Surface Facilities for Oil and Gas Handling

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Pressure Vessel-01

Good morning everybody. Today I will start topic pressure vessel. So, these topics will include pressure vessel sizing, weight calculation, basic fundamental of pressure vessel. Because this pressure vessel you are using in surface production operation system. For example, you have one separator and you are having different amount of pressure. So, this is actually pressure vessel, inside pressure is higher, inside P out, outside is actually atmospheric pressure, inside pressure normally 1500 PSI, 1000 PSI will be there.

And there will be different type of separators, vertical, horizontal, and pressure ratings also will be different for different separators. Again this pressure vessel sizing or wall thickness or material will depend on what type of fluid you are handling and which temperature you are handling. So, those parameters also you need to know when you are selecting, design or selecting or operating a pressure vessel. For example, if you have H2S hydrogen sulfide, this will cause lots of corrosion.

So, when corrosion is there, so after certain time, this metal will be corroded and there will be leakage or there will be other accidental issues. And H2S you already know this is very much dangerous for your environment and your health. So, you have to design a pressure vessel such a way that it will not have any accidental issues or it will not give any pressure loss or it will not be giving any the other pressure systems are like piping systems. In the oil and gas industry, while you are whenever you are producing fluid, fluid may be gas or maybe oil, maybe water or may be sand mixture. So from the wellbore when you are lifting up, so you have a high-pressure pump and it is going through your tubing, your casing, then it is going to surface wellhead, then it is going to choke, then the separator system, then your transfer line.

And gas normally it will be continuously high pressure because you have to transfer to your customer and CNG compressed natural gas or you are creating liquefied natural gas LPG. So every case you actually creating high pressure and some cylindrical system or spherical system will be holding that pressure or maybe a rectangular system also will be holding the pressure. So the pressure system if you are not designing properly then problems will be coming up. So how to design it, what are the basic criteria we will try to discuss in this lecture? So this lecture is taken

from the surface production operation book written by Stewart and Arland, maximum portion of this whole course I am taking is from the surface production operation volume 1 and volume 2.

So this is taken this portion is taken from volume 2, the chapter number is 12 for this course this section. Now what is a pressure vessel, this is a leak type pressure container. So the leak is not allowed, if the liquid is there then pressure already will be reduced. So it must be contained inside the vessel. Cylindrical or spherical in shape possible with different head configuration, head configuration is this two end.

So two end can be like for example vertical separator this type of end also possible and in some cases you can make a rectangular head or you can make hemispherical head different types of head. So whenever you are designing different type of shapes that will decide your strength, pressure vessel strength and sometime it will be applicable for certain application. For example if you have certain amount of sand and sand is getting deposited so conical bottom will be better. Carbon stainless steel is assembled by welding pressure vessels available. So carbon steel or stainless steel, carbon I already told you that mild steel means a lower amount of carbon.

But when you are increasing the amount of carbon that is because carbon steel so strong you are increasing actually. Whenever you are talking about stainless steel the term is stainless, stainless means rust possibility will be reduced. So in that case chromium and other material will be added to improve steel property. And basically welded, so many times riveted also possible but welding is better because welding will be giving higher strength and this is permanent type joining. In previous lecture we have seen this for your tank battery system there we go for welding where higher strength is required.

So pressure vessel require higher strength. So normally it will be going it will be done through welding. The ASME or American Certain Mechanical Engineers have boiler and pressure vessel code and the code is being used worldwide. And there may be other type of agency who are also giving such pressure vessel code. API also has their own code ASME like American National Standard Institute, NC they also uses ASME code.

API code also there for low pressure application but ASME code is more universal. So all over the world people are using ASME code for pressure vessel design. The code will say like what will be the basic formula, what will be the basic criteria so that everything will be operated under safe limit. Because you cannot design one pressure vessel which will be working for all pressure condition. So first you have to know your pressure requirement for example you want to work for 1000 to 1500 psi pressure.

So you will have within that limit you have to design pressure vessel. Let us say you are designing for 5000 psi because you are thinking like my pressure will be 500 and if I design for 5000 then everything will be safe. But it will be increasing cost because then material thickness will be changing, design criteria will be changing. So you do not want to increase your cost again you do not want to create accidental bust or any harmful thing. So that is why all the pressure vessel when you are buying or using you should know what is the rating of the vessel accordingly you are using pressure.

And not only pressure rating you have to check whether it is having it is designed for specific fluid for example H2S, H2O, carbon dioxide or any other chemical you are handling then you have to check material what material you are using for your vessel and what fluid you are handling and which temperature also. If temperature is increasing material property will change because at high temperature material will be creeping quickly or it will be elongating or material properly change finally your system will not work. So you have to check temperature, you have to check pressure, you have to check what type of fluid you are using, fluid properties you have to know actually. So based on that you are selecting, designing and operating pressure vessel. And whenever you are buying pressure vessel actually this some company is saying like we are following ASM standard then those are standard pressure vessel.

But there will be some non-standard pressure vessel also available. So in that case you have to check their design everything because non-standard means they are not following but they may be safe they will using some specific material for that that is why they cannot use American specific code because ASM will say use this type of material for this thickness for this pressure this fluid. But let us say for specific application you are using certain chemical where ASM does not say anything. So in that case that will be non-standard code non-standard design. So in that case you have to check their calculation so that things will be safe.

So whenever you are designing a pressure vessel vertical or horizontal maybe it will be separator, it may be boiler, it may be pipeline. High pressure pipeline also there, pipeline connecting two separators or pipeline connecting from transporting fluid or crude oil from one country to another country cross country pipeline gas pipeline will be there. So in that case you have to check internal external pressure. So normally it will be external pressure atmospheric pressure. But in many cases it may not be atmospheric pressure for example in some chemical industry they are using they may have outside some other pressure also or maybe double pipe heat exchanger.

They will have external pressure in terms of pressure different. So that also you have to know what is the internal pressure, what is the external pressure. So dead load weight of the vessel and contents when you are designing so how much weight is there. So weight will be deciding your actual cost. So you are increasing weight of the vessel that means metal cost is increasing, manufacturing difficulty will be there because of very high weight you design then who will be handling this one.

Then crane will be required, installation will be there. So not only material cost rather other logistical issues are there. So transportation, installation, maintenance everything will be difficult if you are increasing too much load. So you have to try to reduce weight and you have to make everything safe also. External loads, piping and attachment wind, earthquake.

External load if it is static thing then only atmospheric pressure is there. But there may be earthquake and you are handling high pressure oil and gas and if there is a leakage because of this earthquake or other pressure change then there will be disaster. And wind sometime blowing, cyclone will be coming and surface production operation system it will be open to atmosphere. So in that case wind, rain everything will be there. Piping fittings will be there.

So fittings and attachment those are also very important because normal separator system without fittings and everything fine. But when there will be any fitting the more weakest point will be here, weakest point is the joints. So whenever you are designing any mechanical system, so normally the design should be starting from the weakest point. Weakest point will be like joints. Joints will be the weakest point because if pipe fitting is there the joint part will be broken first.

Then maybe nut, bolt, bolt thread, rivet, cut any type of notch because of mis-handling you got some small crack on notch, surface scratching that also will be the weakest point actually. Because that will be giving stress concentration. Stress concentration like this I have one rod, like this. Rod is very smoothly designed that is fine. Now because of mis-handling what you do, you got some small crack.

So what will happen if I apply let us say tensile load. Tensile load I am when I am applying on this rod so pressure or stress will be generated like this F by A. Force you are applying area is there. But when notch is there actual area is reduced actually.

So F by A dash. Now you got lower area. So lower area means you got more stress. So more stress means failure probability higher and breaking will be starting there only. So whenever you have any mis-handling, piping, attachment like say joints, nut, bolt, thread, rivet or any other thing which is creating unevenness on the surface. So that will be giving the breaking point or weakest point actually.

So you have to look at those points also. So whenever you are designing, so you have to consider all these factors. So normally in formula those will be coming as a factor not sensitive factor or some joints or connection factors, bolt factor, those factors will be coming. Operating type load vibration. So if you are transporting fluid using your ships or FPSO floating platform is there or some other platform is there.

So in that case sloshing will be there. Sloshing means like you have one tank and half filled water or partially filled water or liquid or oil or oil, liquid especially. So if wind is moving up and down like this, so inside fluid will be sloshing. So that will be giving lots of vibration to the pressure vessel. Whatever vessel is there it will get lots of vibration.

That vibration also will give weakness to your mechanical system. So even when you are transporting high pressure fluid, so let us say truck transportation, truck will have lots of vibration. We will be having lots of vibration. So it is like CNG or like say LPG or transporting. So LPG will have liquid and sloshing will be there.

So that will be giving lots of vibration and ships, train, truck and those machinery also will have their own vibration. So when vibration is coming then again you have to consider another factor. Startup shutdown load. So initially when you are giving pressure or okay, so whenever you are using some code, let us say a semicode or API code, so those codes will be considering pressure, temperature and all other factors like whatever factors included here. Maybe some more factors also will be coming based on your specific design criteria.

So one is fluid property, will be internal pressure, external pressure and other factors like whether it is dead load or dynamic load. So dynamic load means pressure is fluctuating very much because of certain reason. So fluctuating pressure means it will be dynamic load. But if you have one vessel and you just pump high pressure fluid and then you forget, there is no pressure change.

So there will be static loading. So dynamic loading will be more dangerous. Static loading means you are just putting extra pressure. So system can be safe. But when it may be dynamic, so system may not be so much efficient or it can burst or it can give leakage. External load, piping, attachment, other things are there, operating conditions are there.

So all the factors you have to consider whenever you are considering designing or buying system or operating a system. So allowable stress, also known as allowable working stress or allowable design stress. So maximum level of stress that a material or structural component can endure without experiencing failure or deformation. So one material, let us say I take this one solid metal and if I apply tensile load, after certain time it will be failing. If you see the design table, if I use this one mild steel, mild steel will have specific value up to this much of stress or pressure you can apply.

Here I am saying two terms, stress and pressure, pressure or force I am applying. Stress means body reacting. So stress means reaction. Stress means reaction of the material, of material.

Pressure or force you are applying or load. So you can see like this, like as a professor if you give lots of academic load, like lots of homework, your assignment and presentation, then we are loading you, then what will you get? You will get stressed, you will get depressed maybe. So similar way you are applying pressure and material will be reacting that is called stress. So maximum level of stress, you are pulling it, so material is having specific stress limit. So that stress it will break, but whenever you are designing a certain machine element using same material, you are not applying up to that level of load. So you are saying the customer, you use let us say this is, this will break if I apply 100 Newton per meter square load.

But I will tell the customer use up to 50 meter, 50. I will not tell what is the endosym or anything. I will say you can use only 50 Newton per meter square. Let us say 100 Newton per meter square, certain material is having a breaking load. If you applied load here, it will break. But when I am selling this product, I will tell the customer use only 50.

Why? If I tell customer 100, then they will be applying 100 and things will break. I will say 50. So if they are crossing 50 to 60 also, it is still fine. But many time, customer will not follow designers requirement.

So they may try to overload. For example, it is good to design for two people. Sometime we, in Chennai road you can see three people, four people also riding. So because of factor of safety, this is called factor of safety. Factor of safety means here factor of safety equals 100 divided by 50 equals 2. So many design machine element, you need very high factor of safety.

For example, aircraft design, you need very higher factor of safety. But bicycle design, other design, maybe factor of safety will be 1.5 or 2. But normally factor of safety should not be 1, because factor of safety 1 means if small material fault is there for the small crack or notch or anything, then system will break. So you have to give factor of safety in every design, every mechanical design.

So maximum level of stress that a material or structural component can endure without experience, failure or deformation. So how much you are applying? You are having 50 actually. So that is your allowable stress. So you are allowing this much. But maximum can be 100 to 100, 300 maybe, but I am saying the user, usually 50.

If they are crossing also, they are violating my norm 50 to 60, still things will be safe. Many times failure may not be having much more disaster, but failure will be very much disaster, for example, high speed vehicles, for example, aircraft or train or so high speed vehicle, small failure, one nut failure, bolt failure, that can be very much big accident. But in many cases smaller, let us say pen, if it is getting broken also when I am writing, it may not give big disaster. Consideration to determine sigma A, sigma A means allowable stress.

I am saying allowable stress. I am putting this notation everywhere, allowable stress. Okay, so you have to consider material property. So material property in which temperature also important like say some material will be behaving very good in 100 degree centigrade temperature, but it may not behave same way if you increase temperature to 500 degree centigrade. So material property you have to know and which temperature you have to check. Safety factor, safety factor or factor of safety I already told, accounts for uncertainties in material properties or manufacturing process, etc.

So material property may have some, like whenever manufacturing there will be some vacuole or some small cavity or some small crack, internal crack. So that will give some uncertainty in system. So that is why you give little bit higher factor of safety so the system can be safe. Loading condition, so types of loading with the static loading or dynamic loading.

So if I am putting a static load, this one is okay. But if I continuously change the load, okay, so

this system will be failing quickly. For example, if you take one wear, metal wear also and you bend it one time, it will not break. But if you continuously do like this, after certain time it will be cracked and it will be separated. Loading condition, okay, design code and standard. So you have to follow design code standard because they will have, they will give the limit.

Within that limit this material will be working. Temperature, T for temperature, temperature affects material properties I already told. Allowable stress is not a single or fixed value. Okay, you can see this. Allowable stress is not a single or fixed value because temperature and other condition it will be changing.

Okay. For static loading, factor of safety can be very low. But for dynamic loading, I will, I have to put very large factor of safety. So my allowable stress is changing. Material property I cannot change, material property is fixed.

But allowable stress is changing. Okay. Because if I change material temperature and other or loading condition or anything, so then in that case allowable part I have to change. Okay, material property I cannot change because this is already fixed. Hoop or circumferential stress. A typical, a type of stress that acts in a direction perpendicular to the axis of a cylinder.

Okay. I have this cylinder here. Okay. And I have internal pressure. Internal fluid pressure as per your Pascal law, fluid will be having same pressure in all direction.

Okay. Because of Pascal's law. Okay. Fluid pressure will be exerting all side. Okay. So, now this you see material. Okay. So, material if I draw like thickness like this, so material is getting stress like pressure like this and other half, this also getting pressure.

According to Pascal law, both side pressure must be same. Okay. And this area, this two end, two half you can say this one half, this one half cylinder and you give very high pressure inside, what will happen? It will try to tear off. So, this tear off and this tear off. Okay. Because of internal pressure, this will try to tear off.

So, that is called hoop stress or longitudinal stress. A type of stress that acts directional perpendicular to the axis. So, this is my axis.

Okay. So, and perpendicular to axis, the bottom figure, vertical it will be. Okay. So, perpendicular axis of a cylinder or spherical object, such as a pipe, tube, pressure vessel. So, that is called hoop or circumferential stress. Okay. Due to the internal external pressure applied to the wall of a cylinder or spherical object. Hoop stress, you should remember the formula sigma h equals p d by 2 t, the internal external pressure.

Okay. So, in external pressure, we assume we have atmosphere and it has a pressure higher than p will be like two atmospheric pressure, three atmospheric pressure. D, diameter of the system or cylinder.

T is the thickness of the wall. Okay. Wall thickness also very important. Okay. Very thin wall will be breaking quickly, where thick wall it will not break. Okay. Pressure vessel sigma hoop stress less than sigma allowable stress for the safe operation. Okay. For any other operation sigma allowable, you can use something, but for pressure vessel, it must be lower than that.

Sigma hoop, this is sigma hoop. Okay. Sigma hoop, small h I have given. Sigma hoop stress is a tensile stress acting around the circumference on the cylinder or sphere. So, safety factor, I already explained. Efficiency of a material, maximizing the sigma hoop stress implies efficient use of material while maintaining safety. Efficient use of material means like you cannot, you are not making lots of thick material. Thick material is safe, but unless you are using increasing weights, weight of the system cost also of the system.

So, you have to minimize the thickness and you have to use the system such a way that it will not be giving any accidental leakage or accident. Maximum allowable, SME code section eight governs the design and construction of pressure vessel, pressure vessel, like separator or a piping system with operating pressure more than 15 psig. Okay. This is operating pressure. I just put operating under, I just put operating under pressure more than 15 psig, which is defined in a semi code section eight.

So, they have two section actually. One will be division one, another division two, two divisions are there. So, division one design by rule. So, division one less stringent in all rule, but they will be giving little bit highest factor of safety. So, the little bit of material and other criteria will be little bit lower, but use more factor of safety.

So, do not consider a material too much. So, give more factor of safety. Okay. So, here factor of safety, there is in 3.5. So, previous case I was saying two, but here you can see 3.5 because it is pressure vessel.

2001 edition higher allowable stress or sigma a and thinner wall thickness they are suggesting. For example, material with tensile strength sigma t, tensile strength 60 kilo Pascal, pound per square inch allows 17 into 10 to the power 3 psi sigma allowable. Okay. Because this 3.5 times, but division two, it will be giving lower factor of safety.

You want it want to wants to reduce material thickness and it will have more stringent rules. Okay. So, it will be having three factor of safety. If sigma t factors sigma t, tensile strength 60 into 10 to the power 3, then allowable will be 20 into 10 to the power 3. Many companies uses pressure vessels division two, because it will be giving lower thickness and to be more, it will be following more strict standards. But division one, it will be following less strict standard, but it will be more factor of safety.

Okay. For high pressure vessel, normally it will be going to division two. Many purchase, many company purchase less expensive vessel division one or two. Okay. Normally manufacturer choose division one for low pressure vessel application, division two for high pressure vessel application.

Okay. Here you can see allowable stress. So, material specification, you cannot say like steel or something. You have to say like material specific S A 5 1 5 group 60.

Okay. So, temperature limits 700 degree Fahrenheit. Okay. And allowable stress will be 14,400. Okay. And if you change temperature 700 to 800 to 900, you see this allowable stress also changing. So, allowable stress is going down actually. Okay. Temperature increasing, allowable stress is going down.

Why? At higher temperature, material will be soften actually. Right. Like if you increase very high temperature, it will be like liquid. So, whenever temperature lower, material strength will be more. Temperature higher, material strength will be lower. So, your allowable stress also will be changed.

So, how much stress you can allow? Allowable stress, stress again, I am saying this material reaction. Okay. So, how much material reaction equal to pressure actually. So, that much of pressure you are applying. Okay. So, the temperature increasing your pressure will be lower. So, similar to other materials, if you see temperature changing, your allowable stress also changes.