogen they typically provide the Nitrogen in the range of 98 percent plus minus range.

Now, see the question is that if we go ahead with the highest purity then the cost of Nitrogen production or a cost of inert production would be on the higher side. So, we need to optimize the thing. So Sometimes it is available say 98 percent 95 percent pure and if it is permissible prior to thinking of the concentration of Nitrogen and prior to thinking of out the other impurities present in the Nitrogen string. Then it is always advisable to use such kind of a Nitrogen to reduce the cost of the system.

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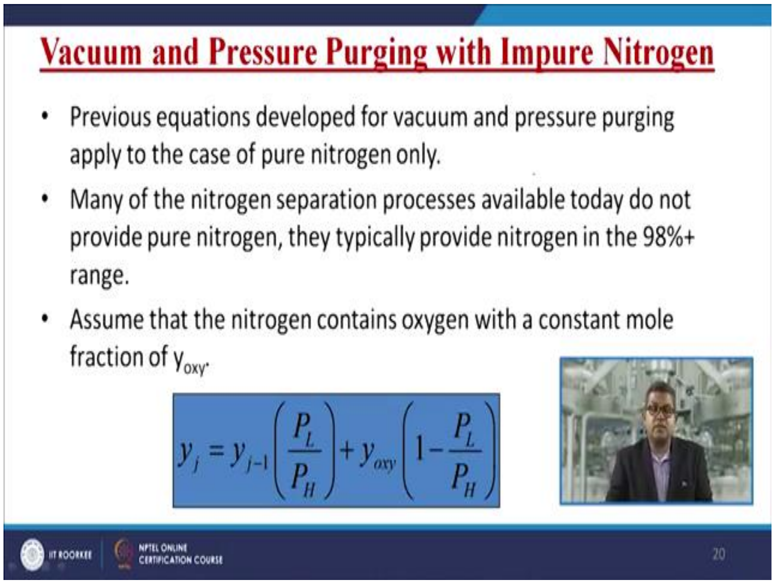

So, assume that the Nitrogen contains oxygen with a constant mole fraction of Y_{oxy} then:

$$y_j = y_{j-1}\left(\frac{P_L}{P_H}\right)^1 + y_{oxy}\left(1 - \frac{P_L}{P_H}\right)^1$$

So, this gives you that what would be the mole concentration of Oxygen in due course of time.

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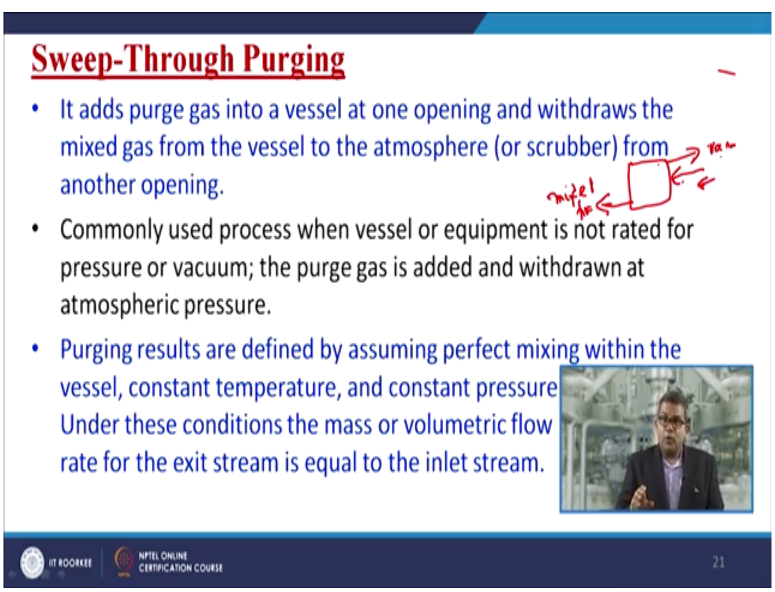

Now, next is the sweep through purging. Now, usually it is a very common phenomenon and it is a very beneficial phenomenon for keeping the low concentration of Oxygen within a vessel. So usually it adds purge gas into a vessel at one opening and withdraws the mixed gas from the vessel to the atmosphere or scrubber from another opening.

It is a commonly used process when vessel or equipment is not rated for pressure or vacuum. The purge gas is added and withdrawn at atmospheric pressure. Sometimes say because of inherent inability you may not be able to have the vacuum system or a pressurized system with in a vessel may be because of mechanical problem, may be the vessel is not designed to withstand such a high or a low pressure then this particular technique is extremely useful.

Now, usually what we used to do in, let us have this is my vessel so from one end we used to draw the vacuum and simultaneously we use to introduce a certain quantity of inert gas over here and continuously we used to draw the mixed gas from that stream. So, once because of because we have to maintain a certain pressure difference, so we draw the vacuum first stage then we close it then we introduce certain quantity of inert gas and continuously we draw the mixed gas from this front. One time in one phase we are having the advantage, another phase we are having a certain disadvantage.

The disadvantage is that whatever mixture is coming out from this we need to treat this mixture appropriately. It may a form inflammable mixture, so it may create a problem at the exit port. Sometimes it may have some toxic material then again, we need to go for the scrubbing system. So, we need to be very careful whenever we are adopting this type of a purging scheme so purging results usually are defined by assuming perfect mixing within the vessel specially applicable whenever we are designing the sweep through purging.

Now, we have to maintain the things at a constant temperature and a constant pressure. Under these conditions the mass or volumetric flow rate of exit stream is equal to the inlet stream. So that we can maintain the properties of the system appropriately.

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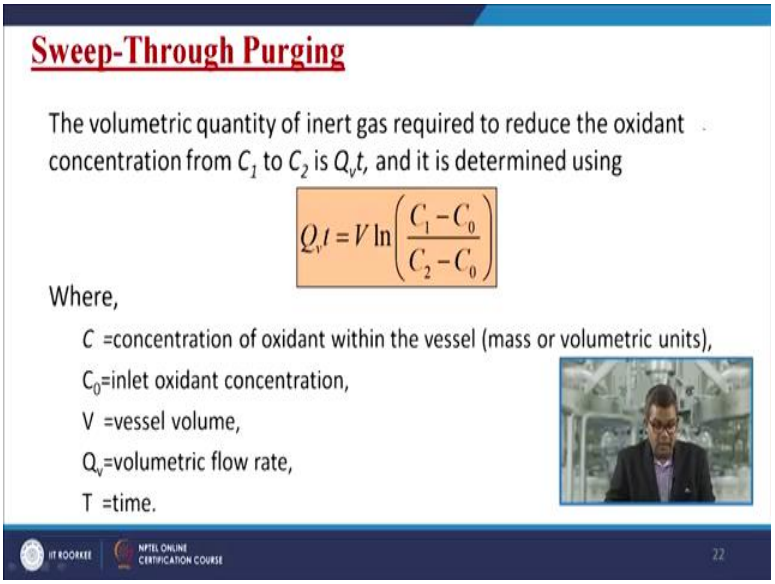

Now, here is one of the mathematical relations through which you can analyze the volumetric flow rate. The volumetric quantity of inert gas require to reduce the oxidant concentration from C_1 to C_2, let us have $Q_v t$ and it is determined using this particular equation:

$$Q_v t = V \ln\left(\frac{C_1 - C_0}{C_2 - C_0}\right)$$

where C is the concentration of oxidant within the vessel, C_0 is the inlet oxidant concentration, V is the vessel volume, Q_v is the volumetric flow rate and t is the time required.

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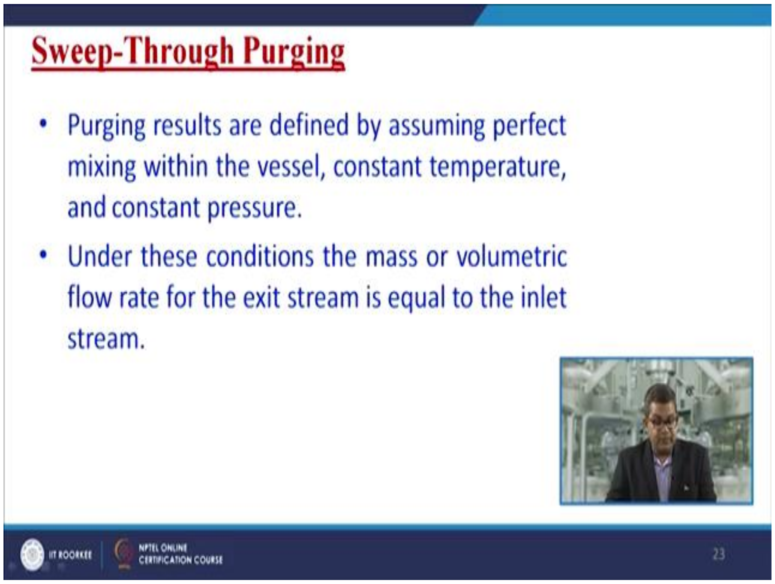

Now, purging results are defined by assuming perfect mixing within the vessel. Constant temperature and a constant pressure. So, under these conditions the mass or a volumetric flow rate for the exit stream is equal to the inlet stream. So, these are certain things we need to keep in mind.

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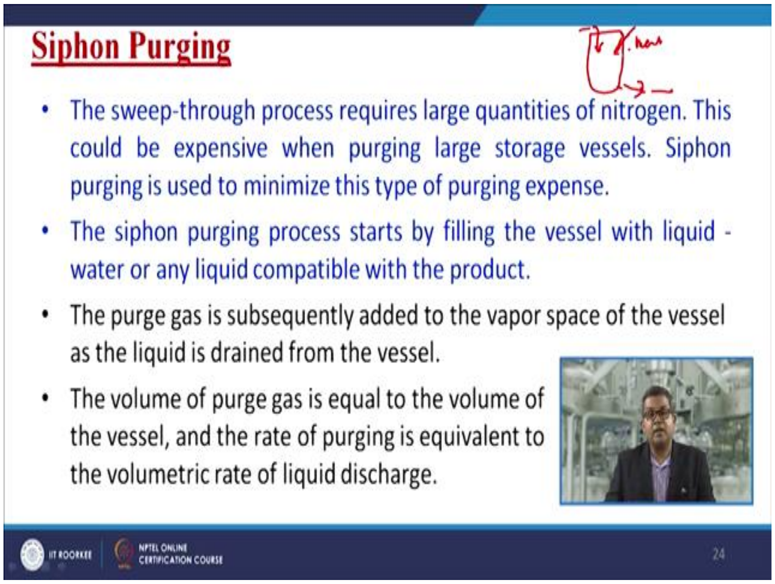

Another purging method is the Siphon purging. Now sweep-through purging process requires large quantity of nitrogen. Because you need to fill the entire mass of I mean entire volume of the vessel with the nitrogen. Now, this could be expensive when purging a large storage vessel. So, Siphon purging is used to minimize this type of purging expenses. Now, it is a very simple and quite effective. The Siphon purging processes starts by filling the vessel with the liquid and sometimes with water or any liquid compatible with the product.

Now, then the purge gas is subsequently added to the vapor space of the vessel and liquid is drained from the vessel simultaneously. So, it is just like this that you are having this vessel. You filled it with liquid and then you introduce the inert gas and simultaneously you withdraw the filled liquid or a water in this case so that you can inert. Because there will be no room for air to entrap so that the concentration of oxygen will remain low as desired. The volume of purge gas is equal to the volume of the vessel and rate of purging is equivalent to the volumetric rate of liquid discharge.

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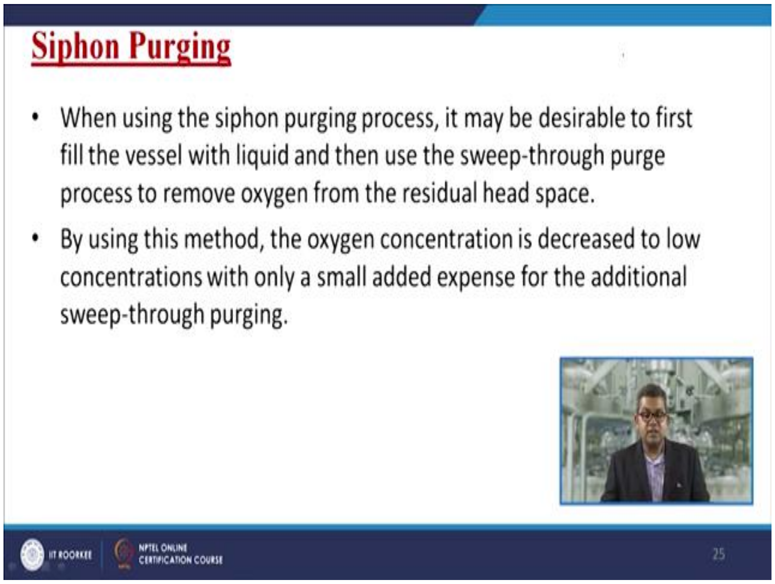

So, when using the siphon purging process it may be desirable to first fill the vessel with the liquid then use sweep-through purging process to remove oxygen from residual head space. Now, by using this method the oxygen concentration is decreased to low concentration with only a small added expense for the additional sweep-through purging. So, these things should be in our mind.

So, in this particular module we have discussed a first phase of design to prevent the fire and explosion and a primarily we discussed about the 3 different purging methodology. Vacuum purging, Pressure purging, combined vacuum and a pressure purging, Siphon purging and Sweep-through purging. So, in the next module we will discuss the other purging methodology and other methods through which we can prevent the disaster of a fire and explosion.

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You can always see the various references those who are enlisted over here for your further reading. Thank you.