Chemical Process Safety
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Lecture 33
Introduction to Reliefs

Welcome to the new chapter that is called Reliefs. Now, before we go into detail, let us have a look at what is the importance of relief. So despite many safety precautions within chemical plants, equipment failure or sometimes operator error can cause increase in pressure that is attributed to the process beyond the safe level. So we are having different line of action for to deal with such kind of scenario.

Now if pressure rise too high, they may exceed to the maximum strength of either pipeline or a vessel, now this can result in the rupturing of the process equipment causing major release of toxic or inflammable vapours. So, in this particular chapter we are going to deal that what are the different things related to the relief, what is the concept of relief, what kind of different sources of over pressure, what are the different lines of defence or defence mechanism.

We will understand the pressure-temperature curve for different runaway reactions. We will discuss about the various guidelines for relief pressures. We will have discussion about the methodology for the safe installation of various relief devices and where we can introduce those relief devices or the location of relief. Now, let us have the discussion about that what are the different safer mechanisms available to you.

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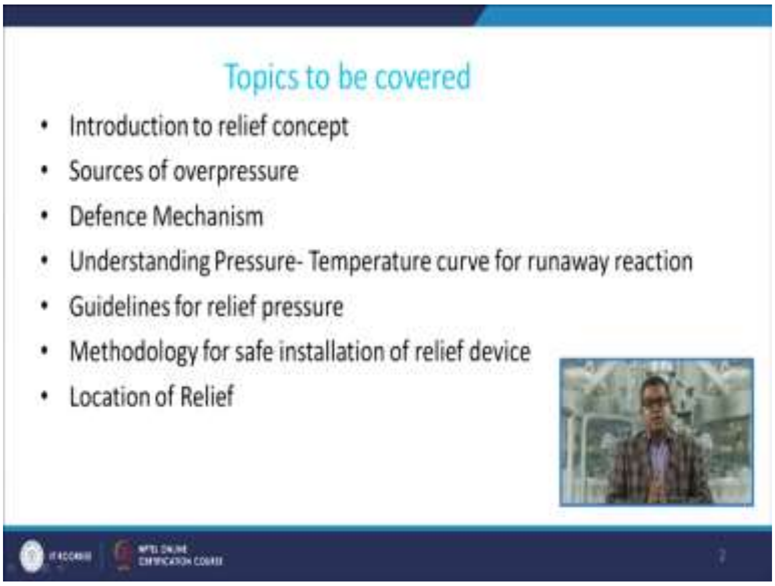

So the defence against any kind of pressure rise or rupture and to prevent the accident, the first place is the inherent apparent safety, which we have already discussed in different modules. The second line of defence is the better process control, obviously we have discussed in industrial hygiene where we can use this type of process control. A major effort in this particular aspect is always directed towards controlling the process which is within the safe operating region.

Now dangerous high-pressure exposure must be prevented or minimized. The third line of defence against the excessive pressure is to install the various relief systems to relieve any kind of liquids or gases before excessive pressures are developed. So usually these relief systems are composed of relief devices and associated downstream process equipment to safely handle the material ejected.

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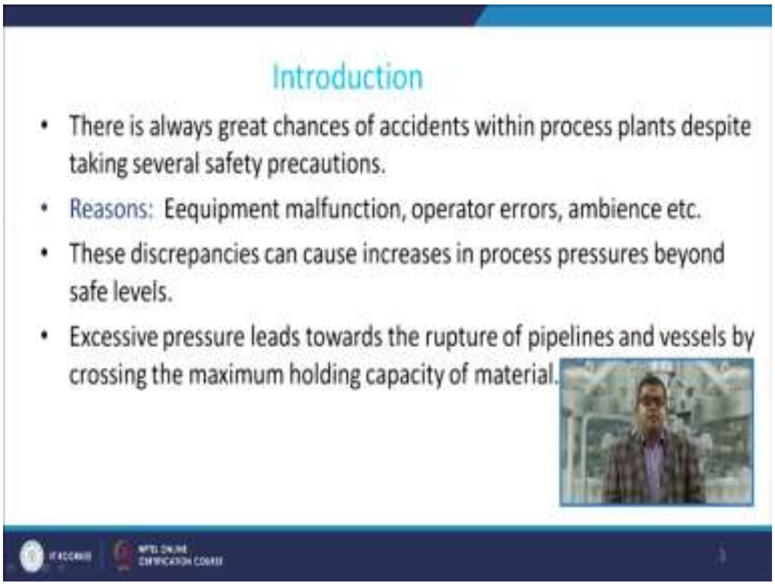

So in nutshell there is always a great chance of accidents within the process plants despite taking several safety precautions. So sometimes, the rise in pressure may attributed to the equipment malfunctioning, operator errors, sometimes ambience or third party inductions, et cetera. So these discrepancies can cause increase in the process pressure beyond the safe level. So, excessive pressure may lead towards the rupture of any kind of things which may be catastrophic for process.

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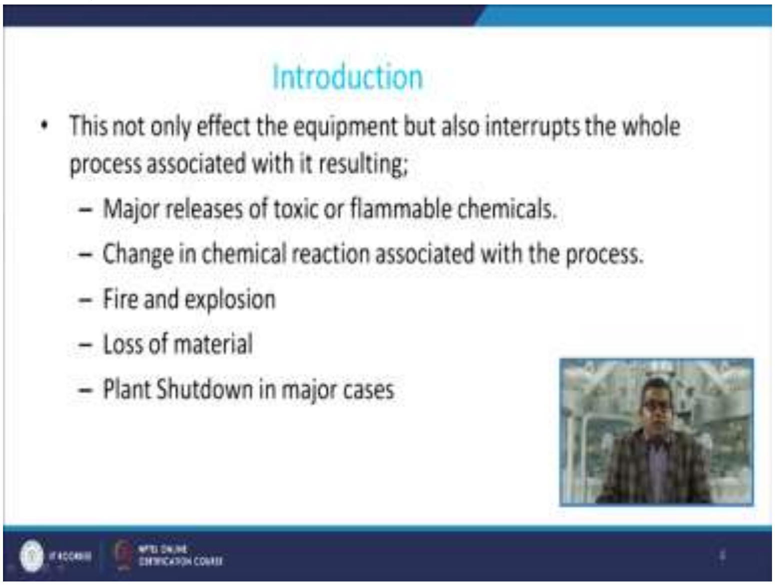

Now, this catastrophe not only affects the equipment but also interrupts the whole process associated with resulting the major release of toxic or flammable chemicals, this may cause serious damage to the outside periphery too. Change in the chemical reaction associated with the process, this may lead to the fire and explosion, this may lead to loss of material ultimately lead to economic losses and the plant shutdown in major cases.

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So, let us have a discussion about that what are the different sources of overpressure. So the excessive overpressure or under pressure in a process plant can be subjected due to the external fire, sometimes maybe conduction, convection so this may lead to the catastrophe that is called the plant fire. Connection to a high-pressure source, now valve is opened in error.

Sometimes disconnection from a low-pressure sink that is valve again may be attributed to the valve opened in error. Increase the heat input that is malfunctioning of heating or cooling equipment as desired within the chemical reactions and it is quite obvious because there are so many reactions or major reactions those involved the endothermicity or exothermicity.

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Others are that decreased heat input that is malfunctioning of heating/cooling equipment or again the chemical reaction. The best example is the loss of reflux or of sub-cooled liquid in distillation column. Sometimes vapour evolution that is admission of the water or high hydro, light hydrocarbon to hot oil, then absorbent failure, failure attributed to the failure to remove the sufficient gas due to the loss of flow from absorbent.

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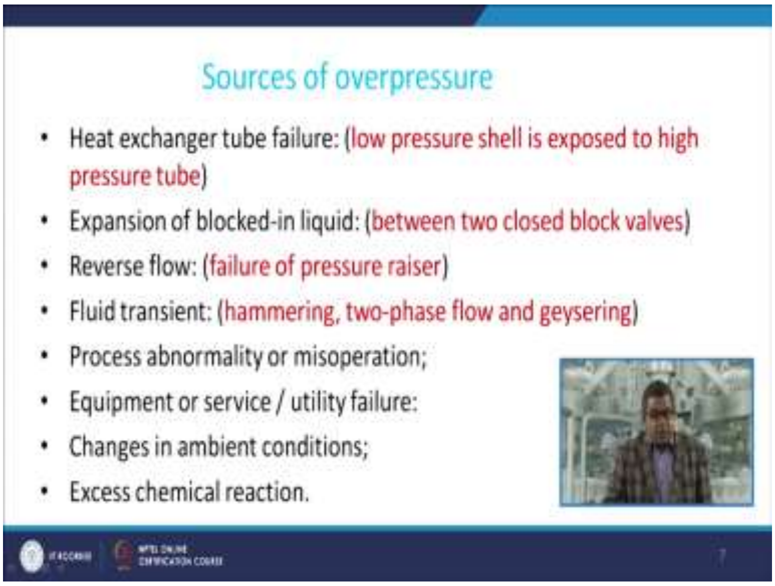

Sometimes it may lead to the heat exchanger tube failure, this may be attributed to low pressure shell is exposed to the high-pressure tube. Expansion of blocked in liquid that is between the two closed block valves, sometimes it is attributed to the reverse flow that is the failure of pressure raiser, sometimes fluid transient that is hammering two phase flow or geysering. Sometimes attributed to the process abnormality or miss-operation, equipment or service utility failure, changes in ambient conditions, excess chemical reactions, so these are the various sources of over pressure.

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Now, question arises that what is the defence mechanism. Now, the first line of defence against such incidents is to try to prevent such accidents at the origin. Now, how you can prevent those things? You may develop the better process control, you may control the process within the safe operating region, and every process is having the safe operating region. Sometimes perforce because of the production demand, because a variety of reasons you may be in a position to violate all those things.

Now dangerous high-pressure exposure must be prevented or minimized. Now in this particular figure you may have a defence against such accidents, you may have to install the relief systems, you may have a better process control. And in the start we have discussed that every process is having some inherent safety, so you may adopt that particular you must have knowledge of all those things.

Now the second line of defence is which we have already discussed at the start of this particular chapter that installation of relief systems, to relieve the liquid or gases before excessive pressures are developed. So the relief system is composed of relief device and associated downstream process equipment to safely handle the material ejected. So you may have installation of these relief systems to relive liquid gases before excessive pressure builds up so you are avoiding the rupturing or vessel failure scenario.

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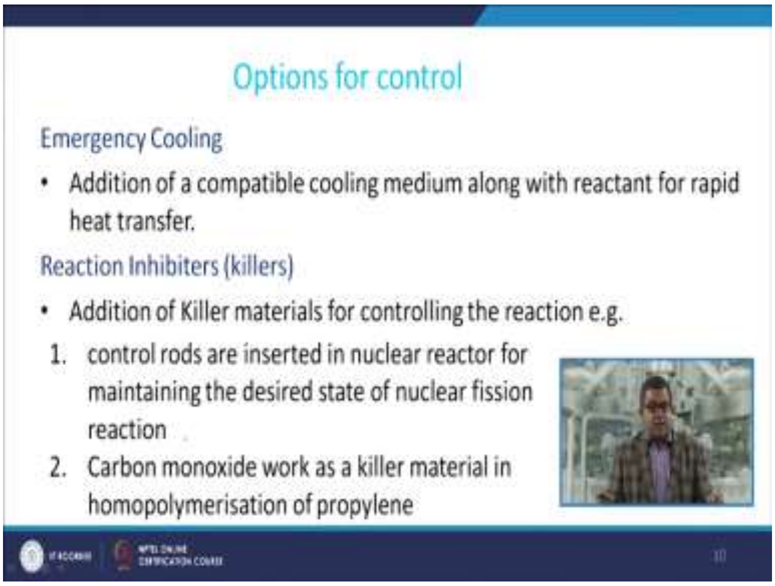

Now, what are the options to control? Now there are a few options available to you. First is that emergency cooling, now you may have addition of a compatible cooling medium along with the reactant for rapid heat transfer. Second is that there are so many reaction inhibitors those who kills the reaction. Now you may add those killing materials for controlling the reaction that is control rods sometimes they are inserted in the nuclear reactor to maintain the desired state of nuclear fission reaction, this is one of the best examples. There are certain carbon monoxide gas induction, they may act as a killer material for various polymerisation reaction especially in case of homopolarisation of propylene.

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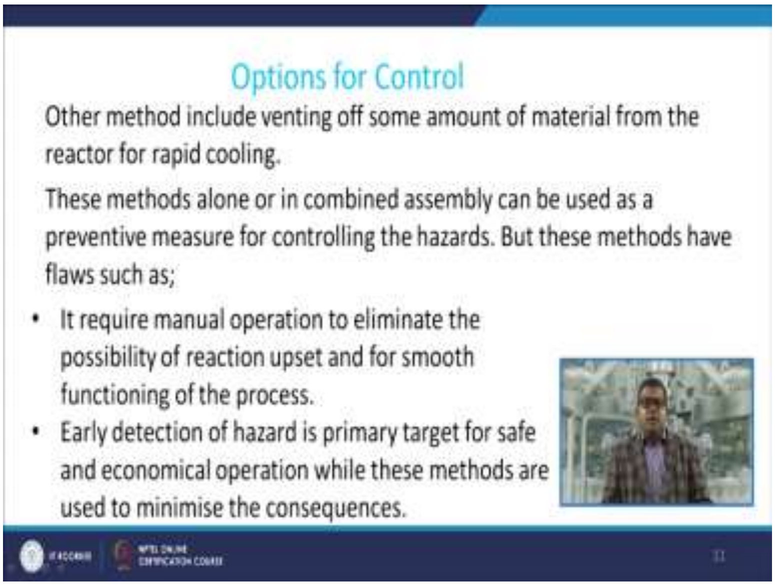

Other methods include the venting off some amount of material from the reactor for rapid cooling. Now, these methods alone or in combination with other assemblies can be used as a preventive measure for controlling the hazard. But these methods have various flaws such as that if you require manual operation to eliminate the possibility of reaction upset and for smooth functioning of the process. The early detection of hazard is primarily target for safe and economical operation while these materials are used to minimise the consequences.

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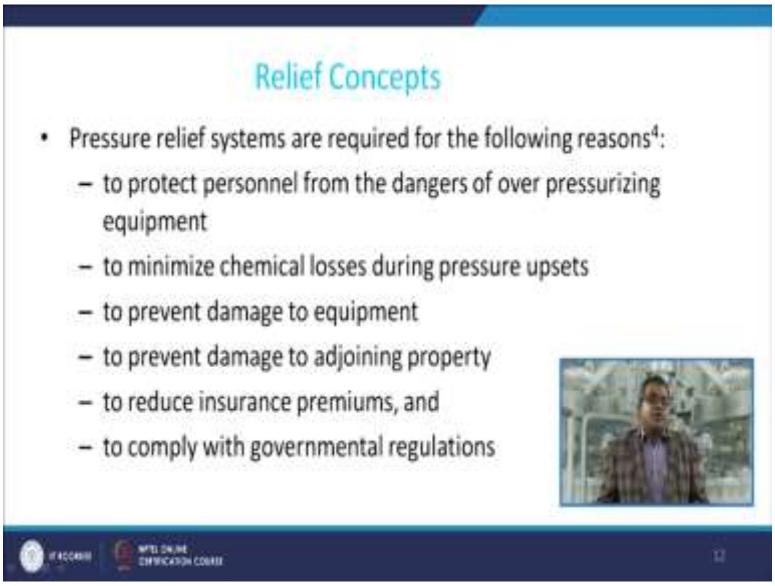

So in nutshell, we must understand that what is the concept of relief, now if special relief systems are required for the variety of reasons, some of them they are summarised as to protect personnel from the dangers of over the over pressurizing equipment, to minimise the chemical losses during the pressure upsets, to prevent the damage of equipment, to prevent the damage to adjoining properties, and sometimes this may lead to the heavy economic losses, to reduce the insurance premiums and to comply with the governmental regulations because nowadays governmental regulations are strict, so you have to comply all these regulations to protect the environment as well as nearby people.

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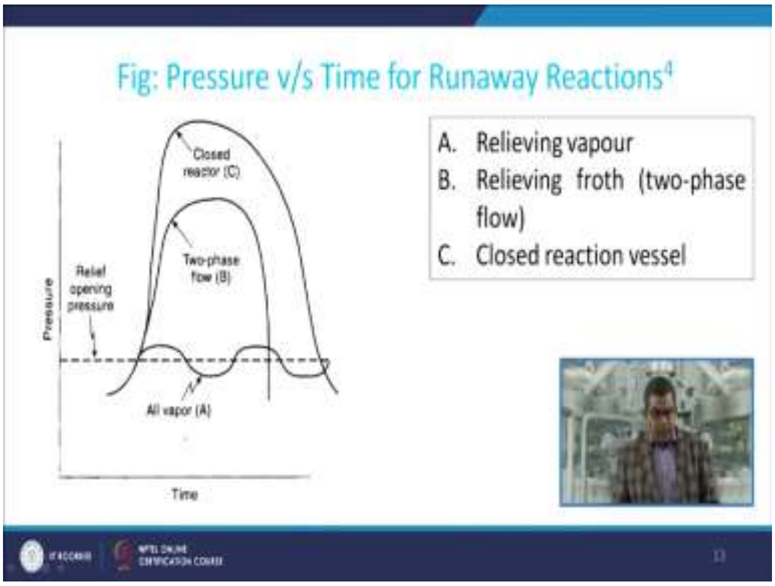

Now, in this particular figure we have pressure versus time for different aspects like this is the further relieving vapour, relieving froth this one that is the two-phase flow, and this is for the closed reaction vessel, we will discuss this particular plot in the subsequent slides.

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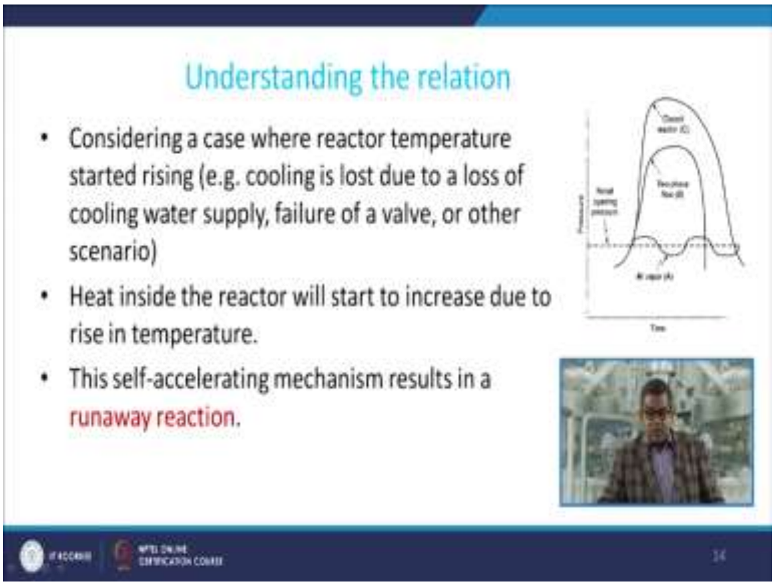

Now, you may consider a case where a reactor temperature starts rising, maybe because of the cooling is lost or loss of cooling water supply or failure of valve with the variety of reasons. So heat inside the reactor will start increase due to the rise in temperature, now this self-accelerating mechanism results in a runaway reaction.

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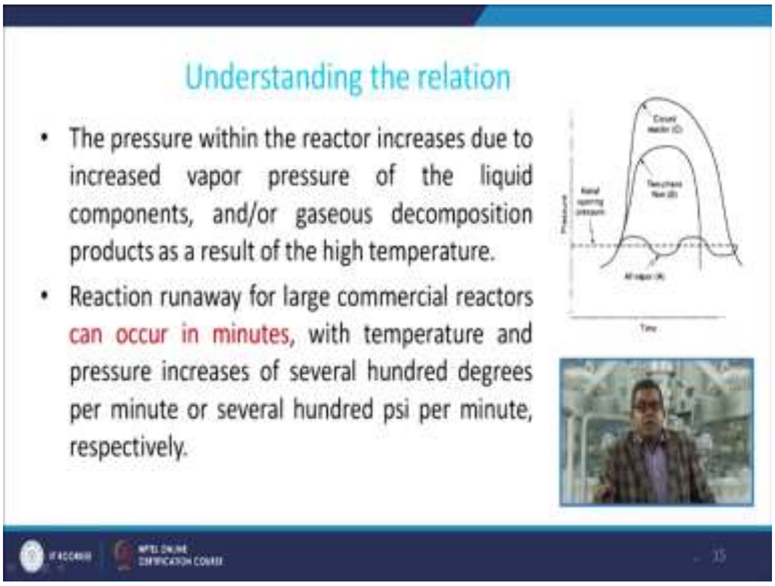

Now the pressure within the reactor increases due to the increased vapour pressure, obviously the vapours are intending to form over a period of time because of the rise in temperature, so the vapour pressure of the liquid component is on the higher side and the gaseous decomposition product as a result of high temperature.

Now this runaway reaction for a large commercial reactor can occur in minutes with temperature and pressure increase of the several hundred degrees per minute or several hundred psi per minute respectively. So you can imagine the scenario because the temperature is on the higher side and the vapour pressure is on the higher side so the temperature and pressure is on the higher side.

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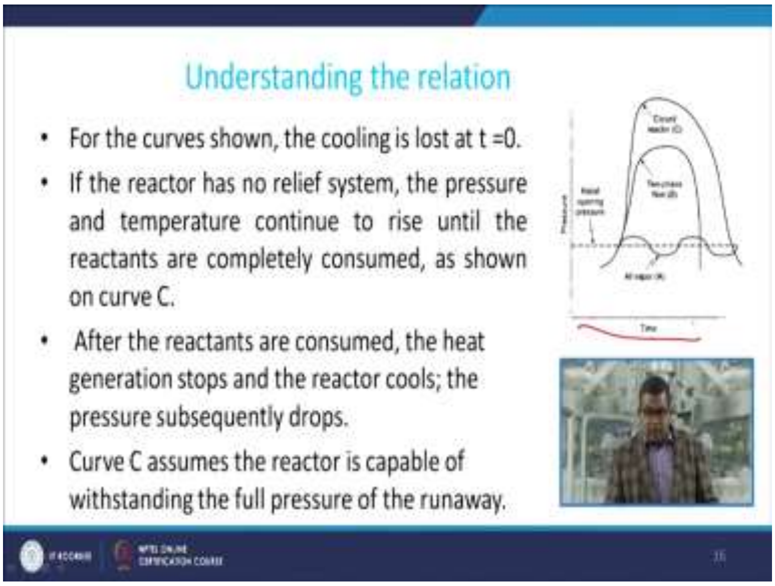

Now for the curve shown this curve, the cooling is lost at times t is equal to 0. Now if reactor has no relief system, the pressure and temperature continues to rise until the reactants are completely consumed, this is as predicted in this particular curve. Now after the reactants are consumed, the heat generation stops and subsequently the reactor cools, the pressure subsequently drops like this. Now this particular curve assumes the reactor is capable of withstanding the full pressure of the runaway.

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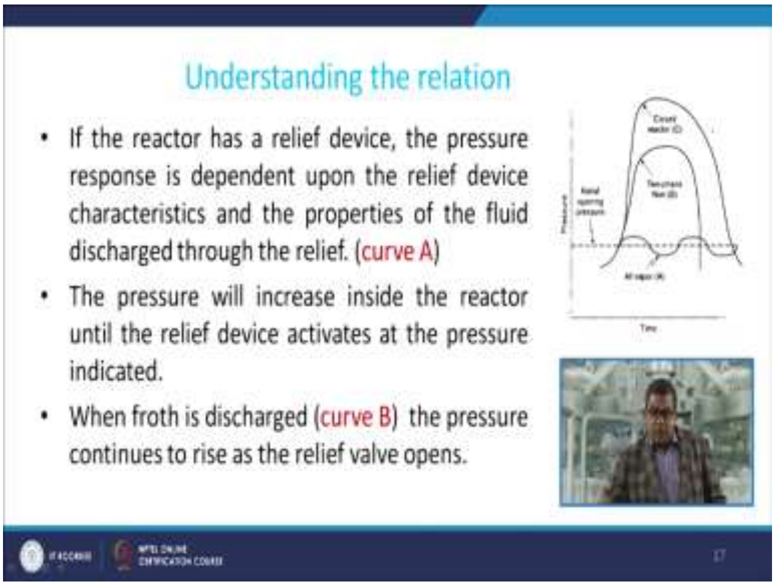

Now, if reactor has a relief device, the pressure response is dependent on the relief device characteristics and the properties of the fluid discharged through the relief and that is represented by the curve this curve A. Now pressure will increase inside the reactor until the relief device activates at the pressure indicated. So when the froth has discharged this is represented in the curve B, the pressure continues to rise as the relief valve opens.

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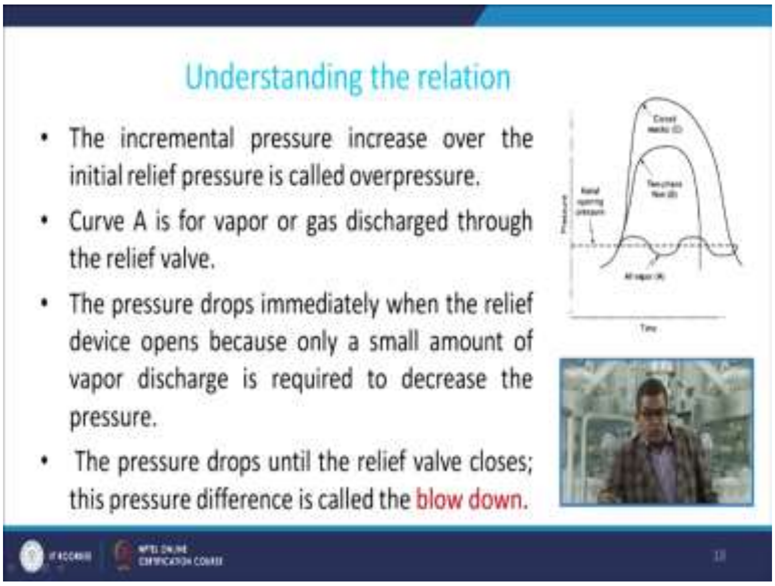

Now, the incremental pressure increases over the initial relief pressure is called the overpressure. Now, this curve A for vapour or gas discharged through the relief valve, this one. The pressure drops immediately when the relief device opens because only small amount of vapour discharge is required to decrease the pressure. Now you can see there is a rise in pressure and then it drops. The pressure drops until the relief valve closed and the pressure difference is called the blow down.

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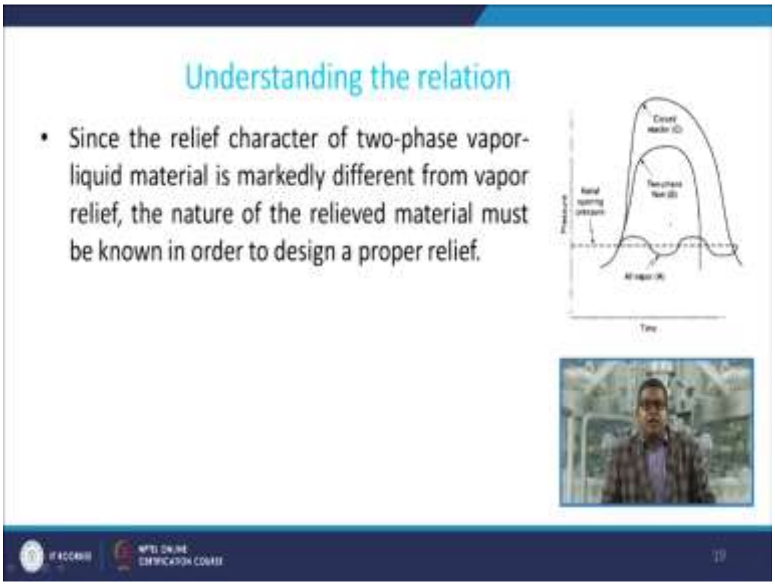

Now, since the relief character of two phase of vapour liquid material is markedly different from the vapour relief, the nature of relief material must be known in order to design a proper relief. Now remember, there is one major accident took place in Italy in the Seveso just because of the failure of these devices, so be careful and you must have this type of pressure, time and temperature relationship with us.

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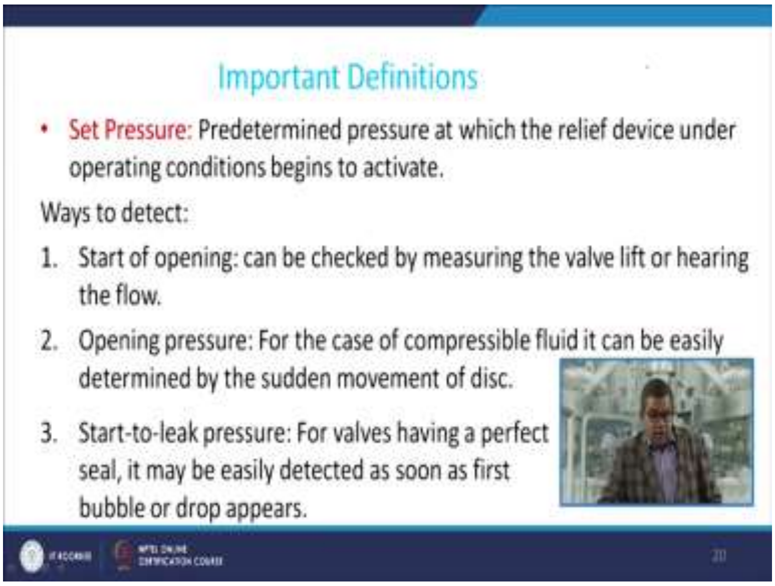

Now, before the go into details, we must look into several important definitions which may be very useful in due course of time. Now the first and foremost important definition is the set pressure, so this is the predetermined pressure at which the relief device under operating condition begins to activate. Now there are various ways to detect; one is the start of opening, this can be checked by measuring the valve lift or hearing the flow. Second is the opening pressure, for the case of compressible fluid it can be easily determined by the sudden movement of disc. Third is the start-to-leak pressure for valves having a perfect seal, it may be easily detected as soon as the first bubble or drop appears.

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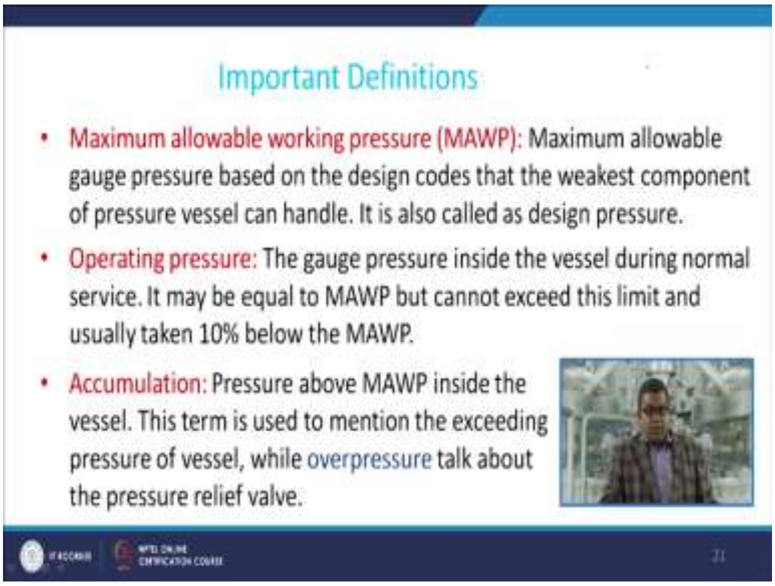

Now second is the Maximum Allowable Working Pressure MAWP, sometimes it is designated in abbreviated form. This maximum allowable gauge pressure based on the design codes that the weakest component of pressure vessel can handle, it is also called the design pressure. Other is the operating pressure, the gauge pressure inside the vessel during the normal service. It may be equal to MAWP but cannot exceed the limit and usually taken 10 percent below MAWP. Accumulation, the pressure above MAWP inside the vessel, now this term is used to mention the exceeding pressure of vessel while overpressure talk about the pressure relief valve.

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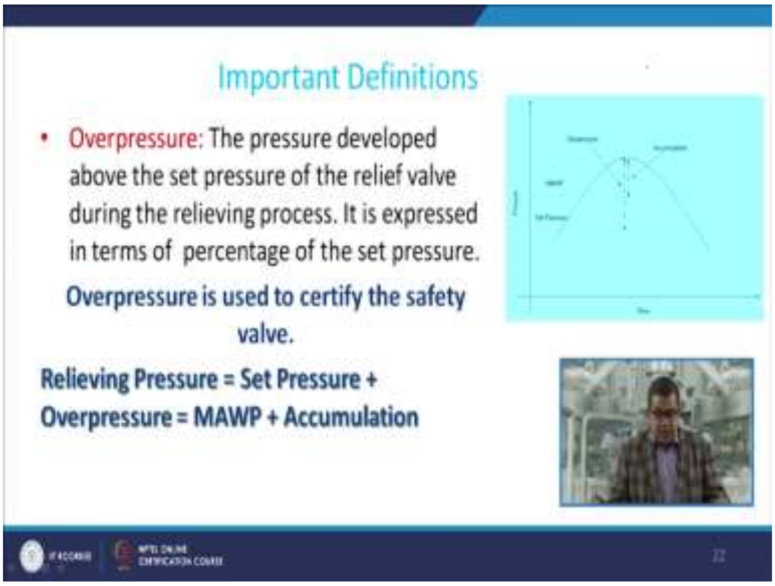

There are certain things related to the overpressure, this pressure the pressure developed above the set pressure of the relief valve during the relieving process and it is expressed in terms of percentage of set pressure. So you can see now this is your set pressure, this is MAWP and this one is the overpressure or this one is the accumulation. So overpressure is used to certify the safety valve, now

Relieving Pressure = Set Pressure + Overpressure = MAWP + Accumulation

This is the standard equation for dealing such overpressure, temperature and MAWP.

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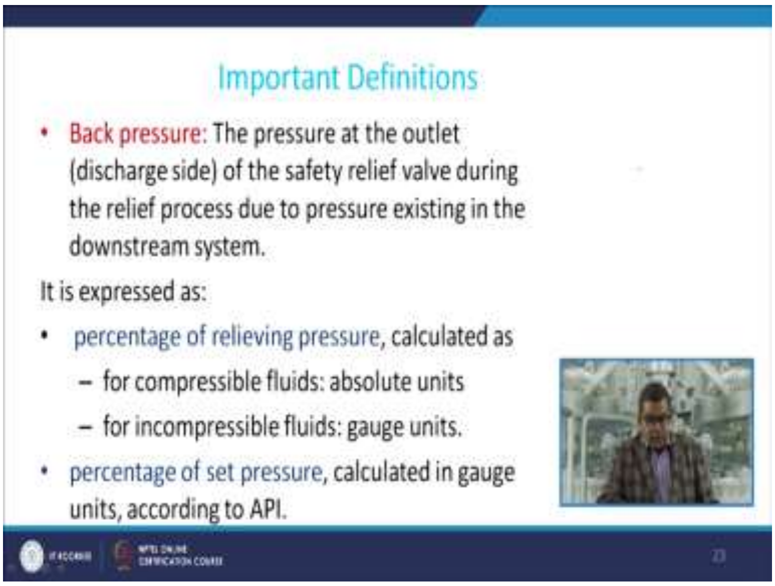

Another one is the backpressure, the pressure at the outlet the discharge side of the safety relief valve during the relief process due to the pressure existing in the downstream system. Now usually it is expressed as percentage of relieving pressure, usually calculated as for the compressible fluid that is in terms of absolute units and for incompressible fluid it is calculated in terms of a gauge unit. The percentage of set pressure, this is calculated in gauge unit as per API.

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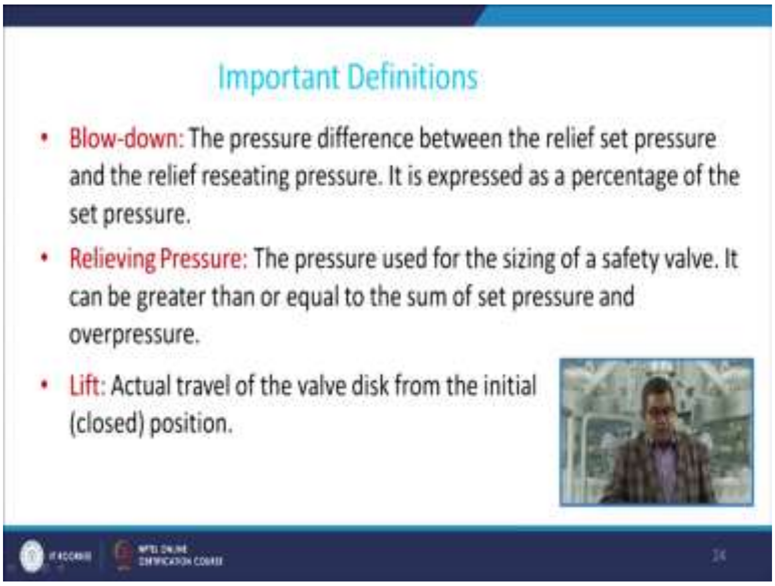

Blow-down; the pressure difference between the relief set pressure and the relief reseating pressure, it is expressed as a percentage of the set pressure. Reseating means when the pressure is relieved and the valve or disc may be re-seated to its original position. Now relieving pressure, the pressure used for the sizing of the safety valve, it can be greater than or equal to the sum of set pressure and overpressure. Lift; the actual travel of the valve disc from the initial or the closed position, so whenever it acquires the original position it is called the reseating.

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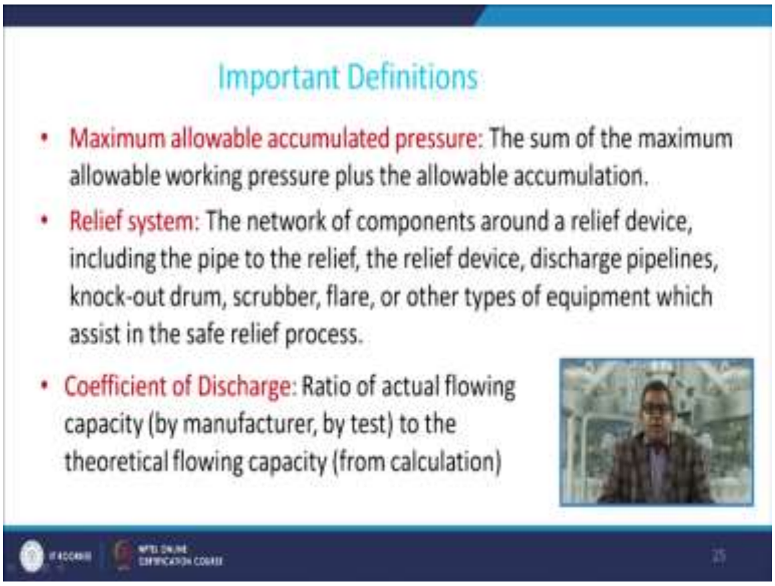

The maximum allowable accumulated pressure, the sum of the maximum allowable working pressure plus the allowable accumulation, you may refer to the previous plot. The relief system; the network of components around the relief device including the pipe to the relief, the relief device, the discharge pipelines, knockout drum, scrubber, flare, or other types of equipment which assist in the safe relief process. The coefficient of discharge; this is the ratio of actual flowing capacity that is decided either by the manufacturer or by testing to the theoretical flowing capacity that is purely from the calculation.

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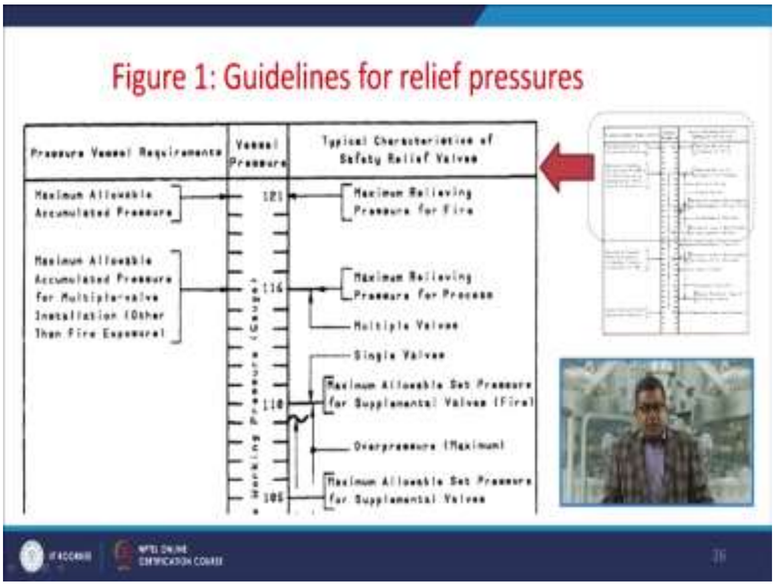

Now here you can see, the guidelines for the relief pressure this is the two-step slide. Now here you are having the pressure vessel requirement that is the maximum allowable accumulated pressure, and here you are having the vessel pressure which is having the numerical value. Now this is the typical characteristics of safety relief valve, so maximum allowable accumulated pressure say that is 121, the maximum relieving pressure for fire is this one.

So maximum allowable accumulated pressure for multiple valve installation other than the fire exposure is given by this one. So every industry or every process they must have these types of guidelines for the relief pressure. Now before we go for this guideline, you must be acquainted with these types of definitions that is why we have taken these definitions a priory before we go into the details.

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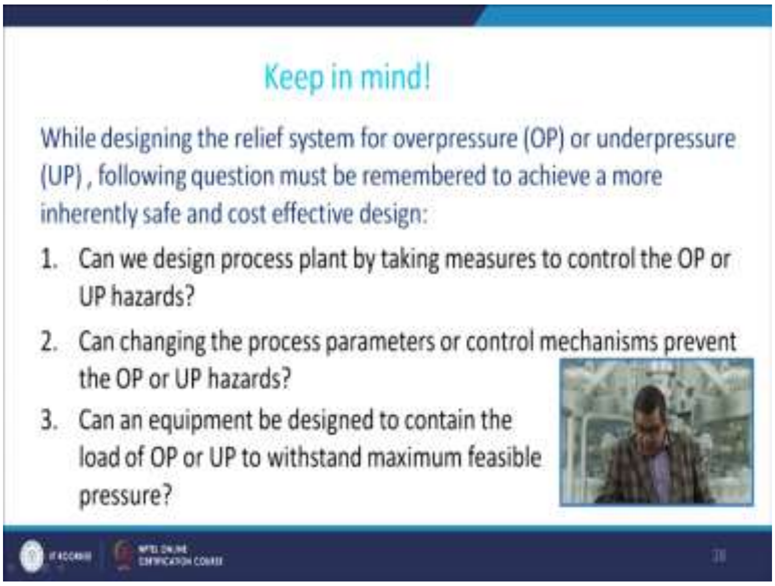

Now there are certain things you must keep in your mind that while designing the relief system for overpressure sometimes it is designated as OP or under pressure, the following questions must be remembered to achieve more inherent safer and cost-effective design. You must ask different questions and you must frame different questions. Now the sample questions are: Can we design process plant by taking measures to control the overpressure or under pressure hazard?

First thing, second, Can changing the process parameters or control mechanisms prevent the overpressure or under pressure hazard? Again because sometimes maybe because of the variety of reasons you are compelled to change the process parameters so you must ask this particular question. Now can an equipment be designed to contain the load of overpressure or under pressure to withstand the maximum feasible pressure?

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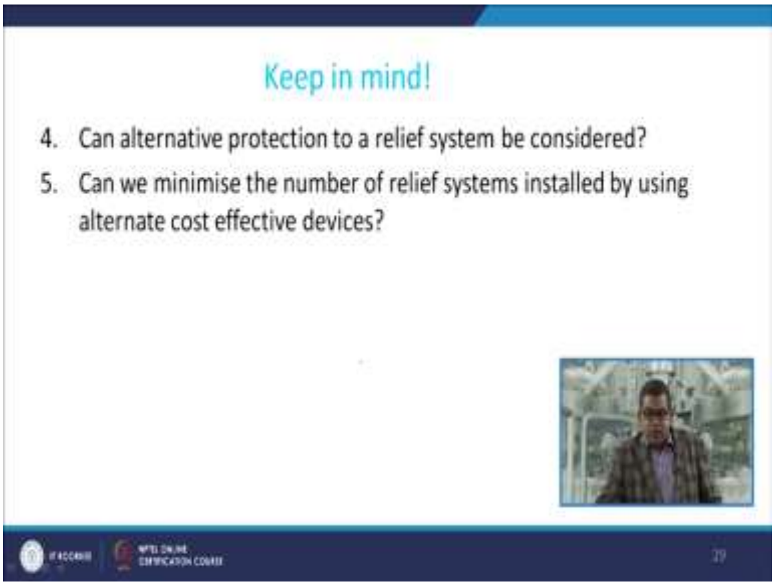

Now can alternative protection to a relief system be considered? Because it provides you variety of options. Can we minimise the number of relief systems installed by using alternate cost-effective devices? So these are the couple of things which you must keep in your mind.

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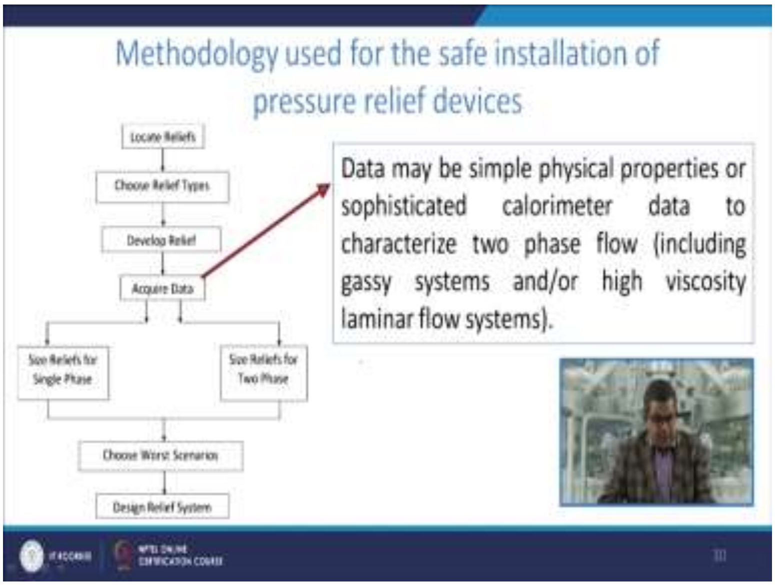

Now in the next part we are discussing that methodology used for the safe installation of a pressure relief device. Now this particular flow sheet gives you an idea about this particular methodology, you must locate the various relief desired on the basis of your knowledge and on the basis of the questions framed you must choose the proper relief pipes, then you develop the relief protocols for that particular process.

You may acquire the desired data, and these data may be simple physical properties or sophisticated calorimeter data or characterised two phase flow including the gassy systems or high viscosity or a laminar slow system so that is purely based on the variety and the quality of the question being asked for the particular process.

Now this acquire data you may select the size relief for the single phase and size relief for two phase that depends on your requirement. Then you adopt or you choose the worst scenario, and on the basis of this particular information you may design the proper relief system for that particular process. So this is the proper methodology for the safe installation of any kind of pressure relief devices.

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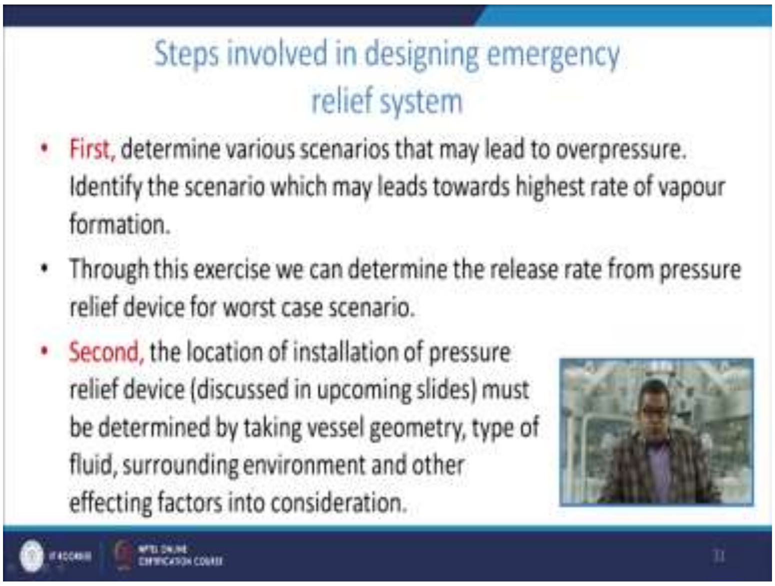

Now there are several steps involved in designing the emergency relief system. The first is that determine the various scenarios that may lead to overpressure, identify those scenario which may lead towards the highest rate of vapour formation this is one of the examples. Now through this exercise we can determine the release rate from pressure relief device for worst-case scenario it may lead to the rupture of vessel, et cetera.

Now second, that the location of installation of pressure relief devices we are going to discuss in upcoming slides must be determined by taking vessel geometry, type of fluid, what are the surroundings or surrounding environment and other effecting factors you have to take into consideration. So location is again very important because if location is wrong then definitely the relief device will not serve its desired purpose.

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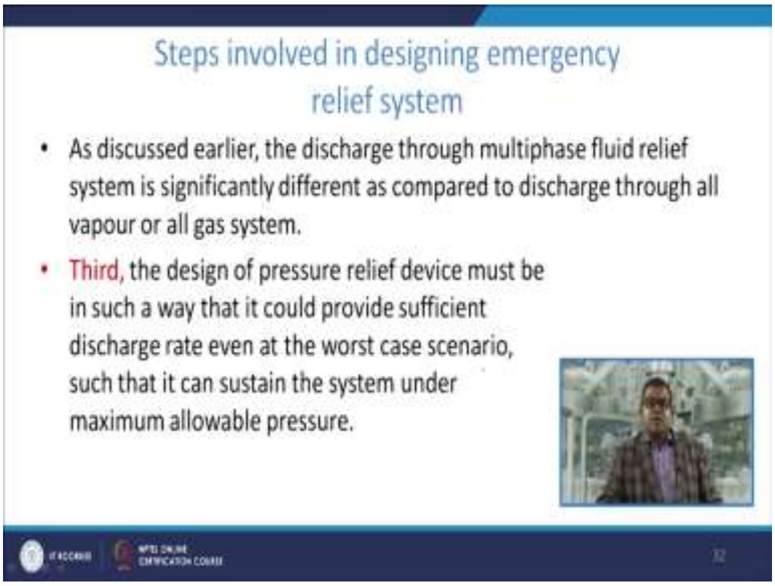

Now, we had discussed earlier that the discharge through multiphase fluid relief system is significantly different as compared to the discharge through all vapour or all gas system. Now the third case is the design of pressure relief device must be such a way that it could provide the sufficient discharge rate even at the worst-case scenario such that it can sustain the system under maximum allowable pressure, this is again a very important point to note.

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So keep in mind that if the relief device is designed much larger as desired, it not only lead to the higher costing but also add to a loss of material and treatment costs for the relief fluid to be handled so you must have an appropriate or an optimum relief device. The last step is to design a treatment system for handling the relieved fluid discharged from the relief device, it is just like that the steam is discharged to the atmosphere at a very high temperature, so you must know that what is the treatment protocol for the relieved fluid. Now this step is very important as the fluid discharge if not treated properly can lead to bigger consequences than the rupture of pressure vessel, so you must know all these things.

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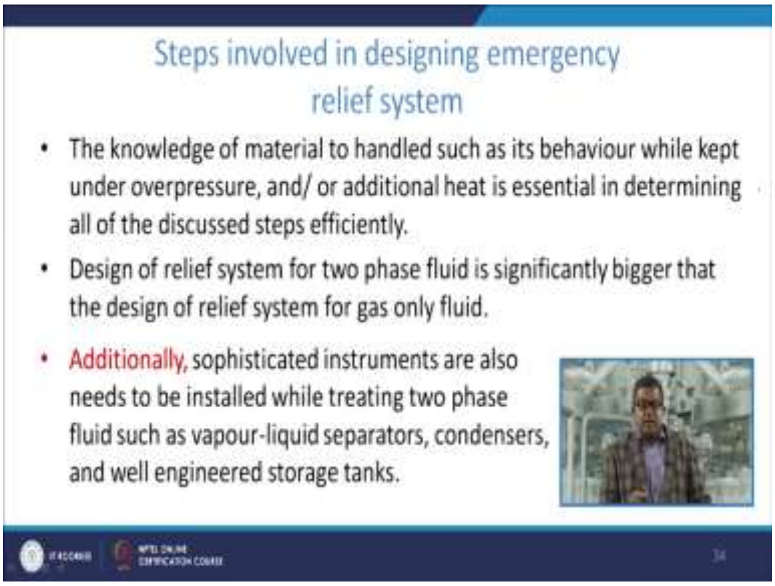

The knowledge of material to handle such as the behaviour while kept under overpressure and other additional heat is essential in determining all the discussed steps effectively. Now design of relief system for two phase fluid is significantly bigger that the design of relief system for gas only fluid. Now, additionally there are sophisticated instruments requirement which need to be installed while treating two phase fluids such as vapour liquid separators, condensers and well-engineered storage tanks, so these are the need of time to have these sophisticated instruments.

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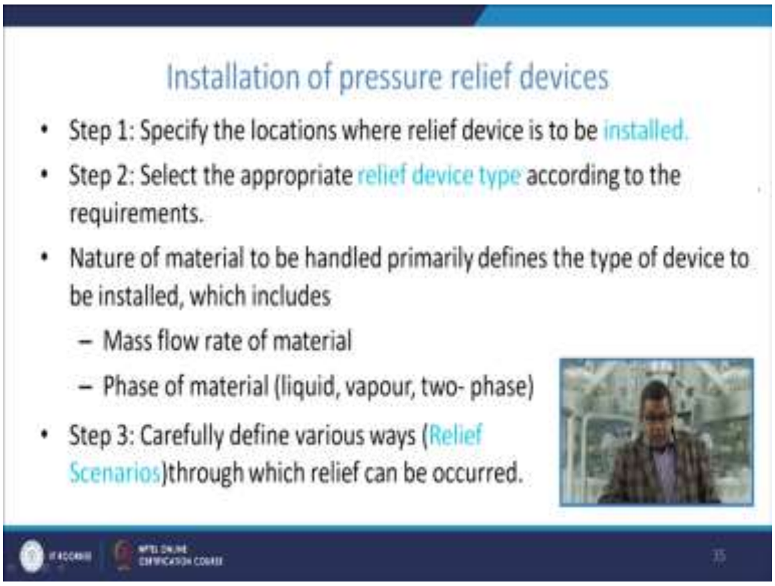

Now question arises, how to install the pressure relief devices. Again it is a multistep process, first step is that you need to specify the location where the relief device is to be installed. Now again we have discussed in the previous slides that the location is very important, relief location is very important for installation. The reason is that if it is not at a proper place then the results or the outcome would be extremely dangerous.

Now step 2 is to select the appropriate relief device type according to the requirement. So nature of material to be handled primarily defines the type of device to be installed, which includes the mass flow rate of the material, phase of the material and the characteristics of the material because it should not be so reactive with the relief device otherwise it may cause the choking, it may cause the following, et cetera.

Step 3, the carefully define the various ways that is the relief scenario through which the relief can be occurred. This is again achieved by plotting various temperature, versus pressure plots or pressure versus Time plots, et cetera so you can device or you can develop the systems carefully.

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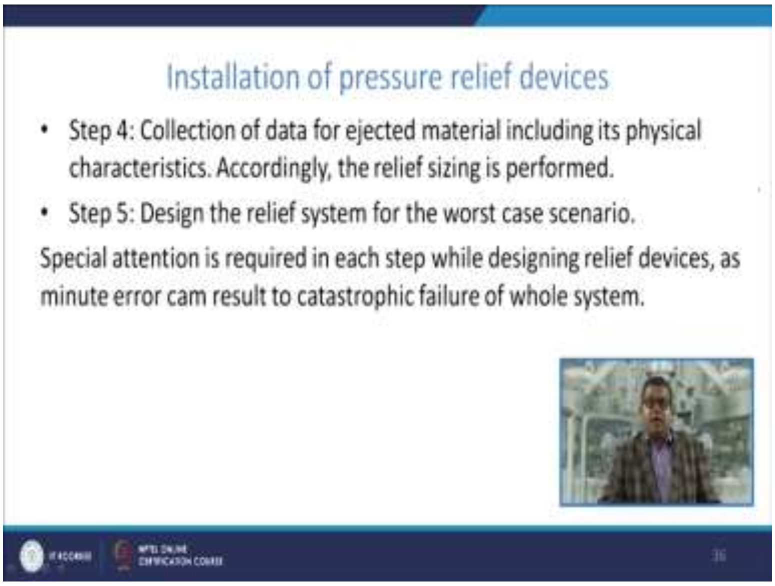

Step 5 is collection of data for ejected material including the physical characteristics, and accordingly the relief sizing need to be performed. The last step is the design the relief system for the worst-case scenario. Means extreme pressure, extreme scenario so that you must aware that what are the consequences may take place in due course of time. So, special attention is required in each step while designing relief devices as a minute error can cause, can result to a catastrophic failure of the whole system entire system.

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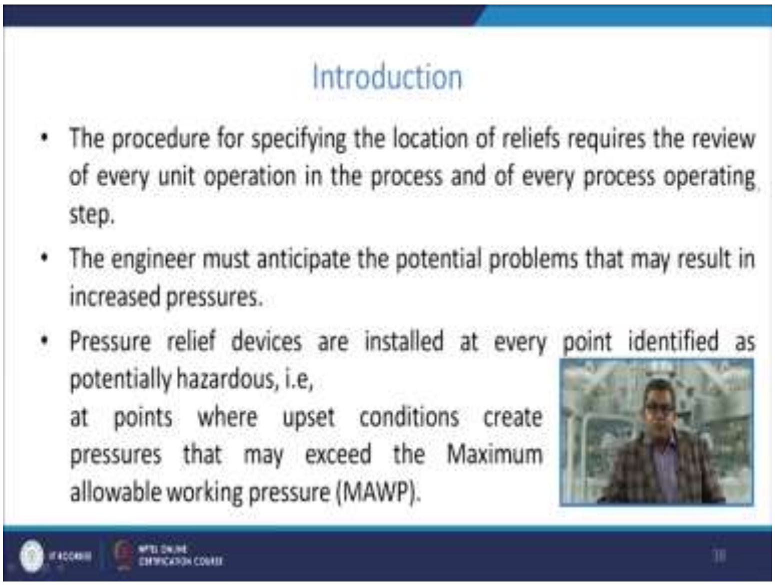

Now, next aspect is the location of relief, this is again a very important aspect which need to be addressed. Now procedure for specifying the location of relief requires the review of every unit operation in the process in question and every process operating step, so be careful about this one. The engineer must anticipate the potential problems that may result in the increased pressure. The pressure relief devices are installed at every point identified as potential hazard that is at points where the upset condition create pressure that may exceed to the Maximum allowable working pressure.

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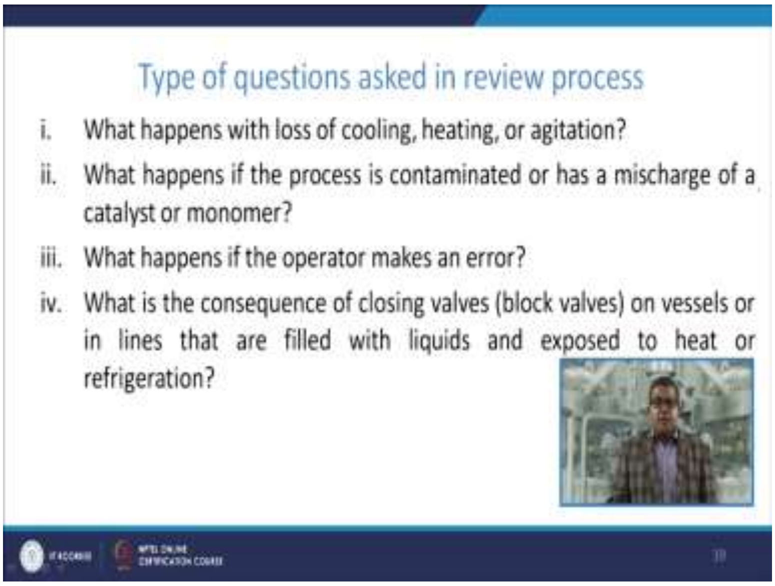

Then the type and the quality of the questions asked in the review process. Remember, you may design, you may develop your own questions. Now, the sample questions are that what happened with loss of cooling, heating or agitation? What happens if the process is contaminated or has a mischarge of catalyst or monomer? What happens if the operator makes an error? What is the consequence of closing valve that is maybe block valve on vessel or in-line that are filled with the liquid exposed to heat or refrigeration?

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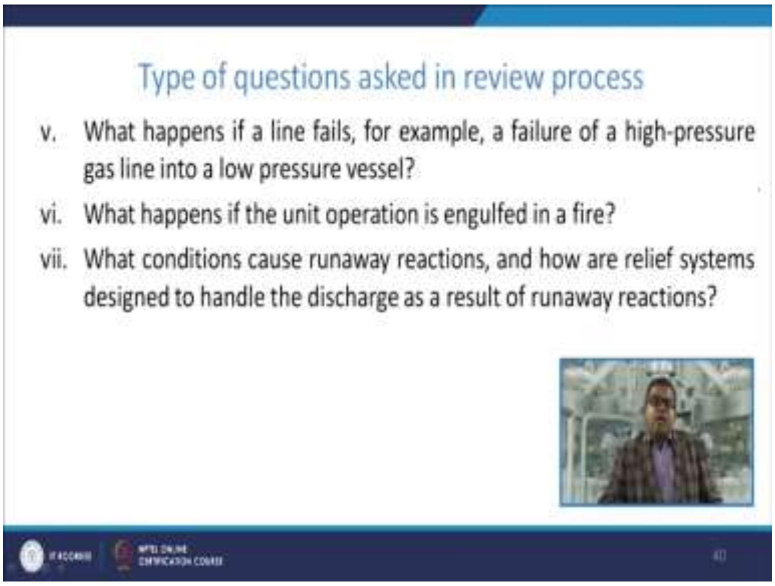

What happens if a line fails for example, a failure of a high-pressure gas line into a low-pressure vessel? What happens if the unit operation is engulfed in fire? What conditions cause runaway reaction and how are the relief systems designed to handle the discharge as a result of runaway reactions? So these are the various sample questions which need to be asked before designing any kind of relief system.

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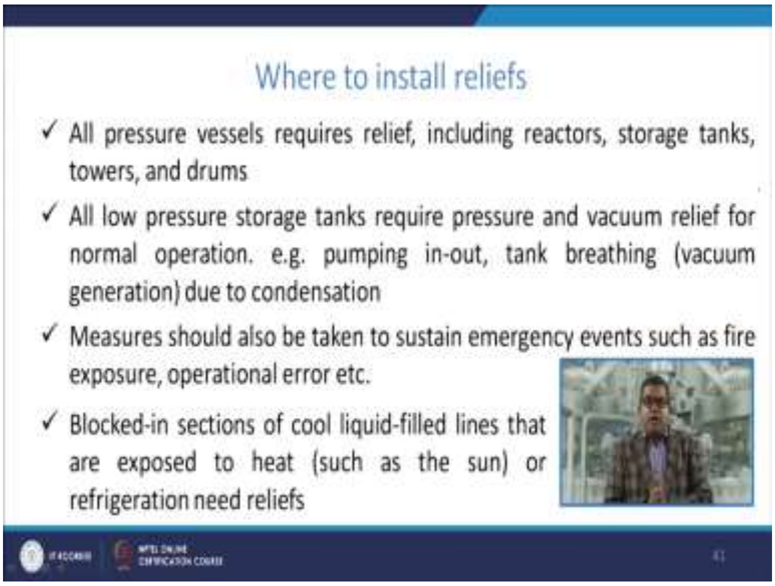

Now where to install those reliefs? The all pressure vessels requires relief, including reactors, storage tanks, towers, drums, et cetera, so you need to locate all those pressure vessels. All low-pressure storage tanks require the pressure and vacuum relief for normal operation that is pumping in-out, tank breathing vacuum generation due to condensation. Measures should also be taken to sustain emergency events such as fire exposure, operational error, et cetera. Blocked-in sections of cool liquid-filled lines such as lines that are exposed to heat such as the sun or refrigeration, they needs the relief.

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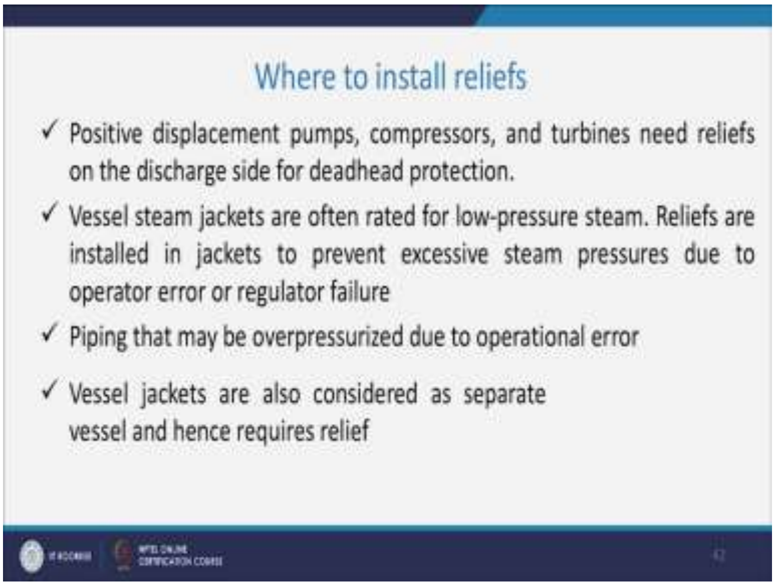

The positive displacement pumps, compressors, turbines, they need the relief on the discharge side of dead head protection. Vessel steam jackets are often rated for low-pressure steam. Reliefs are installed in jackets to prevent excessive steam pressures due to the operator error or regulator failure. The piping that maybe over pressurised due to the operational error, sometimes vessel jackets are also considered as a separate vessel and hence requires relief.

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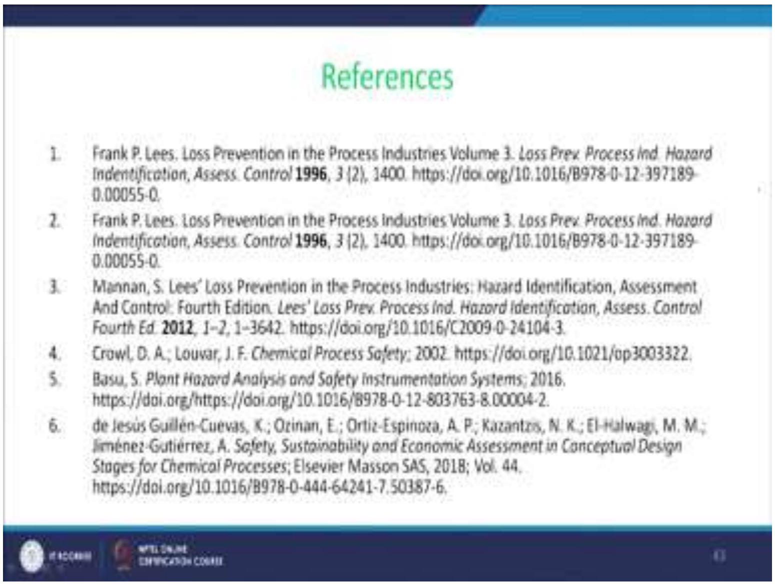

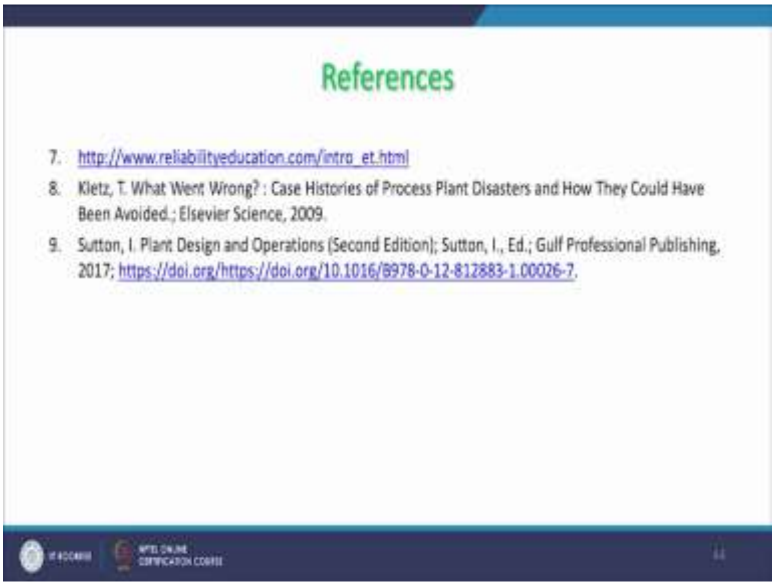

Now, in this particular module we have discussed a brief introduction about various relief devices. We have discussed about various aspects of overpressure, and for your convenience you may have a look of these references which are enlisted in this slide. Thank you very much.