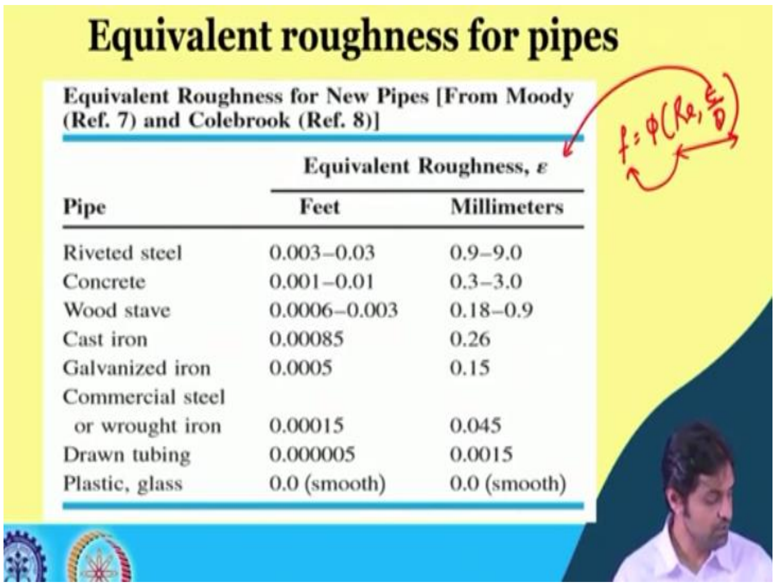
Hydraulic Engineering
Prof. Mohammad Saud Afzal
Department of Civil Engineering
Indian Institute of Technology – Kharagpur

Lecture - 43
Pipe Networks

Welcome back student to this new week, where we are still continuing the pipe flow.

(Refer Slide Time: 00:30)

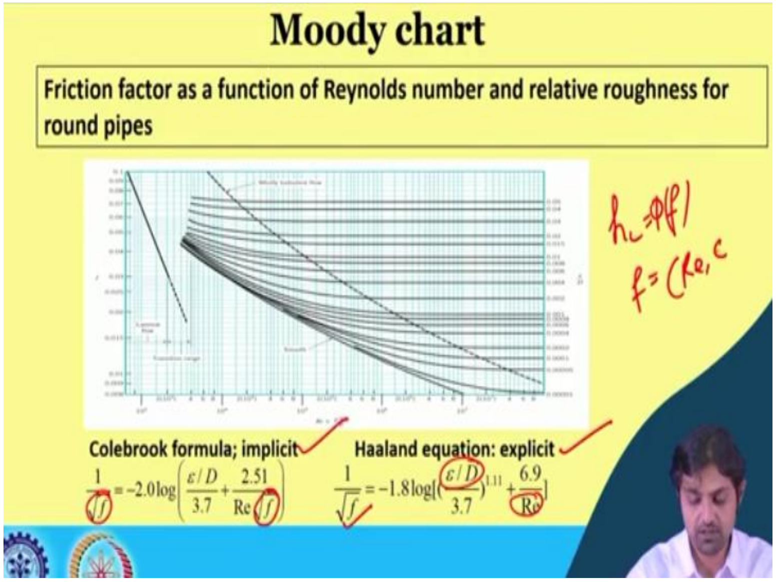


Pipe	Equivalent Roughness, ε Feet	Equivalent Roughness, ε Millimeters
Riveted steel	0.003–0.03	0.9–9.0
Concrete	0.001–0.01	0.3–3.0
Wood stave	0.0006–0.003	0.18–0.9
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Commercial steel or wrought iron	0.00015	0.045
Drawn tubing	0.000005	0.0015
Plastic, glass	0.0 (smooth)	0.0 (smooth)

Last week, we finished the lecture at finding equivalent roughness of pipes and said that we are going to solve one particular problem, but I will think it is better to take that problem after I complete this particular topic. So until this point in time, what are the things that we know? We need to find to an f, f is the Darcy Weisbach friction factor. Darcy's friction factor and that is f is equal to phi of function of Reynolds number and epsilon by D.

So Reynolds number we can calculate if the flow is given, D is the pipe diameter, so epsilon, we saw that we can find through these tables. Most of the cases, for your significance in practice for the numerical, you will be given the value of epsilon by D. So if you are able to calculate the value of epsilon by D and Reynolds number, then there is a dependence of these two parameters, Re and D on the friction factor f and if we know the friction factor, we can calculate by using these values and find out the head loss, the major head loss.

(Refer Slide Time: 01:53)



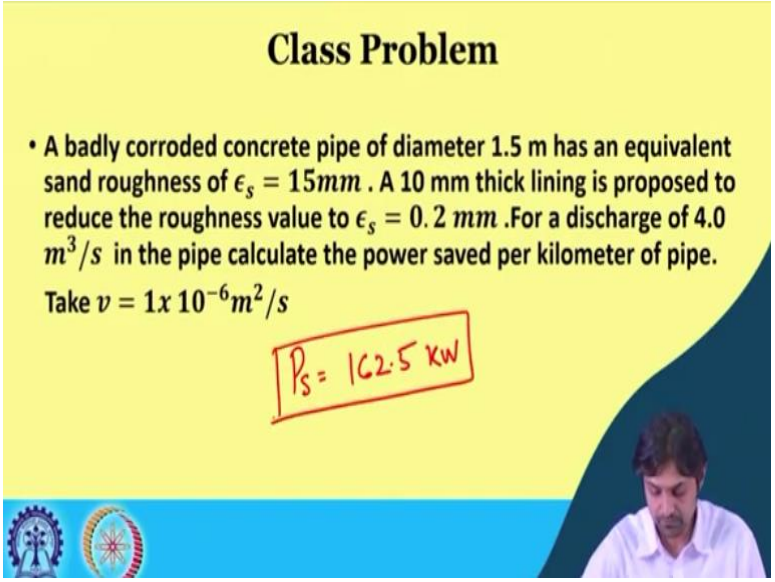
So do that there is something called a Moody chart. So friction factor is a function of Reynolds number and relative roughness for round pipes is a chart like this, okay, where this is Reynolds number on x-axis and f you can find out and epsilon by D is plotted in the right. So this is the oldest method of finding these friction factors, Darcy friction factor. However, for this course, of course, if you are given this Moody chart, you should be able to find a corresponding Reynolds number and a corresponding epsilon by D line here and then go ahead and find out the respective f, friction factor.

But for your convenience, I am going to provide you two formulas, one is a Colebrook formula, which relates this friction factor f to epsilon by D and Reynolds number. Can you see there is one trick in this formula? If you note, you will see f is also in the left hand side and f is also on the right hand side, that makes it implicit in nature, alright. But I still expect you to remember this formula. The solution for this formula can be done through trial and error, alright.

Or you can use another formula, which is totally explicit in nature, which is called Haaland equation. So here you see, there is friction factor unknown is only on the left hand side, so if you know epsilon by D and you know Reynolds number, you will be able to find out the value of f. So this equation you must remember and also this, because some of the questions could be based on Colebrook formula as well, alright.

With this thing in mind, we can solve the problems now. Head loss was a function of friction factor, right? I mean, it was dependent on friction factor and f was a function of Reynolds number and epsilon by D, so we can find f using these two formulas or Moody chart and therefore, we will be easily able to calculate the head loss.

(Refer Slide Time: 04:12)



To demonstrate that, we have a problem question here, that we are going to solve now. So the question is this, a badly corroded concrete pipe of diameter 1.5 m has an equivalent sand roughness of epsilon S 15 mm. So we have already been given epsilon S. At 10 mm thick lining is proposed to reduce the roughness value to epsilon S of 0.2 mm. So a thick lining would be put, which is 10 mm long and this will bring down the roughness to 0.2 mm.

The question is, for a discharge of 4 meter cube per second, calculate the power saved per kilometer of the pipe. If you see, because of this epsilon, there is going to be a head loss. So head loss is related with energy loss. If you reduce that energy loss, you will save some power. So that is the idea of this particular question. So like always we are going to start the solution on the white screen.

(Refer Slide Time: 05:20)

Soln 7

Before the lining:

$$V_1 = \frac{Q}{A} = \frac{4.0}{\frac{\pi}{4}(1.5)^2} = 2.264 \text{ m/s}$$

Reynold's number $$Re_1 = \frac{V_1 D_1}{\nu} = \frac{2.265 \times 1.5}{1 \times 10^{-6}} = 3.395 \times 10^{6}$$

$$\frac{\epsilon_{s1}}{D_1} = \frac{15 \times 10^{-3}}{1.5} = 10^{-2}$$

If we use the empirical equation of Haaland

$$\frac{1}{\sqrt{f_1}} = \_\_\_\_\_\_ \quad \text{(Explicit formula)}$$

$$\Rightarrow f_1 = 0.0379$$

After the lining was put

$$D_2 = 1.50 - 2 \times 0.01 = 1.48 \text{ m}$$

$$V_2 = \frac{4}{\frac{\pi}{4}(1.48)^2} = 2.325 \text{ m/s}$$

Reynolds number $$Re_2 = \frac{V_2 D_2}{\nu} = \frac{2.325 \times 1.48}{1 \times 10^{-6}} = 3.44 \times 10^{6}$$

$$\frac{\epsilon_{s2}}{D} = \frac{0.2 \times 10^{-3}}{1.48} = 1.35 \times 10^{-4}$$

$f_2 = 0.0132$ (Haaland formula)

So we see, before the measure of reducing the head loss, before the lining was put, V1 is going to be Q/A, so Q was 4 meter cube per second, area is pi by 4 into 1.5 whole square. So this is going to be 2.264 meter per second, alright. For this particular case, Reynold's number is going to be, we call it Re1 as V1 D1 by nu. So V1 we have already found 2.264, diameter we know, it was 1.5 meter and nu is 1 into 10 to the power -6.

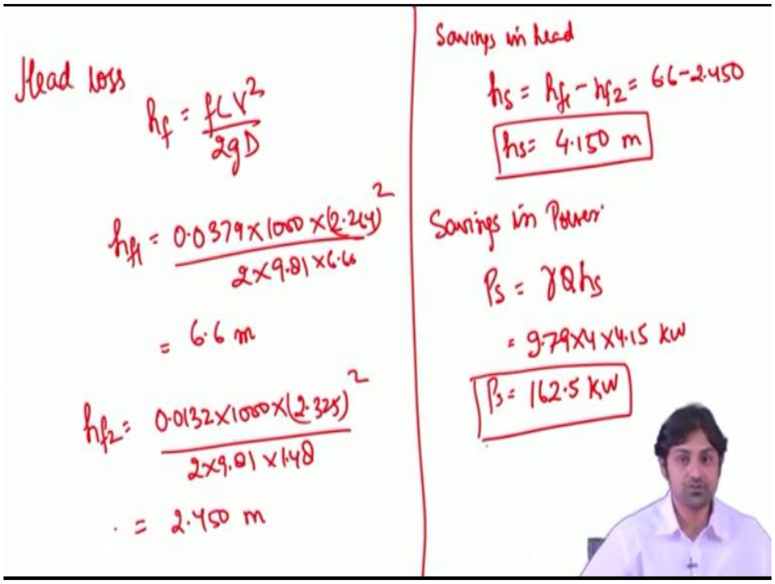
So Reynolds number comes out to be 3.395 into 10 to the power 6. Similarly, epsilon S1 by D1, the value we have already been given in the question is 15 into 10 to the power -3 meter divided by 1.5. So it comes to 10 to the power -2 alright. So if the empirical equation of Haaland, okay, then we can find under root 1 by f1 is equal to the things on the right hand side and on calculating, we can get because this is an explicit formula, alright.

So f1 we can get 0.0379. Now we have talked about the friction factor we have calculated before the lining was there. Similarly, let us talk after the lining was put. So after the lining is put, diameter will be reduced, how much? 1.50 was the diameter and lining of this, so the diameter becomes 1.48 meters. Therefore, the velocity will be 4Q by A pi by 4 into 1.48 to the whole square, that means 2.325 meters per second, alright.

Corresponding Reynolds number Re2 as we call it is V2 D2 by nu. So 2.325 into 1.48 divided by 1 into 10 to the power -6. So it comes out to be 3.44 into 10 to the power 6. Similarly, friction epsilon S2 by D, we said it has been reduced to 0.2, so it has become 0.2 into 10 to the power -3 meter divided by 1.48, so this value come out to be 1.35 into 10 to the power -4, alright. So similarly using the Haaland formula, you can calculate that f will come out to be 0.0132.

So now we have calculated f1 and f2, f1 is the friction factor before the lining was put and f2 is the friction factor after the lining was put. So to continue further, alright.

(Refer Slide Time: 10:04)

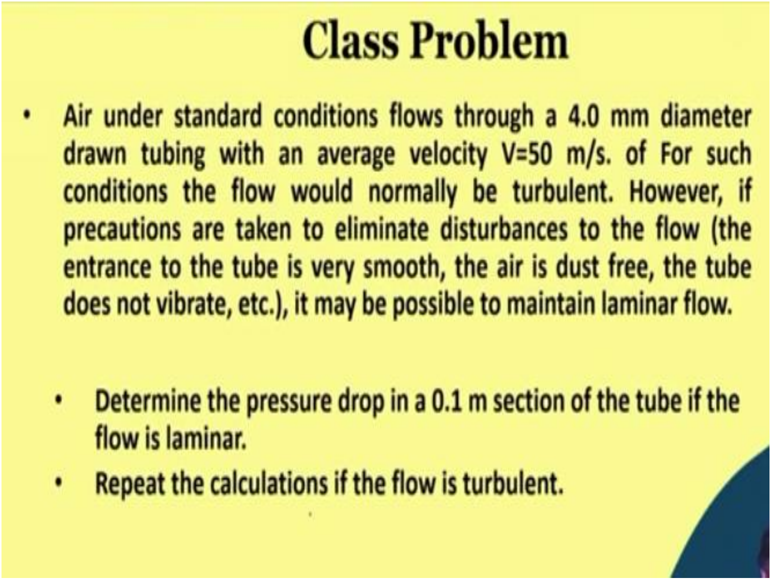


We are going to calculate head loss hf is equal to fLV square by 2gD. So before the lining was put, hf1 would be 0.0379 that was the friction factor 1, length is 1000 and velocity was 2.264 whole square divided by 2 into 9.81 into 6.60. So hf1 comes out to be 6.6 meter. Similarly, we will calculate hf2, same formula, f here now the new f was 0.0132 into 1000 into 2.325, the velocity had changed divided by 2 into 9.81 into 1.48 and this comes out to be 2.450 meter head loss.

So savings in head, you see the frictional loss before the lining was 6.6 meter and after the lining is put as 2.450. So saving in head, hs is hf1 – hf2 and this will come out to be 6.6 – 2.450, so hs is 4.150 meter. This is saving in the head. Now for power, savings in power would be nothing but gamma Qhs, right. So gamma is 9.79 into 4 into 4.15 kilowatt, because we have taken this 9.79 into 10 to the power 979 into g.

So 9790 instead we did 9.79 therefore we are telling in kilowatt and this will come to be 162.5 kilowatt. So this is the saving in power. So you see how we were able to find the major loss and the savings in major loss, if we put the lining, which will reduce the friction factor in a pipe. This was a quite illustrative example, alright. So just writing it down the final result here that the power saving is 162.5 kilowatt, alright.

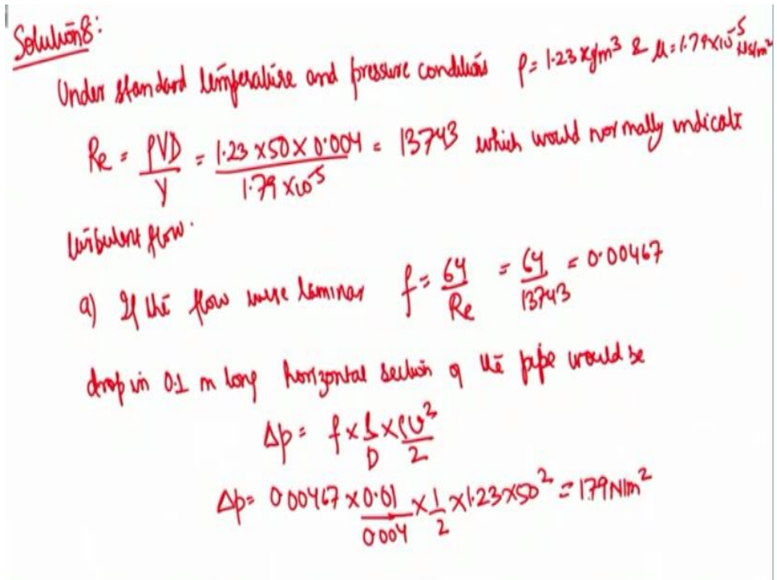
(Refer Slide Time: 13:20)



Moving ahead, there is another question that says air under standard condition flows through a 4 mm diameter drawn tubing with an average velocity of 50 meter per second. For such conditions, the flow would normally be turbulent, however the precautions are taken to eliminate disturbances to the flow. It may be possible to maintain laminar flow. So the first part is determine the pressure drop in 0.1 meter section of the tube, if the flow is laminar.

And the second part is repeat the calculations if the flow is turbulent, alright. So we will solve this question again on the white screen.

(Refer Slide Time: 14:06)

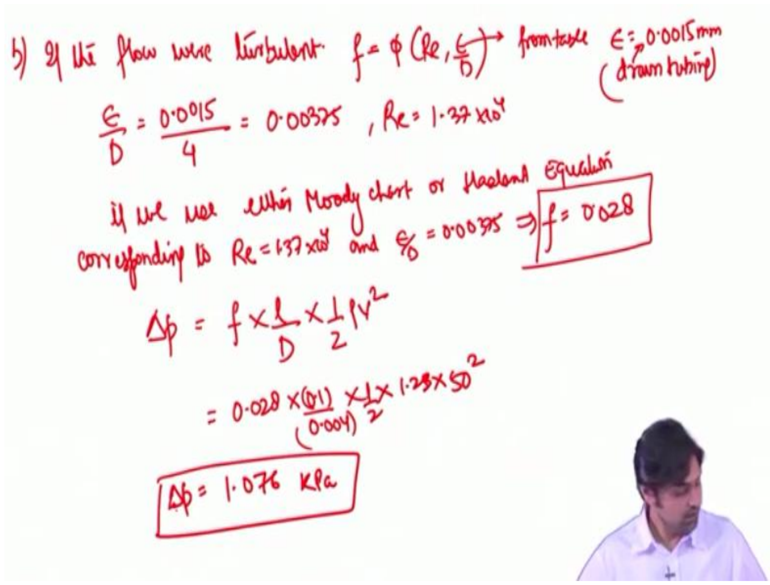


So solution number 8, so under standard temperature and pressure conditions, rho is 1.23 kilogram per meter cube and mu is 1.79 into 10 to the power -5 Newton second per meter square, because we are talking about air, alright. Therefore, the Reynolds number will be rho VD by nu. So if you put 1.23 into 50, because velocity of 50 meters per second is given, diameter is 4 mm, so 0.004 meter divided by 1.79 into 10 to the power -5 and this will come to be almost 13,743, which would normally indicate turbulent flow, alright.

However, since we have been told, assume this as a laminar flow, we say, if the flow were laminar, friction factor will be given by 64/Re. Therefore, in this particular case, although it is turbulent, but we still assume that it is laminar, so we will find the friction factor, which will come almost to 0.00467. Therefore, drop in 0.1 meter long horizontal section of the pipe would be delta p is equal to f into L by D, our formula into rho V square by 2, alright.

So delta p is going to be f 0.00467, length is 0.01, diameter you already know 0.004 into half into rho is 1.23 and V square is 50 and this is going to be 179 Newton per meter square, alright. So we can calculate everything here. So 179 Newton per meter square, alright. So we could actually have reduced directly the formula for delta p.

(Refer Slide Time: 18:20)

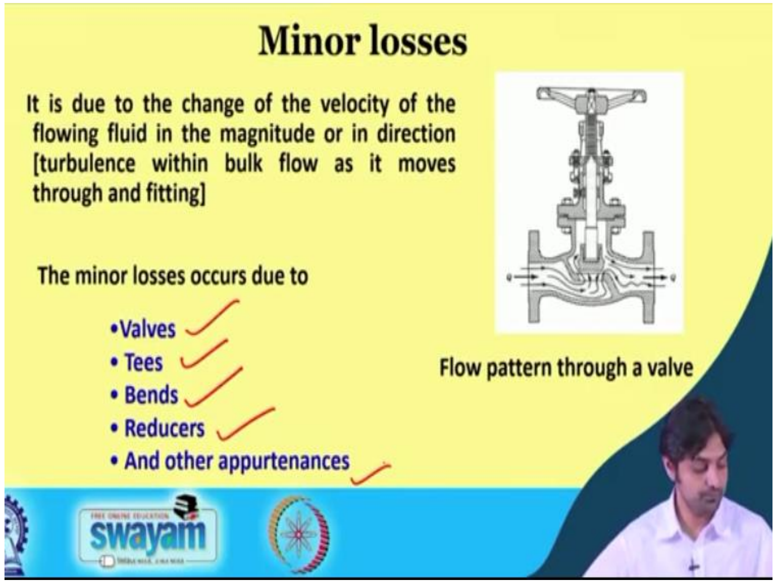


But now before we go to the next part, it says if the flow were turbulent, then f is a function of Reynolds number to epsilon by D. So if we look at the, I told you if we know what type of pipe it is, we can look down the epsilon value. So of course, I have not given it here written in the question, but if you look at the table, from table, epsilon will come to be 0.0015 mm, okay, because it is a drawn tubing, alright. So epsilon is 0.0015 for drawn tubing, okay.

So we calculate epsilon by D, which is 0.0015 by diameter is 4 mm, so we get 0.00375, alright and Reynolds number came out to be earlier 1.37 into 10 to the power 4, alright. So if use either Moody chart or Haaland equation corresponding to Reynolds number is equal to 1.37 into 10 to the power 4 and epsilon by D of 0.00375, we will get fs 0.028, alright. Therefore, the pressure drop will be f into L by D into half rho V square.

And after putting 0.028 into length will still be the same, diameter will still be the same, rho is 1.23 into 50 square, so delta p is going to be 0.076 kilopascal. So the pressure drop as you see is much, much more when the flow is turbulent, alright. In the first case, it was only 0.179 kilopascal, alright.

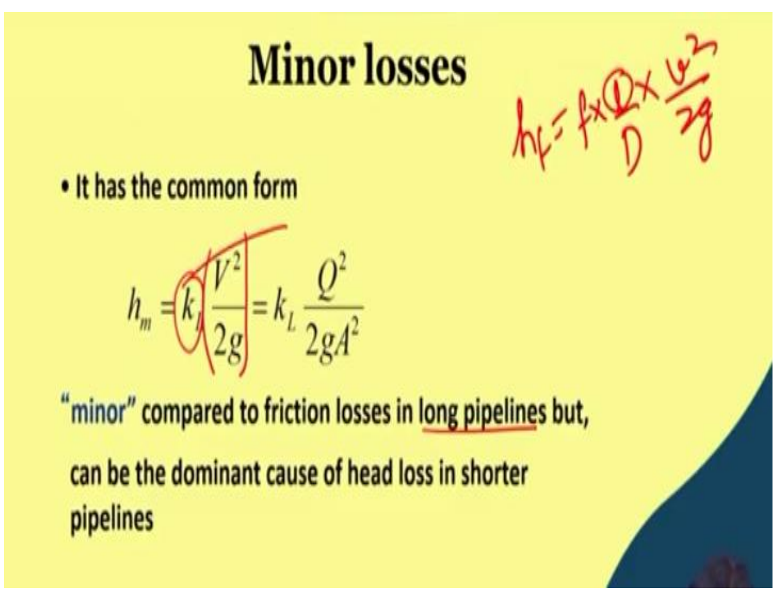
(Refer Slide Time: 21:49)



So we talk about the minor losses. We have talked much about the major losses, but now we must put our focus a little bit on the minor losses. So minor losses is due to the change of the velocity of the flowing fluid either in the magnitude or in the direction, okay. If the magnitude or the direction, any of them would change or both will change, the loss is associated with them is called minor loss in pipes. So this is a typical flow pattern through a valve, that is shown here.

It will comprise of both major and minor losses. The minor losses occur due to, if there are walls present, if there are Ts, if there are bends in the pipes, if there are reduces and there are other appurtenances, alright.

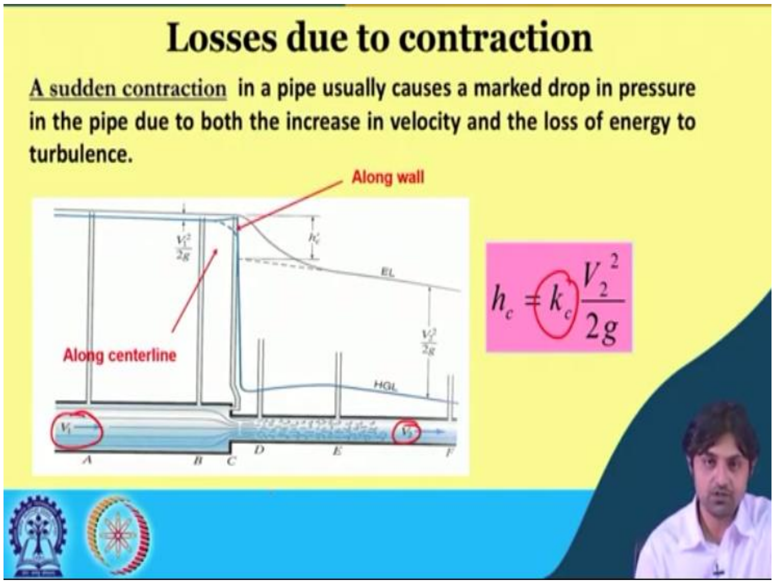
(Refer Slide Time: 22:48)



So minor losses also have a common form of this. So it is kl multiplied by V square by 2g, okay and this kl is the minor loss coefficient. In terms of Q, we can also write Q square by 2ga square. So this is minor compared to friction losses in long pipes, but can be dominant cause of head loss in shorter pipes. So if the pipe is long, because the major loss is given by f into L by D, remember 2V square by 2g, alright. So if the pipe is long, the major losses would be too much.

But minor losses, this is called minor because the frictional loss is due to these phenomenon like bending, contraction and expansion are less in case of long pipes. Therefore, it is called minor losses, but it is not always minor. If the pipes are of shorter length, the term minor losses actually will be dominant.

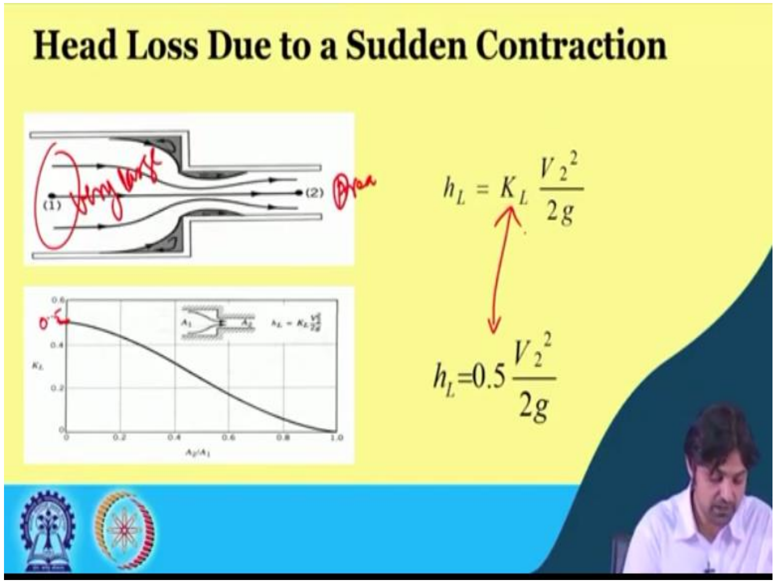
(Refer Slide Time: 24:01)



Now, let us see the loss due to contraction. A sudden contraction in a pipe usually causes a marked drop in pressure in the pipe due to both increase in the velocity and loss of energy due to turbulence, that is a well established fact, correct. So you see there is a fluid that is coming with velocity V and after the sudden contraction, the velocity changes to V2. So in this case, for a contraction, the minor head loss will be kc that we do not know yet into V2 square by 2g, not V1.

So V2 you should be able to find using the continuity equation and kc either you can derive it or but most of the cases in many general scenarios, it is given, okay.

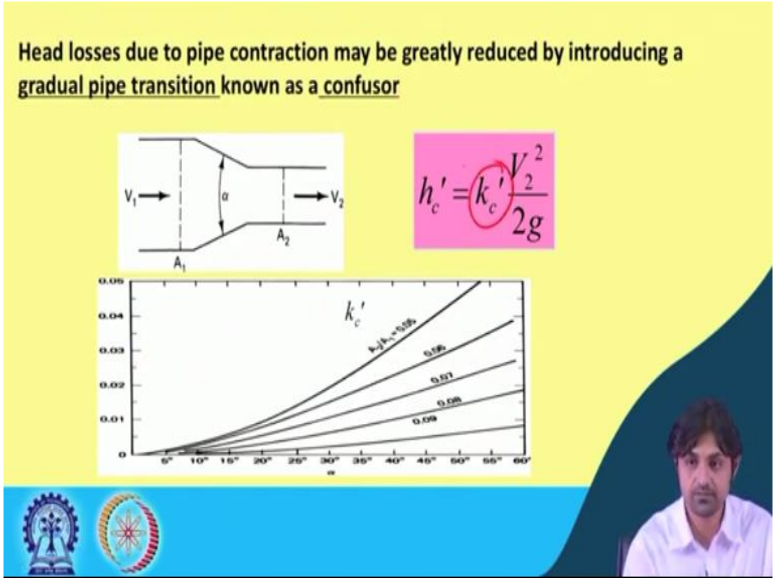
(Refer Slide Time: 25:00)



So if this is the contraction depicted by 0.2, it is a fluid at 0.1 goes a contraction and is at 0.2, we write head loss is kl into V2 square by 2g and what is this kl, kl can be found out as a function of A2 by A1. What the area 2 and area 1 is, okay, ratio of the areas, so A2 by A1. So most of the time, you would be given these values directly or a curve like this will appear, but for certain standard conditions, you are expected to know this.

So in case of sudden contraction, okay, you see, you can assume safely kl as 0.5. This means A2 was 0, okay. Basically, A2 is not 0, but A1 is so large this area is very large, like reservoir compared to this area. In that case, you see according to the curve, this comes at around 0.5. so sudden contraction when it means, it will always be implied that you have to assume kl is equal to 0.5. Please remember this. In case of a sudden contraction, kl is 0.5 and V2 square by 2g when multiplied with this will give the minor losses.

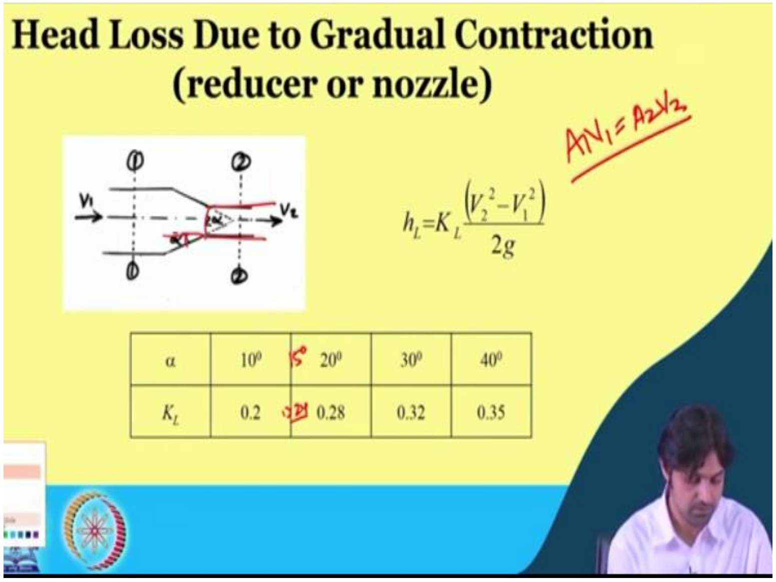
(Refer Slide Time: 26:49)



So head losses due to pipe contraction may be greatly introduced, so you see due to sudden contraction, there is going to be head losses. Now our aim as an engineer is to reduce those head losses, correct and that can be done by introducing a gradual pipe transition called as confusor. So confusors are used to introduce a gradual pipe transition, something like this. You see there is an angle alpha.

In that case also, the head loss is going to be kc dash, another coefficient k into V2 square by 2g in case of contraction. But what that kc is, is given by this graph. So this is kc on this side, for every alpha, we go and look at what is A2 by A1 ratio or A2 by A1 is and we pick a point for example and try to find out what that kc is. In such cases, either you will be given this graph or you will be exactly told what the kc is, alright.

(Refer Slide Time: 28:14)

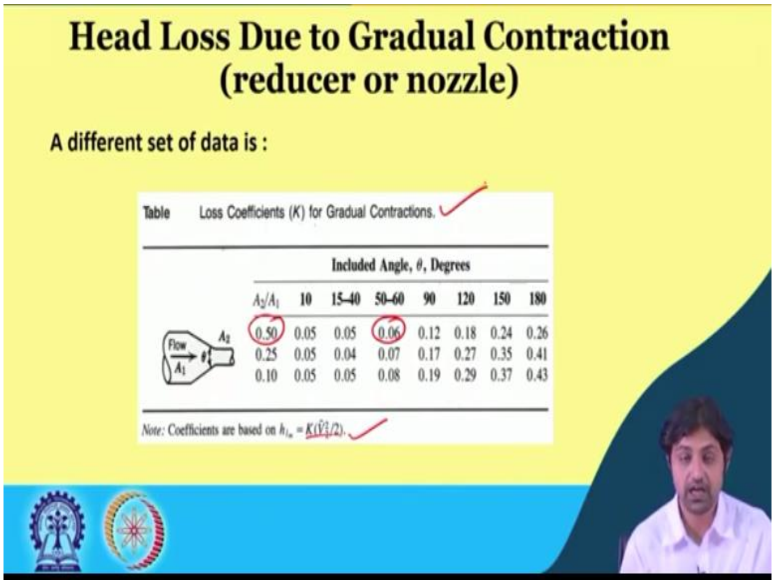


Now, in this particular case, head loss due to gradual contraction, you see, we had one equation and we can also write this in form of another thing where both V2 and V1 could be used. So kl into V2 square minus V1 square by 2g, okay in case of contraction like this, you see. This is 2 alpha and this is alpha and here also we are going to use for different alpha, we have different kls, in that case, you do not have to worry about area of 1 and area of 2.

Because it will already be taken care by the velocity continuity equation A1B1 is equal to A2B2, just a different way of writing. So this will simply give you, suppose if you have 15 degree, you can assume like if there is a 15 degree alpha is there, then you just take the linear interpolation as 0.24 will be the kl. So one advantage here is we do not have to worry about the ration of A2 by A1, just looking at the table is pretty simple. I do not expect you to remember this.

But you can be given this type of table in your assignments and exams and could be asked to find out the value of kl and corresponding head losses. So in that case, it will be V2 square – V1 square by 2g, alright.

(Refer Slide Time: 30:00)



	Included Angle, θ, Degrees						
A_2/A_1	10	15–40	50–60	90	120	150	180
0.50	0.05	0.05	0.06	0.12	0.18	0.24	0.26
0.25	0.05	0.04	0.07	0.17	0.27	0.35	0.41
0.10	0.05	0.05	0.08	0.19	0.29	0.37	0.43

So a different set of data, see many people have done a lot of experiments and different set of data gives this for different angle, gives ratio of, I mean the value of k as a function of A2 by A1. So for example, first you calculate A2 by A1, if it comes 0.50 and look at the angle. Let us say it was between 50 to 60 degrees, so this k can be assumed as 0.06, alright and head loss can be calculated as k into V2 square by 2. So whole thing has already been given here. Now I think, I should finish this lecture here with the gradual contraction.

(Refer Slide Time: 30:50)

When we meet in the next lecture, we will talk about enlargement. When there is a pipe enlargement, what is going to be the minor loss. So this is all for this lecture and I will see you next. Thank you so much.