Principles and Practices of Process Equipment and Plant Design

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Module - 04
Lecture - 54
Plant Hydraulics

Welcome to you all. Today we are going to start the topic Plant Hydraulics. So far what we have done is - we have done the basic introductory course, beyond that we have talked about mass transfer processes distillation and so on, we also have talked about heat transfer processes where we have covered mostly the heat exchangers.

Now, in order to have a complete plant only the separation process and the associated heat exchange is not enough, most of the chemical plants will be handling fluids gas or liquid or slurries or whatever it could be. So, you require pipelines, you require pumps, you require compressors in order to have a complete plant idea you have to know about these as well.

Today, we are going to discuss the plant hydraulics initial part and this will be followed by some details on the different equipment which are used for transferring fluids, which are basically the pumps of the compressors. No one buys the piping, no one does the; I mean no one manufactures designs the pipe as such these are all bought out items along with the pumps and the compressors. So, what you will be required is primary to learn about the basics on which these are sized and how to specify these. So, that shall be the focus of this specific lecture today.

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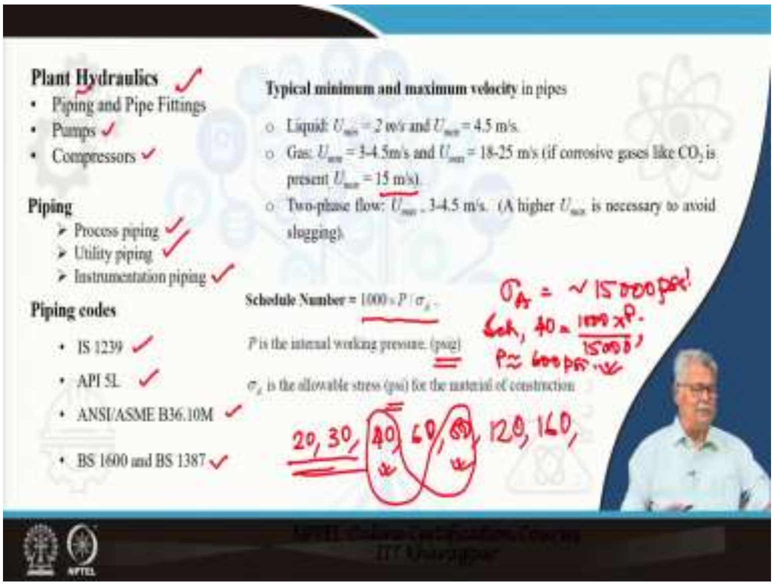

This is what we already have here in front of us that means, we need to talk about the piping definitely and the pipe fittings, what are the pipe fittings? You have the valves, you have bends and you are very much aware of the other fittings which are there you have flanges of different type, you have got reducers, you have got expanders and so on.

You definitely have to learn about the pumps and the compressors as I have just mentioned and if you are talking about piping with which we start first. The piping can be classified as the process piping the utility piping when I say utility piping. That means, any plant will always have apart from the process being process material being handled you will have facilities for steam you will have facilities for water of different grades possibly raw water, fire water, demineralized water and so on.

And you definitely will be having a system for your instrumentation which will be powered in most of the cases by compressed air of a particular quality which is called instrumentation air. You may also require or you may have utility which is a compressed air which is called plant air, your piping will also be required for the instruments.

For example, you will have the instrument tappings you will have possibly connection between instruments also and quite likely you may have piping which will be connecting the instruments to their readouts. The standard piping codes and many the Indian standard piping code is IS 1239, American Petroleum Institute the code is API 5L, ANSI ASME is B36 10M and in case of British standard it is BS 1600 and BS 1387.

This you need to know because whenever you specify a particular piping it should be following a particular standard usually the standard which has been followed in manufacturing or rather in specifying your other equipment in your plant. So they this allows compatibility between the piping that you choose and the rest of the equipment which is there in your plant.

You have maximum and minimum velocity limits. Typically for limit the limits are 2 and 4.5 for liquids for gas it is higher the minimum is 3 to 4 and half meter per second and your maximum limit is typically up to 25 meter per second. And quite naturally if the gas is corrosive something like carbon dioxide it is limited to about 15 meter per second.

The reason is simple if you have too lesser velocity there will all it is always that some amount of material will always be in your fluid which will settle down, you do not want that you want it to flow out you do not want it to accumulate in your pipeline. So, your velocity should be above the minimum velocity and if you have too higher velocity there will be erosion.

So, this is what guides the minimum and the maximum limits, this is also obvious that in case of two phase flow particularly liquid and gas or liquid and vapor together the maximum velocity is much lower it is 3 to 4 and a half meter per second. Here there is one more thing you may prefer to have towards a higher U max to avoid slugging. That means, you would not like hammering to take place and if you have a low velocity of two phase flow usually it leads to hammering which is a big amount of vibration in your piping.

Which may even damage your piping if the piping is not damaged what gets what happens actually is your piping’s are always anchored on supports they get dislodged from the supports. So, that has to be avoided and for that we have to avoid slugging and we usually take the velocity close to around 4, 4 and a half meters per second.

Next comes the strength of the piping the strength of the piping naturally will depend on the diameter and the corresponding thickness of the pipe, it is in most of the cases specified in terms of a schedule number. Which is having an expression 1000 multiplied by P divided by sigma allowable, sigma allowable is the allowable stress for the material construction of the pipe in psi note this and your P is the working pressure in psi gauge remember it is gauge.

Now, if you are talking about steel typical carbon steel the value of sigma A is around 15000 psi. Now, what happens the schedule number say if it is 40 then it will be 1000 multiplied by P divided by 15000 and what you find here is P is close to around 600 psi.

So, if you have a 40 schedule ferrous pipe possibly it can withstand around 600 pounds. The typical commercially available schedule numbers it can be 20, 30, 40, 60, 80, 120, 160 sometimes 180, even the most common schedule the most common schedule numbers which are used are 40 and 80.

So, these are the most common two schedule numbers, you will notice one thing and its obvious also for the same material if you go for larger pressure that has to be withstood that means, your working pressure is high your wall thickness would go up. Most of the cases you will find these 20 and 30 and 40 schedules up to 40 schedules. Being used for large diameter pipes in general it is obvious from the expression of schedule number that higher the schedule number we expect a relative increase in your wall thickness.

In case you have a large diameter pipe in case of a 20 schedule if you are going to use a 60 schedule or an 80 schedule the thickness would be much more. So, you go for the minimum schedule thickness required. So, that you save something in the material cost and it comes out cheaper. So, 20 and 30 up to 40 is mostly used for say 22 or 24 inches onwards. 120 and 160 they are very strong pipes they are used mostly for high pressures.

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Steel pipes and tubes dimensions IS 1239(Pt.-I) equivalent to BS 1387/1985									
Nominal bore		Outside diameter		Light (A-class)		Medium (B class)		Heavy (C class)	
				Thickness	Weight	Thickness	Weight	Thickness	Weight
Inch	mm	Inch	mm	mm	Kg/m	mm	Kg/m	mm	Kg/m
1/2"	15	0.844	21.43	2	0.952	2.65	1.122	3.25	1.45
3/4"	20	1.094	27.2	2.35	1.41	2.65	1.58	3.25	1.9
1"	25	1.312	33.8	2.65	2.01	3.25	2.44	4.05	2.97
1 1/4"	[illegible]	1.656	42.9	2.65	2.58	3.25	3.14	4.05	3.84
1 1/2"	40	1.906	48.4	2.9	3.25	3.25	3.61	4.05	4.43
2"	50	2.375	60.3	2.9	4.11	3.65	5.1	4.47	6.17
2 1/2"	65	3.004	76.2	3.25	5.84	3.65	6.61	4.47	7.9
3"	80	3.5	88.9	3.25	6.81	4.05	8.47	4.85	10.1
4"	100	4.5	114.3	3.65	9.89	4.5	12.1	5.4	14.4
5"	125	5.5	139.7	-	-	4.85	16.2	5.4	17.8
6"	150	6.5	165.1	-	-	4.85	19.2	5.4	21.2

Now I talked about the standard ok the standard is IS 1239 which is equivalent to it is corresponding British standard here. There are three grades light medium and heavy class A class B and class C and they are sized according to the nominal bore. Incidentally the IS codes specify the bore the nominal bore in terms of millimeters. So, you will see here the nominal bore is 15, 20, 25 and so on.

So, this is a nominal borer (Refer Time: 10:29). So, this is a standard which is very often will be required and you will notice that two things are there you have here the outer diameter specified you also have the thickness specified. That means, you know the inner and outer diameter both and you also know for the steel pipe, what is the weight in kilograms per meter?

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Big diameter steel pipes, ERW pipes: IS 3589, Grade FE330, Grade FE410

Wall thickness	Nominal bore 7", 193.7mm OD	Nominal bore 8", 219.1mm OD	Nominal bore 10", 273mm OD	Nominal bore 12", 323.7mm OD	Nominal bore 14", 355.6mm OD	Nominal bore 16", 406.4mm OD	Nominal bore 18", 457mm OD
mm	Kg/m	Kg/m	Kg/m	Kg/m	Kg/m	Kg/m	Kg/m
4.85	22.59	25.62	32.07	38.13	-	-	-
5.2	24.17	27.43	34.34	40.85	-	-	-
5.6	26	29.28	36.93	43.93	48.11	-	-
6	27.88	31.53	39.5	47.02	51.49	61	69
6.35	29.34	33.28	41.73	49.67	54.43	62.34	70.5
7.01	32.77	36.76	46.43	55.45	61.82	69.04	-
7.94	-	41	50.95	61.85	67.98	77.94	87.8
8.18	-	42.56	53.42	65.12	-	-	-
9.53	-	51.5	60.24	73.75	81.21	93.13	105
12.7	-	-	-	-	107.28	123.3	139

The same thing we have here for the large diameter electric resistance welded pipes which is according to IS again 3589 and there are different grades of it the two grades are common in fact. Here the nominal bores are 7 inch 8 inch, 10 inch, 12 inch, 14 inch, 16 inch and 18 inch the kg per meter values are all available here and the OD is also there and the wall thickness is also there in the same table. It is in fact, very similar to the other table only the rows and the columns are interchanged.

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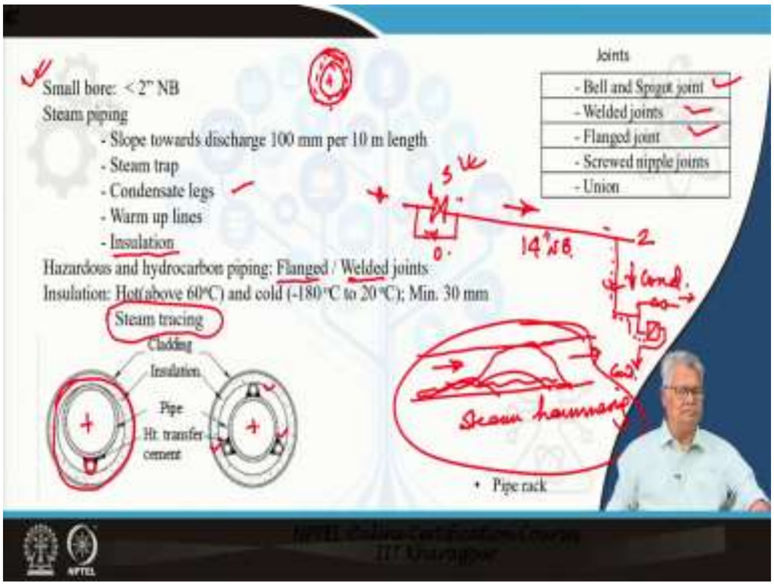

Now, industrially whenever you are talking about a large industry in general the pipeline which has got a nominal diameter below 2 inches we call these are small bore piping quite often if you talk about go to a refinery. And you will say that this project we had roughly these many kilometers of small bore piping.

That means, the piping involved with diameter 2 inch and lower was of this length this nominal length in fact. Now, there are special pipings we look at particularly the steam piping itself. That means, it is supposed to contain steam that means, at one end it will be fed with steam and we are supposed to get a delivery of steam at the other end.

So, the steam flows from the point 1 to the point 2, the two things are very important in case of steam in case of steam piping. First some amount of heat loss from the piping is inevitable. So, part of the steam is bound to condense even if your steam is super heat there will be situations in which some amount of condensate would form.

So, the first thing to allow this you have to have a slope towards the discharge end that means, elevation at 2 has to be lower than 1 first. The second thing the number of bends should be kept to a minimum, typical slope which is kept is about 100 millimeters per 10 millimeter of length of piping the nominal length.

Then the condensate has to be removed if you do not remove the condensate what happens is the condensate would form a layer here and you have the steam flowing above it. So, you will be getting ripples you will be getting ripples and the ripples would form slugs ultimately and there will be slugging which is also called steam hammering in this case.

So you cannot afford to have steam hammering because it will lead to a large amount of huge vibration of your steam piping and quite expectedly many of the cases what we have seen is the anchoring basically comes out that means, your pipe vibrates. So, much that, it does not stay where it is supposed to stay.

So, how to get rid of it what is done is basically, you have condensate legs. The condensate leg means you have a connection of a small pipe typically about half inch or even three fourth inch at times from the bottom of your piping which will take down the condensate and here the condensate comes. Now, what happens is you usually will have here a split, there will be a valve quite often a half inch gate valve. If I open this the condenser would come out I keep it open as long as the condensate comes out then when I find that my condensate has totally been drained I shut it back again.

That means, I can drain the condensate by opening this valve manually, the other option is the other option is what? I can always have a steam trap I can always have a steam trap and a steam trap is a contraption which allows only the condensate. That means, once this leg gets filled up with condensate the steam trap opens up allows a condenser down and automatically shuts.

So, a condensate at the end of the condensate leg so, this is the condensate leg along with a manual arrangement to drain out the condensate is always provided in steam piping this is very important. Now, whenever you charges steam pipe initially the pipe is cold. So, quite naturally what would happen is the amount of steam which enters the cold pipe would condense.

So, you will be having a huge amount of condensation initially. So, the steam trap is not enough what you have in that particular case is the condensate bypass line which is there which also take out this extra amount of condensate and this also is an essential part in that particular system. And it is open in order to cope up with any additional condensation.

Now, possibly this line will be charged with a line and if it is say a 14 inch nominal bore header now what happens is if it is a large pipe it is a its a large pipe and a large valve. So, if I have a 14 inch line ideally what I should do is I should open it very little amount which is called crack opening of the valve, the steam comes it condenses here and it is drained off. I should not allow too much of steam together because it would leave lead to steam hammering in that case.

So, in such cases what you should have is a small valve possibly a 1 inch valve before you open this and it remains shut you open this it is also called at times the warm up line and the warm up line valve, which would allow a small quantity of steam to come in condense heat up the line and then you shut and then you start opening your main header.

That means the charging of the steam header can take anything between half an hour to 6 hours depending on the size and the length we typically used to take a roughly around 4 hours, now you will notice one more thing steams steam is hot. So, steam lines have to be insulated the typical insulation in the industrial scale is done with glass wool.

The glass wool thickness could be anything between 20 or 40 millimeters and you usually will have a you usually have the pipe here a layer of glass wool on it and an aluminum cladding to protect the glass wool. And in fact, between the aluminum cladding and the glass wool you usually have a chicken net to hold the glass wool together.

So that is the insulation and you must have insulations, this is a typical insulation in large industries for short lines as you have in the laboratories you may use other options also other insulating materials, but that is much less common in industry. Now, if you are handling something hazardous and hydrocarbon which is inflammable.

The pipe joints and the fitting joints have to be either welded or flanged it cannot be screwed, you usually will be using insulation when the temperature is above 60 degree centigrade because only then it becomes economic to insulate a particular line and reduce the heat losses and if it is cold, the insulation is there if it is below 20 degree centigrade itself.

Now, you have something here you may have an arrangement which is called steam tracing when you are handling something like furnace oil or something even more viscous which congeals when cold, what you have in this case you will have a another pipe which carries steam, usually low pressure steam.

Typically around 3 kg per cm square gauge or 5 kg per cm square kg its lower it is kept within the same insulating boundary and this is your main pipe in this case you have 3 steam tracing pipes you have 1 here. So, since they are insulated together the heat from your steam tracing keeps the line warm and this is particularly important if you are anticipating that your you may not have flow in your large pipe for some time when it may cool down and get congealed, to avoid congealing you add steam tracing arrangements.

Here we have also the types of joints which are used in pipes the bell and spigot joint which is used is usually for large diameter either ceramic pipes or very large diameter pipes, which will be carrying either sewage or some low pressure something under gravity or under a very little of pressure.

You have welded joints which we have just talked about and the flanged joints also and these two are the most reliable ones, quite naturally you go for flange joints when you require a reliable joint which should not leak, but you cannot have a permanent fixing because welding will permanently make the joint permanent. Screwed nipple joints and union joints are used for low pressure systems like water lines.

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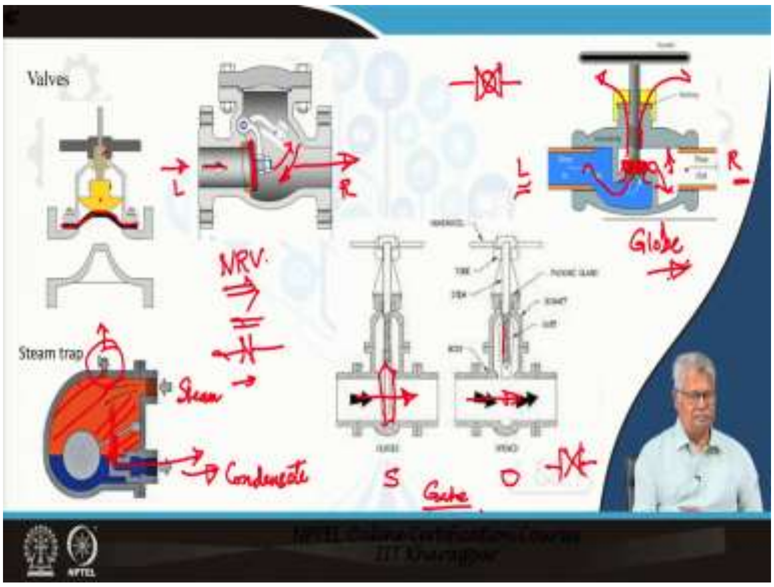

We definitely will be having valves, here we have a little I mean few types of valves. The valves can be classified as the valves which regulate a flow or the valves which either open or remain shut. For example, this is a shut valve this is the steam valve which is under open condition, what is this?

This one is a gate valve, what you have here is the gate which is closing the flow here and it has been pulled up at the flow happens from here to here. You will notice one thing here that the flow could be from left to right or from the right to left also though the marking is from left to right in this specific drawing the other type of valve what you have is a globe valve in a globe valve what you have you want regulation of your flow.

So, what you have is something like this you have a valve seat, this is the valve seat, this is the valve seat on which a bob comes usually the bob has got a contoured surface like this, when you turn your hand well this goes up this goes up and the flow happens this way.

That means the flow here is from left to the right. Now, I have got a question for you, how or rather why is it that it is from left to the right? The reason is very simple the weakest thing through which the liquid inside can come out of it is through this particular sealing this through this particular seal.

The upstream is always at a higher pressure if you have this configuration your downstream is basically your packing on your seal is exposed to the downstream which is at a lower pressure. So, your chance of leakage is much less. So, how do you identify a globe valve without opening it?

Here the construction is very open you can see what is there inside, but when you have a valve in your hand or if you have it in your store you will always find that the globe valve will have a direction mark on it at direction mark will be absent on the gate valve. Now, we have talked about regulation, we have talked about open and shut type of valves which is a gate.

Now, it is also possible that you must have some valve which will be allowing flow in one direction only. That means, you have a non return valve a typical non return valve construction is shown here, what you have here is a disc which closes this enclosure the entry. So, under normal conditions this is close the moment there is a flow here it will force this open to this swing open like this. So, it is a swing it is a swing check valve or it is a swing type non return valve and since this goes up after that the liquid can go out.

That means it will open up only when your left side pressure is more than your right side pressure what happens when your right side pressure is more. For example, this is coming from a pump and your pump is tripped that means, the right side pressure is still high, but your left side pressure is low, it will immediately close this back.

So, that there is no back flow of liquid this is a swing check you can have a ball check also, there is one warning or one advice I like to say here. This also will have no hand will obviously, but it must be having a direction marked on the valve itself it will and by that you can always identify.

This is a swing check instead of a swing type of closure you could also have a ball, the ball will be shifted when there is a flow and when the flow stop or the upstream pressure is less the ball would come back and close the opening. And it gets tightened because of the right side pressure being even higher, what I would like to say here is something like this, when you are mounting any non return valve it will work only if it is like this you cannot rotate it by 90 degrees and have this particular closure in the horizontal plane.

Exactly in the similar way if you have any non return valve anytime if you find it is advisable that you look at the manual and find out at what orientation you should fix it. The symbol of a globe valve is this, the symbol of a gate valve is this and the symbol of a non return valve is this. Now, apart from this if you are handling something very corrosive or even a slurry you may have instead of a regular seat the seat you must have, but not something which goes up and down and closes like this.

And you would not like the fluid to come in contact with your weakest part of your valve which is just sealed. So, what you have in the that case? You have a diaphragm the diaphragm is moved up or down using a plunger. Now, there is one more thing which I have talked about I have talked about the steam trap and you know the use of the steam trap.

So, when you talk about the steam trap let us see how the steam trap works there are different types of steam traps, but here I am showing you only a ball type and ball float type of arrangement. The steam comes in from the top and what is allowed to come out is only the condensate the steam comes in as long as steam comes in the level is low. So the ball is at the lowest position in this lowest position what it does it keeps this shut.

Then what happens when it flows floats up this particular closure this particular closure which was keeping this particular opening shut opens up and the flow starts and the condensate flows out. When will it float up? When there will be condensate rising up in this enclosure. You will also notice something very interesting you in all such steam traps you will have here a small manual valve.

Because steam is supposed to be condensed it condenses, but if it is contaminated with a small quantity of air the air would not condense or any other gas for that matter and it will keep on accumulating here. So, periodically maybe once in 2 days you will come there and open this valve and if any steam any air has accumulated inside you will be sending it off, you will be bleeding it off. In fact, it is definitely required when you charge your steam header for the first time.

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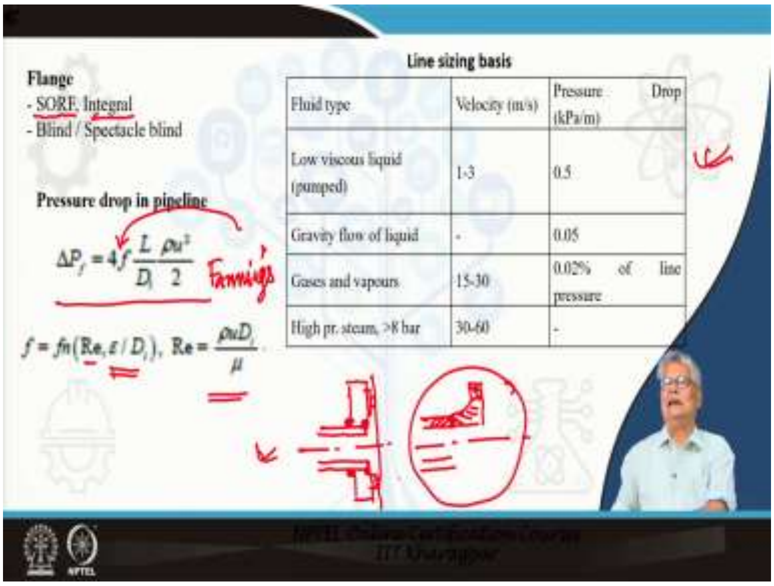

Now, we talk about the flanges the flanges the most common flanges are, if I have a pipe like this I could always have a flange mounted on this, this is a slip on type of flange it will be welded here or I could also have an arrangement of a flange which looks like this. I am not drawing the lower part it is symmetric where it will be welded here, it is basically an integral hub this is the slip on type.

If you have the phase raised if you have the phase raised and there will be a matching flange here with a gasket in between it is going to be called slip on raised phase which is the most common type of flange which is used in industry. It provides sufficiently leak proof connection between most of the equipment until and unless something special is required and the integral type is also common.

It is supposed to have more strength as compared to this obviously, because your area of joining is more and it is an integral part of the pipe itself the way it is put. Next comes the sizing of the pipe, the sizing of the pipe depends on I mean if you have a large bore pipe the cost is more the pressure drop is less, when I say cost more you have to spend more in order to buy that pipe.

But since your pressure drop is less you are going to spend less on your pumping power. So, we must have an idea that how you find out or estimate the pressure drop in the piping. One component of pressure drop is static head which basically depends on the difference in elevation the other is the frictional drop, the frictional drop obviously by your fluid mechanics course from your fluid mechanics course you already know.

That the frictional flow frictional pressure drop is given by the Fanning's equations it is a Fanning's equation and quite naturally this small f is a Fanning's friction factor. The Fanning friction factor is a function of the Reynolds number the Reynolds number given by the fluid properties and the inside diameter of a pipe and the velocity certainly. And it is also a function of the roughness factor we will see what these are.

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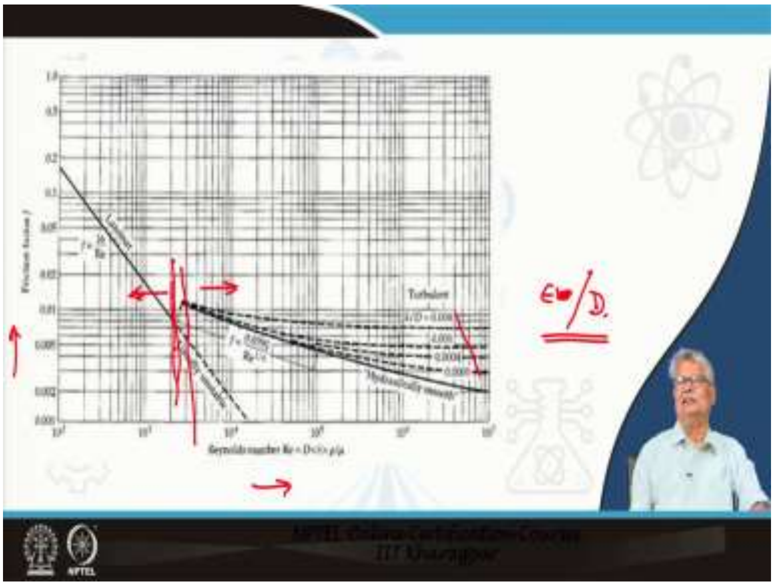

What I assume right now is basically, you all know about this friction factor chart where you have the Reynolds number in the x axis where you have the small f and you have this in your turbulent zone you have different values of it is k by d here k by D is same as here either epsilon is equal to I mean d v u d finite ah. It is basically epsilon by D d a is d i or its k by D, k is basically the height of the roughness.

So, this is a non dimensional parameter that you have here. The friction I mean up to a Reynolds number of this limit it is laminar beyond this it is turbulent and in between I mean this part of it is already covered to in your fluid mechanics course. So, we will not go into the details of this, but you definitely will be reading this chart in your design.

Next comes the line sizing basis, the pressure drop which I can afford is one option, but in industry the typical range of velocities and the typical range of pressure drop per meter are as per this table. For most low viscous stable low viscous liquids it could be water, it could be kerosene, it could be diesel oil even the velocity range is 1.3 and typical pressure drop in kilopascal per meter minded it is around 0.5.

In case of gravity basically the pressure drop that you can afford to have is one tenth of this. So, its 0.05 kilo pascal per meter the in case of gases and vapour the velocity is much higher 15 to 30 in case of high pressure steam above 8 bar its much higher even almost a double of it and the pressure drop is typically 0.02 percent of the line pressure.

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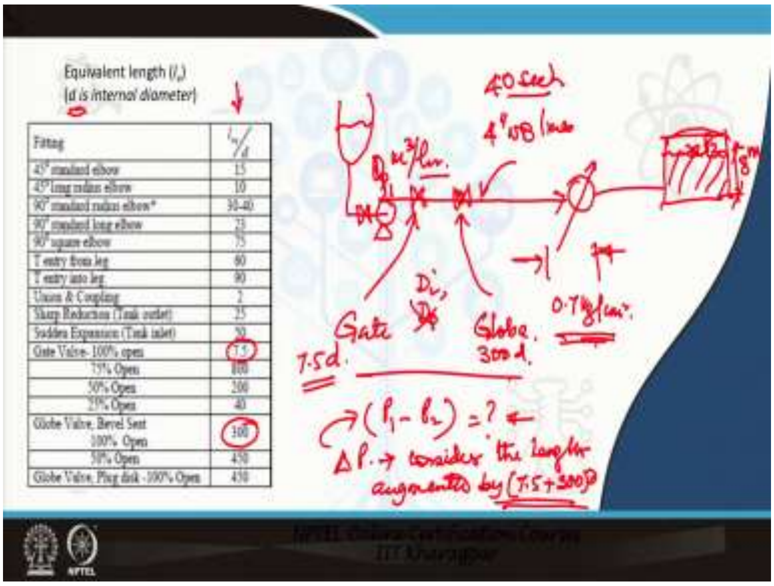

Now, comes the pressure drop in a total pipe suppose I have a distillation column from here the liquid is taken out, it has got valves here, it has a valve here both are gate valves and in order to regulate that flow I also have a globe valve here. Then what do I do I send it to a cooler cooling it, then what do I do then I send it to a tankage.

So, this is typically the system, the maximum level of the tank which is called the safe filling height will be typically something around say 8 meters. The pressure drop across a exchanger will be of the order of 0.7 kg per cm square. Now, the question comes see hypothetically all these are 4 inch nominal bore lines and these are of 40 schedule.

That means, what I would like to say is we already have seen the standard and we know already that the ID is known the OD is also known the OD is of no consent to us. So, we know the D i. We know the it is a distillation column. So, we have definitely we are aware of the flow rate Q in meter cube per hour.

Now, the question comes in case of straight pipe we know in case of the exchanger we have designed with a pressure drop not exceeding 0.7 kg per cm square and in case of the tank we know that the height to which it has to be pushed up against which it has to be pumped in is about 8 meters of liquid head and it is open to the atmosphere.

So the question now comes, how do I account for the pressure drop here for this valve and this valve? This one is a gate valve, this one is a globe valve. And I need to find out the delta P between P 1 point and the point P 2, I would like to find out basically P 1 minus P 2, how much is it? Because I would like to find out my pumping power requirement. What is done that the gate valve if I know and since I know that it is a 40 schedule 4 inch bore. So, I know its internal diameter small d.

Let us look at here, if it is my gate valve normally is supposed to remain 1.5, I mean 100 percent open. So, what I will do is I will consider 7.5 into d to be additional length of this pipe. Similarly, for the globe valve I will contain I will include 300 times of this d. So, your total delta P, when you find out which is basically this P 1 minus P 2.

Consider the length augmented by 7.5 plus 300 d and then calculate the pressure drop. Basically how do I do? Because I know that my equivalent length for the fitting is given by in terms of the internal diameter of the pipeline or the fitting itself and the factor is given here and it is listed in later lecture. I think with this I will stop here and start with the detailed piping around certain specific situations.

Thank you.