Chemical Process Utilities
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Lecture – 38
Design of Pipelines – Elements of Pipeline Design

Welcome to the new chapter pertaining to the design of pipeline system. Now, pipelines, they play a very important role whether it is a steam distribution network, whether we talk about the water pipeline, whether you talk about the gas pipeline, especially the air pipeline. So, pipeline plays a very vital role in the utility design, etc. Now, in this particular lecture, we are going to discuss about the various elements of pipeline design.

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Now, before we go into detail, we have already gone through about the gas solid flow in which we discussed about the conveying distance, pressure available, conveying air velocity. etc. Then we discussed about the material conveying characteristics in which we discussed about the conveying modes and air only datum, pressure drop evaluation, conveying air velocity. We discussed about the pneumatic conveying. We have given an idea about the slip velocity and we have already discussed one example pertaining to the conveying of cement.

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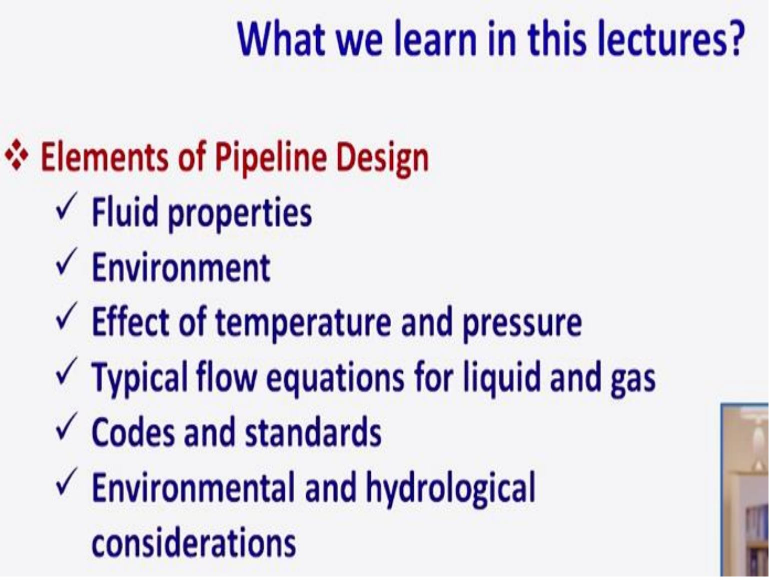

In this particular chapter as implicated that this is attributed to the pipeline design, so we will discuss about the various elements of pipeline design this including the fluid properties, we will discuss about the various environment. We will discuss about the effect of temperature and pressure over the pipeline design. Apart from this, we will discuss about the typical flow equations for liquid and gas.

Since all these things are attributed to the various standards and codes, so we will give a brief idea about these codes and standards. And apart from this, we will discuss about the environmental and hydrological consideration. So, let us talk about the pipeline. Now, as I discussed during the start of this particular lecture that pipelines play a very vital role in utility aspect and also it affects the daily lives in most parts of the world.

Whether you talk about the drinking water supply, whether you talk about the natural gas supply, whether you talk about the gas pipelines, etc. So, pipeline plays a very vital role in all aspects of our day-to-day life. Now, when we talk about the broad spectrum of pipelines, the oil and gas they are the major participants in the supply of energy and pipelines are the primary means by which they are transported. So, entire distribution network solely depends on the design of pipeline.

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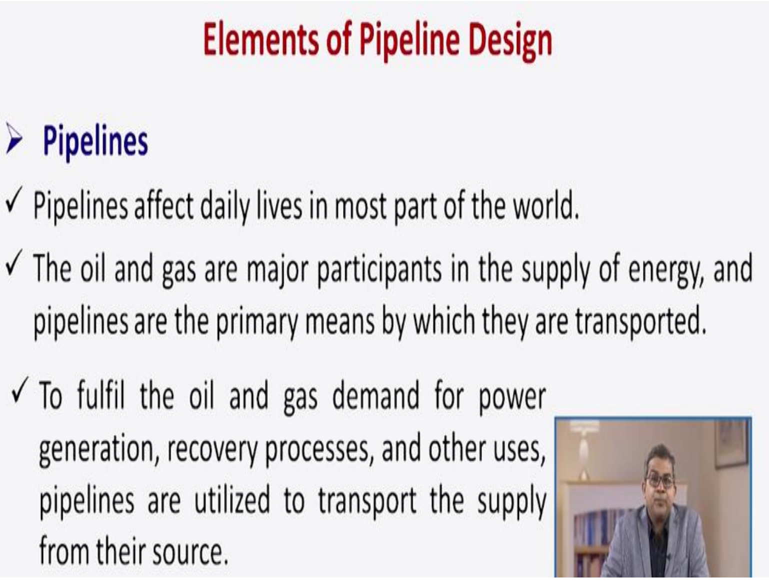

Now, again when we discuss about the engineering aspect, then we cannot nullify the impact of pipeline, design component of pipeline and allied fields. To fulfil the oil and gas demand for power generation, recovery process, and other uses pipelines are utilized to transport the supply from their source and that is very vital. If you talk about the steam distribution network, it all depends on the pipelines.

If you talk about the water supply network all depends on the pipelines. Now similarly, you cannot overlook the importance respect to the whether the crude oil distribution or the refined product distribution, everywhere you will find that pipelines are natural source of transportation of these means.

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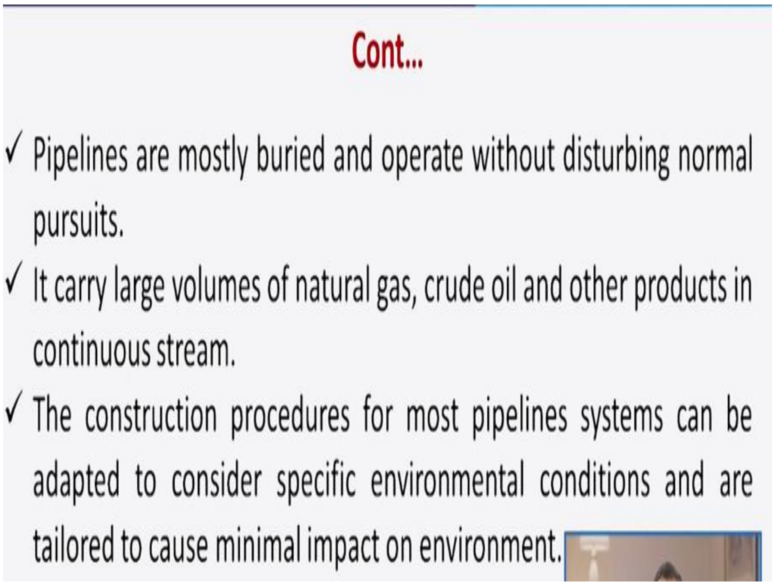

Now pipelines are mostly buried and operated without disturbing the normal pursuit with the underground maybe overhead, etc. So, normal functioning of day-to-day life usually does not affect by the pipeline distribution. It carries large volume of natural gas, crude oil and other products in continuous stream. The construction procedure for most pipelines system can be adopted to consider specific environmental conditions and are tailored to cause minimum impact on environment.

So, when we talk about the designing aspect, you see everywhere in pipeline there may be certain bends, joints, T's, elbows, etc. Apart from this, the inner material and outer material this all depends on the different kind of the material being transported.

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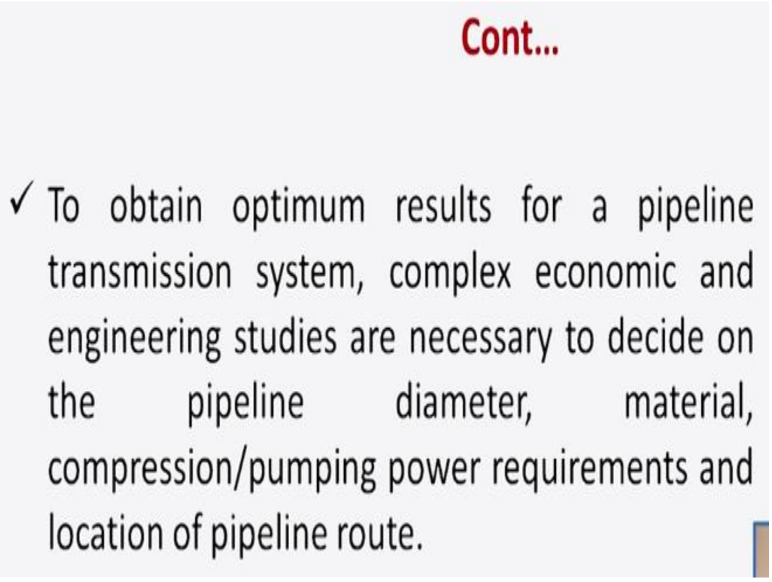

To obtain optimum results for a pipeline transmission system, complex economics and engineering studies are necessary to decide on the pipeline diameter, pipeline material, compression pumping power requirement and location of pipeline route. See, when we talk about all these things because the material, the source, the discharge port all these things again play a very crucial role while designing aspects, how much power required because sometimes unnecessary bends and joints, etc.

They may cause unnecessary friction and thereby more requirement towards the power and thereby economics may be on the lower side. So, all these things I mean when the material of transportation is reactive, then again you need to change the pipeline material. Similarly, if you need the more power and compression, the diameter and the length maybe changed accordingly. So, a lot of verticals are there in the designing of the pipeline distribution network.

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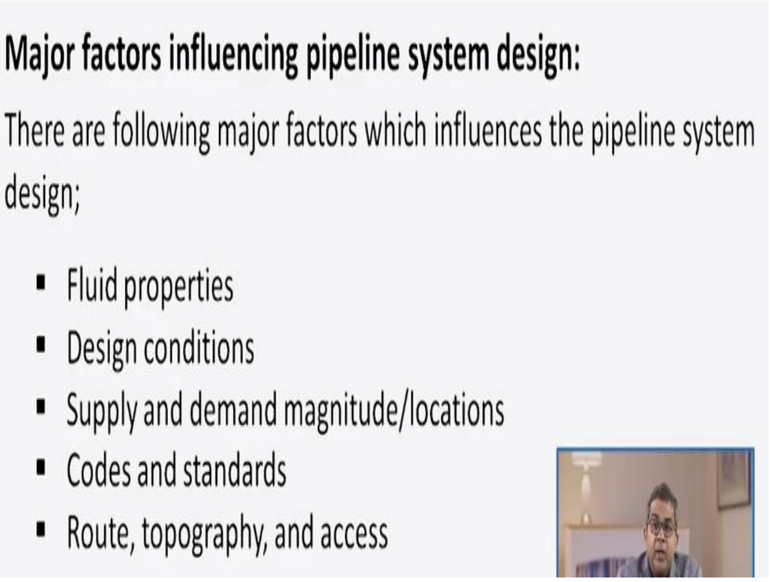

So, when we talk about the pipeline system designing, there are various major factors which are influencing in the pipeline system design. One is the fluid properties whether it is compressible, noncompressible, reactive, nonreactive, temperature maintenance requirement or not. Then other thing that is attributed to the design conditions, supply and demand magnitude locations.

And sometimes if you are having a very less supply and a few built a pipeline with the larger diameter, then automatically the pumping cost, material cost, power requirement would be on the higher side. Then every country, every state and every material have its own code and standards. You need to abide all these codes and standards and you need to look all the aspects of these codes and standards while you are designing the pipeline network.

Then route and topography and access; there are two three core issues. One is the route because usually it is desirable that during the laydown of pipeline system the normal day to day life or normal operation of any industry should not affect. Similarly, all parts of the pipeline must be accessible, this is quite essential for the maintenance, wear and tears, leakage all these things can be repaired if the pipeline is easily accessible.

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Cont…

- Environmental impact
- Economics
- Hydrological impact
- Seismic and volcanic impacts
- Material
- Construction
- Operation
- Protection
- Long-term Integrity

Apart from this, the environment impact also plays a very vital role. Economics, the mother of all kind of parameter is economics. The reason is that you need to look various parameters attributed to the economics. Sometimes if materials are reactive, then corrosion may take place and then you need to replace the pipeline more frequently, economics would be on the lower side. Sometimes your fluid characters are not up to the mark, in that case you may require the lesser or more power.

In that case again the economics would be on the lower side. Sometimes a fluid is more viscous and if you are imparting less power, then again, the economics would be on the lower side. So, all these things are roaming here in there with respect to the economics. Apart from this, hydrological impact, then seismic and volcanic impact. Seismic and volcanic impact is again very vital.

The reason is in case if the pipeline falls in these zones, then you need to pay a special care or a special attention while designing the pipeline network, especially if you are having the flammable material or environmental hazardous material in question, in that case small amount of seismic disturbance may create major hazard. Then material, both the material of construction as well as material needs to be transported.

Then construction, how you are laying down the things, may be buried, may be overhead, maybe some side pipelines. So, all these things play a vital role. Then operating conditions. Then sometimes you need to put forward with the protection of these pipelines. The reason is that if it is broken then again, the economics would be on the lower side. And obviously, you are always looking for the long-term integrity of all these pipeline networks.

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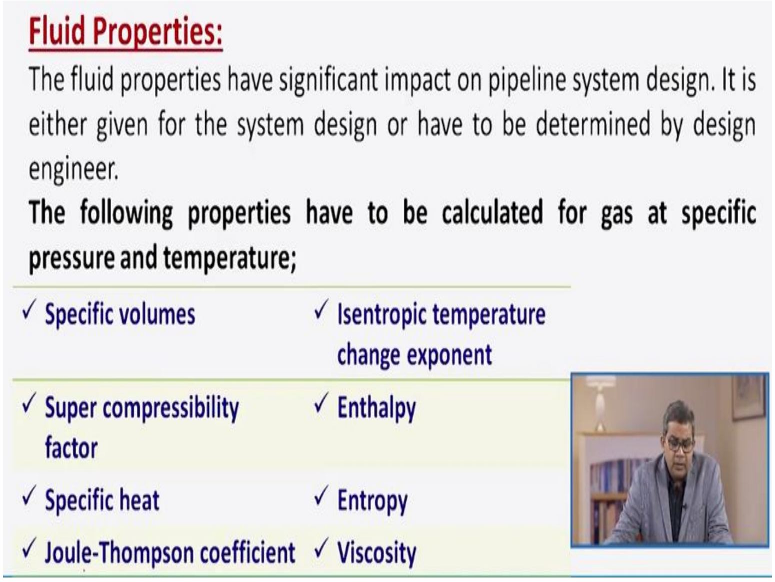

Now let us talk about the fluid properties. Now the fluid properties they have significant impact on pipeline system design. It is either given for the system designed or have to be determined by the design engineer. Now, there are various properties which we need to calculate for gas at a specific pressure and temperature because the pressure and temperature is supposed to be the variable and one need to look this particular approach a priori.

Now, sometimes you need to look at the specific volume, super compressibility factor, specific heat, then Joule-Thomson coefficient with respect to the expansion and contraction, isentropic temperature change, enthalpy, entropy, viscosity. So, all these things you need to look at with respect to the pressure and temperature.

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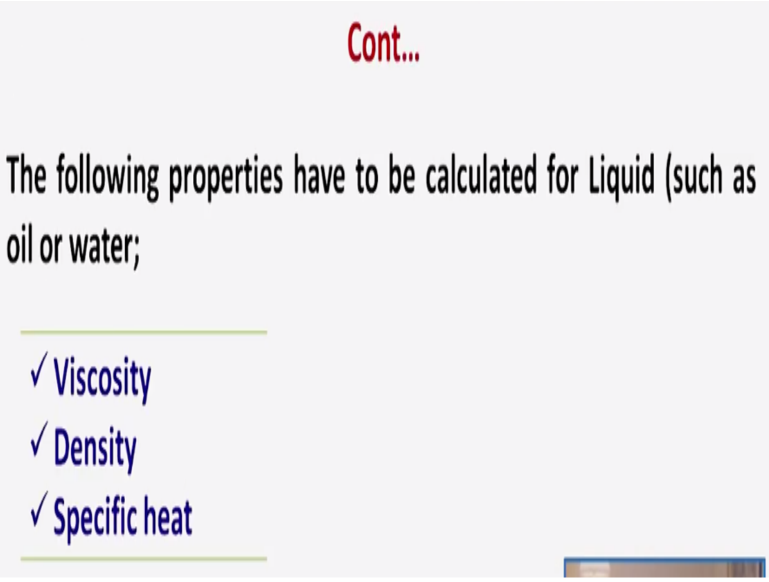

There are several other properties which have to be calculated for liquid like if you are transporting oil or water then you need to look the viscosity aspect. If highly viscous material in that case either you need to preheat or you need to put more power for the transportation. Similarly, density and specific heat. So, all these different properties you need to look prior to designing of pipeline to carry out the liquid. Then environmental effects.

Now, environment have effects on both below and above ground pipeline design as I told you that it may be buried inside the earth or it may be overhead, it may be side wise, etc. So, only air temperature and velocity have impact on the design of above ground facilities. Now, the ground stability influences the pipeline design support system. The significant variation in ground elevation particularly affects the liquid pipeline design.

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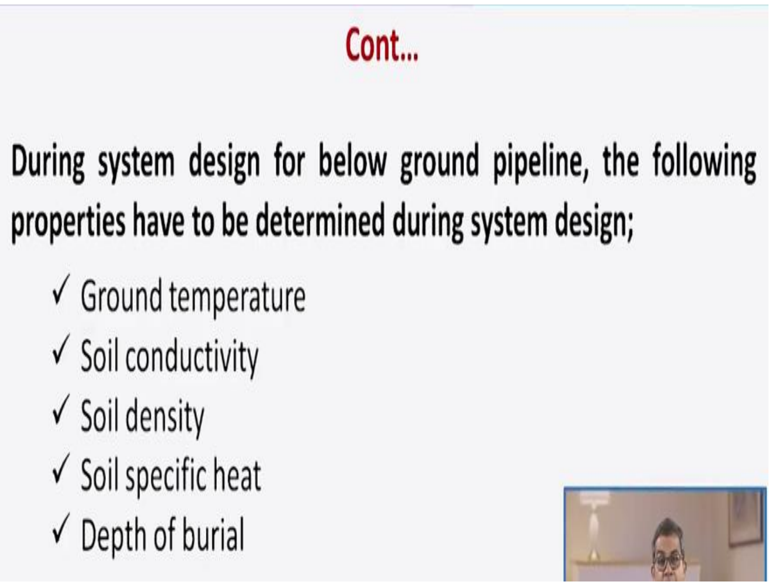

Now, during system design for below ground pipeline, there are various properties you need to look and determine especially with respect to the system design. One is that the ground temperature, you need to look the overall ground temperature or you must have a meteorological information. Then you must know about the soil conductivity. You should have a knowledge about the soil density, then soil specific heat and depth of burial. So, up to what depth you need to put and you need to have all kinds of information pertaining to that depth.

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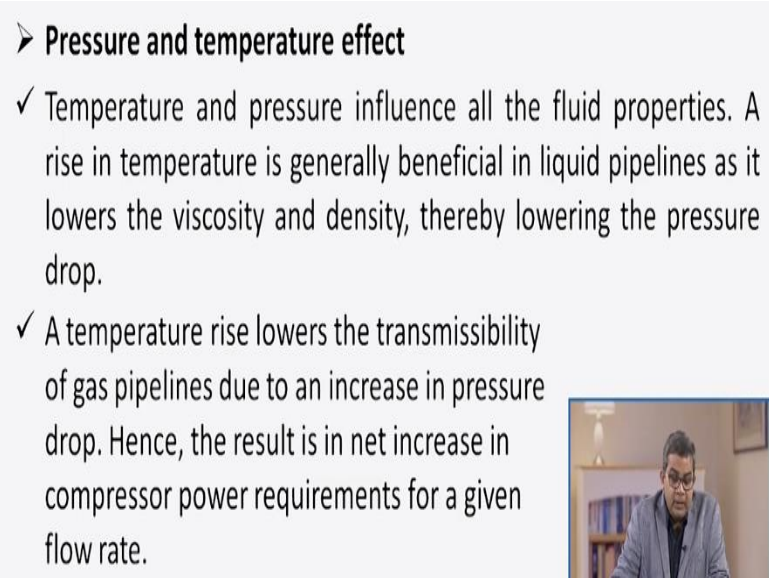

Let us talk about the pressure and temperature effect. The temperature and pressure usually influence all the fluid properties. A rise in temperature is generally beneficial in liquid pipeline as it lowers the viscosity and density thereby lowering the pressure drop as well as you may experience less power requirement and then the power requirement is less that case your economics will be beneficial. A temperature rise lowers the transmissibility of gas pipelines due to an increase in the pressure drop. Therefore, the result is in net increase in compressor power requirement for a given flow rate.

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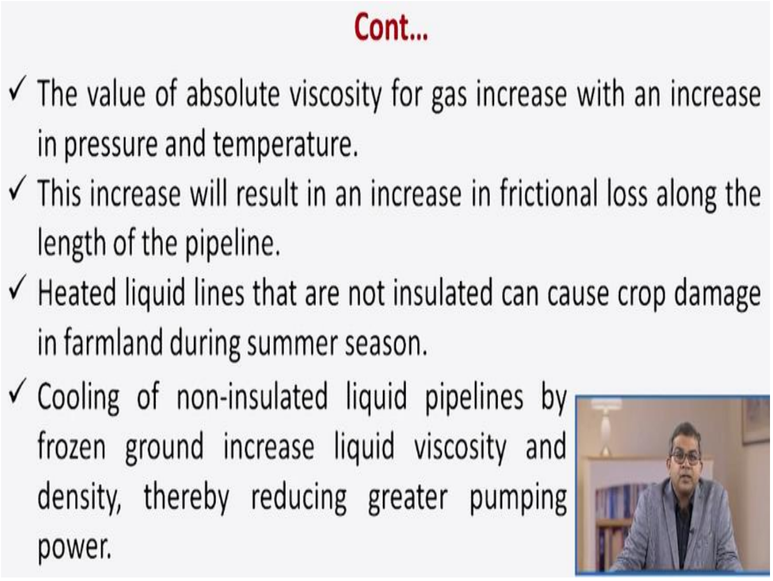

The value of absolute viscosity for gas increase with an increase in pressure and temperature. Usually, this increase will result in an increase in frictional loss along the length of the pipeline. Sometimes heated liquid lines that are not insulated, this can cause the crop damage on farmland during the summer seasons. Cooling of non-insulated liquid pipelines by frozen ground increase the liquid viscosity and density thereby reducing greater pumping power.

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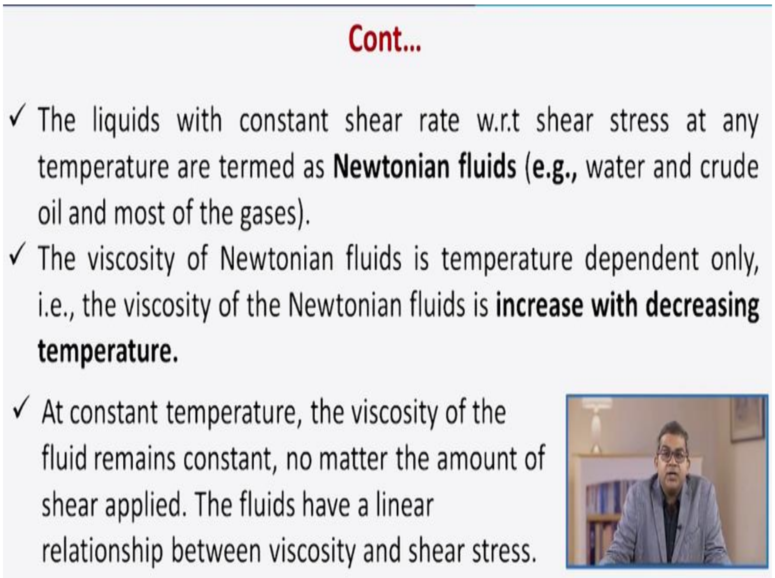

Now, sometimes the liquid with the constant shear rate with respect to shear stress at any temperature are termed as Newtonian fluids like water and crude oil and most of the gases. The viscosity of Newtonian fluid is temperature dependent only that is the viscosity of the Newtonian fluid is increased with decreasing temperature. At constant temperature, the viscosity of the fluid remains constant no matter the amount of shear applied. The fluids have a linear relationship between viscosity and shear stress.

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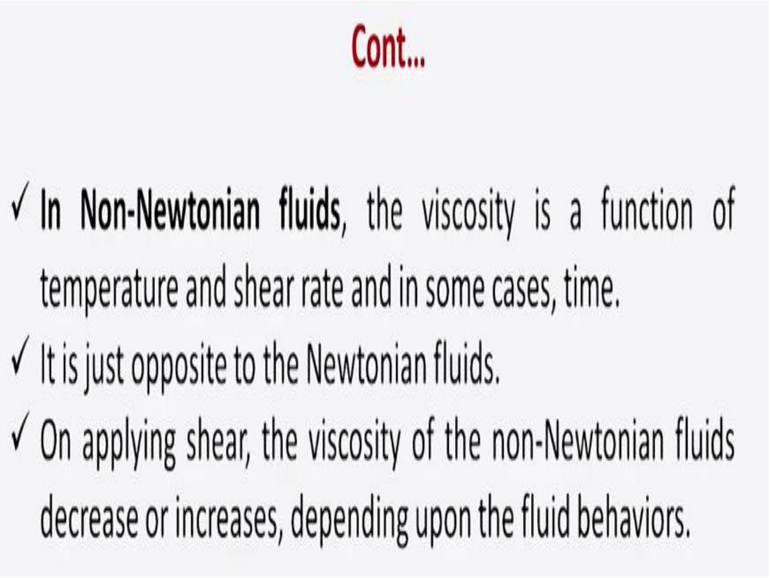

Now, when we talk about the non-Newtonian fluid, so in non-Newtonian fluids the viscosity is a function of temperature and shear rate and in some cases time. It is just opposite to the Newtonian fluid. So, on applying shear the viscosity of non-Newtonian fluid decreases or increases depending upon the fluid behaviour.

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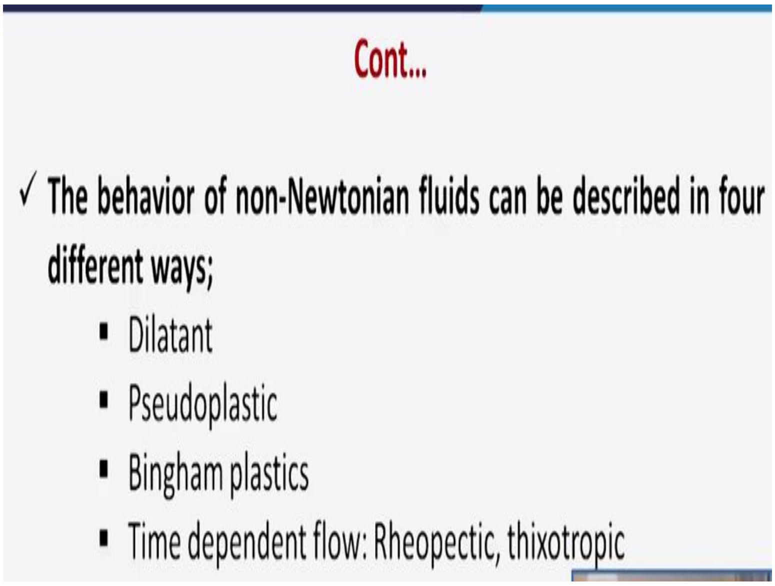

Now, the behaviour of non-Newtonian fluid can be described in four different ways. One is the dilatant, then pseudoplastic, third one is the Bingham plastic and fourth one is a time dependent flow rheopectic thixotropic. So, all these things are fluid dynamics or fluid mechanics phenomena.

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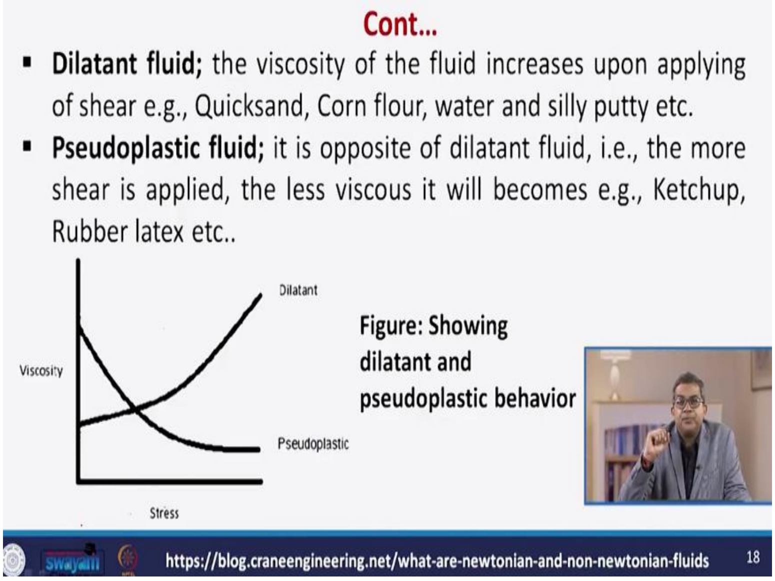

Let us talk about the dilatant fluid. The viscosity of the fluid increases upon applying of shear that is the quicksand, corn flour, water and silly putty, etc. Now, pseudoplastic fluid it is opposite to the dilatant fluid that is the more shear is applied, the less viscous it will become like ketchup, rubber, latex, etc. So, if we plot the viscosity stress curve then you will find that the dilatant and pseudoplastic, this showing the dilated and pseudoplastic behaviour. So, upon increasing the shear the viscosity will go down in the pseudoplastic and if you increase the stress then obviously the viscosity will go on the higher trend in case of dilatant.

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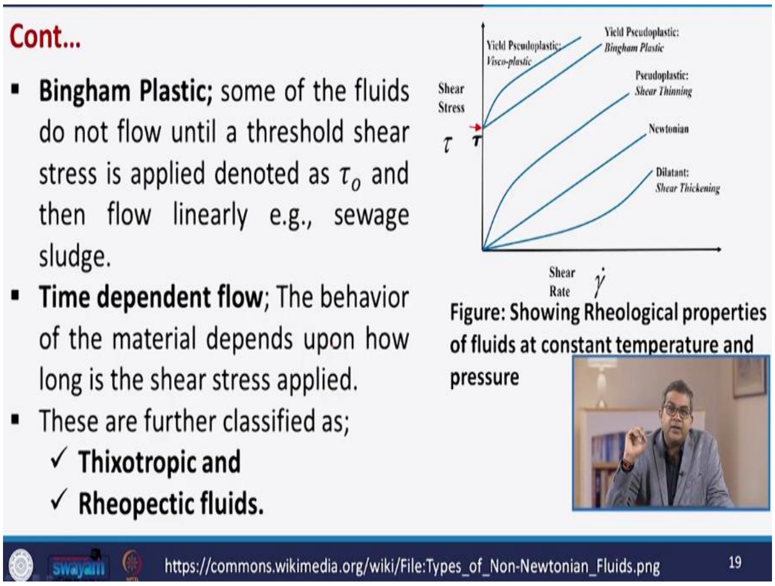

Let us talk about the Bingham plastic. Some of the fluids do not flow until a threshold shear stress is applied denoted as tau 0 and then the flow linearly that is the sewage sludge. Now when we talk about a time dependent flow, the behaviour of the material depends upon how long is the shear stress applied. Now, these are further classified in thixotropic or rheopectic fluids.

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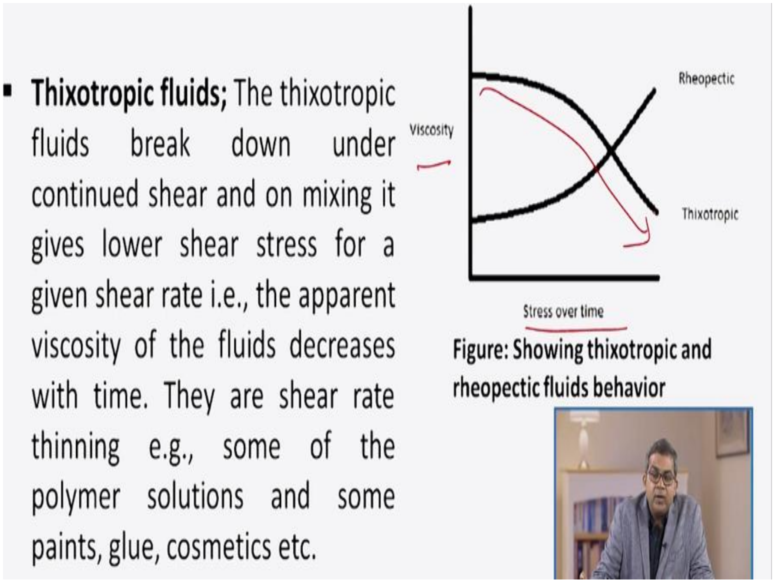

Now, thixotropic fluids, the thixotropic fluids break down under continued shear and on mixing it, it gives lower shear stress for a given shear rate, that is apparent to viscosity of the fluid decreases with time. Here you can see this is the stress over time and viscosity. So, for thixotropic fluid, the viscosity gradually decreases. Now, they are shear rate thinning, that is some of the polymer solutions and some paint, glue, cosmetics, etc.

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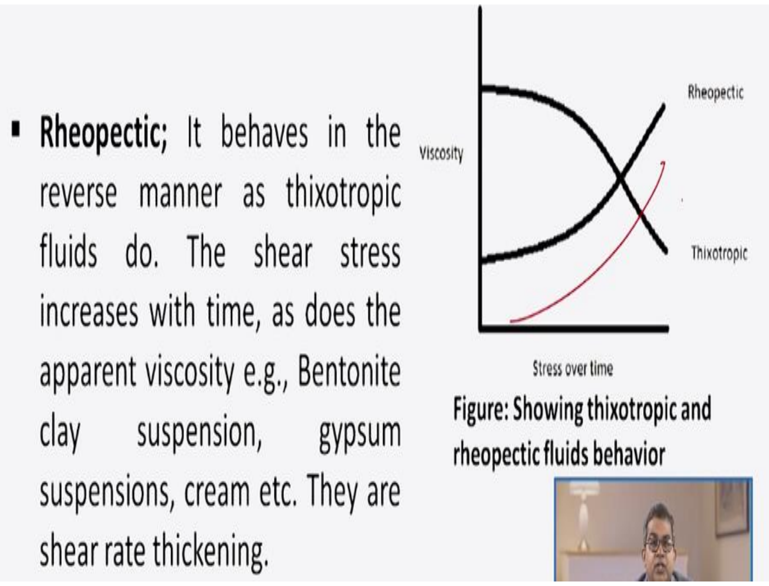

Now, if we talk about the rheopectic, it behaves in the reverse manner as against the thixotropic fluids do. The shear stress increases with time. Here you see that shear stress increases with time as does the apparent viscosity. The best example is Bentonite clay suspension, gypsum suspension, cream, etc. They are shear rate thickening.

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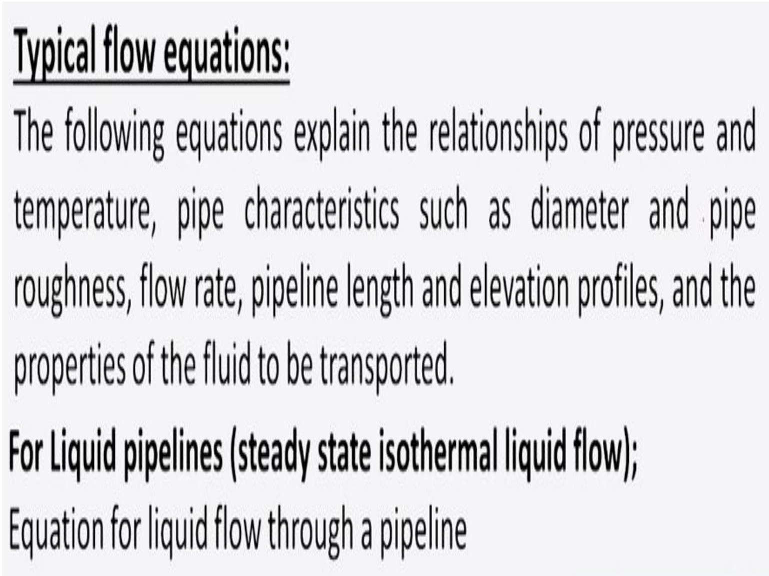

Now, let us talk about some typical flow equations. Now, we will discuss about several equations. These equations explain the relationship of pressure and temperature by characteristics such as a diameter and pipe roughness, flow rate, pipeline length, elevation profile and the properties of the fluid to be transported. So, one case is that for liquid pipelines under a steady state isothermal liquid flow.

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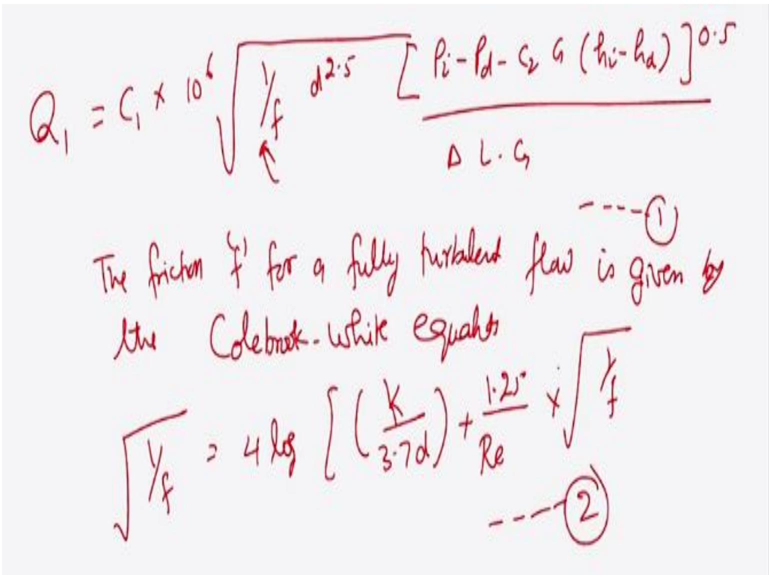

So, the equation for liquid flow through a pipeline can be represented as Q 1 = C 1 into 10 to the power 6 quare root of 1 upon f d to the power 2.5 P i – P d – C 2 G h i –h d whole to the power 0.5 upon delta L G. We can say this is the equation number 1. The friction factor, this f is the friction factor, the friction factor ‘f’ for a fully turbulent flow is given by the Colebrook-White equation. Now, what is this equation. This is the square root of 1 upon f = 4 log K upon 3.7 d + 1.25 Re stands for Reynolds number 1 upon f that is equation number 2.

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The equation for liquid flow through the pipeline:

$$Q_1 = C_1 \times 10^6 \sqrt{1/f}\, d^{2.5} \frac{[P_i - P_d - C_2 G(h_i - h_d)]^{0.5}}{\triangle LG}$$

The friction factor f for a fully turbulent flow is given by the Colebrook-White equation;

$$\sqrt{1/f} = 4\log\left[\left(\frac{k}{3.7d}\right) + \frac{1.25}{Re} \times \sqrt{1/f}\right]$$

Where,

Q_1= flow rate (in turbulent region)	**f**= Friction factor
k=Pipe roughness	h_d= downstream elevation
d= pipe internal diameter	h_i= upstream elevation
P_d= downstream or outlet pressure	$\triangle L$= Pipe segment length
P_i= Inlet or upstream pressure	$\triangle L_e = \triangle L(e^S - 1)/S$
G= specific gravity of fluid	**Re**= Reynolds Number

Now, here Q 1 is equal to flow rate in the turbulent region, K is the pipe roughness, d is the pipe internal diameter, P d is the downstream or outlet pressure, P i is the inlet or upstream pressure, G is that specific gravity of fluid. Now, h d is the downstream elevation and h i which we had in this equation h i is the upstream elevation, delta L is the pipe segment length, delta L e = delta L e to the power s – 1 upon S and R e is the Reynolds number.

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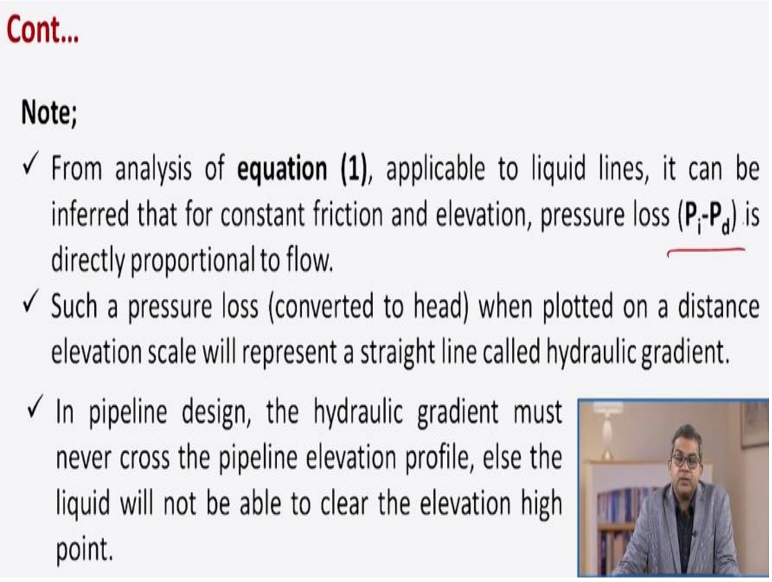

Now, if we analyse the equation number 1, this equation, this is applicable to the liquid lines and it can be inferred that for constant friction and elevation the pressure loss that is P i –P d is directly proportional to flow. Such a pressure loss converted to head sometimes when plotted on a distance elevation scale will represent a straight line that is called the hydraulic gradient. Now in pipeline design, the hydraulic gradient must never cross the pipeline elevation profile, else the liquid will not be able to clear the elevation high point and the result would be not up to the mark.

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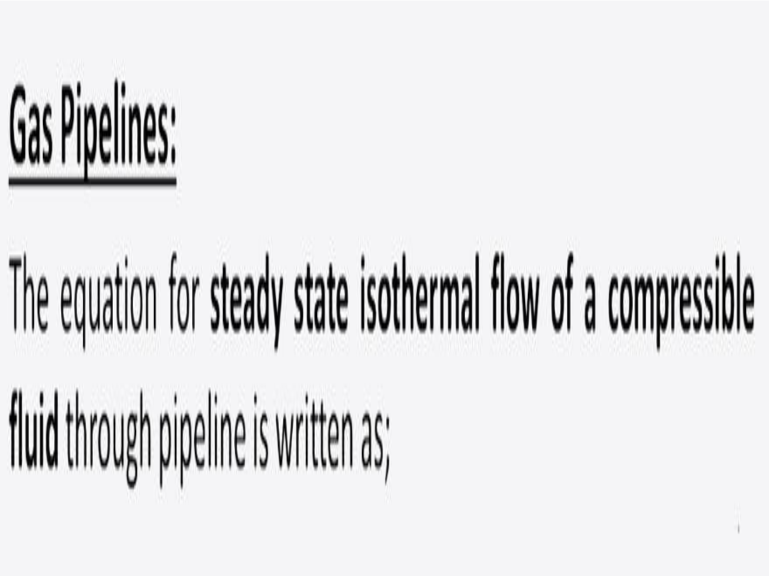

Let us talk about the gas pipeline. Now, when we talk about the gas pipeline, the equation for a steady state isothermal flow of a compressible fluid to the pipeline.

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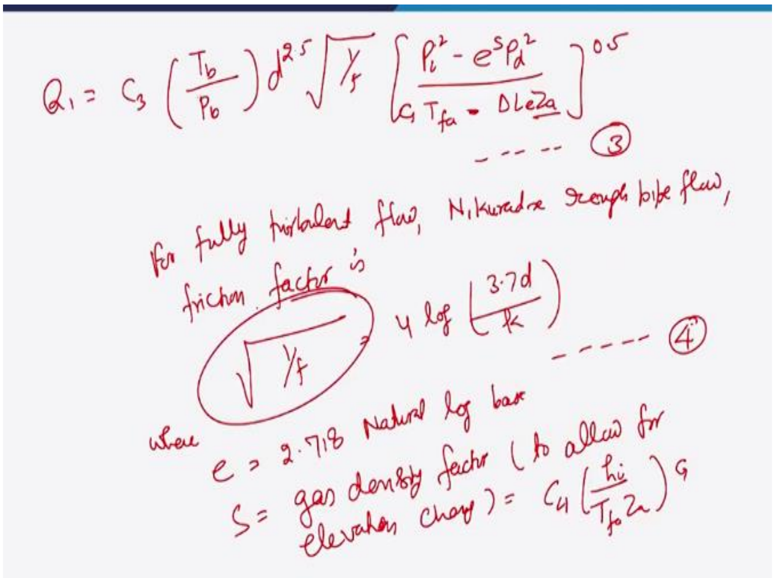

This can be represented as Q 1 = C 3 T b upon P b d to the power 2.5 1 upon f P i square minus e to the power s P d square G T fa into delta L e Z a now this is the question number 3. Now if we talk about the fully turbulent flow now Nikuradse rough pipe line or pipe flow, the friction factor is 1 upon f = 4 log 3.7 d upon K this is equation number 4. Where e = 2.718 natural log base, S is the gas density factor to allow for elevation change is equal to C 4 h i upon T fa Z a G.

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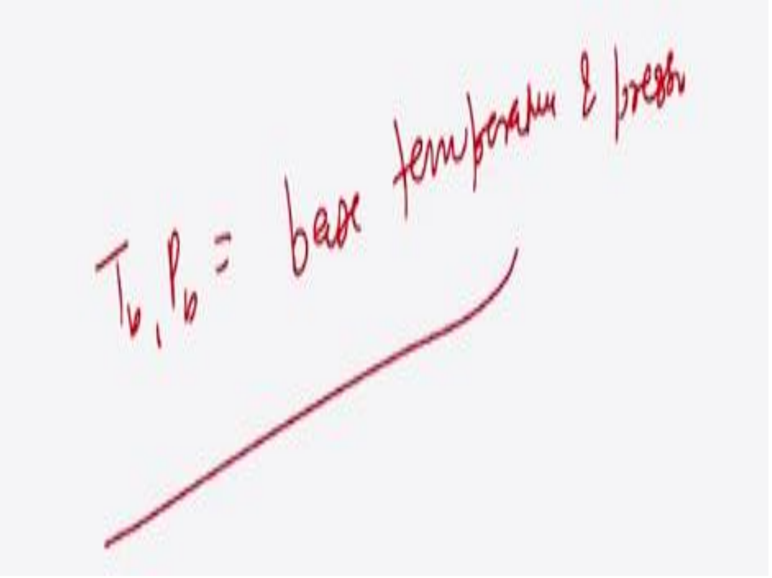
The equation for steady state isothermal flow of a compressible fluid through pipeline is written as;

$$\boldsymbol{Q_1 = C_3\left(\frac{T_b}{P_b}\right) d^{\,2.5}\sqrt{1/f}\left[\frac{P_i^2 - e^s P_d^2}{GT_{fa}\Delta L_e Z_a}\right]^{0.5}}$$

For fully turbulent flow, Nikuradse rough pipe flow, friction factor is:

$$\boldsymbol{\sqrt{1/f} = 4\log\left(\frac{3.7d}{k}\right)}$$



And T b and P b these are the base temperature and pressure.

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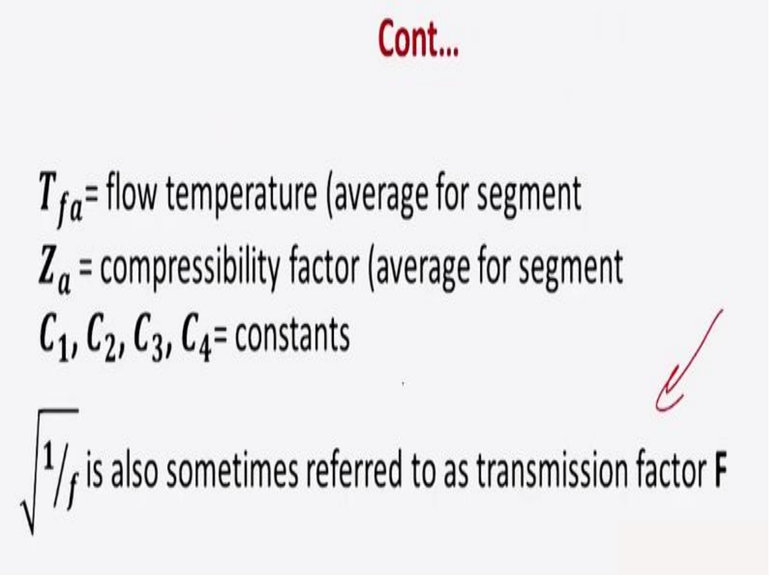

So, the T f a that is a flow temperature average for a segment Z a, if you see that here Z a is the compressibility factor that is average for segment C 1, C 2, C 3, C 4 and this is equal to constant and 1 upon f square root is also sometimes referred as the transmission factor F. So, here if you see that this, this is the transmission factor.

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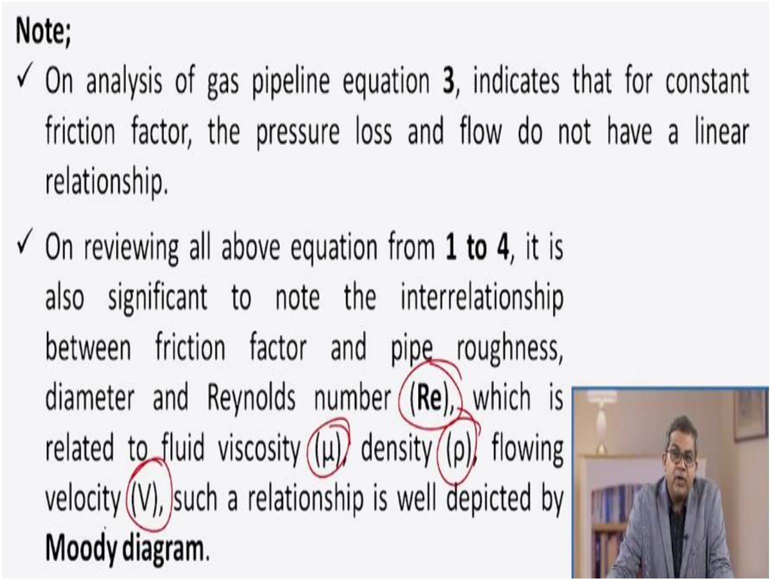

Now, if we analyse the gas pipeline equation number 3, it indicates that for constant friction factor the pressure loss and flow do not have a linear relationship. Let us have a look about this equation. This is your equation 3. Now, if we review all above equation from 1 to 4, I am taking this example of fourth equation this one it is significant to note that interrelationship between the friction factor and the pipe roughness diameter and Reynolds number Re which is related to fluid viscosity mu, density rho and flowing velocity V, such relationship is very depicted by this Moody's diagram.

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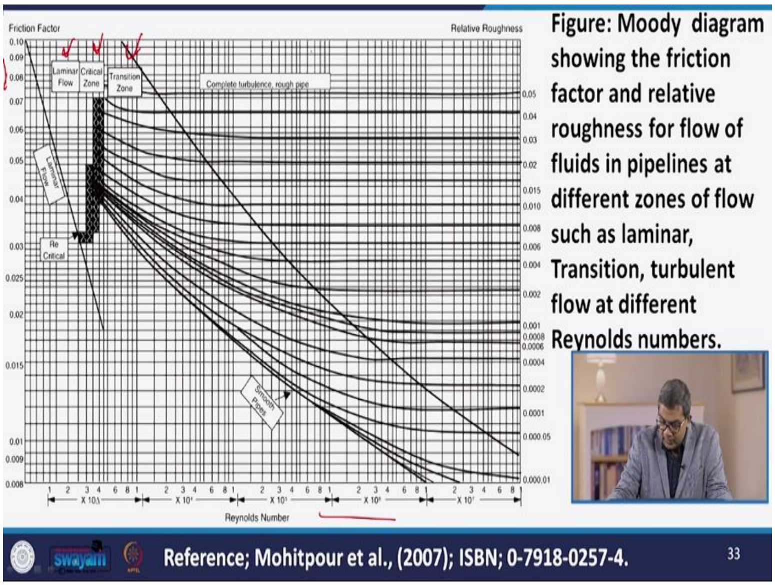

This Moody's diagram this is showing for the friction factor and relative roughness of flow of fluids in pipelines at different zones such as laminar, transition, turbulent flow at different Reynolds number. So, you see that X axis Reynolds number and the Y axis this represent the friction factor and you may have a different zones like laminar, critical zone, transition zone. So, all these flow profiling is there.

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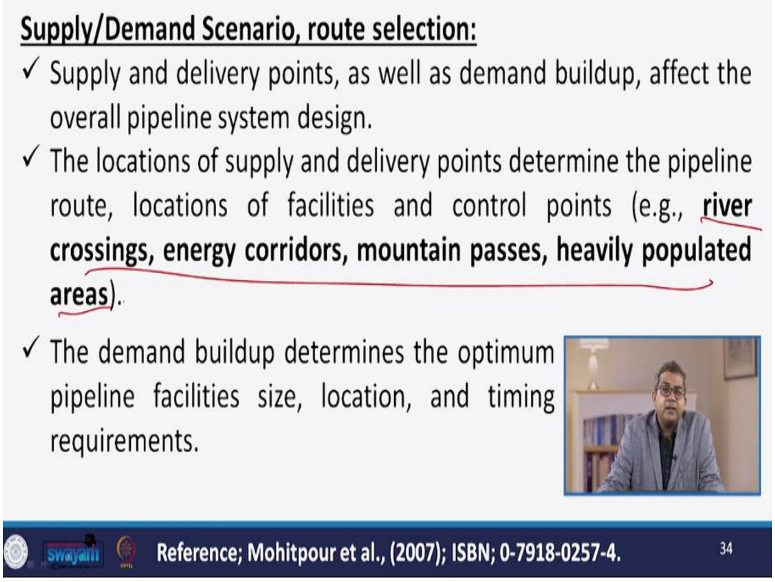

Then, next aspect is the supply demand scenario or the route selection. Now, supply and delivery points as well as demand build up affect the overall pipeline system design. The location of supply and delivery point this determines the pipeline route, location of facilities and control points may be river crossing, there may be certain energy corridors, mountain passes, heavily populated area all these things are the contributing parameters in the designing aspect.

The demand build-up this usually determines the optimum pipeline facilities sometimes with respect to size, sometimes with respect to the location and the time requirement.

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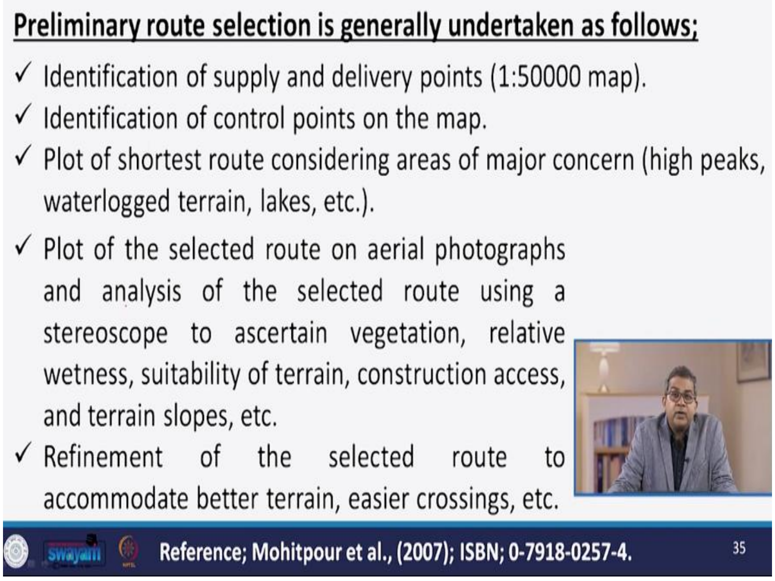

Now, preliminary route selection is usually undertaken based on various factors. The one factor is the identification of supply and delivery points. Then another factor is identification of the control point on the map. Then the plot of shortest route considering areas of major concern may be high peak, waterlogging, waterlogged terrains, lakes, etc.

Then the plot for selected route on aerial photographs and analysis of the selected route using a stereoscope to ascertain vegetation, relative wetness, suitability of terrain, construction access and terrain slopes. Then the refinement of the selected route to accommodate better terrain, easier crossing, etc.

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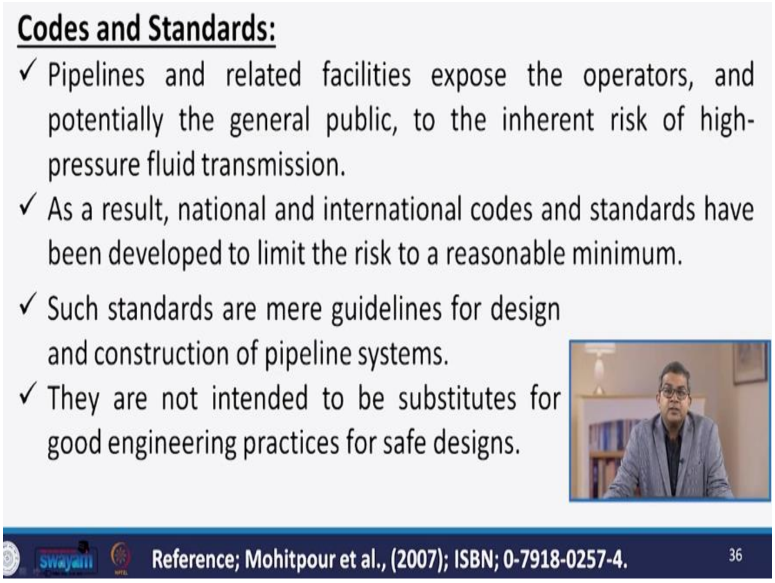

Now, let us briefly talk about the codes and standards. The pipeline and related facilities expose the operators and potentially the general public to inherent risk of high-pressure fluid transmission and you can notice that sometimes a play card with the respective notifications is displayed during the pipeline passages. Now as a result, national and international codes and standards have been developed to limit the risk to a reasonable minimum. Such standards are mere guidelines for design and construction of pipeline system. They are not intended to substitute for good engineering practices for safe design.

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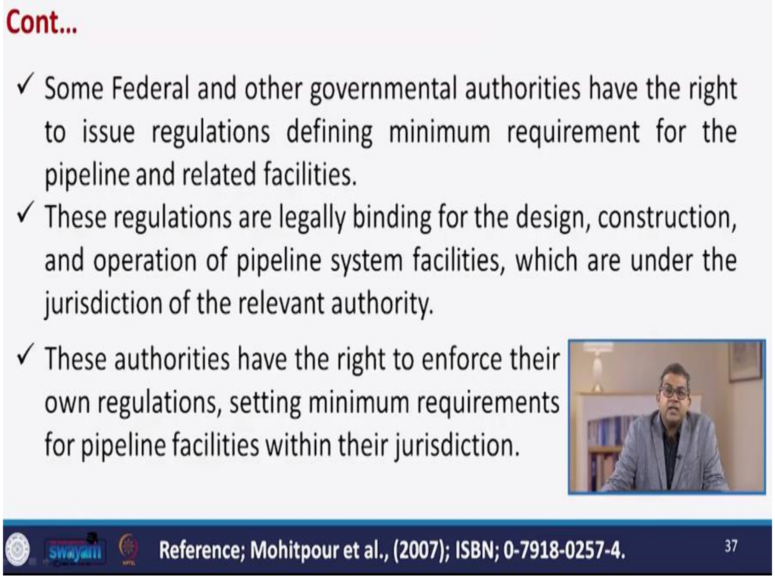

Some central or federal and other government authorities have the right to issue regulations defining minimum requirement for the pipeline and related facilities. These regulations are legally binding for the design, construction and operation of pipeline system facilities which are under the jurisdiction of the relevant authorities. These authorities have the right to enforce their own regulations, setting minimum requirements for pipeline facilities within their jurisdiction.

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Codes and Standards

Major organization codes and standards affecting pipeline design, construction and operation;

Acronym	Organization/topic
ACI	American Concrete Institute
AGA	American Gas Association
ANSI	American National Standard Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
CSA	Canadian Standards Association
IEEE	Institute of Electronic and Electrical Engineers
ISO	International Standards Organization

Reference; Mohitpour et al., (2007); ISBN; 0-7918-0257-4. 38

Now we have enlisted various codes and standards like ACI American Concrete Institute, AGA American Gas Association, ANSI American National Standard Institute, ASME, American Society for Mechanical Engineers, ASTM American Society for Testing Materials, CSA Canadian Standard Association, IEEE Institute of Electronic and Electrical Engineering, ISO International Standards Organizations.

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Cont...

Acronym	Organization/topic
MSS	Manufacturers Standardization Society
NACE	National Association of Corrosion Engineers
NAG	Normas Argentinas de Gas
NEMA	National Electrical Manufacturing Association
NFPA	National Fire Protection Association
SIS	Standards Institute of Sweden
SSPC	Steel Structures Painting Council
ANSI B16.5	Pipe Flanges and Flanged Fittings
ASTM A 350	Pipe Flanges and Flanged Fittings Material
MSS SP-25	Standard Marking System for Valves, Fittings, Flanges, and Unions

Reference; Mohitpour et al., (2007); ISBN; 0-7918-0257-4. 39

MSS Manufacturers Standardization Society, NACE National Association of Corrosion Engineers, NAG Normas Argentinas de Gas, NEMA National Electrical Manufacturing Association, NFPA National Fire Protection Association, SIS Standard Institute of Sweden, SSPC Steel Structures Painting Council, ANSI B 16.5 this is Pipe Flanges and Flanged Fittings. So, this is also very crucial for joining of the pipelines. ASTM A 350 that is Pipe Flanges and

Flanged Fittings Materials, MSS SP 25 Standard Marking System for Valves, Fittings, Flanges and Unions.

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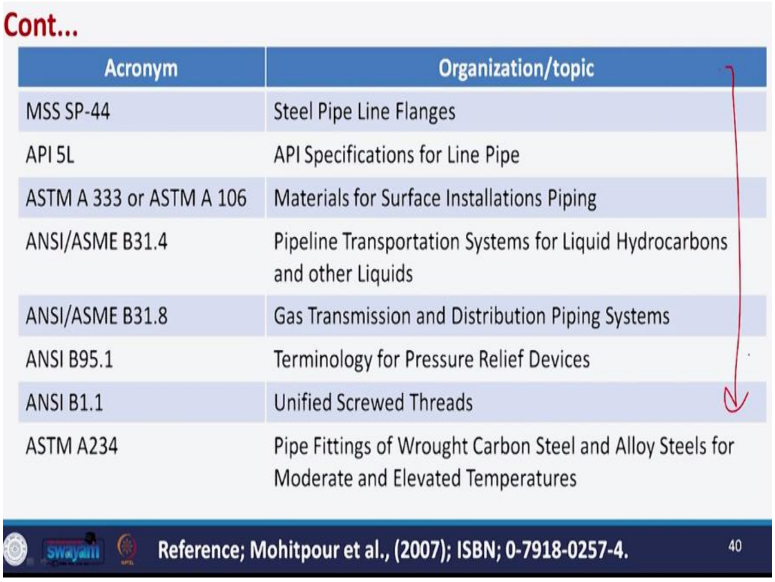

And other codes and different types of organization and topic which have enlisted.

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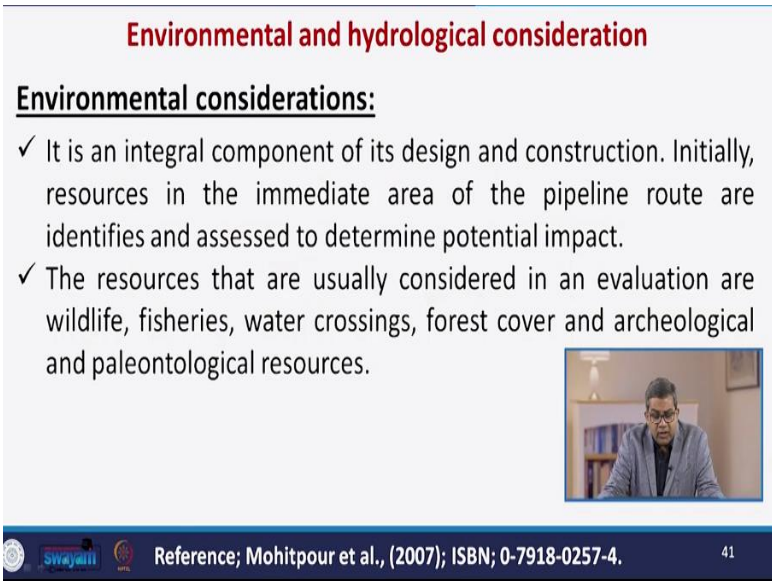

Now let us talk about the environmental and hydrological consideration. Now environmental consideration is an integral component of its design construction. Initially, resources in the immediate area of pipeline route are identified and assessed to determine the potential impact. The resources that are usually considered in an evaluation are wildlife, fisheries, water crossings, forest cover, archaeological, paleontological resources.

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The land use in immediate area of the pipeline route is also identified and evaluated to ensure the conflicts do not arise with other companies or individuals or government jurisdictions. So during the construction of pipeline, environmental inspection is ongoing to ensure the compliance with environmental design and protection procedure and maintain consistency with the various regulatory approvals.

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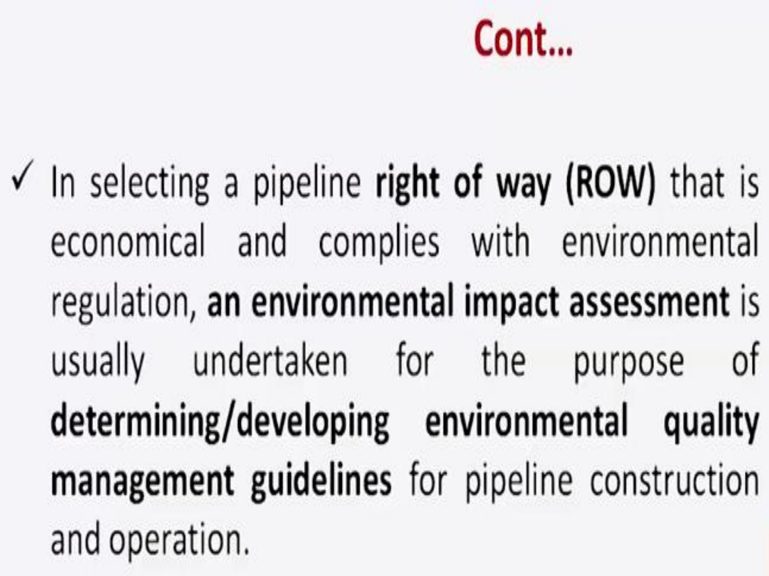

Now while selecting a pipeline right of way that is ROW that is economical and complies with the environmental regulation. So, an environmental impact assessment is usually undertaken for the purpose of determining, developing environmental quality management guidelines for pipeline construction and operation.

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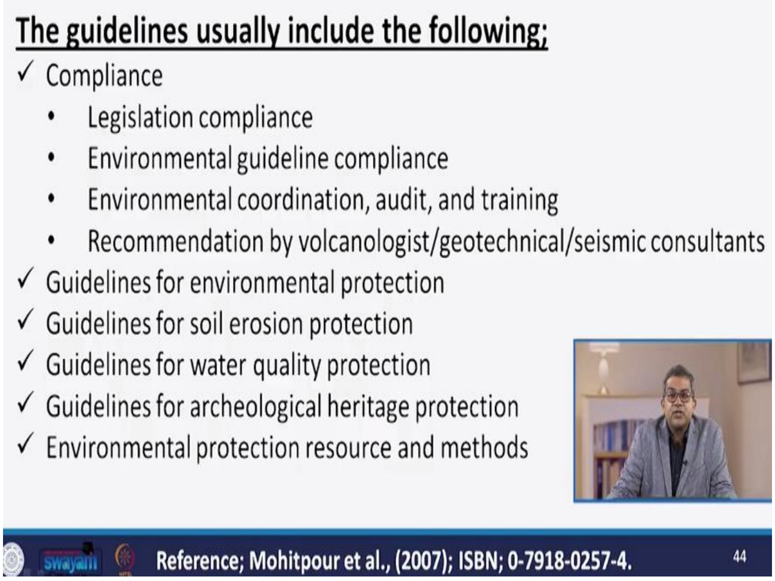

So, the guidelines usually include the compliances. Legislation compliance, environmental guideline compliance; environmental coordination, audit and training; recommendation of volcanologist, geotechnical, seismic consultants. Guidelines for environmental protection, guidelines for soil erosion protection, guidelines for water quality protection, guidelines for archaeological heritage protection, environmental protection resource and methods.

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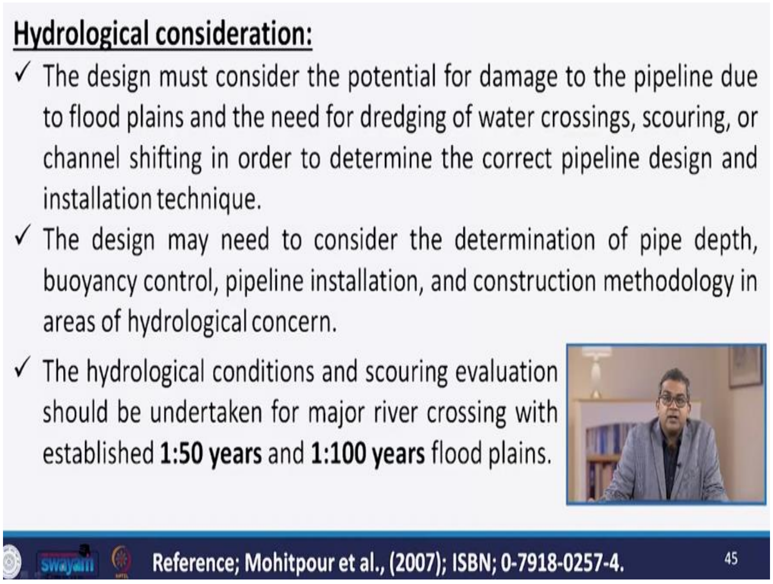

Now, let us talk about the hydrological consideration. The design must consider the potential for damage to the pipeline due to flood plains and the need for dredging of water crossings, scouring and channel shifting in order to determine the correct pipeline design and installation technique. The design may need to consider the determination of pipe depth, buoyancy control, pipeline installation, construction methodology in areas of hydrological concerns. The hydrological conditions and scouring evaluation it should be undertaken for a major river crossing with established 1 is to 50 years and 1 is to 100 years flood plains.

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So, in this particular lecture we discussed about the various components attributed to the pipeline design and we discussed about the various impact of these parameters over the pipeline designs. For your convenience we have listed one reference. You can go through this reference. Thank you very much.