

**COURSE NAME: INDUSTRIAL PIPING SYSTEM**

**LECTURE VIII-WEEK VIII: DESIGNING PIPING SYSTEM**

**COMPONENTS**

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# OBJECTIVES

By the end of this session the learner/student will be able to:

- ✓ Calculate pipe parameters
- ✓ Calculate pump head
- ✓ Calculate Pipe Pressure Drop
- ✓ Calculate fluid flowrate and velocity

## **VIII.1 Introduction**

Designing piping system components involves different parameters because piping system is composed of many components as it was highlighted in the second Lecture which was about the main components of piping system. Each component must be appropriate and compatible with others that is why deep analysis of different parameters is very important. When designing a piping system, several parameters need to be considered to ensure its efficiency, safety, and effectiveness.

## **VIII.2. Key parameters to take into account when designing piping components**

**a. Fluid Characteristics:** Understand the properties of the fluid being transported, including its type, temperature, pressure, flow rate, viscosity, corrosiveness, and potential for erosion or scaling.

**b. Pipe Material:** Choose the appropriate material based on the fluid characteristics, environmental factors, and cost considerations.

## Key parameters to take into account Cont'd

**c. Pipe Sizing:** Calculate the required pipe diameter based on the flow rate, fluid velocity, and pressure drop limitations. The chosen diameter should ensure efficient flow without excessive pressure losses.

**d. Pressure Rating:** Determine the maximum pressure that the piping system needs to handle, including normal operating pressure and potential pressure surges.

## **Key parameters to take into account Cont'd**

**e. Pipe Routing and Layout:** Plan the route and layout of the piping system, considering factors such as space constraints, accessibility for maintenance, expansion and contraction due to temperature changes, and avoiding interference with other structures or equipment.

**f. Support and Anchoring:** Determine the appropriate support mechanisms to prevent excessive movement or sagging of the pipes.

# Key parameters to take into account Cont'd

## **g. Thermal Expansion and Contraction:**

Account for the thermal expansion and contraction of the piping system due to temperature changes.

**h. Valves and Fittings:** Select appropriate valves and fittings based on the system requirements, fluid characteristics, and flow control needs.

## **i. Insulation:**

Determine if the piping system requires insulation to maintain the desired fluid temperature, prevent heat loss or gain, or protect against condensation.

## **Key parameters to take into account Cont'd**

### **j. Safety Considerations:**

Ensure compliance with applicable safety codes, standards, and regulations.

### **k. Maintenance and Accessibility:**

Design the system to allow for ease of maintenance, inspection, and repair.

### **l. Cost Considerations:**

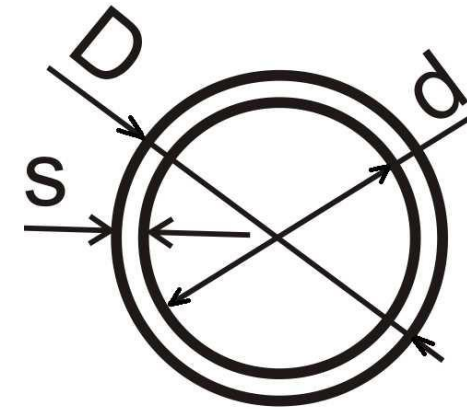
Balance the performance requirements with cost considerations.

## **Key parameters to take into account Cont'd**

These parameters, among others, play a crucial role in the design process and contribute to the overall efficiency, reliability, and safety of the piping system.

## VIII.3. Inner and outer diameter, wall thickness, radius

Pipes have an inner and outer diameter, since their wall is thick, its thickness depends on the type of pipe and the material from which it is made. The technical specifications often indicate the outer diameter and wall thickness.



*Figure:1. Internal and external pipe diameter, wall thickness*

*Source:*<https://myhouse.it.desigusxpro.com/sub/en/strojmaterialy-i-tehnologii/raschet-parametrov-trub#i-5>

## Inner and outer diameter, wall thickness, radius Cont'd

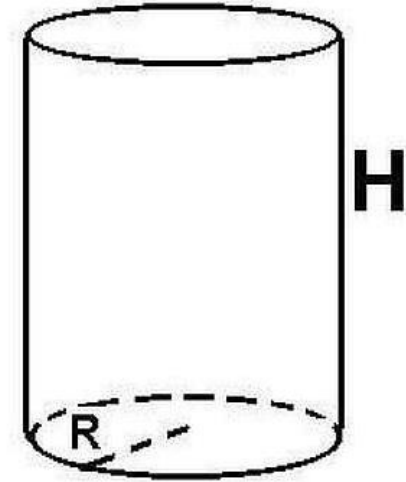
- Having the two values (**outer diameter-D** and **wall thickness-S**), it is easy to calculate the **inner diameter-d** by subtracting twice the wall thickness from the outer diameter:  $d = D - 2 * S$ . If you have an outer diameter of 32 mm, a wall thickness of 3 mm, then the inner diameter will be:  $32 \text{ mm} - 2 * 3 \text{ mm} = 26 \text{ mm}$ .
- If, on the contrary, there is an inner diameter and wall thickness, but an outer one is needed, add double the thickness of the stack to the existing value. This means that:  $D=d+2*S$

## **Inner and outer diameter, wall thickness, radius Cont'd**

With radius (denoted by the letter R) it is even simpler - this is half of the diameter:  $R = 1/2 D$ . For example, we find the radius of a pipe with an outer diameter of 32 mm. Just divide 32 by two, we get 16 mm. This applies the same for the inner diameter, the diameter is just divided by 2 to get the inner radius (r)

## VIII.4. Calculation of pipe surface/lateral area

- The pipe is a very long cylinder and the surface area of the pipe is calculated as the area of the cylinder. For calculations, you need a radius (inner or outer - it depends on which surface you need to calculate) and the length of the segment that you need.



$$S=2\times\pi\times R\times H$$

*Figure:2. The formula for calculating the lateral surface of the pipe*

**H:** Height or length of the pipe

**R or r:** Outer or inner radius of the pipe

**S:** Lateral area of the cylinder.

## Calculation of pipe surface/lateral area Cont'd

To find the lateral area of the cylinder, we multiply the radius- $R$  and length- $H$ , multiply the resulting value by two, and then by the number “Pi” ( $2\pi * R * H$ ), we get the desired value. If you want, you can calculate the surface of one meter, then you can multiply it by the desired length. The same formula can also apply for calculating the internal lateral area.

## Calculation of pipe surface/lateral area Cont'd

For example, let's calculate the outer surface of a piece of pipe 5 meters long, with a diameter of 12 cm. First, let's calculate the diameter: we divide the diameter by 2, and get 6 cm. Now all the values must be reduced to the same units of measurement. Since the area is calculated in square meters, we translate centimeters into meters.  $6 \text{ cm} = 0.06 \text{ m}$ . Then we substitute everything into the formula:  $S = 2 * 3.14 * 0.06 * 5 = 1.884 \text{ sqm}$ . If you round up, you get 1.9 sqm.

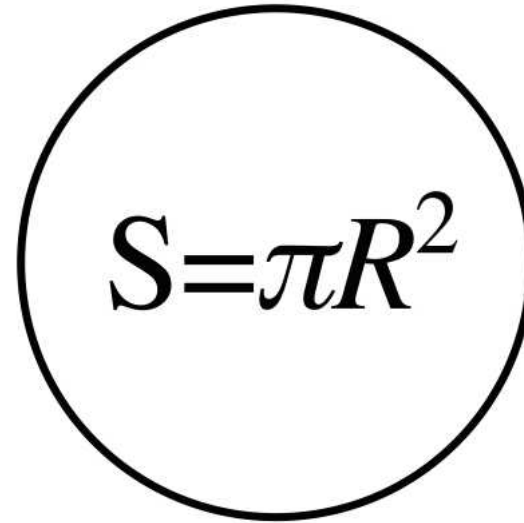
## VIII.5. Calculate pipe's cross-sectional area

- If the pipe is round, the cross-sectional area must be calculated using the formula for the area of a circle:  $S = \pi * R^2$ ...
- Where R is the radius (inner),  $\pi = 3.14$ . For the total area, you need to square the radius and multiply it by 3.14.

# Calculate pipe's cross-sectional area Cont'd

## For example;

The cross-sectional area of a pipe with a diameter of 90 mm. Find the radius -  $90 \text{ mm} / 2 = 45 \text{ mm}$ . In centimeters, this is 4.5 cm square:  $4.5 * 4.5 = 2.025 \text{ cm}^2$ , we substitute in the formula  $S = 2 * 20.25 \text{ cm}^2 = 40.5 \text{ cm}^2$ . in this case the pipe's cross-sectional area we must consider the internal diameter.


$$S = \pi R^2$$

*Figure:3. The formula for finding the cross-sectional area of a round pipe*

**Source:**<https://myhouse.it.desigusxpro.com/sub/en/strojmaterialy-i-tehnologii/raschet-parametrov-trub#i-5>

## VIII.6. Calculate the volume of liquid flowing in a pipeline

When organizing a piping system, it is sometimes necessary to have such a parameter as the volume of water that will fit in the pipe. This is necessary when calculating the amount of coolant in the system. For this case, you need a cylinder volume formula.

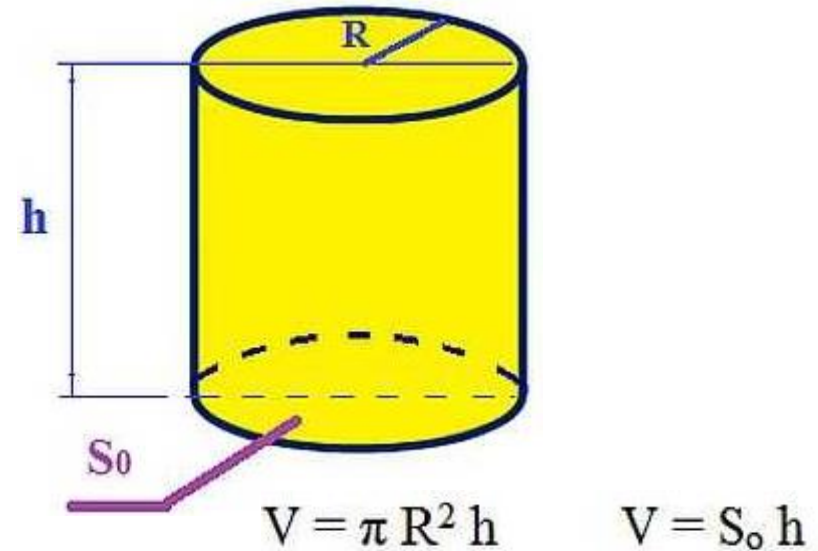


Figure:4. The formula for calculating the volume of water in a pipe

*Source:* <https://myhouseit.designusxpro.com/sub/en/strojmaterialy-i-tehnologii/raschet-parametrov-trub#i-5>

# Calculate the volume of liquid flowing in a pipeline Cont'd

There are two ways here: first, calculate the cross-sectional area (described above) and multiply it by the length of the pipeline. If you count everything according to the formula, you will need an inner radius and the total length of the pipeline. Let's calculate how much liquid will fit in a system of 32 mm pipes 30 meters long.

## Calculate the volume of liquid flowing in a pipeline Cont'd

### Answer:

First, we translate millimeters into meters:  $32 \text{ mm} = 0.032 \text{ m}$ , we find the radius (halved)  $= 0.016 \text{ m}$ . We substitute  $V = 3.14 * (0.016)^2 * 30 \text{ m} = 0.0241 \text{ m}^3$ ... It turned out  $=$  a little more than two hundredths of a cubic meter. But we are used to measuring the volume of the system in liters. To convert cubic meters into liters, you need to multiply the resulting figure by 1000. It turns out 24.1 liters

## **VIII.7. Fluid flowrate calculation**

Fluid flow rate calculations are essential in various engineering applications, including piping systems, and fluid dynamics. The flow rate represents the volume or mass of fluid passing through a given point per unit time. The most common methods to calculate flow rate are based on the principle of conservation of mass, which states that the mass entering a system must be equal to the mass leaving the system.

## **i. Formulas to calculate flowrate**

There are different formulas to calculate flow rate depending on the specific scenario and the properties of the fluid. Here are some examples:

**Flow Rate Calculation for Incompressible Fluids:** For incompressible fluids (liquids), the flow rate can be calculated using the following formula:

$$\mathbf{Flow\ Rate\ (Q) = Area\ (A) \times Velocity\ (V)}$$

**Example:** A water pipe has a cross-sectional area of 0.2 square meters, and the water velocity inside the pipe is measured at 2 meters per second. Calculate the flow rate of water through the pipe.

**Solution:**

$$Q = A \times V$$

$$Q = 0.2 \text{ m}^2 \times 2 \text{ m/s}$$

$$Q = 0.4 \text{ m}^3$$

The flow rate of water through the pipe is 0.4 cubic meters per second.

## **ii. Flow Rate Calculation for Compressible Fluids**

Flow Rate Calculation for Compressible Fluids: For compressible fluids (gases), the flow rate can be calculated using the following formula:

$$\text{Flow Rate (Q)} = \text{Area (A)} \times \text{Velocity (V)} \times \text{Density } (\rho)$$

## Example:

A gas flows through a pipe with a cross-sectional area of 0.1 square meters. The gas velocity is 5 meters per second, and its density is 1.2 kilograms per cubic meter. Calculate the flow rate of the gas.

## Solution:

$$Q = A \times V \times \rho$$

$$Q = 0.1 \text{ m}^2 \times 5 \text{ m/s} \times 1.2 \text{ kg/ m}^3$$

$$Q = 0.6 \text{ kilograms per second}$$

The flow rate of the gas is 0.6 kg per second.

### **iii. Flow Rate Calculation using Bernoulli's Equation**

In certain cases where pressure differences exist, Bernoulli's equation can be utilized to calculate the flow rate. Bernoulli's equation relates the pressure, velocity, and height of a fluid in a flowing system.

## **Example:**

Water flows through a pipe with a diameter of 0.1 meters. The pressure at one end is 200,000 Pascals, and the pressure at the other end is 180,000 Pascals. The height difference between the two ends is 5 meters. Calculate the flow rate of water.

## Solution:

Using Bernoulli's equation:

$$\text{Pressure at point 1} + 0.5 \times \rho \times (V1)^2 + \rho \times g \times h1 = \text{Pressure at point 2} + 0.5 \times \rho \times (V2)^2 + \rho \times g \times h2$$

Assuming the pipe is horizontal, the velocity term can be neglected:

$$\text{Pressure at point 1} + \rho \times g \times h1 = \text{Pressure at point 2} + \rho \times g \times h2$$

$$200,000 \text{ Pascals} + 1000 \text{ kg/ m}^3 \times 9.8 \text{ m/s}^2 \times 0 \text{ meters} =$$

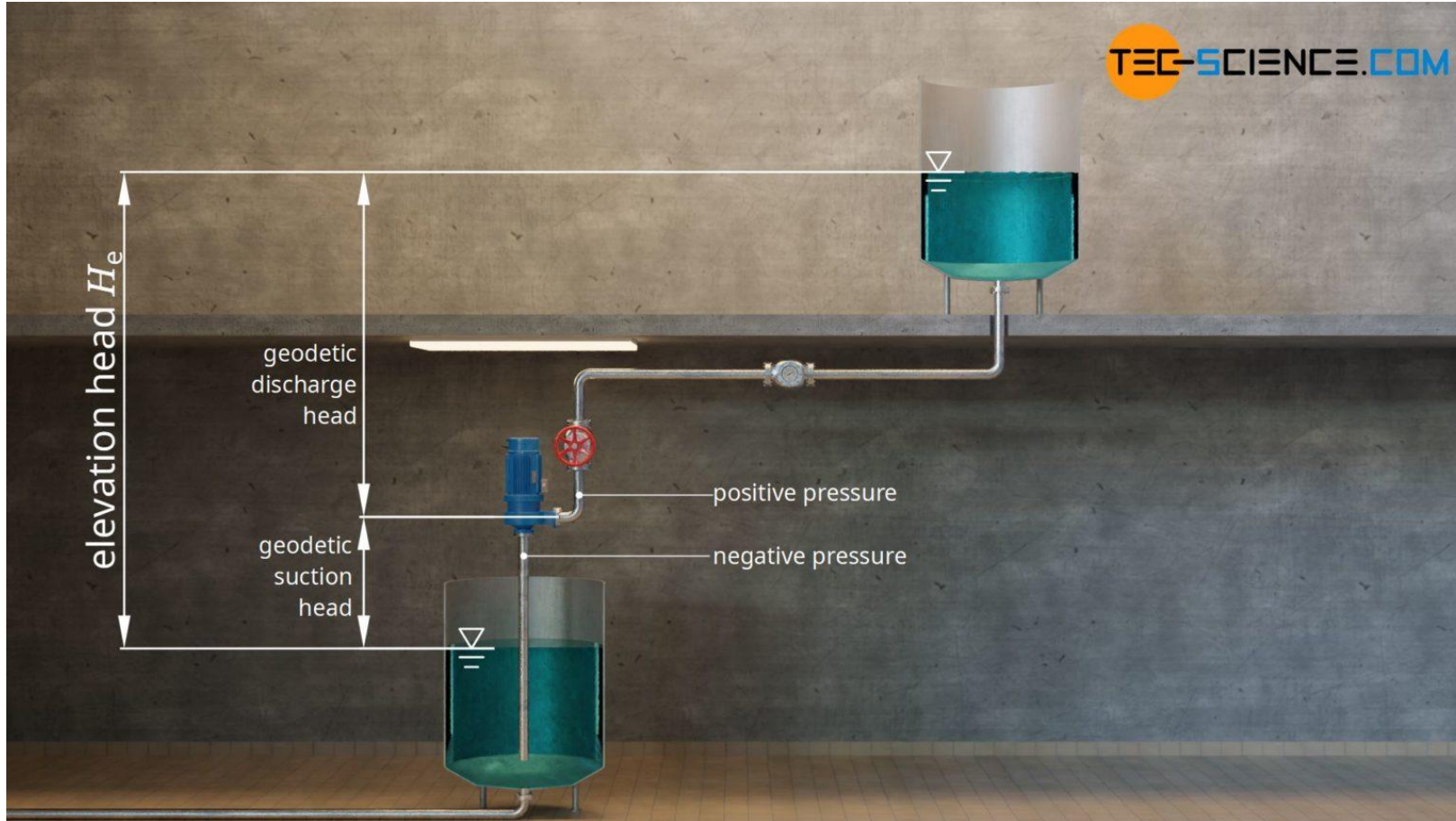
$$180,000 \text{ Pascals} + 1000 \text{ kg/ m}^3 \times 9.8 \text{ m/s}^2 \times 5 \text{ meters}$$

$$20,000 \text{ Pascals} = 49,000 \text{ Pascals}$$

## **VIII.8. Pressure head calculation in piping system**

In a piping system, pressure head refers to the energy per unit weight of fluid due to its elevation above a reference point. It is often used to determine the pressure difference between two points in the system. The pressure head can be calculated using the following formula:

$$\text{Pressure Head (H)} = (P - P_0) / (\rho \times g)$$



## Example

A centrifugal pump is required to deliver water from a reservoir to a higher elevation. The pump is located 5 meters above the water surface, and the discharge pipe has a length of 20 meters with a pipe diameter of 10 cm. Calculate the total head required for the pump.

### Solution:

To calculate the total head, we need to consider the elevation head, friction head, and any additional losses in the system.

# Example

## **Elevation Head:**

The elevation head is the vertical distance between the water surface and the pump. In this case, it is 5 meters.

## **Friction Head Loss:**

Assuming a certain flow rate and pipe roughness, we can calculate the friction head loss using the Darcy-Weisbach equation or other appropriate methods.

For simplicity, let's assume a friction head loss of 1 meter.

# Example

## Additional Losses:

If there are any additional losses, such as losses through fittings or valves, they should be included in the total head calculation. Let's assume no additional losses for this example.

## Total Head:

Total Head = Elevation Head + Friction Head Loss + Additional Losses = 5 meters + 1 meter + 0 meters = 6 meters

Therefore, the total head required for the pump is **6 meters**.

## VIII.9. Pipe Pressure Drop Calculation

- When fluid flows through a pipe there will be a pressure drop that occurs as a result of resistance to flow. There may also be a pressure gain/loss due a change in elevation between the start and end of the pipe. This overall pressure difference across the pipe is related to a number of factors:
  - Friction between the fluid and the wall of the pipe
  - Friction between adjacent layers of the fluid itself
  - Friction loss as the fluid passes through any pipe fittings, bends, valves, or components
  - Pressure loss due to a change in elevation of the fluid (if the pipe is not horizontal)
  - Pressure gain due to any fluid head that is added by a pump

## i. Darcy-Weisbach equation

The Darcy-Weisbach equation is widely used for calculating pressure drop in pipes, especially for turbulent flow. It relates the pressure drop ( $\Delta P$ ) to the friction factor ( $f$ ), pipe length ( $L$ ), pipe diameter ( $D$ ), average velocity ( $V$ ), and fluid density ( $\rho$ ).

$$\Delta P = f \cdot (L/D) \cdot (\rho \cdot V^2 / 2g)$$

Where:

- ✓  $\Delta P$  is the pressure drop
- ✓  $f$  is the friction factor
- ✓  $L$  is the pipe length
- ✓  $D$  is the pipe diameter
- ✓  $\rho$  is the fluid density
- ✓  $V$  is the average velocity of the fluid

# Examples

## Example 1:

Calculating head loss in a pipe Given that:

$f = 0.02$  (friction factor)

$L = 100$  m (pipe length)

$D = 0.5$  m (pipe diameter)

$V = 2$  m/s (fluid velocity)

$g = 9.81$  m/s<sup>2</sup> (acceleration due to gravity)

Calculate the head loss ( $h_L$ ).

### Solution:

$$h_L = (f * (L/D) * (V^2/2g))$$

$$h_L = (0.02) * (100 \text{ m} / 0.5 \text{ m}) * (2 \text{ m/s})^2 / (2 * 9.81 \text{ m/s}^2)$$

$$h_L = 2.040 \text{ m}$$

Therefore, the head loss in the pipe is 2.040 meters.

## Example 2:

Calculate head loss in a pipe with different parameters;

Given that:

$f = 0.03$  (friction factor)

$L = 50$  m (pipe length)

$D = 0.3$  m (pipe diameter)

$V = 1.5$  m/s (fluid velocity)

$g = 9.81$  m/s<sup>2</sup> (acceleration due to gravity)

Calculate the head loss ( $h_L$ ).

### Solution:

$$h_L = (f * (L/D) * (V^2/2g))$$

$$h_L = (0.03) * (50 \text{ m} / 0.3 \text{ m}) * (1.5 \text{ m/s})^2 / (2 * 9.81 \text{ m/s}^2)$$

$$h_L = 0.457 \text{ m}$$

Therefore, the head loss in the pipe is 0.457 meters.

### **Example 3:**

Calculating head loss in a pipe with high velocity

Given that:  $f = 0.025$  (friction factor)

$L = 200$  m (pipe length)

$D = 0.4$  m (pipe diameter)

$V = 5$  m/s (fluid velocity)

$g = 9.81$  m/s<sup>2</sup> (acceleration due to gravity)

Calculate the head loss ( $h_L$ ).

### **Solution:**

$$h_L = (f * (L/D) * (V^2/2g))$$

$$h_L = (0.025) * (200 \text{ m} / 0.4 \text{ m}) * (5 \text{ m/s})^2 / (2 * 9.81 \text{ m/s}^2)$$

$$h_L = 12.690 \text{ m}$$

Therefore, the head loss in the pipe is 12.690 meters.

## Example 4

A water pipe with a diameter of 10 cm and a length of 100 m is carrying a flow rate of 0.2 m<sup>3</sup>/s. The pipe roughness is 0.03 mm. Calculate the head loss using the Darcy-Weisbach equation.

### Solution:

Given:

$$\text{Diameter (D)} = 10 \text{ cm} = 0.1 \text{ m}$$

$$\text{Length (L)} = 100 \text{ m}$$

$$\text{Flow rate (Q)} = 0.2 \text{ m}^3/\text{s}$$

$$\text{Roughness } (\epsilon) = 0.03 \text{ mm} = 0.03 \times 10^{-3} \text{ m}$$

## Example 4 Cont'd

To calculate the head loss, we need to determine the average velocity ( $V$ ) and the friction factor ( $f$ ).

Average velocity:  $V=Q/(\pi*(D/2)^2)=0.2/(\pi*(0.1/2)^2)\approx 2.54$  m/s

Reynolds number:  $Re=(\rho*V*D)/\mu=(1000*2.54*0.1)/1e-3=254,000$  (approx.).

Let's assume a value of  $f = 0.02$  for this example.

Head loss:  $hL =f*(L/D)*(V^2/2g)=0.02*(100/0.1)*(2.54^2/(2*9.81))\approx 5.12$  m.

Therefore, the head loss in this pipe is approximately 5.12 meters.

# References

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