Introduction to Fluid Mechanics
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Lecture – 56
Pipe Flow-Part-II

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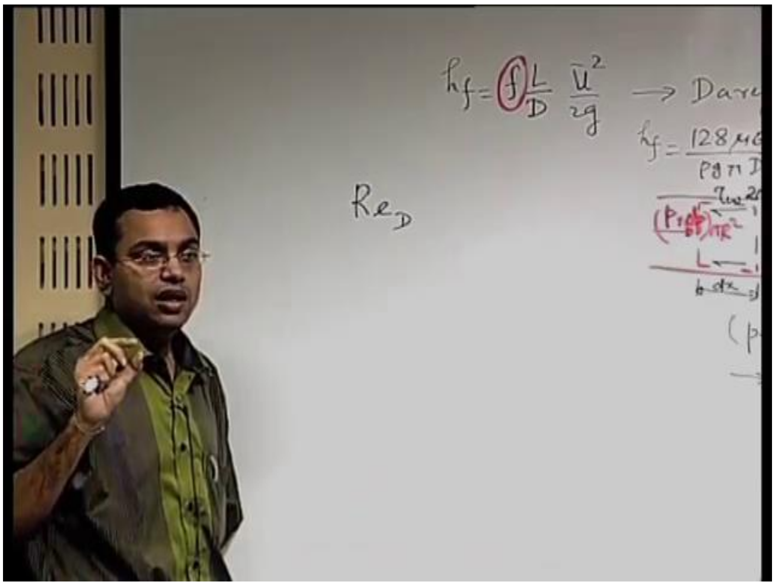

For a fully developed laminar flow, we may determine it exactly, by a very simple analysis which we have already done through exact solution of the Navier-Stokes equation. As the flow becomes turbulent we have seen that such simple exact solutions are not possible, because you may only statistically operate on certain quantities, and you may get an estimate of the velocity profiles with certain fitting parameters.

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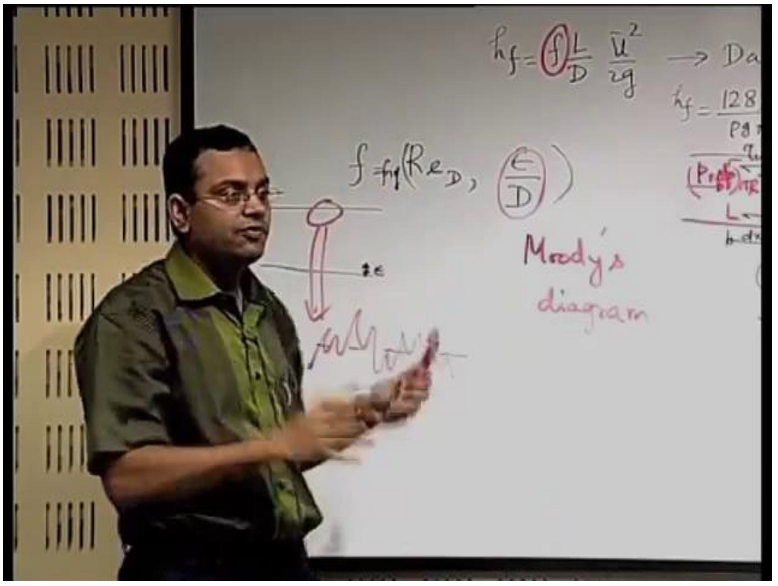

The roughness should have a strong role to play in terms of triggering the onset of turbulence by having a disturbance when the fluid is going beyond the critical when the flow is beyond the critical Reynolds number.

Say the average roughness is 1 millimeter. Let us say you have two pipes, one pipe is having a nominal diameter of 1 centimeter, another pipe is having a nominal diameter of one kilometer. So, 1 millimeter of roughness will be more influential in case of the smaller one, because it is important that on an average what is the roughness relative to the characteristic length scale of the system.

$$f = fn.\ \ of\left(\mathrm{Re}_D, \frac{\varepsilon}{D}\right)$$

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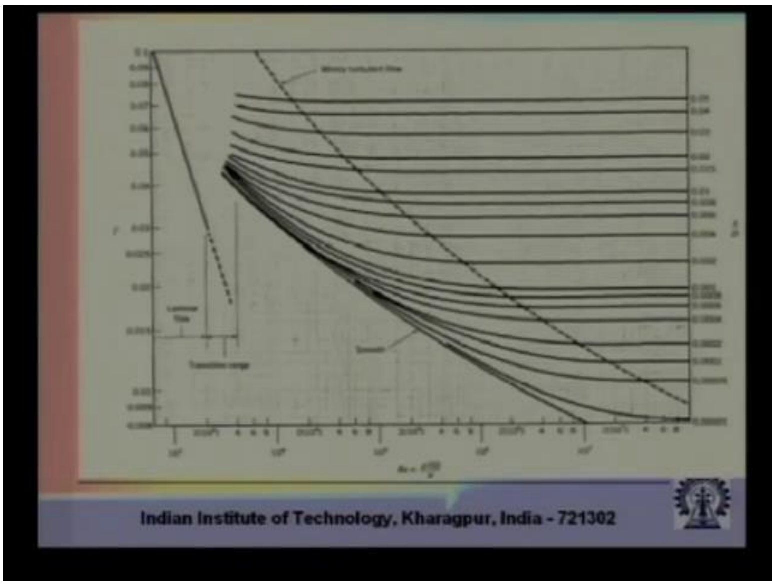

Reynolds number is a sort of the independent variable here, it is plotted in a logarithmic scale, because we want to cover a very wide range of Reynolds number in a in a single diagram.

As you have almost a uniform velocity profile in a turbulent flow, so you have very high velocity gradient close to the wall. So, for a given flow rate the wall shear stress is higher for the turbulent flow and that is why the friction factor suddenly jumps from a low value to a high value. Friction factor it becomes a function of $\frac{\varepsilon}{D}$.

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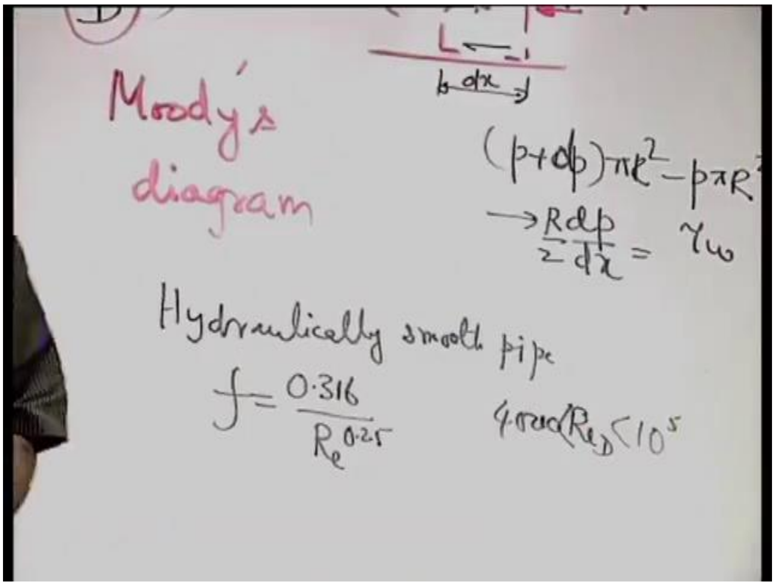

For very high Reynolds number, the friction factor is almost independent of Reynolds number. The lines which are there towards the end are parallel lines; that means, only if you change the $\frac{\varepsilon}{D}$, the friction factor is changing, but with respect to the Reynolds number variation it is a horizontal line. So, it does not change with Reynolds number.

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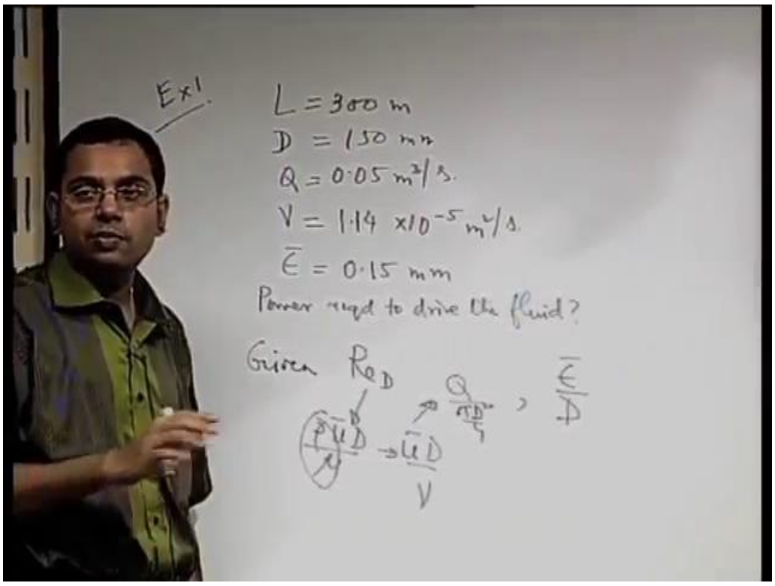

let us say that you have a length of a pipe, L=300 m, diameter of the pipe as 150 mm, flow rate is 0.05 m^3/s . The kinematic viscosity of the water at that prevailing condition is

$1.14\times10^{-5}\ m^2/s$. The average surface roughness is 0.15 mm. So, we have to find out that what is the power required to drive the fluid.

Given $Re_D \rightarrow \dfrac{\rho\bar{u}D}{\mu} = \dfrac{\bar{u}D}{\nu}$, $\bar{u} \rightarrow \dfrac{Q}{\dfrac{\pi D^2}{4}}$

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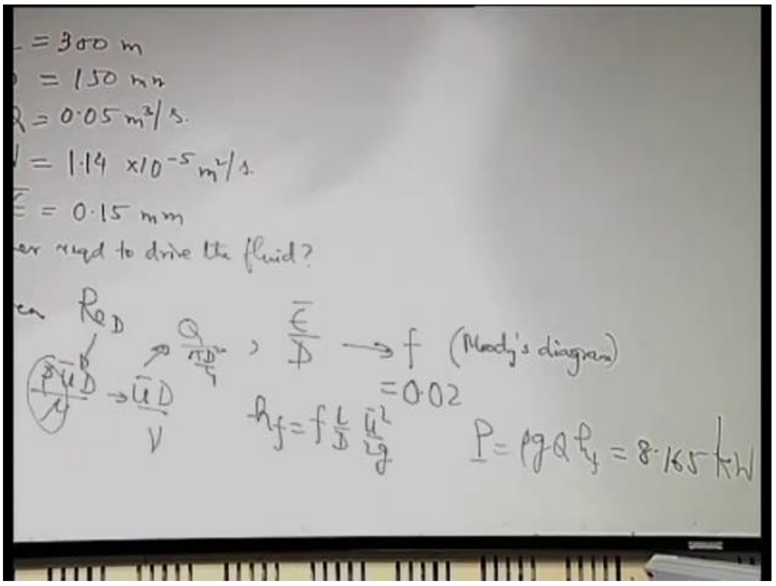

$$\frac{\bar{\varepsilon}}{D} \rightarrow f\left(Moody's\ \ diagram\right)$$

$$h_f = f\,\frac{L}{D}\frac{\bar{u}^2}{2g}$$

$$P = \rho g Q h_f = 8.165 kW$$

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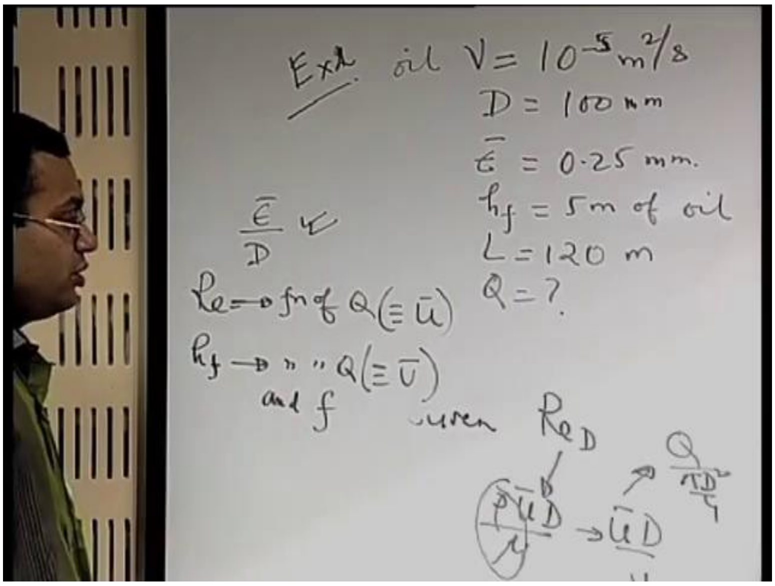

$$\nu = 10^{-5} m^2 / s$$
$$D = 100mm$$
$$\bar{\varepsilon} = 0.25mm$$
$$h_f = 5m \ of \ \ oil$$
$$L = 120m$$
$$Q = ?$$

$$\text{Re} \rightarrow \text{ funcn of } \mathrm{Q}(\equiv \bar{u})$$

$$h_f \rightarrow func^n \ of \ \ Q(\equiv \bar{u}) \& \ \ f$$

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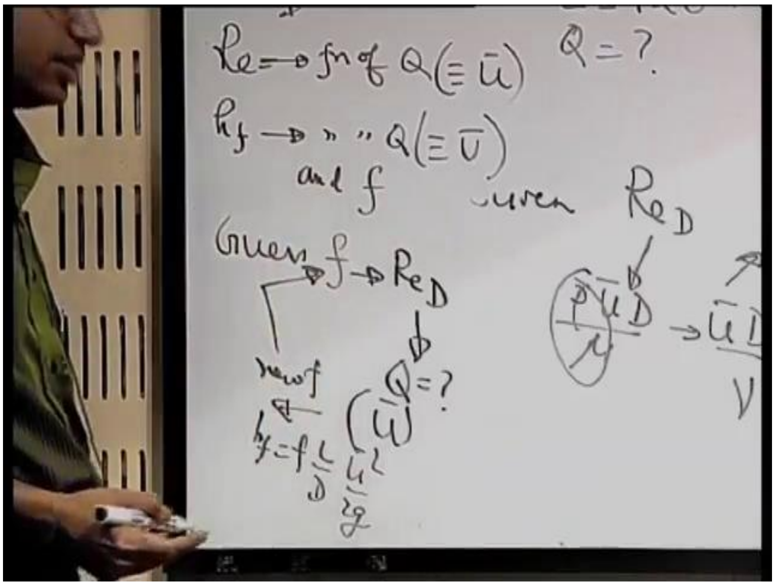

Given $f \rightarrow \mathrm{Re}_D$

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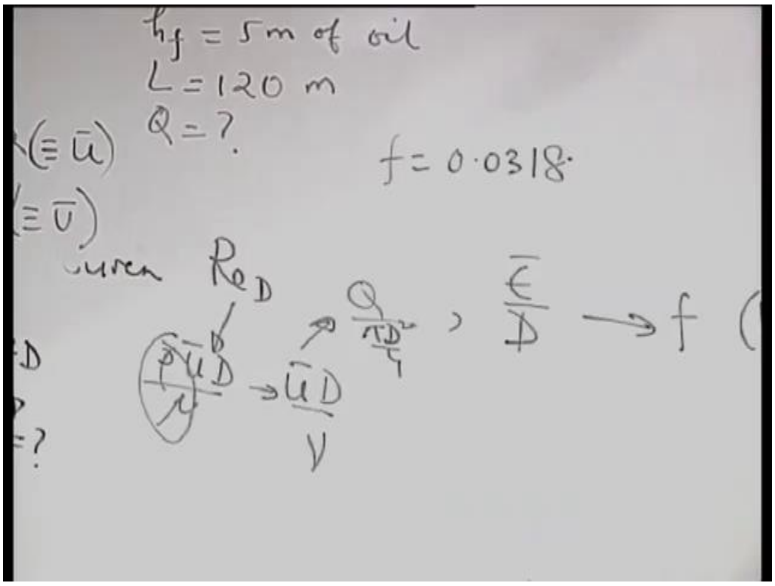

f=0.0318

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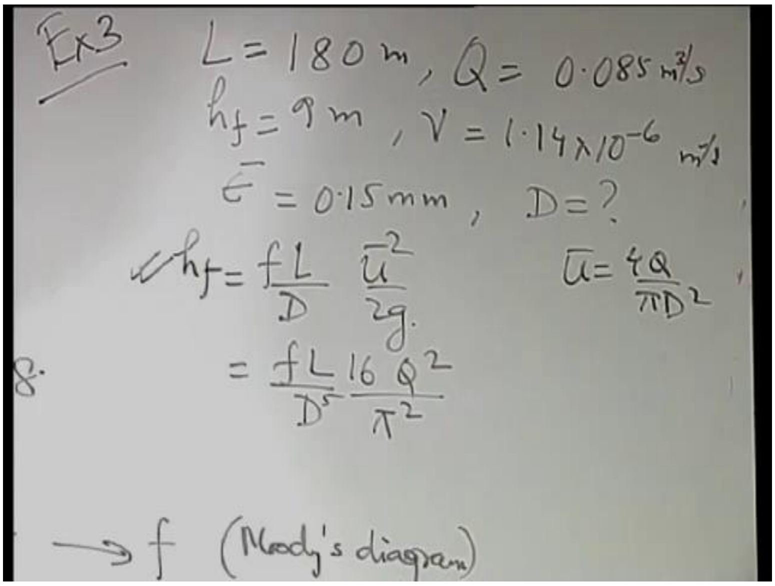

L=180m, Q=0.085m^2/s, h_f = 9m, $\nu = 1.14 \times 10^{-6} m^2 / s, \bar{\varepsilon} = 0.15mm$

$$h_f = \frac{fL}{D}\frac{\bar{u}^2}{2g} \qquad , \qquad \bar{u} = \frac{4Q}{\pi D^2}$$

$$= \frac{fL}{D^5}\frac{16Q^2}{\pi^2}$$

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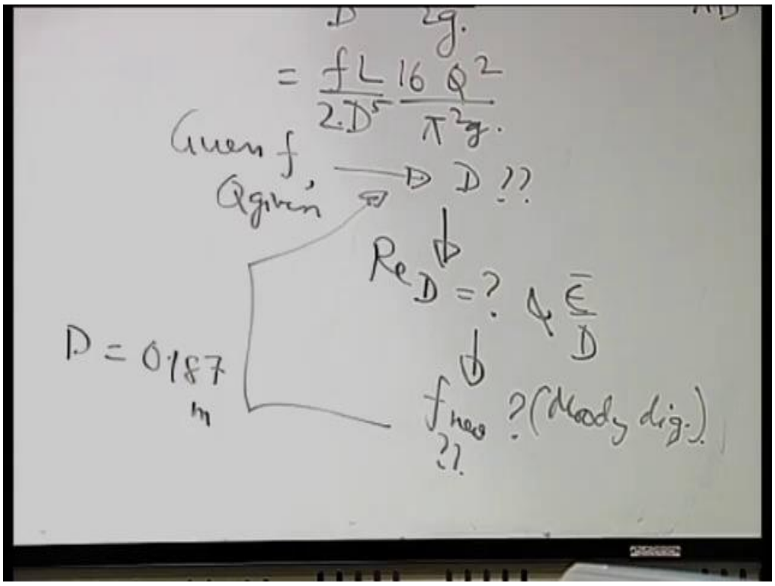

Guess f$, Q\ given \rightarrow D$??

$$\mathrm{Re}_D = ?\ \&\ \frac{\bar{\varepsilon}}{D} \to f\ ?\left(Moody's\ diagram\right)$$

D=0.187m