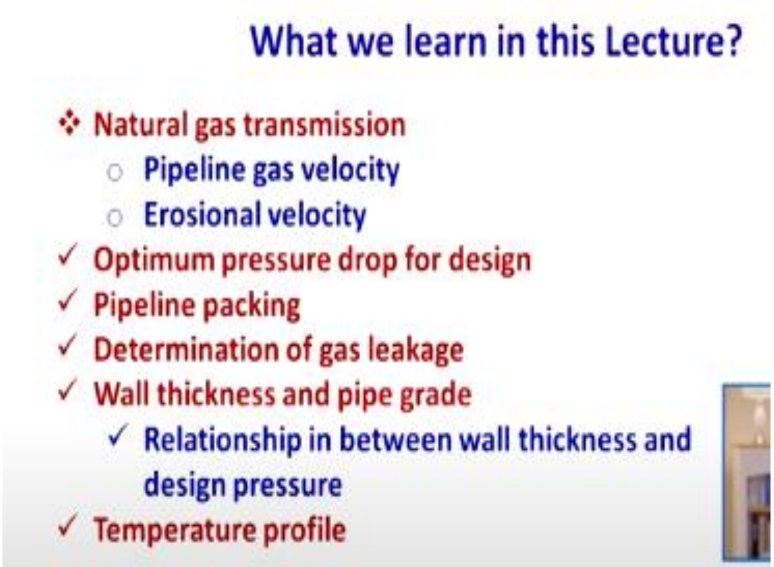
**Chemical Process Utilities**
**Prof. Shishir Sinha**
**Department of Chemical Engineering,**
**Indian Institute of Technology, Roorkee**

**Module No # 08**
**Lecture No # 41**
**Natural Gas Transmission -III**

Welcome to the next aspect of design of pipeline and as you know that we were discussing about the natural gas transmission. Let us have the brief outlook that what we discussed in the previous lecture. We discussed about the various flow regimes like fully turbulent flow, rough pipe flow, partially turbulent flow with the, smooth pipe flow pressure drop calculation. We discussed both the cases like pipeline in series and pipeline in parallel and we discussed about the pipeline segmental looping.

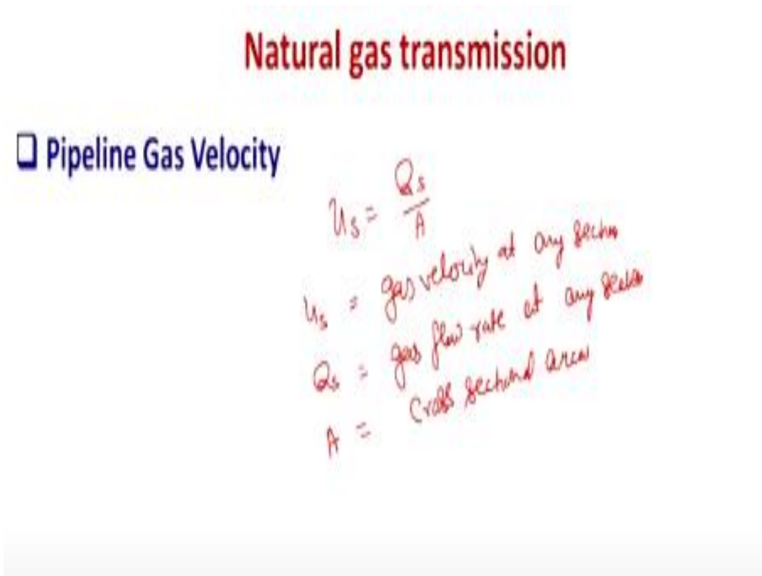
In this particular lecture we are going to discuss about the natural gas transmission with the pipeline gas velocity then erosional velocity. Apart from this we will discuss about the optimum pressure drop for design.

**(Refer Slide Time: 01:15)**




We will discuss about the pipeline packing how we can determine the gas leakage, what is the concept of wall thickness and pipe grade? In this we will discuss about the relationship in between wall thickness and design pressure, apart from this we will discuss about the temperature profile. So let us discuss about the pipeline velocity.

**(Refer Slide Time: 01:39)**




Now the gas velocity in a pipeline can be obtained by u s = Q s upon A where u s is equal to gas velocity at any section. Q s is equal to gas flow rate at any section and A is equal to cross sectional area.

**(Refer Slide Time: 02:22)**

**The gas velocity in a pipeline can be obtained from;**

$$\boldsymbol{u_s = \frac{Q_s}{A}}$$

**Where,**

**$u_s$= gas velocity at any section**

**$Q_s$= gas flow rate at any section**

**A= cross sectional area**

$$Q_b \rho_b = Q_s \rho_s$$

$$\rho_s = \frac{P_s M}{T_s R} \qquad \rho_b = \frac{P_b M}{T_b R}$$

$$\frac{\rho_b}{\rho_s} = \frac{P_b T_s}{T_b P_s} \quad \& \quad A = \frac{\pi D^2}{4}$$

$$u_s = \frac{Q_b}{\frac{\pi D^2}{4}} \quad \frac{P_b T_s}{}$$

Now if you take the steady state condition so under steady state condition Q b rho b = Q s rho s and rho s = P s M upon T s R and rho b = P b M upon T b R. So, rho B upon rho s = P b T s upon T b P s. Now if we take A = pi D square upon 4 so if we combine these equations, we get u s = Q b upon pi D square upon 4 P b T s upon T b P s.

**(Refer Slide Time: 03:17)**

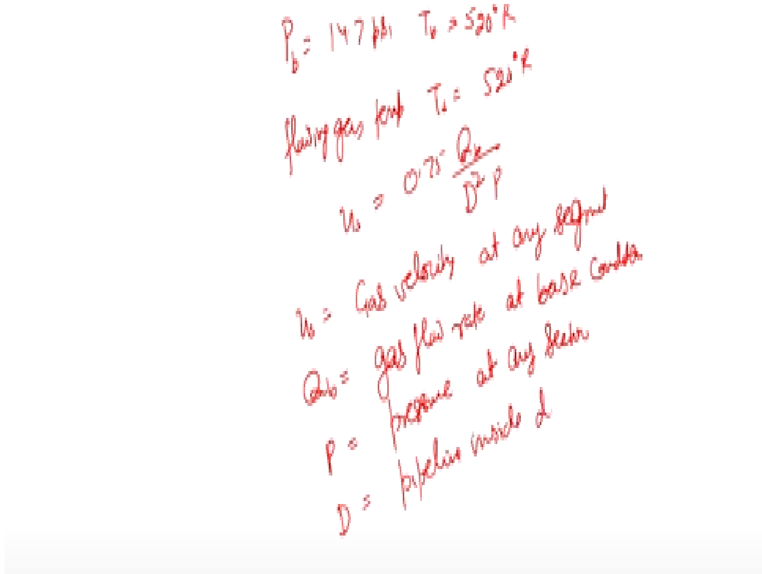
**At steady state condition;** $\boldsymbol{Q_b.\ \rho_b = Q_s.\ \rho_s}$

**And,** $\boldsymbol{\rho_s = \frac{P_s.M}{T_s.R}}$; $\boldsymbol{\rho_b = \frac{P_b.M}{T_b.R}}$

**or,** $\boldsymbol{\frac{\rho_b}{\rho_s} = \frac{P_b.T_s}{T_b.P_s}}$ **If,** $\boldsymbol{A = \frac{\pi D^2}{4}}$

On combining these equations, we have;

$$\boldsymbol{u_s = \frac{Q_b}{\frac{\pi D^2}{4}} . \frac{P_b.T_s}{T_b.P_s}}$$




Now if we substitute P b = 14.7 psi and T b = say 520 degree Rankine and the flowing gas temperature T s = 520 Rankine's. So, we have u s = 0.75 Q b upon D square P. Where u s is equal to gas velocity at any segment q b is equal to gas flow rate at base condition. P is equal to pressure at any section and D is equal to pipeline inside diameter. This equation gives good estimation of gas velocity in pipeline at any segment.

**(Refer Slide Time: 04:37)**

**On substituting $P_b$= 14.7 Psi, $T_b$= 520 ºR, and flowing gas temperature ($T_s$)= 520 ºR, we have;**

$$u_s = 0.75.\frac{Q_b}{D^2.P}$$

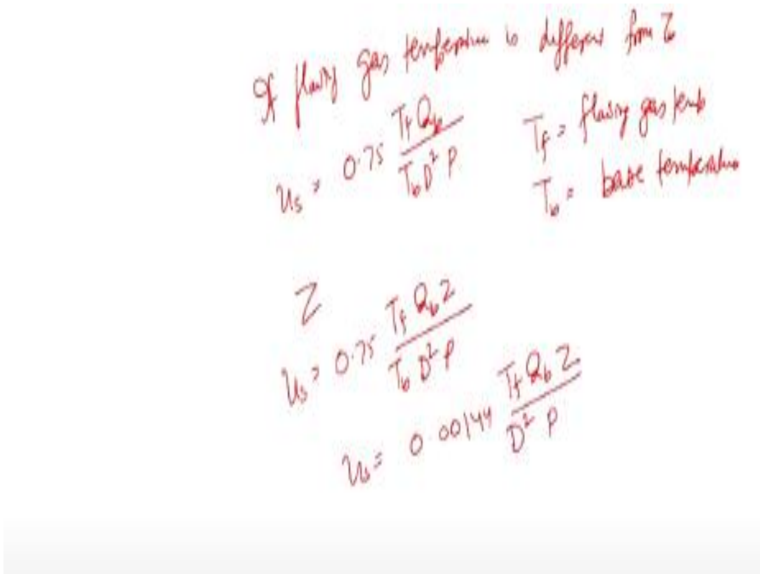
**Where,**

**$u_s$= Gas velocity at any segment (ft/s)**

**$Q_b$= gas flow rate at base condition ($ft^3/h$)**

**P= pressure at any section (Psi)**

**D= pipeline inside diameter (inches)**




Now if flowing gas temperature is different a flowing gas temperature is different from T b then u s = 0.75 T f Q b upon T b D square p. Where T f is equal to flowing gas temperature, T b is equal to base temperature.  Now if we consider the compressibility factors effect then u s would be 0.75 T f Q b z upon T b D square p or u s = 0.0014 T f Q b Z upon D square p.

**(Refer Slide Time: 05:37)**

**If flowing gas temperature is different from $T_b$ then;**

$$\boldsymbol{u_s = 0.75.\frac{T_f}{T_b}\frac{Q_b}{D^2.P}}$$

**Where,**

$\boldsymbol{T_f}$***= flowing gas temperature ( $^oR$)***

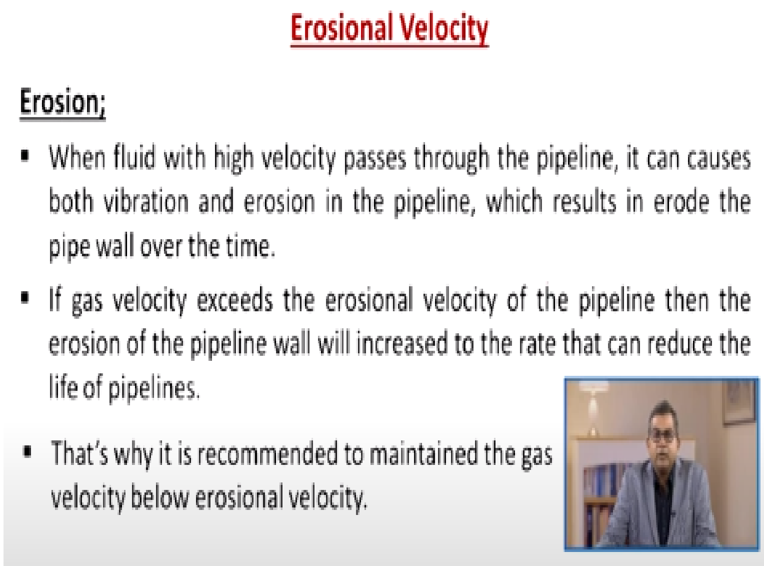
$\boldsymbol{T_b}$***= base temperature (520 $^oR$)***

If effect of compressibility factor (**Z**) is also considered;

$$\boldsymbol{u_s = 0.75.\frac{T_f}{T_b}\frac{Q_b.Z}{D^2.P}}$$

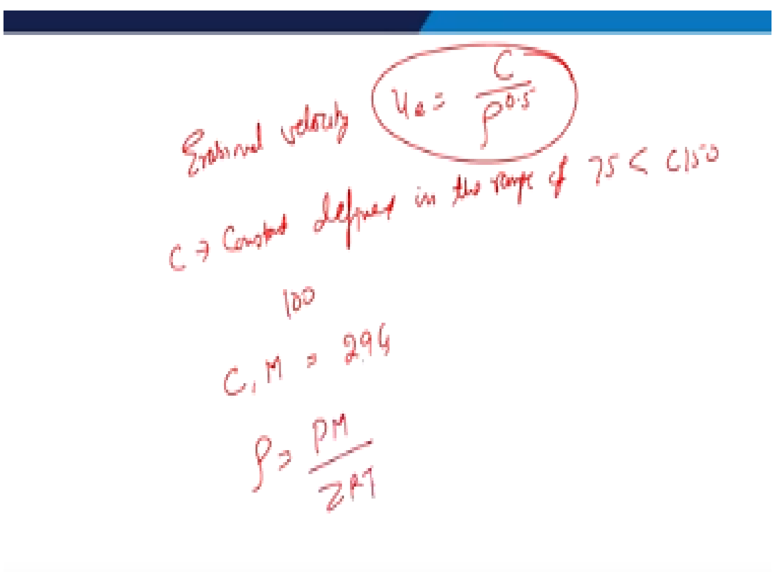
Or,

$$\boldsymbol{u_s = 0.00144.\ \frac{T_f Q_b.Z}{D^2.P}}$$




Now let us talk about the erosional velocity now when fluid with high velocity passes through the pipeline it can cause both vibration and erosion in the pipeline which results in erode the pipe wall over the period of time. Now if gas velocity exceeds the erosional velocity of the pipeline then the erosion of the pipeline wall will increase so to the rate that can reduce the life of pipeline. And that is why it is recommended to maintain the gas velocity below the erosional velocity.

**(Refer Slide Time: 06:22)**




Now erosional velocity can be expressed as velocity u e = C upon rho to the power half. Now where u e is the original velocity and rho is the gas density and c is the constant defined in the range of 75 less than c 150. The recommended value for gas transmission in the pipeline is 100.

So if we substitute the value of C M = 29 G and gas density in this particular equation then we have rho = P M upon Z R T.

**(Refer Slide Time: 07:15)**

**Erosional velocity can be expressed as;**

$$u_e = \frac{C}{\rho^{0.5}}$$

**Where,**

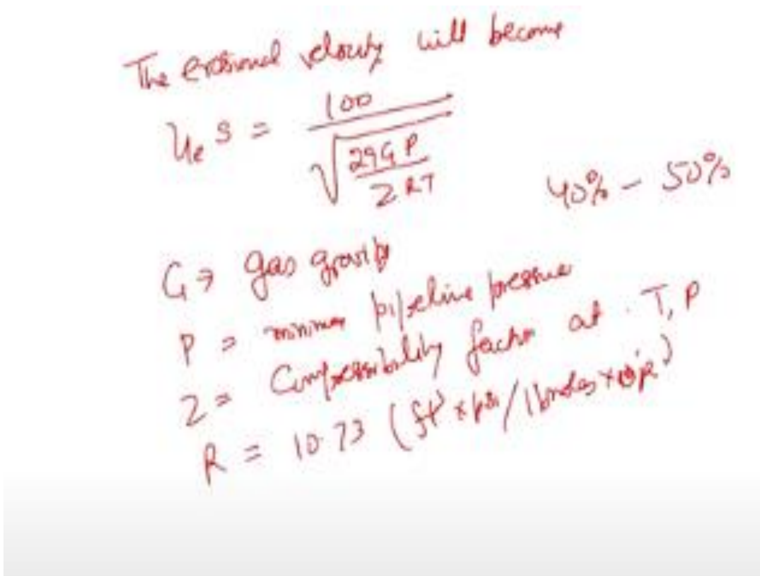
$u_e$**= *Erosion velocity (ft/s)***

***ρ= gas density (*** $lb_m/ft^3$ ***)***

And **C** is a constant defined in the range of $\mathbf{75 < C150}$, the recommended value for the gas transmission in pipeline is $\mathbf{100}$.

So, on substituting the value of **C**, **M = 29 G** and gas density ($\boldsymbol{\rho}$) in above equation, we have;

$$\rho = \frac{P.M}{Z.R.T}$$




The erosional velocity will become u e s =100 upon square root of 29 G P, Z R T. The recommended value for the gas velocity in the gas pipeline is normally 40 % to 50 % of the erosional value. Now here G is the gas gravity and this is dimensionless, P is the minimum pipeline pressure, Z is the compressibility factor at given temperature and pressure. Which is dimensionless r = 10.73 feet cube into psi bonds moles into Rankine now this is the usual value of R.

Now let us talk about the optimum pressure drop for design now it is most important factor used to design the cost-effective system. The maintaining of optimum pressure drop along each section of the pipeline system is necessary to minimize the required facilities and operating expenses including pipeline, compressor and fuel consumption cost.  People have performed a lot of studies over the pipeline system design.

**(Refer Slide Time: 09:08)**

**The erosional velocity will becomes;**

$$u_e s = \frac{100}{\sqrt{\frac{29G.P}{ZRT}}}$$

The recommended value for the gas velocity in gas pipeline in normally **40%** to **50%** of the erosional value.

**Where,**

***G*= gas gravity (dimensionless)**

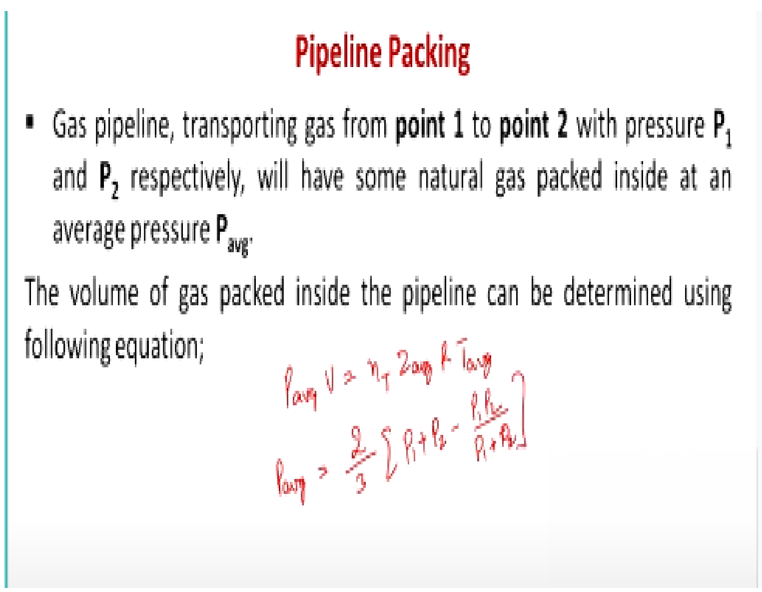
**P= minimum pipeline pressure (Psi)**

**Z= compressibility factor at (T,P) (dimensionless)**

**R= 10.73 ($ft^3$ x Psi/lbmoles x $^oR$)**


Now department of Trans Canada pipeline they have pressure measured the pressure drop of say 15 to 20 kilo Pascal per kilometer which is they found to be optimum. Now pressure drop out of range either below 15 kilo Pascal or above 25 kilo Pascal can result in variation of extra equipment installation and fuel cost respectively so the economics should be on the different side.

**(Refer Slide Time: 09:32)**



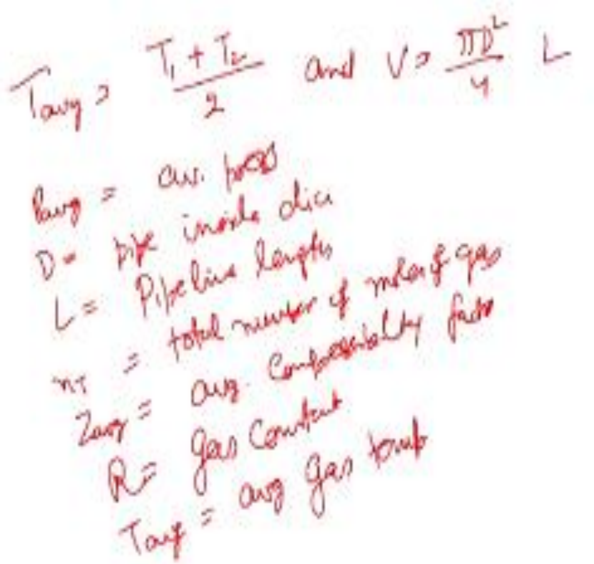
Now if you take the gas pipeline in the let us take the gas pipeline transporting gas from section 1 to section 2 with the pressure P 1 and P 2 respectively. Will have some natural gas packed inside at an average pressure of P average. So the volume of gas packed inside the pipeline can be determined using the equation this P average V = n T z average R T average. Now P average = 2 upon 3 P 1 + P 2 - P 1 P 2 upon P 1 + P 2.

**(Refer Slide Time: 10:26)**

**The volume of gas packed inside the pipeline can be determined using following equation;**

$$\mathbf{P_{avg}.V = n_T.Z_{avg}.R.T_{avg}}$$

Where, $$\mathbf{P_{avg}} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1.P_2}{P_1 + P_2}\right]$$




Now T average = T 1 + T 2 upon 2 and V = pi D square upon 4 L. Where P average is equal to average pressure, D is equal to pipe inside diameter, L is the pipeline length and T is equal to total number of moles of gas. Z average is average compressibility factor; R is gas constant T average is the average gas temperature,

**(Refer Slide Time: 11:30)**

$$\mathbf{T_{avg}} = \frac{T_1 + T_2}{2} \qquad \text{and,} \qquad \mathbf{V} = \frac{\pi D^2}{4}.L$$

**Where,**

**$P_{avg}$= average pressure (Psi)**

**D= pipe inside diameter (ft)**

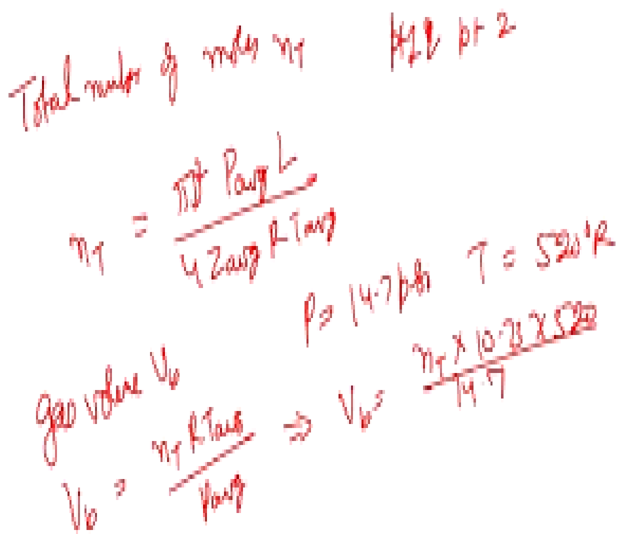
**L= Pipeline length (ft)**

**$n_T$= total number of moles of gas (lb.moles)**

**$Z_{avg}$= average compressibility factor (dimensionless)**

**R= gas constant**

**$T_{avg}$= average gas temperature ($^oR$)**




Now the total number of moles n t packed between point 1 and point 2 at average pipeline condition is given as n T = pi D square p average L upon 4 Z average R T average. Now that then the gas volume V b existing in the pipeline at base condition that is P = 14.7 psi and T = 520 Rankine. So, V b = n T R T average upon p average that is comes out to be V b = n T into 10.73 into 520 upon 14.7. Now for accurate calculation of storage capacity at packed and unpacked condition one may use the (())(12:39) equation.

**(Refer Slide Time: 12:42)**

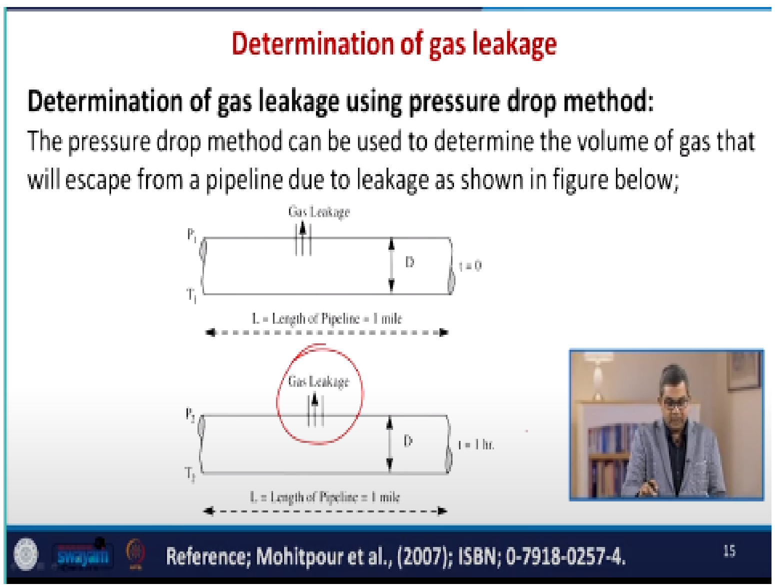
**Total number of moles ($n_T$) packed in between point 1 and 2 at average pipeline condition is;**

$$n_T = \frac{\pi D^2 . P_{avg} . L}{4. \, Z_{avg} . R . T_{avg}}$$

**Then the gas volume ($V_b$) existing in the pipeline at base condition (P=14.7 Psi and T= 520 ºR);**

$$V_b = \frac{n_T . R . T_{avg}}{P_{avg}} \qquad \Longrightarrow V_b = \frac{n_T \, x \, 10.73 x \, 520}{14.7}$$

For accurate calculation of storage capacity at packed and unpacked condition, use Clinedinst equation.




Now let us talk about the determination of gas leakage now using the pressure drop method. The pressure drop method can be used to determine the volume of gas that will escape from pipeline due to the leakage which you can see over in this particular figure. Now here we are having a length of pipeline say 1 mile and initial P 1 and P 2 the condition and diameter of the pipeline is D so T = 0.

Suppose this is a gas leakage port and after 1 hour then you need to find out that the amount of gas leakage or determination of the gas leakage over the period of time say 1 hour so how you can calculate this?

**(Refer Slide Time: 13:36)**

no of moles of gas in pipe line

at t=0

$P_1 V_1 = n_1 R T_1$

Then in that case number of moles of gas in pipeline at T = 0 that is P 1 V 1= n 1 R T 1. Where P 1 is the initial pressure V 1 is the initial gas volume, n 1 is the initial number of moles, R is the gas constant and T 1 is the initial gas temperature.

**(Refer Slide Time: 14:14)**

**No. of moles of gas in pipeline at initial time (t=0);**

$$\mathbf{P_1 . V_1 = n_1 . R . T_1}$$

**Where,**

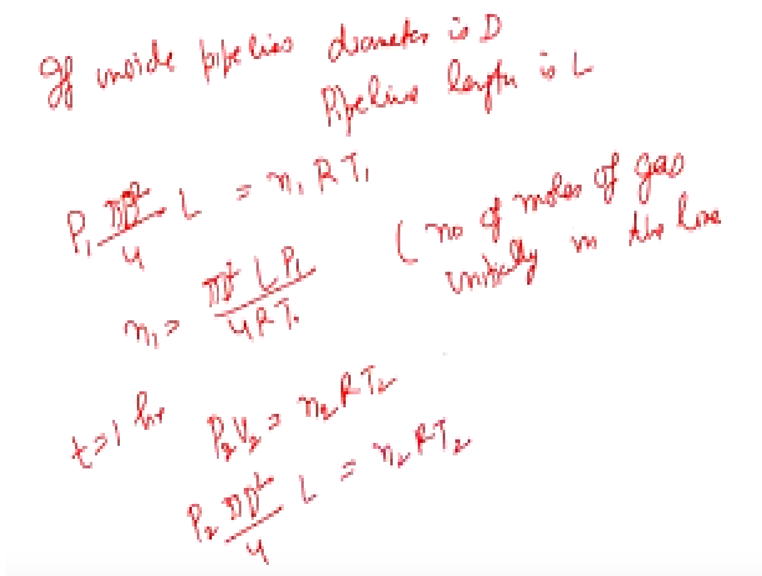
**$P_1$= initial pressure (Psi)**

**$V_1$= initial gas volume ($ft^3$)**

**$n_1$= Initial number of moles (lb.moles)**

**R= gas constant**

**$T_1$= initial gas temperature ($^oR$)**




Now if inside pipeline diameter is D and pipeline length is l then P 1 pi D square upon 4 l = n 1 R T 1. So the number of moles of gas initially in the line is n 1 = pi D square L P 1 upon 4 R T 1 that is the number of moles of gas initially in the line. Now if after 1 hour say T = 1 hour say after 1 hour of leakage the volume of the gas in the pipeline is reduced to P 2 V 2 = n 2 R T 2. And P 2 pi D square D is the diameter upon pi d square upon 4 L = n 2 R T 2.

**(Refer Slide Time: 15:37)**

**If inside pipelines diameter is D and pipeline length is L;**

$$\mathbf{P_1.\frac{\pi D^2}{4}.L = n_1.\ R.T_1}$$

So, the number of moles of gas initially in the line is;

$\boldsymbol{n}$

If after one hour of leakage, the volume of gas in pipeline is reduced to;

$$\mathbf{P_2.V_2 = n_2.\ R.T_2}$$

$$\Rightarrow \mathbf{P_2.\frac{\pi D^2}{4}.L = n_2.\ R.T_2}$$

$$n_2 = \frac{\pi D^2 L P_2}{4 R T_2}$$

The Amount of gas escaped due to Leakage can be obtained as

$$n = n_1 - n_2$$

$$n_2 = \frac{\pi D^2 L}{4R}\left(\frac{P_1}{T_1} - \frac{P_2}{T_2}\right)$$

Or you can say that n 2 = pi D square L P 2 upon 4 R T 2. So the amount of gas escaped due to leakage can be obtained as n = n 1 – n 2. So if we substitute the values of n 1 and n 2 then we get n 2 = pi D square L upon 4 R P1 upon T 1 – P 2 upon T 2.

**(Refer Slide Time: 16:23)**

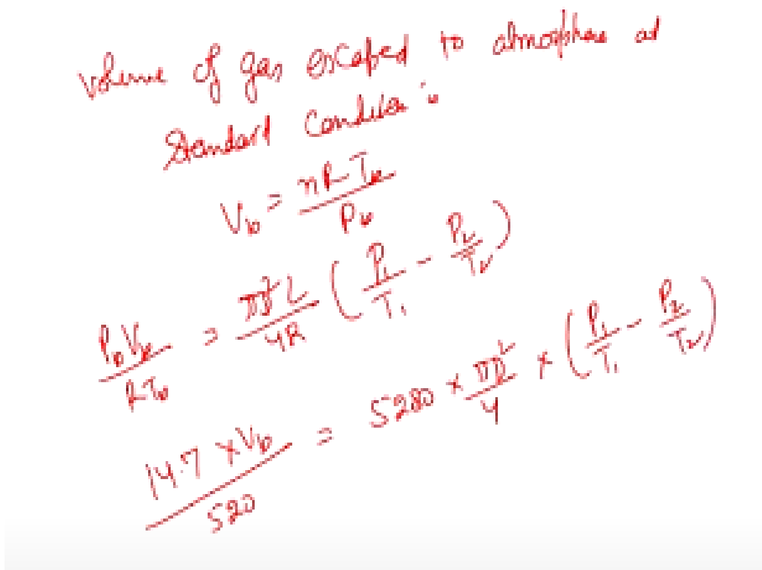
Or, $$\boldsymbol{n_2 = \frac{\pi D^2 . L . P_2}{4 . R . T_2}}$$

The amount of gas escaped due to leakage can be obtained as;

$$\boldsymbol{n = n_1 - n_2}$$

On substitution the value of $\mathbf{n_1}$ and $\mathbf{n_2}$ we have;

$$\boldsymbol{n_2 = \frac{\pi D^2 L}{4R}\left(\frac{P_1}{T_1} - \frac{P_2}{T_2}\right)}$$



So the volume of gas escaped to atmosphere at standard condition is V b = n R T b upon P b therefore P b V b upon R T b = pi d square l upon 4 R P 1 T 1 P 2 over T 2. So after putting the values of constant to say and substitute the R then we can get 14.7 into V b upon 520 = 5280 into pi D square upon 4 into V 1 over T 1 - P 2 over T 2.

**(Refer Slide Time: 17:30)**

**Volume of gas escaped to atmosphere at standard condition is;**

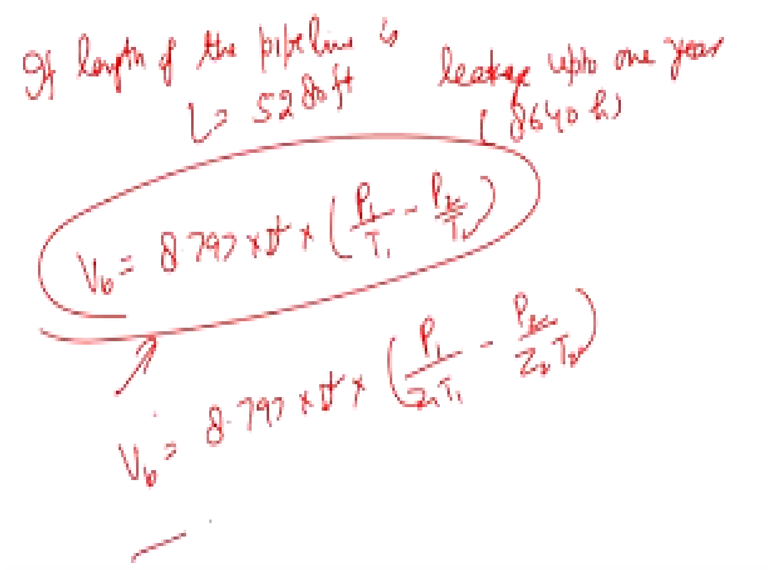
$$\mathbf{V_b} = \frac{\boldsymbol{n}.\mathbf{R}.\mathbf{T_b}}{\boldsymbol{P_b}}$$

Therefore;

$$\frac{\mathbf{P_b V_b}}{\mathbf{RT_b}} = \frac{\boldsymbol{\pi D^2 L}}{\boldsymbol{4R}}\left(\frac{\boldsymbol{P_1}}{\boldsymbol{T_1}} - \frac{\boldsymbol{P_2}}{\boldsymbol{T_2}}\right)$$

After putting the value constants and substitute R;

$$\frac{\mathbf{14.7 \times V_b}}{\mathbf{520}} = \mathbf{5280} \times \frac{\boldsymbol{\pi D^2}}{\mathbf{4}} \times \left(\frac{\boldsymbol{P_1}}{\boldsymbol{T_1}} - \frac{\boldsymbol{P_2}}{\boldsymbol{T_2}}\right)$$




Now if say if length of the pipeline is L = 5280 fit and leakage up to 1 year is that is 8640 hours then V b = 8.797 into D square into P 1 upon T 1 - P 2 upon T 2. Now this equation gives the volume of gas escaped due to leakage from 1 mile of pipeline over the period of 1 year. This is also applicable if a small change is occurred in temperature and pressure now if we include the compressibility factor then it becomes V b = 8.797 into D square into P 1 Z 1 T 1 - P 2 Z 2 T 2.

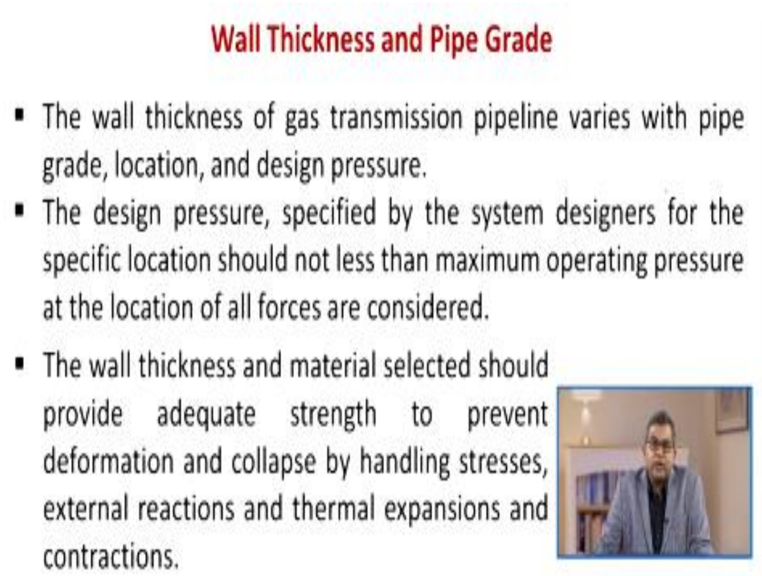
**(Refer Slide Time: 18:41)**

**If length of the pipeline is L= 5280 ft and leakage upto one years (8640 h) then;**

$$\boldsymbol{V_b = 8.797 \times D^2 \times \left(\frac{P_1}{T_1} - \frac{P_2}{T_2}\right)}$$

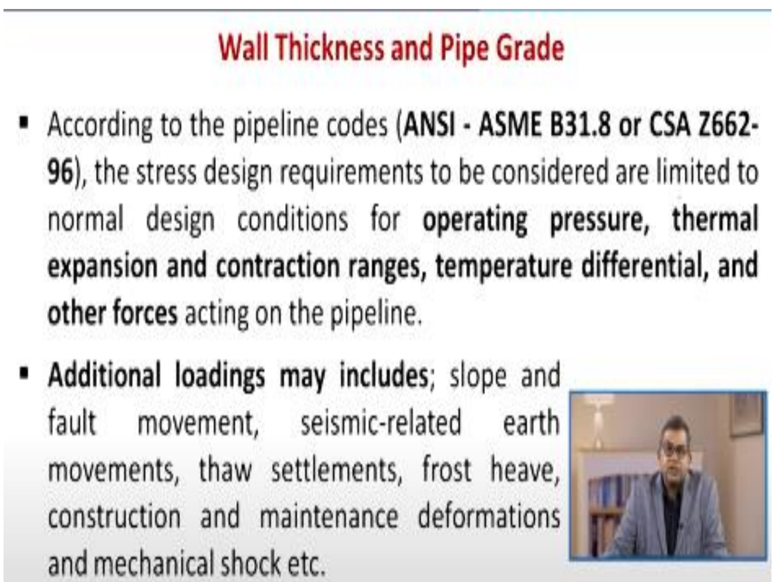
If compressibility factor includes then;

$$\boldsymbol{V_b = 8.797 \times D^2 \times \left(\frac{P_1}{Z_1 T_1} - \frac{P_2}{Z_2 T_2}\right)}$$



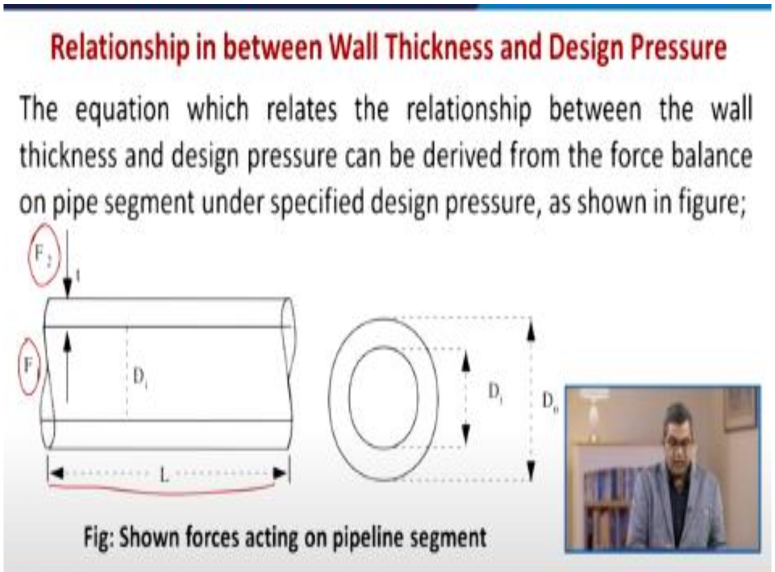

Now let us think about the wall thickness and pipe grid the wall thickness of gas transmission pipeline varies with pipe grade location and design pressure. The design pressure is specified by the system designer for the specific location it should not less than the maximum operating pressure at the location of all forces are considered. The wall thickness and material selected should provide adequate strength to prevent deformation and collapse by handling stresses external reactions and thermal expansion and contraction.

**(Refer Slide Time: 19:23)**



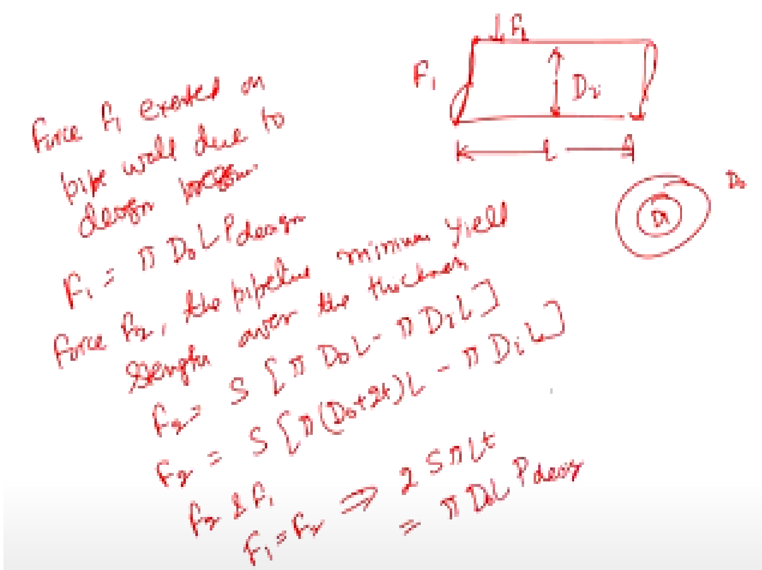

Wall thickness and pipe grades now according to pipeline code ANSI –ASME BE31.8 or CSA Z662-96 the stress design requirement to be considered are limited to normal design condition. For operating pressure, thermal expansion and contraction ranges, temperature differential and other forces acting on the pipeline. The additional loading may include slope and fault movement, seismic related earth movement, thaw settlement, frost heave construction and maintenance deformation and mechanical shocks etcetera.

**(Refer Slide Time: 20:10)**




Now we need to establish the relationship between the wall thickness and design pressure. The equation which relates the relationship between the wall thickness and design pressure it can be derived from the force balance on pipe segment under specified design pressure. Now here we have shown this thing now this is the pipe length and force it is acting over here and this one is F 1 and F 2 with the diameter internal diameter is D i.

**(Refer Slide Time: 20:51)**



Now this try to establish the relationship so force exerted now again I am redrawing the figure now here this is F 2 and this one is F 1 and diameter is D i the length l. And the internal diameter is D i and outer diameter is D o so force f 1 exerted on pipe wall due to design pressure is F 1 = pi D 0 L P design. Now force F 2 the pipeline minimum yield strength over the thickness F 2 = S pi D 0 L - pi D i L, this is D o that is the outer diameter.

F 2 = S pi D o + 2 T L- pi D i that is the internal diameter. Now on balancing force F 2 and F 1 we have F 1 = F 2 and that is 2 S pi L T and that is equal to pi D o L P design.

**(Refer Slide Time: 22:54)**

**Force $F_1$ exerted on pipe wall due to design pressure is;** $\mathbf{F_1 = \pi . D_o . L . P_{design}}$

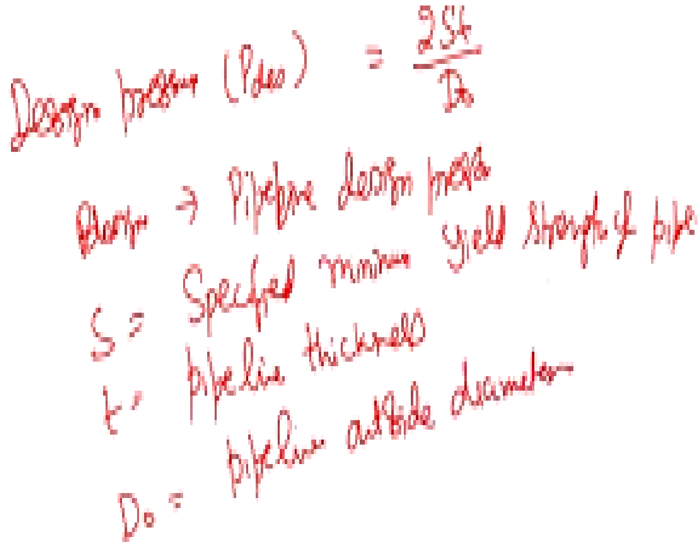
For Force $F_2$, the pipeline minimum yield strength over the thickness

$$\mathbf{F_2 = S[\pi . D_o . L - \pi . D_i . L]}$$

$$\mathbf{Or,\quad F_2 = S[\pi . (D_o + 2t)L - \pi . D_i . L]}$$

On balancing Force $F_2$ and $F_1$ we have;

$$\boldsymbol{F_1 = F_2 \qquad \Longrightarrow 2S\pi Lt = \pi . D_o . L . P_{design}}$$




Now design pressure that is P design is equal to 2ST upon Do where P design is the pipeline design pressure, S is specified minimum yield strength of pipe in pressure unit, T is pipeline thickness and Do is pipeline in outside diameter.

**(Refer Slide Time: 24:02)**

Design pressure (**$P_{design}$**) is; $$P_{design} = \frac{2St}{D_o}$$

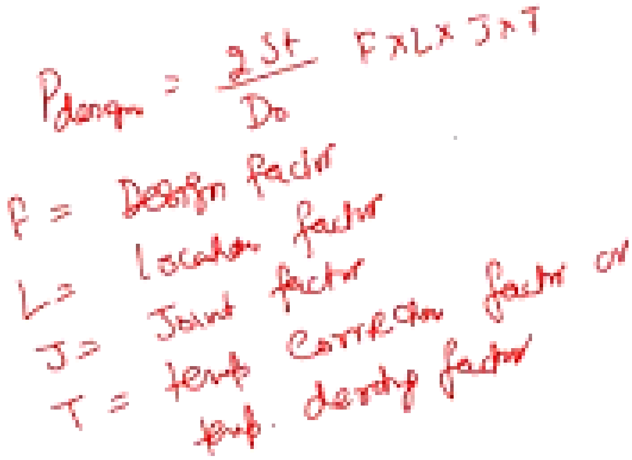
**Where,**

***$P_{design}$= pipeline design pressure (Psi)***

S= specified minimum yield strength of pipe (Psi)

t= pipeline thickness (inches)

***$D_o$= pipeline outside diameter (inches)***




Now after considering all these safety factors the design pressure can be given as P design 2 S t upon D o F L J and T. Where F is the design factor, L is the location factor, J is the joint factor and T is the temperature correction factor or temperature derating factor.

**(Refer Slide Time: 24:02)**

After considering all these safety factors, the design pressure can be given as;

$$P_{design} = \frac{2St}{D_o}.F.L.J.T$$

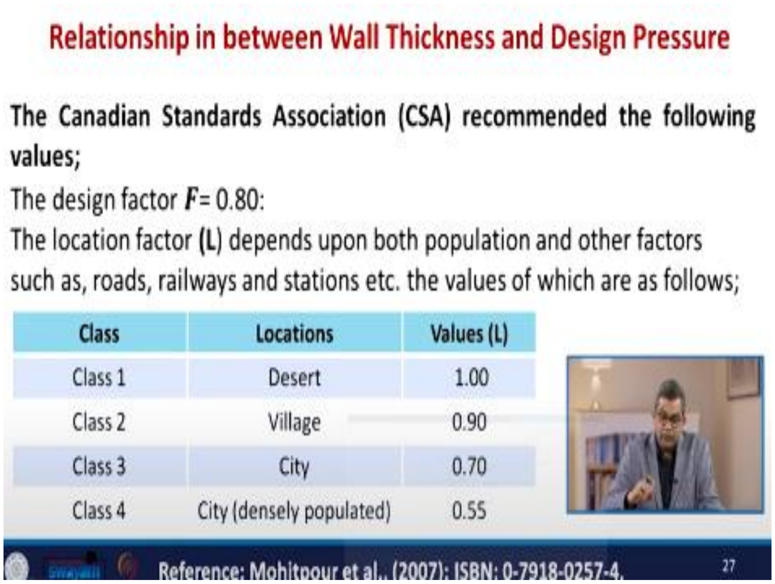
**Where,**

***F= design factor***

**L= location factor**

**J= joint factor**

**T= temperature correction factor or temperature derating factor**

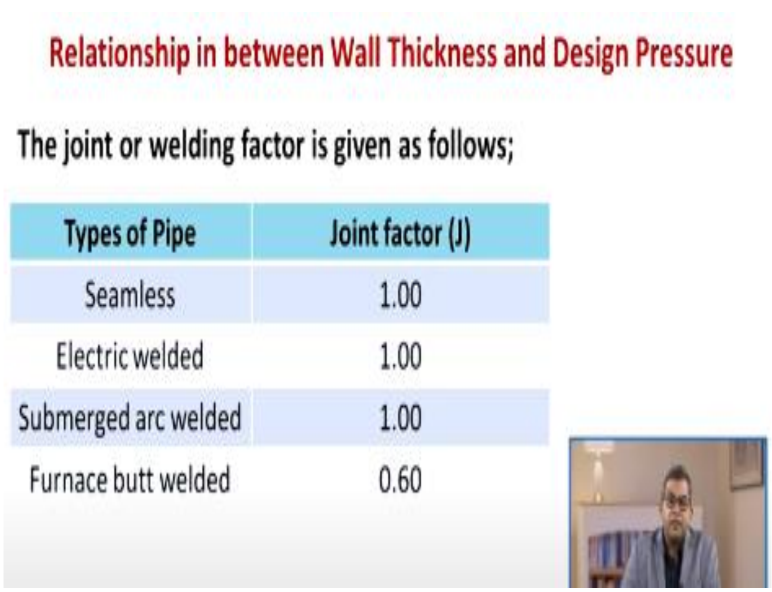



Now the Canadian Standard Association CSA they recommend the following values like the design factor F = 0.80. The location factor l depends upon both, population and other factors such as, roads railways, various stations, gas stations or railway stations or buses station etcetera. The values for them which are as given like class 1 when the location is desert so value of l = 1.00.

Class 2 when we are considering the village then the values value of l is 0.90 class 3 city then l is 0.70 and a class 4 city which is densely populated the value of l is 0.55.

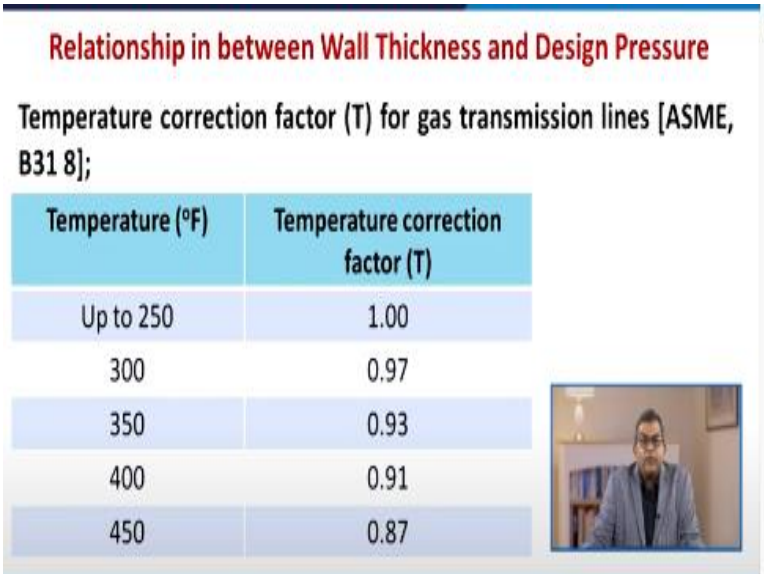
**(Refer Slide Time: 25:43)**

Similarly the joint or welding factor which is given as in different types like seamless the joint




factor J is 1.00, electric welded then again joint factor is 1.00. And if we say the submerged arc welded then again the joint factor is 1.00 and if we take the furnace butt welded then the joint factor is 0.60.

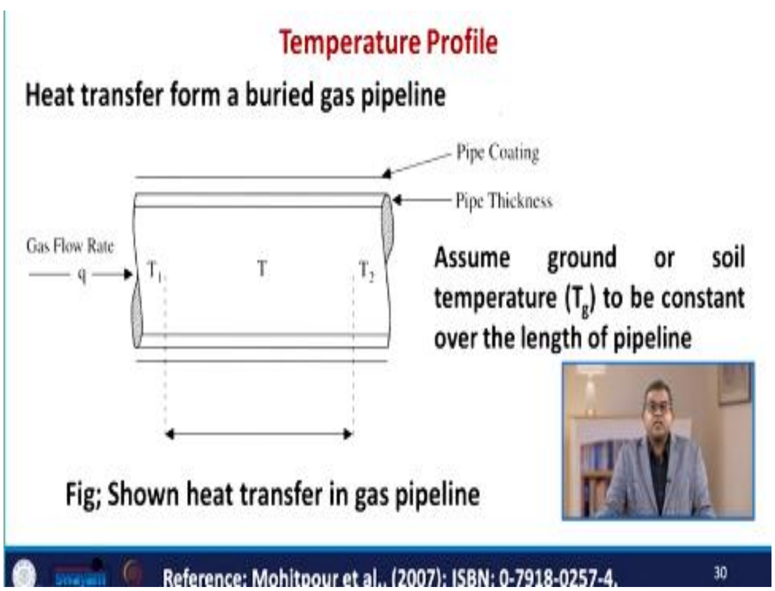
**(Refer Slide Time: 26:15)**




| Temperature (°F) | Temperature correction factor (T) |
|---|---|
| Up to 250 | 1.00 |
| 300 | 0.97 |
| 350 | 0.93 |
| 400 | 0.91 |
| 450 | 0.87 |

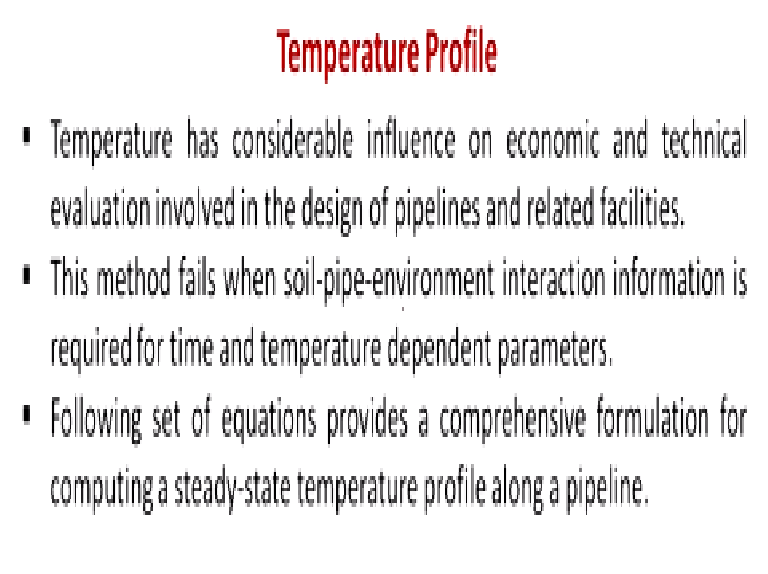
Then the temperature correction factor, the temperature correction factor for gas transmission lines based on ASME, B31 8; the temperature in Fahrenheit that is up to 250 the temperature correction factor T is 1.00. Up to say 300 then 0.97; 350 is .93; 400 carries the temperature correction factor 0.91 and 450 the temperature correction factor is 0.87.

**(Refer Slide Time: 26:48)**



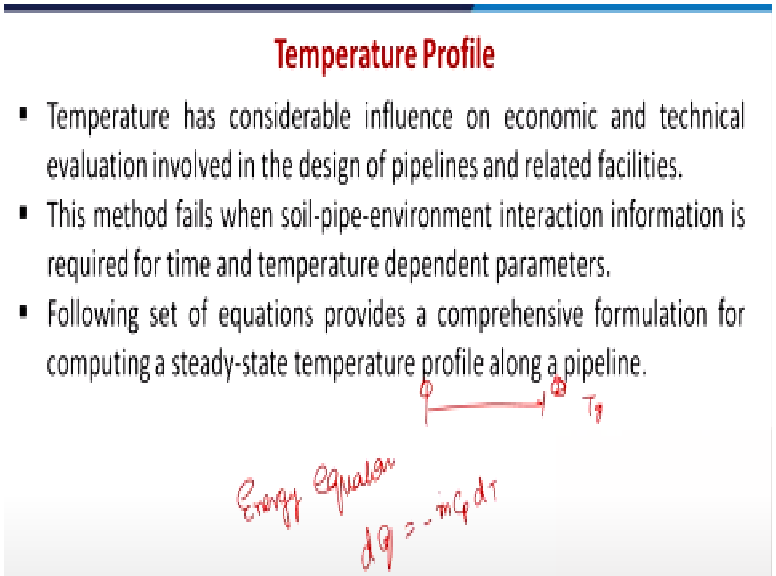

Now let us talk about the heat transfer from buried gas pipeline. Again we are having a gas flow rate over here with the q and then T 1 the temperature and the T 2 at the outlet temperature, this is the pipeline coating and this is the pipeline thickness. Now assume the ground or the soil temperature T g to be constant over the length of pipeline which is approximately L.

**(Refer Slide Time: 27:17)**




Now temperature has a considerable influence on economic and technical evaluation involved in the design of pipeline and related facilities. Now this method fails when soil pipe environment interaction information is required for time and temperature dependent parameters. We are having the set of equations which provide the comprehensive formulation of computing steady state temperature profile along a pipeline.

**(Refer Slide Time: 27:54)**



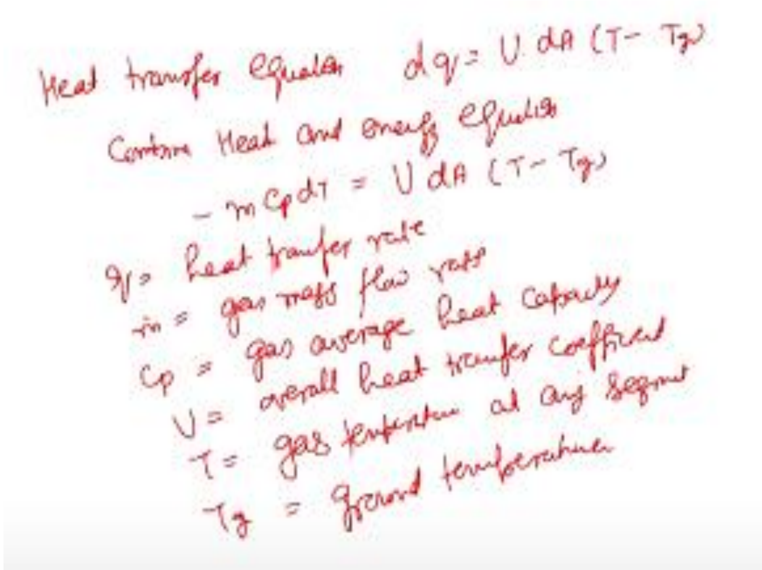

Now if we consider a segment of transmission line between 0.1 to 0.2 assuming the ground and soil temperature is T g then energy equation d q = - dot m C p d T.

**(Refer Slide Time: 28:17)**

**On considering a segment of transmission line between point 1 and 2 with assuming the ground and soil temperature is $T_g$.**

Energy equation;

$$\mathbf{dq = -\dot{m}.C_P.dT}$$




Now heat transfer equation that is d q = U d A T - T g, now if we combine heat and energy equation we have - m dot C p d T = U d A T - T g. Where q is heat transfer rate, dot m is the gas mass flow rate, C p is gas average heat capacity, U is overall heat transfer coefficient, T is gas temperature at any segment, T g is ground temperature.

**(Refer Slide Time: 29:44)**

Heat transfer equation; $$\mathbf{dq = U.\,dA.\,(T - T_g)}$$

Combining heat and energy equation we have;

$$\mathbf{-\dot{m}.\,C_P.\,dT = U.\,dA.\,(T - T_g)}$$

**Where,**

**q= heat transfer rate (BTU/h)**

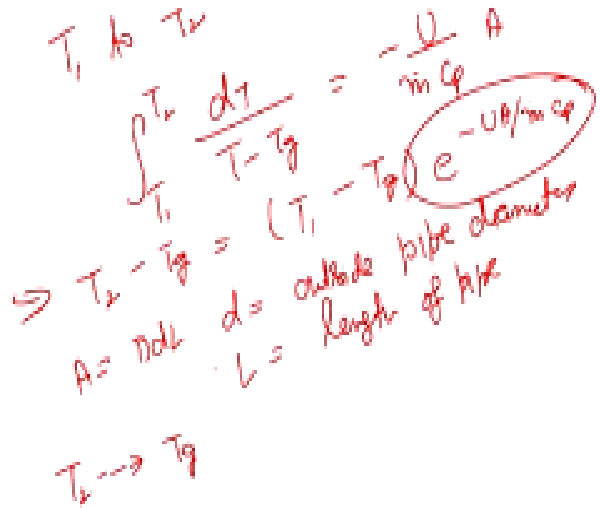
***$\dot{m}$= gas mass flow rate ($lb_m$/h)***

***$C_P$= gas average heat capacity (BTU/$lb_m$ x $^oF$)***

**U=overall heat transfer coefficient (BTU/h.$ft^2$ x $^oF$)**

**T= gas temperature at any segment ($^oF$)**

**Tg= ground temperature ($^oF$)**




Now, if we rearrange the things and integrating from T 1 to T 2 then T 1 to T 2 d T upon T - T g = - U upon dot m C p a. Or $T_2$ - $T_g$ = $T_1$ – $T_g$, e to the power – U a upon dot m C p. Where A = pi d L, d is equal to outside pipe diameter and L is length of pipe. Now as length increases this factor approaches to 0 so T 2 tends to T g. This means that for long pipelines the gas temperature cools closer to ground temperature over the length of pipeline.

**(Refer Slide Time: 30:54)**

**After rearranging and integrating from $T_1$ to $T_2$;**

$$\int_{T_1}^{T_2} \frac{dT}{T - T_g} = \frac{-U}{\dot{m}.C_P}.\ \mathbf{A}$$

$$\Rightarrow T_2 - T_g = (T_1 - T_g)e^{-UA/\dot{m}.C_P}$$

Where A=$\pi$dL; **d**= outside pipe diameter, **L**= length of pipe

**Note; as length increase, $e^{-UA/\dot{m}.C_P}$ approaches zero, so $T_2 \dashrightarrow T_g$. This means that for long pipelines, the gas temperature cools closer to ground temperature over the length of the pipeline.**

$$dA = \pi d \, dL \qquad \dot{m} C_p$$

$$dT = \frac{\pi U d}{\dot{m} C_p} (T - T_g) dL - j . dL$$

U & $C_p$ are Constant

$$a = \frac{\pi U d}{\dot{m} C_p}$$

$$dT = a \, dL [(T - T_g) - j]$$

Now on substituting the value of d A, = pi d dl and dividing by dot m C p we have d T = pi U d dot m C p T - t g d L - j d L. Now let us assume that U and C p are constant so a, = pi U d m C p now d T = a d L T - T g – j.

**(Refer Slide Time: 31:48)**

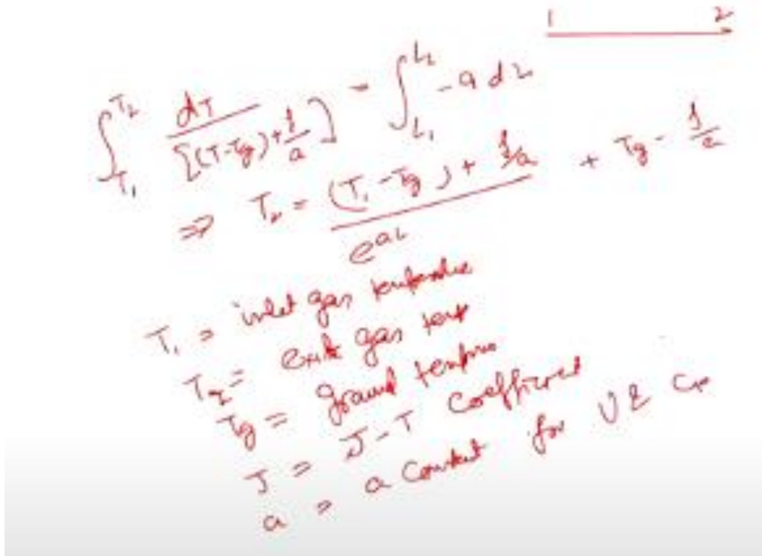
**On substituting value of dA= π.d.dL and dividing by $\dot{m}.C_P$ we have;**

$$dT = \frac{\pi . U . d}{\dot{m} . C_P}\left(T - T_g\right) dL - j . dL$$

Let U and $C_p$ are constant;

$$a = \frac{\pi . U . d}{\dot{m} . C_P}$$

$$\Rightarrow dT = a . dL[\left(T - T_g\right) - j]$$



Now if we rearrange the things and taking integral from point 1 to 2 then T 1 to T 2 integration d T upon T - t g + j upon, j is Joule Thomson coefficient is equal to L 1 to L 2 - a d l. And that is equal to T 2 = T 1 - T g + j upon a is a constant value for constant U and C p upon e a L + T g - j upon a. Now here T 1 is the inlet gas temperature, T 2 is the exit gas temperature, T g is the ground temperature, j as i told you the Joule Thomson coefficient, a is a constant for U and C p.

**(Refer Slide Time: 33:12)**

**On rearranging and taking integral from point 1 to 2 we have;**

$$\int_{T_1}^{T_2} \frac{dT}{\left[\left(T - T_g\right) + \frac{j}{a}\right]} = \int_{L_1}^{L_2} -a\, dL \qquad \Rightarrow T_2 = \frac{\left(T_1 - T_g\right) + \frac{j}{a}}{e^{aL}} + T_g - \frac{j}{a}$$

**Where,**

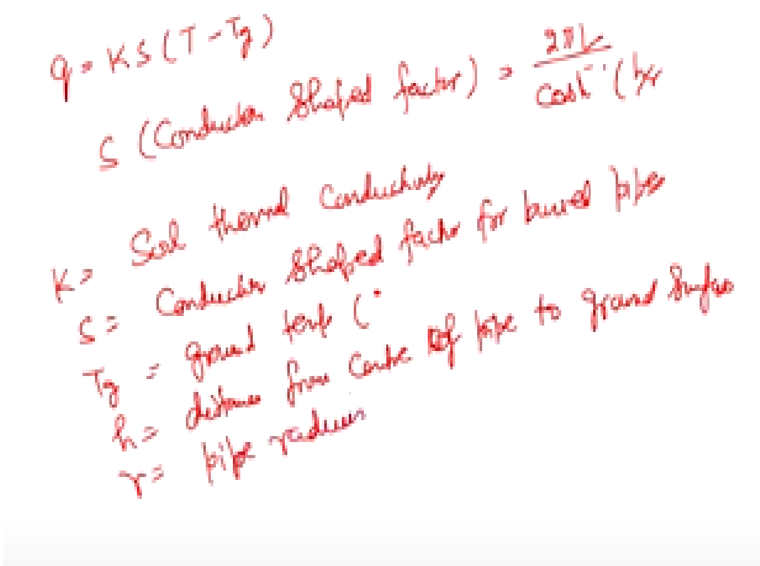
**$T_1$ = inlet gas temperature ($^{o}$F)**

**$T_2$ = exit gas temperature ($^{o}$F)**

**$T_g$ = ground temperature ($^{o}$F)**

**j= Joule-Thompson coefficient ($^{o}$F/ft)**

**a= a constant vale for constant U and Cp (ft$^{-1}$)**




To find out the heat passes from the pipe coating to the soil in case of buried pipeline q = K S T - T g now s the conduction shaped factor is equal to 2 pi L upon h upon r. Where K is soil thermal conductivity, S is the conduction shaped factor for buried pipes, T g already discussed that ground temperature, h is the distance from center of pipe to ground surface and r is the pipe radius. Now so in this particular chapter we discussed the various aspect related to the natural gas transmission and we discussed about the various design factors.

**(Refer Slide Time: 34:46)**

**To find out heat passes from the pipe coating to the soil in the case of buried pipelines;**

$$q = \mathrm{K.S.}(\mathrm{T} - T_g) \qquad \mathbf{S}\ (\textbf{Conduction shaped factor}) = \frac{2\pi L}{\cosh^{-1}\left(\frac{h}{r}\right)}$$

**Where,**

**K= Soil thermal conductivity**

**S= Conduction shape factor for buried pipes**

**$T_g$ = ground temperature ($^{o}$F)**

**h= distance from centre of pipe to ground surface**

**r= pipe radius**

# References


- M. Mohitpour, H. Golshan, A. Murray, PIPELINE DESIGN & CONSTRUCTION: A Practical Approach; Third Edition, American Society of Mechanical Engineers., (2007), ISBN 0-7918-0257-4.


Now in case if you need any further resistance, we have enlisted on one reference for your convenience thank you very much.