Applied Thermodynamics for Marine Systems

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Lecture - 16

Pipe Friction, Major Loss, Minor Loss

Good afternoon. We were discussing some basic laws of fluid mechanics. If you remember, we had started our discussion on Bernoulli's equation.

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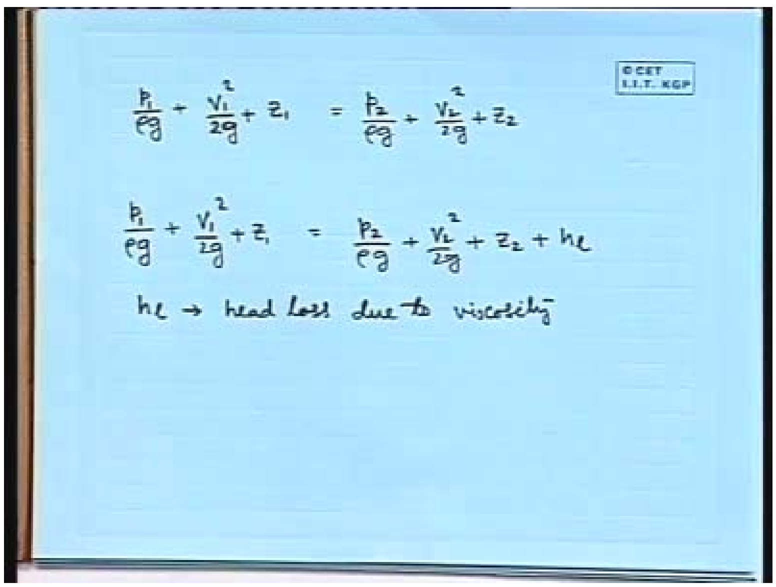

Bernoulli's equation is having this form p_1 by rho g plus V_1 square by 2g plus Z_1 is equal to p_2 by rho g plus V_2 square by 2g plus Z_2. For the validity of this equation there are a few assumptions, I have told, and these are steady, incompressible fluid, flow along a streamline and frictionless flow. Now regarding flow along a streamline I have told you that if the flow is irrotational then for any two points in the flow field this equation is valid and large numbers of flow situations are there which are irrotational. I have told you that in all the fluid there will be the effect of viscosity and due to that there will be some sort of dissipation and one can take care of the dissipation in the Bernoulli's equation by adding an extra term. We can modify Bernoulli's equation p_1 by rho g plus V_1 square by 2g plus Z_1 that is equal to p_2 by rho g plus V_2 square by

2g plus Z_2 plus h_1 which is head loss due to viscous dissipation. h_1 is the head loss due to viscosity. Now we can elaborate this concept. First, let us say we are having some sort of an arbitrary fluid path duct, something like this.

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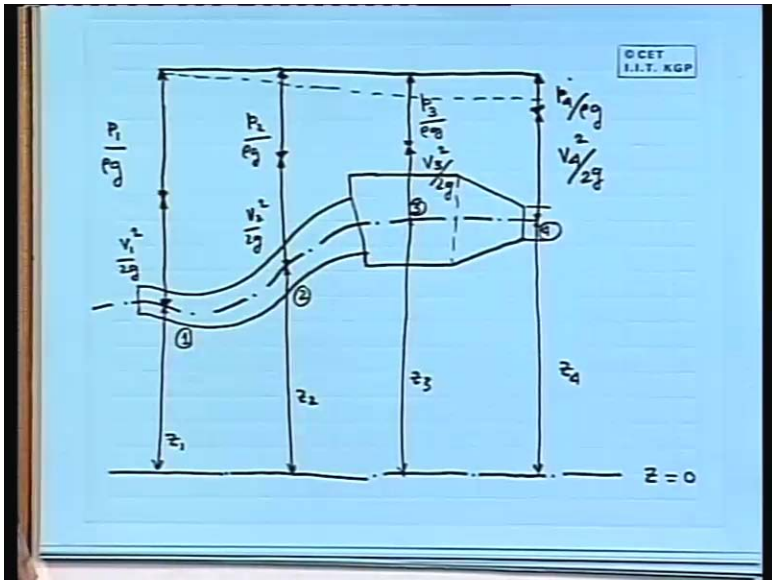

This is a highly arbitrary thing; it does not represent any specific system it is something arbitrary. Let us say we have this and then there is something like this. Let us say, in this example we do not have any sort of viscous dissipation. If we apply Bernoulli's equation it is like this. If we try to analyze what is happening applying Bernoulli's equation this is your Z is equal to 0, our datum plane. Let us take different point. This as your point 1, this is point 2, this is point 3 and this is point 4. Here you see this is nothing but Z_1. This one is nothing but Z_2. This is your Z_3 and this one is your Z_4.

The velocity here is given by a particular quantity. So, this will be V_1 square by 2g and pressure here is given by another quantity, let us say, this is p_1 by rho g. At this point what will happen, at point 2? At point 2, we will have a slight decrease in velocity because we can see or we can take this is a constant area duct; so, there is no change between points 1 and 2, no change of area or very slight change in area. Almost same kinetic energy will be there. This is V_2 square by 2g. We will have this one as p_2 by rho g. What we will see is that the static pressure will reduce. If we have got some technique for measurement, if we have got some sort of a pressure gauge here, some sort of pressure gauge here, we will find at point 2 we have got lower pressure compared to point 1 because the total amount of energy, total amount of head is remaining constant. If we go to point 3, what is happening?

Here the area is much larger, so the velocity will be much lower, kinetic energy will be lower. Let us say, this is the kinetic energy and we will have the pressure here. This is your V_3 square by 2g and this is p_3 by rho g; whereas, if we consider point 4, both of them are at the same datum level but here the area is much smaller compared to 3. You will have a larger velocity, larger kinetic energy and the pressure will be smaller here compared to 3. If we measure the pressure at point 3 and at point 4, we will have sufficiently smaller pressure at point 4 compared to point 3. This is how the different heads or different components of energy will change from point to point. This is how we will have the change, how the pressure will change, velocity will change and this static head will also change.

In this example, we have assumed that there is no viscous dissipation. If viscous dissipation is there, there will be continuous change in this line because certain part of energy is getting transferred into non-recoverable form of energy; there is no destruction of energy but it is getting transferred in some form which cannot be recovered and that is why we will have a change in this line. What I mean to say is that if we consider the viscous dissipation term then the total energy term or the total energy head which I have represented here by some sort of a horizontal line, which is parallel to the datum line, that will change and depending on this we will get some line like this. It may be a straight line or it may be a curved line. We will get total energy line like this or total head line like this.

Once I have explained a problem like this; more important for a practicing engineer is to determine h_1. How we can determine h_1?

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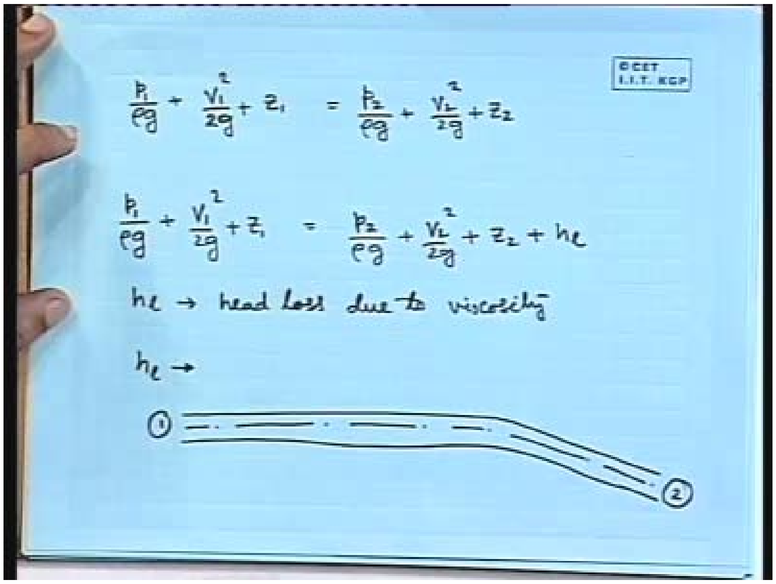

We can determine this head loss, h_l through analytical means and in some cases by some experiment. As a design engineer, suppose we want to do some theoretical calculation; we have to see the methods available or formula available for the computation of h_1. Most often we come across with this when we are designing or analyzing a pipe line. Let me not discuss this h_1 in a very general term. Let us take it as if it is the loss in a pipe line and in light of this pipe line design let me discuss it because that will be most beneficial for this particular course. In other cases we can discuss it in some other manner. Let us say, we have got a pipe line, any arbitrary pipe line like this and we want to analyze between two given points, point 1 and point 2. Here, we have to determine what h_1 is.

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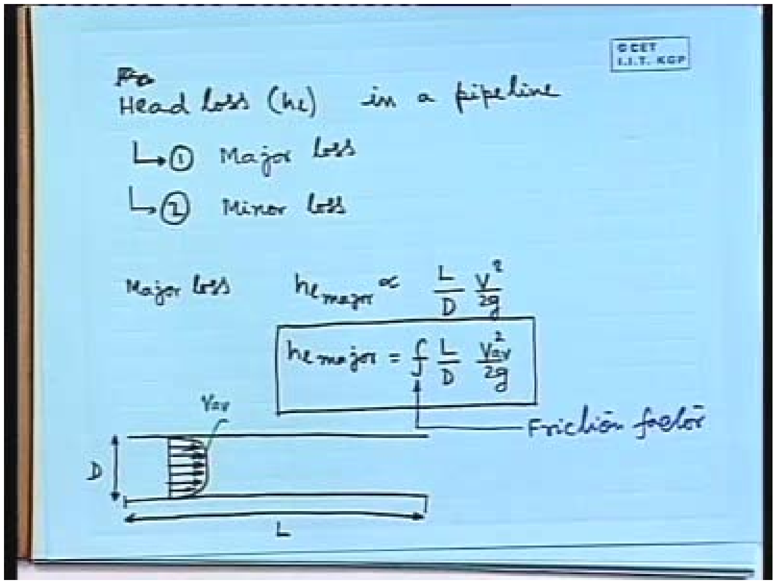

Head loss in a pipe line, h_1 in a pipe line can be divided into two categories. One is major loss and another is minor loss. Major loss is mainly due to the friction in the pipe wall or due to the friction between the pipe wall and the fluid flowing through it. Friction I want to put within quotation marks because it is friction between liquid and solid which comes due to viscosity. We call it in general friction but it is different compared to friction between two solid surfaces. A major loss comes due to the friction between the adjacent fluid layer and the solid. It has been observed that major loss, if we call it h_{1major}, then this is proportional to length of the pipe line, this is inversely proportional to the diameter of the pipe line and it is proportional to V square by 2g. One can write h_{1major} is equal to some constant of proportionality. Let us introduce f, f is the constant of proportionality; f L by D V square by 2g is the formula for the major loss, where L is the length of the pipe line, D is the diameter and V is the average velocity. This we have to remember.

Let me draw it. This is your L, this is the diameter D and we will get some sort of a velocity distribution in the pipe line. At the wall you will have 0 velocity, then the velocity will rise and at the central region you will have larger velocity. But if we take the average velocity, this can be called V average. Basically, this velocity is nothing but V average. This is h_{1major} is f L by D V average square divided by 2g. I can determine h_{1major} very easily because L is known to me, D is known to me; if I know the total flow rate, we can determine V average. Only thing is that f is unknown to me. f in the language of fluid mechanics, has got a name. We call it friction factor. f is called friction factor. This friction factor is not known to me or known to us. Now our problem boils down to determination of f.

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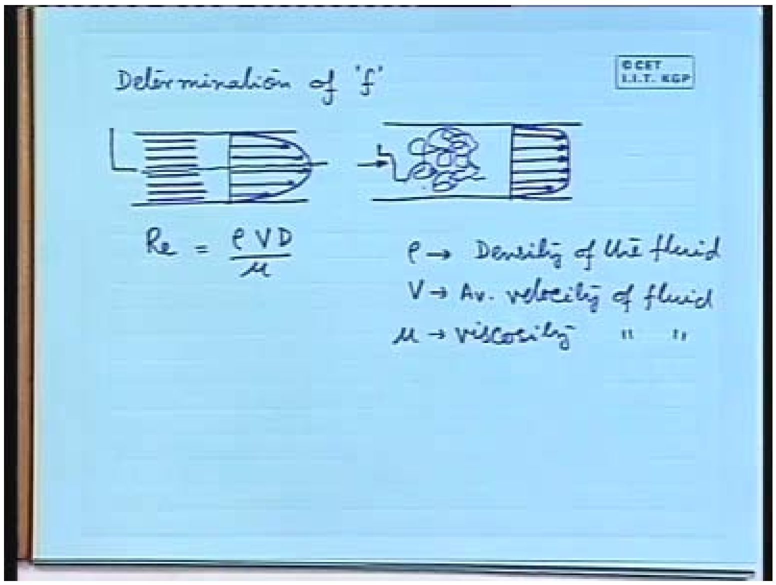

The determination of f friction factor: If I want to determine f, I have to know the nature of the flow. Unfortunately we do not have much time to discuss the details of fluid mechanics. But by the word nature of the flow, I mean to say whether the flow is laminar or turbulent and I suppose that you have got some basic idea of laminar flow and turbulent flow. Even then I like to elaborate a little bit. In laminar flow you will have fluid layers flowing in an undisturbed way as if there are parallel layers of fluid flowing like this, without interacting much with each other; without disturbing this layered pattern of the fluid flow. This is called laminar flow.

In laminar flow if we make a velocity measurement we will have some sort of parabolic velocity distribution like this; in laminar flow, some sort of parabolic distribution like this we will have. Whereas, in case of turbulent flow what will happen if we track the movement of a fluid particle you will see that it will have some sort of random motion like this. Though the main movement is in the direction of the pipe axis it will have some sort of mixing like this. In other words let us say in laminar flow if, by a nozzle, I inject some amount of dye then, you will find this coloured fluid or the dye is moving almost in an undisturbed way like this. But here if I inject the dye, let us say whatever I have drawn that is the dye itself, after certain time it will mix together and if some small quantity of dye has been injected you will not be able to identify that. If some large quantity of dye has been injected then you will find that entire liquid is coloured. Here you will have the velocity profile, something like this, that means very near the wall there is variation of velocity but after that the velocity profile is almost flat.

Here, there are two competing effects. One the effect of inertia that means fluid particle has got certain velocity of its own and the effect of velocity is known as the inertia. What is inertia? We know that if the fluid particle is having certain velocity due to inertia it will try to retain its velocity. Then there is effect of viscosity. Viscosity - the other particle which is adjacent to this first particle and if the other particle is having a different velocity then it will try to resist the motion of the first particle. If I create somewhere some disturbance, due to inertia that disturbance will try to remain as long as possible. Due to viscosity that disturbance will try to die out as fast as possible; so, there are two competing effects. When the inertia effect is more we will have turbulent flow, if I create any disturbance that will persist. When the viscous effect or influence of viscosity is more we will have a laminar flow; if I create any disturbance then due to viscosity it will try to die down fast.

The laminar flow and turbulent flow again they are defined by taking a ratio of these two effects. Taking a ratio of the inertia force and the viscous force one can get a non-dimensional number which is known as Reynolds number. Reynolds number or R_e, for pipe line flow or for flow through circular conduit, is given by rho VD by mu, where rho is the density of the fluid, V is the average velocity of the fluid and mu is the viscosity of fluid. If you put their respective units you will find that R_e is unit less or dimensionless. This is a non-dimensional number; this is basically the ratio of inertia force by viscous force.

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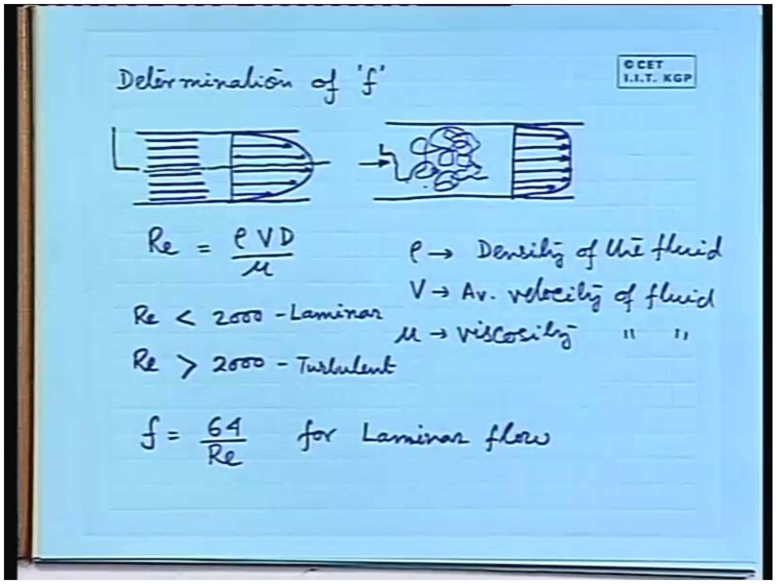

In case of circular tube it has been seen that when R_e is less than 2000 then the flow is always laminar. If R_e is greater than 2000, then you can make a transformation from laminar to turbulent. Kindly remember that laminar flow can exist even for R_e greater than 2000, but if you create certain disturbance then the flow will get transformed into turbulent flow. That is why sometimes this R_e is equal to 2000 it is known as lower critical Reynolds number meaning that below which we will always have laminar flow. Reynolds number is equal to 2000 for pipe flow or flow through circular conduits. It is termed as lower critical Reynolds number meaning that below this we will always have laminar flow. Whatever disturbance you may create you will find that after that for some time this disturbance will die down and we will have laminar flow. We can have laminar flow for Reynolds number greater than 2000 also but if you create some sort of disturbance it is possible that, that flow will get transformed into turbulent flow.

Let me write this is laminar and this is turbulent. For determination of f first we have to know whether the flow is laminar or turbulent. Once we know the flow is laminar or turbulent there are different methodology for determining f. f is equal to 64 by R_e for laminar flow. If the flow is laminar flow, then we will have friction factor is equal to 64 by R_e. If our flow is turbulent flow then unfortunately we do not have a very good relationship like this which can be readily used.

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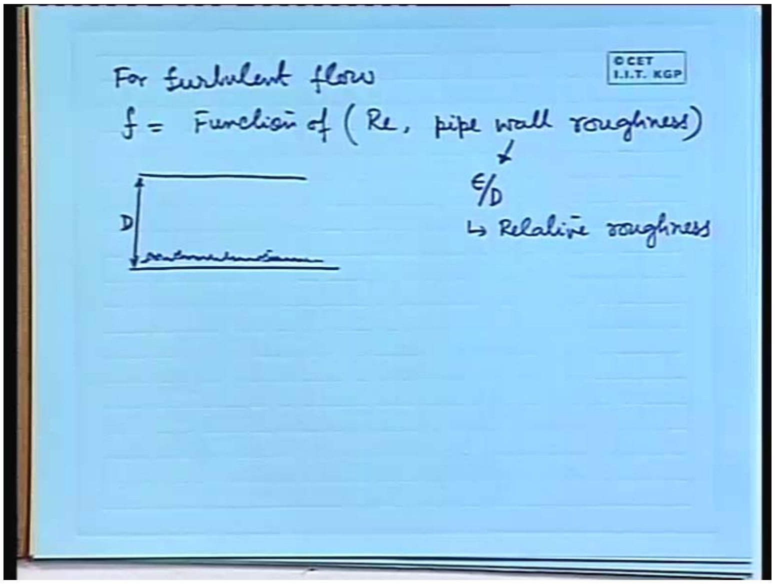

If the flow is turbulent f is a function of R_e, definitely it is a function of Reynolds number, and pipe wall roughness. Though in naked eye all the pipes or the pipe surface may appear smooth there will always have some sort of roughness. Let us say this is the pipe wall, inner wall of the pipe; the pipe wall will have some roughness and this roughness will induce some sort of resistance. That is why ‘f’ for turbulent flow will depend not only on the Reynolds number but also pipe wall roughness. Actually, this pipe wall roughness or f depends on epsilon by D which is called the relative roughness. What is relative roughness?

You can easily understand that D is the diameter of the pipe line and epsilon is the average height of the roughness parameter. Let us say this is the nominal diameter of the pipe line; so, from there this height will be different for different roughness element but we can have some average height, so that is epsilon. f will be dependent on Reynolds number and this relative roughness parameter which is epsilon by D. Both are non-dimensional; this is also non-dimensional, this is also non-dimensional. There are certain formula expressing f as a function of R_e and epsilon by D, but those are bit cumbersome and all the formulae are not valid for entire range. Rather there is a chart or some sort of a graph which is known as Moody’s diagram or Moody’s chart. That is very extensively used for the determination of f. Moody’s diagram looks like this.

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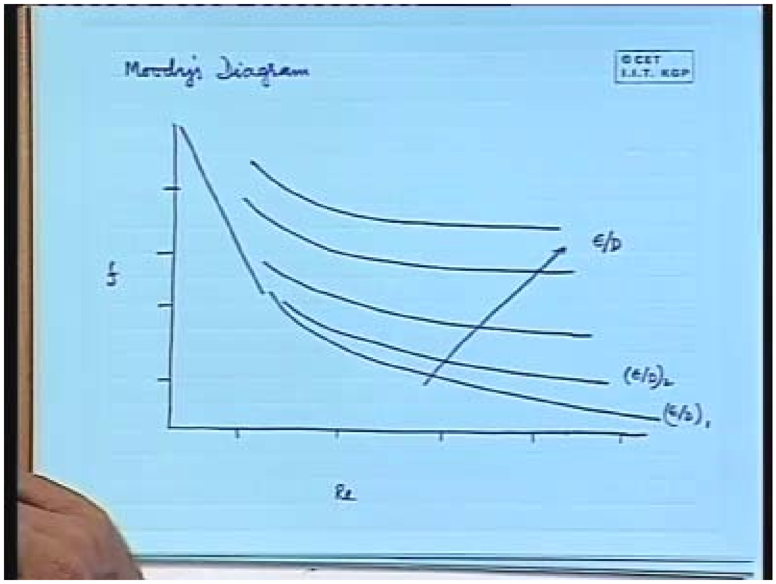

This side we have got Reynolds number and this is actually in a log scale. These are cycles obtained 100, 1000, 10,000 like that and on this side we will have f. For the laminar flow we will have a relationship like this; for laminar flow we know it is 64 by $R_{e,}$ f is equal to 64 by r_e; so, we will have a relationship like this. For turbulent flow we will have number of curves like this and each of the curves are for a particular value of epsilon by D. This is one value of epsilon by D and this is another value of epsilon by D like this and in this direction, the epsilon by D increases. That means epsilon by D_1 is less than epsilon by $D_{2.}$ This is the laminar range and this is turbulent range.

In Moody's diagram there are quite a few other things also. The first thing you see is that laminar and turbulent are not connected. In between there is a zone which is not connected, there is no curve; we can see this zone. This is called the transition zone. If we go on increasing the Reynolds number, the transformation from laminar to turbulent is not instantaneous. There is a certain zone where you will have some sort of a fluctuation but the fluctuation is not as high as turbulent flow so that is called transition zone, which is a transition between laminar and turbulent. Though there are certain formulae which can cater to this zone but we do not have a very reliable relationship for this zone, but this is a small zone. For pipe flow calculation we take it like this; if it is below 2000 we will use laminar formula, if it is above 2000, we will use Moody's chart for determination of f.

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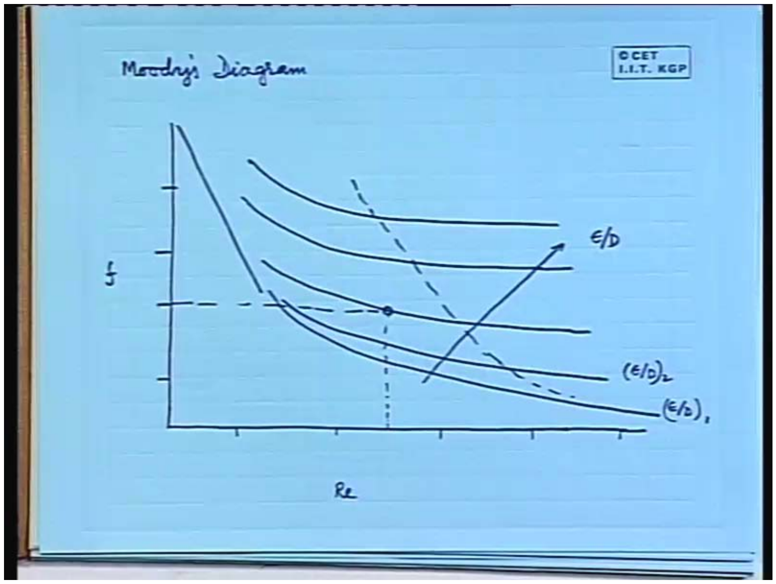

Then you can see one thing, you can see that this turbulent region curves, initially that means at low Reynolds number, they are function of Reynolds number; they are changing with Reynolds number. But when the value of Reynolds number is large they are almost independent of Reynolds number. I will repeat it once again. Let us see this curve. This is for turbulent flow. At low value of Reynolds number, the value of f is changing with Reynolds number. At high value of Reynolds number this becomes almost independent of Reynolds number. We can have something like this; that is left side of the dotted line it is a function of Reynolds number and right side of the dotted line it is not a function of Reynolds number. This zone is known as fully turbulent zone and here it is a function of only epsilon by D. At a very low value of epsilon by D we will find that this curve is a function of Reynolds number for a large region. This is known as the equation for the smooth pipe. That means epsilon by D value is very small. Some sort of co-relation can be written for this.

Basically what we have to do? Suppose we want to calculate h_l, head loss and that too major head loss, first we have to know whether the flow is laminar or turbulent. If it is laminar then our problem is not that much; f is equal to 64 by R_e. I mean almost in no practical flow situation we will have laminar flow. In most of the practical flow situation we will have turbulent flow. If it is turbulent then we have to use Moody's chart. Then what we have to do is we have to first calculate Reynolds number. We know the Reynolds number and then we have to know the material of the pipe line, condition of the pipe line. The diameter is already known so we have to know epsilon by D. If I know epsilon by D, I know that my friction factor will lie somewhere here, then I know Reynolds number. The Reynolds number is somewhere here, so my point will be here and then from this point I can calculate the value of f. Then with that I will go back to the formula h_1 is equal to f L by D V square by 2g. Then I can calculate the head loss. I think you were familiar with this but I though this is a very useful piece of information for any practicing engineer. That is why again I have recapitulated this one.

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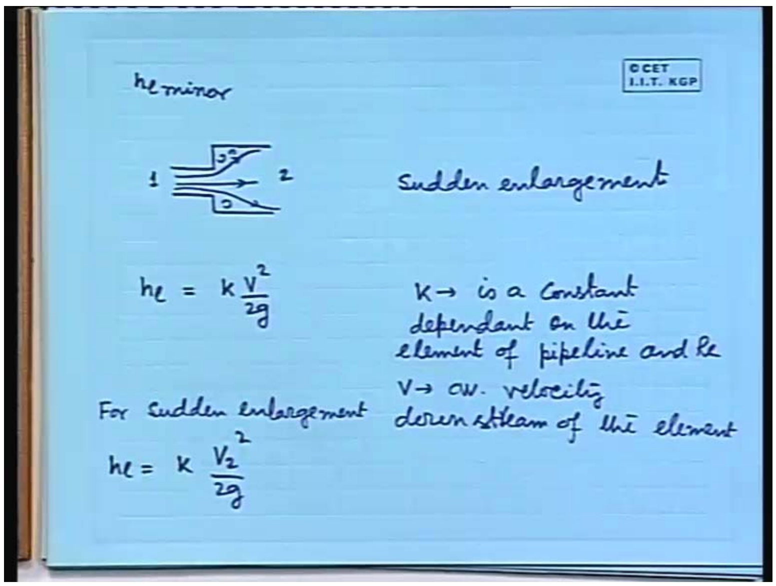

Then I am coming to h_{1minor}. What is minor loss? In a pipe line there will be number of pipe fittings or some sort of elements where we will have loss of head. If we have in a pipe line a construction like this, this is called sudden enlargement. If we see the stream lines, the stream lines are like this here you will have head structures. In this sudden enlargement there will be certain head loss and one can measure this head loss and if we have to estimate this head loss it is estimated by a formula like this, K V square by 2g. K is a constant which is dependent on the element of pipeline and Reynolds number. V is the average velocity downstream of the element. This is 1 and this is 2. For sudden enlargement, we will have h_1 is equal to K V_2 square by 2g. We are taking the downstream velocity, not the upstream velocity. Then the question comes, from where we will get the value of K? That is the most important question here, from where we ill get the value of K? Only in limited cases one can determine this value K which is known as the loss coefficient; K is known as loss coefficient from some theoretical analysis. In most of the cases, this K is determined experimentally and the K values are tabulated in hand books. There are different hand books. K values are tabulated in those hand books and from there one can calculate or take the value of K. What are the cases where we need this minor loss? There are a large number of examples where one has to take care of minor loss.

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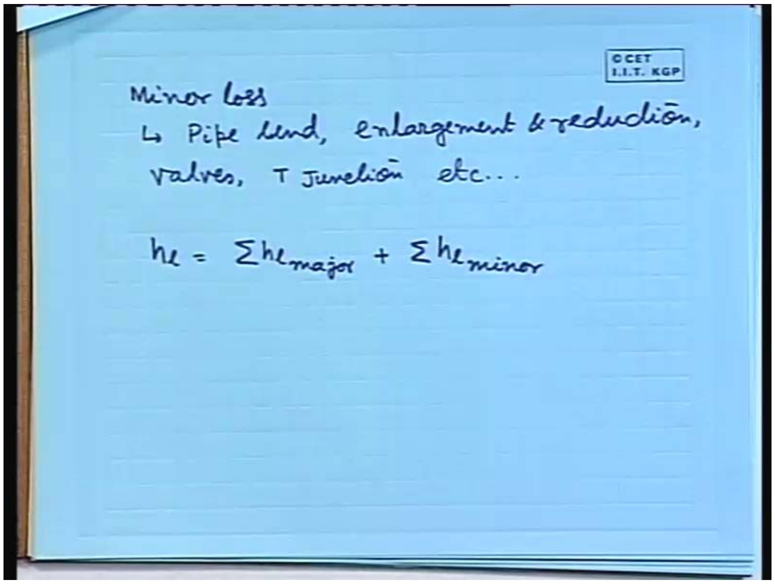

Let us say, pipe bend, pipe enlargement and pipe reduction, then there are number of valves and then T junctions. In the pipe line there is T junction. These are the cases where you need to consider and there are other examples also, where we need to consider the minor loss. You will get h_1 is equal to sigma $h_{1major,}$ all the major losses plus sigma h_{1minor}, all the minor losses.

Let us see what is the manifestation of this head loss?

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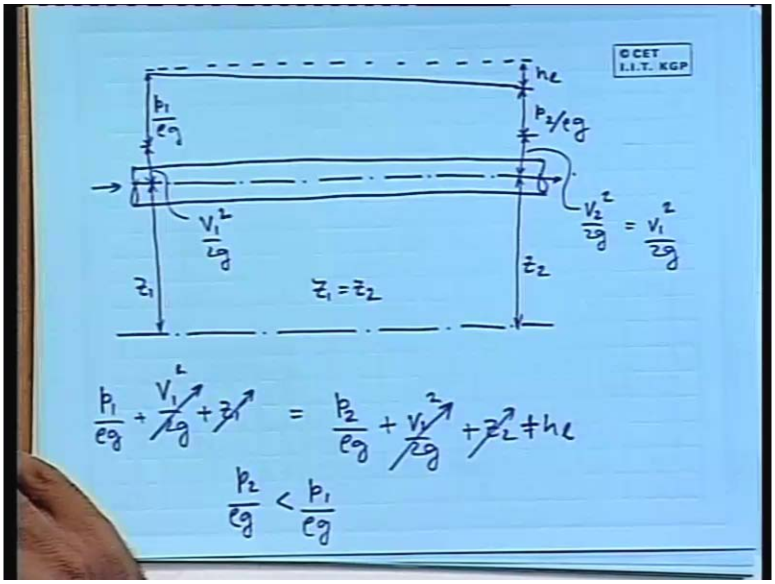

We have got a pipe line and the way I have drawn it, it is a horizontal pipe line and flow is taking place in this direction. We have got datum line like this. We will have Z_1 and we will have Z_2. Z_1 is equal to Z_2 that we will have. What about the kinetic energy? Pipe line is having same cross sectional area, so it will have identical kinetic energy. The kinetic energy is the same here and here, so this is V_1 square by 2g. This will be V_2 square by 2g. That is equal to V_1 square by 2g, so the kinetic energy is same.

What about the pressure? Let me write down the Bernoulli's equation p_1 by rho g plus V_1 square by 2 g plus Z_1 that is equal to p_2 by rho g plus V_2 square by 2g plus Z_2 plus h_l, head loss. What are we getting? Z_1 and Z_2, cancel from both the sides; V_1 square by 2g, V_2 square by 2g they also cancel because they are identical. h_1 is having some finite value. What does it mean? p_2 by rho g will be lesser compared to p_1 by rho g. So, p_2 by rho g will be lesser compared to p_1 by rho g. There will be a drop in pressure. That means if there is no viscous dissipation, This is the total energy line. This is p_1 by rho g. But now we will have a drop in pressure and this will be p_2 by rho g and this one is nothing but h_1. In general, we will have a manifestation of this head loss that there will be a drop in pressure. To compensate this, what we need is somewhere some sort of a pumping agency either a pump or a blower or a compressor depending on the fluid. To compensate this we need at the upstream somewhere a pump or a blower. That means to run the pump we have to spend some sort of energy and what will be that energy?

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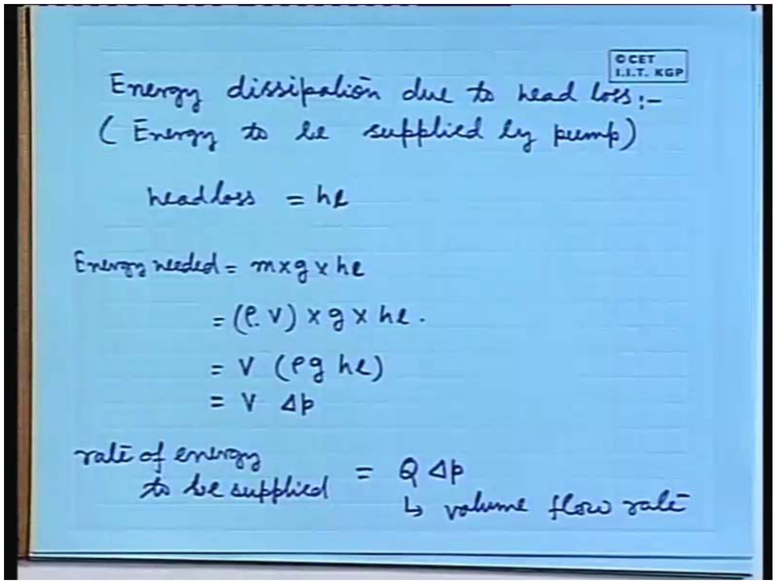

Energy dissipation due to head loss or we can call it energy to be supplied by pump. How much energy is to be supplied by the pump? One can do some analogy and estimate what is the energy to be supplied. It is like this. Let us say, h_1 is head loss. If head loss is h_l then if we assume that the energy which is to be supplied that is equal to raising of certain mass across this height h_l, from there we can estimate what is the energy to be supplied. Let us say, m amount of mass is to be raised across this height h_1. So, what is the energy needed? m into g into h_1 is the amount of energy which has to be supplied or which is needed to raise m mass across the attraction of gravity, this amount of height h_1. We can write this is rho into volume into g into h_1. Again we can write energy needed is V into rho g into h_1; we can write V into delta p. Rho g h_1 is the pressure; that has got some unit of pressure. Generally, in case of fluid it is not a solid body. Instead of mass, we like to handle mass flow rate and instead of volume, we like to handle or we like to specify the flow situation with the help of volume flow rate. The rate of energy g to be supplied we will have Q that is the volume flow rate into delta p. Q is the volume flow rate.

I think we will take a small break and again we will start with this topic.