COURSE NAME: INDUSTRIAL PIPING SYSTEM

LECTURE IX-WEEK IX: 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

IX.1. Introduction

The factors to consider when designing piping system components were discussed in the previous slides. In this presentation few other parameters like Reynolds number, different types of flows inside the pipe and pump head will also be discussed and then procced with Practical exercises about designing piping system components parameters.

IX.2. Reynolds number

The Reynolds number, is a dimensionless parameter used in fluid mechanics to characterize the flow regime of a fluid in relation to its velocity, viscosity, and characteristic dimensions. It provides information about the relative importance of inertial forces to viscous forces in a flowing fluid.

Reynolds number Cont'd

The Reynolds number (Re) is defined as the ratio of inertial forces to viscous forces and is calculated using the following formula:

$Re = (\rho * v * L) / \mu$

Where:

- ✓ ρ is the density of the fluid
- ✓ v is the velocity of the fluid
- ✓ L is a characteristic length or characteristic dimension of the flow (such as pipe diameter, hydraulic radius, or chord length)
- ✓ μ is the dynamic viscosity of the fluid.

Reynolds number Cont'd

The Reynolds number helps determine the flow regime in a fluid, whether it is laminar or turbulent. At low Reynolds numbers, viscous forces dominate, and the flow tends to be smooth and ordered, known as laminar flow. At high Reynolds numbers, inertial forces dominate, and the flow becomes turbulent, characterized by chaotic and irregular motion with mixing and fluctuations.

IX.3. Laminar flow

Laminar flow is characterized by smooth and orderly fluid motion with parallel layers or streamlines. In laminar flow, the fluid particles move in a well-organized manner, with each layer sliding past adjacent layers without significant mixing or cross-movement. The flow is typically characterized by low velocities and high fluid viscosity. Laminar flow is stable and predictable, and the fluid particles follow a continuous and uninterrupted path.

Laminar flow Cont’d

Key characteristics of laminar flow include:

✓Streamlined flow with well-defined layers or streamlines.

✓Smooth and predictable flow patterns.

✓Lower fluid velocities.

✓Minimal mixing between adjacent fluid layers.

✓Lower energy losses due to friction.

IX.4. Turbulent Flow

Turbulent flow, on the other hand, is characterized by chaotic and irregular fluid motion. In turbulent flow, the fluid particles move in random and unsteady patterns, with frequent mixing, eddies, and vortices. The flow is typically characterized by higher velocities and lower fluid viscosity. Turbulent flow is unstable and less predictable compared to laminar flow.

Turbulent Flow Cont'd

- ✓Key characteristics of turbulent flow include:
- ✓Chaotic and irregular flow patterns.
- ✓Random fluctuations in velocity and pressure.
- ✓Mixing and interaction between adjacent fluid layers.
- ✓Higher fluid velocities.
- ✓Greater energy losses due to friction.

IX.5. Transition from Laminar to Turbulent Flow

The transition from laminar to turbulent flow in a pipe depends on various factors such as fluid velocity, viscosity, pipe diameter, and surface roughness.

Generally, as the fluid velocity increases or the pipe diameter increases, the flow is more likely to transition from laminar to turbulent. Higher fluid viscosity tends to favour laminar flow, while lower viscosity promotes turbulent flow.

Transition from Laminar to Turbulent Flow Cont'd

In summary, the main difference between laminar and turbulent flow in a pipe lies in the orderliness and predictability of fluid motion. Laminar flow features smooth, parallel layers, while turbulent flow is characterized by chaotic and irregular motion with mixing and fluctuations.

The transition from laminar to turbulent flow depends on factors such as fluid velocity, viscosity, pipe diameter, and Reynolds number.

Transition from Laminar to Turbulent Flow Cont'd

For flow in a smooth pipe, the critical Reynolds number (Rec) is typically considered to be around 2,300. Below Rec, the flow is more likely to be laminar, while above Rec, the flow tends to be turbulent.

It's important to note that this value is an approximation and can vary depending on factors such as pipe roughness, boundary conditions, and flow disturbances.

Examples of Reynolds number calculation

Example 1:

Consider water flowing through a pipe with a velocity of 2 m/s. The pipe has a diameter of 0.5 m. The density of water is 1000 kg/m³, and the dynamic viscosity is 0.001 kg/(m·s). Is this a turbulent or laminar flow?

$Re = (\rho * v * D) / \mu$

Given:

ρ = 1000 kg/m^3 (density of water)

v = 2 m/s (velocity of water)

D = 0.5 m (pipe diameter)

μ = 0.001 kg/(m·s) (dynamic viscosity of water)

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Examples of Reynolds number calculation

Substituting these values into the formula:

Re = (1000 kg/m^3 * 2 m/s * 0.5 m) / (0.001 kg/(m·s))

Re = 1,000,000

Therefore, the Reynolds number for this turbulent flow scenario is 1,000,000. As the Reynolds number exceeds 2300.

In this example, since the Reynolds number is very high (well above the critical value for most systems), it indicates that the flow is in the turbulent regime.

Examples of Reynolds number calculation Cont'd

Calculating Reynolds Number to Determine Flow Regime given that:

Fluid velocity (v) = 1 m/s

Pipe diameter (D) = 0.1 m

Fluid density (ρ) = 1000 kg/m^3

Fluid viscosity (μ) = 0.01 kg/(m·s)

Calculate the Reynolds number (Re) to determine if the flow is laminar or turbulent.

Examples of Reynolds number calculation Cont'd

Solution:

Reynolds number is calculated using the formula:

$Re = (\rho v D) / \mu$

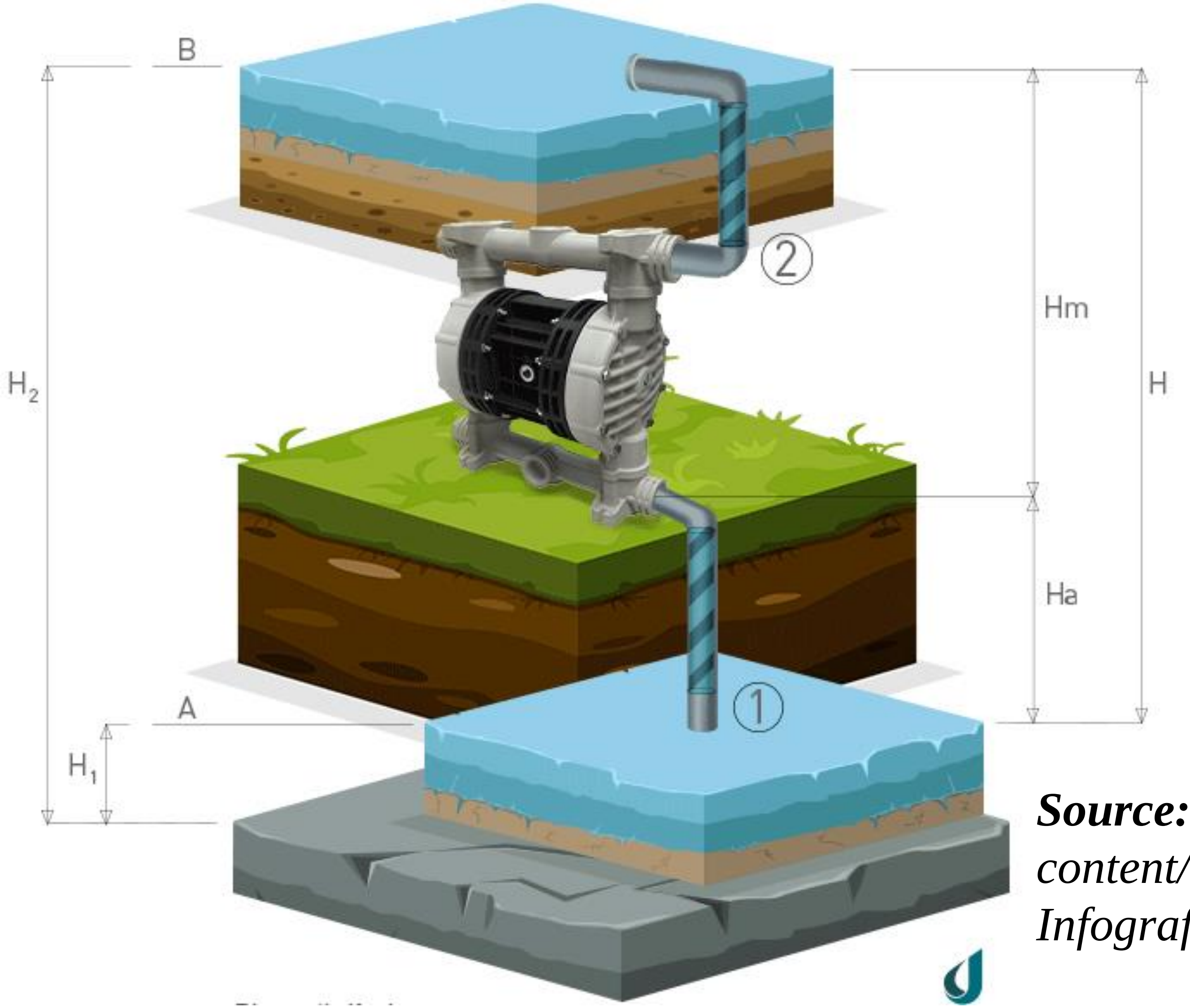
$Re = (1000\ kg/m^3 * 1\ m/s * 0.1\ m) / (0.01\ kg/(m \cdot s))$

$Re = 10{,}000$

In this case, since the Reynolds number is 10,000, the flow is considered turbulent.

IX.6. Pump head

The pump head is defined
as the maximum lifting
height that a pump is able
to transmit to the pumped fluid.



Source: *https://www.debem.com/wp-content/uploads/2018/12/Debem-Infografica.gif*

In the operating diagram of a pumped water lifting system with references for calculating the head (1) suction pipe (2) delivery pipe is defined as:

- ✓Geodetic suction height Ha: the difference in level between point A and the pump
- ✓Geodetic delivery height Hm: the difference in level between point B and the pump
- ✓Geodetic head H: the difference between liquid levels at discharge and suction

The geodetic head H, commonly referred to as head, is therefore the sum of the suction and discharge geodetic heights Ha and Hm.

Pump head Cont’d

The clearest example is that of a vertical pipe rising directly from the delivery outlet. Fluid will be pumped down the pipe 5 meters from the discharge outlet by a pump with a head of 5 meters. The head of a pump is inversely correlated with the flow rate. The higher the flow rate of the pump, the lower the head.

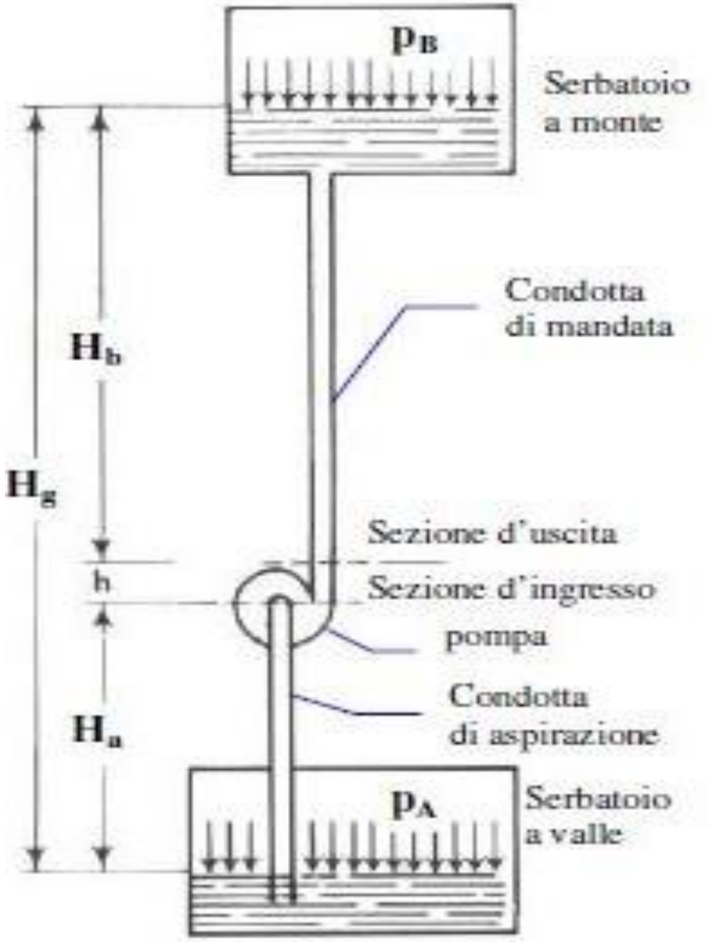
In a centrifugal pump, as the flow rate increases, the pump needs to work harder to push a larger volume of fluid. This increased flow rate results in greater fluid velocity within the pump, which leads to higher kinetic energy.

Pump head Cont’d

According to the Bernoulli's principle, an increase in fluid velocity is accompanied by a decrease in pressure. Therefore, as the flow rate increases, the pressure at the pump outlet decreases. This decrease in pressure is reflected as a decrease in the pump head.

Conversely, if the flow rate decreases, the pump has an easier job moving a smaller volume of fluid, allowing it to generate higher pressure at the outlet. This results in an increase in pump head.

Pump head Cont’d



Pumps play **a fundamental role in transferring fluids.**

There are two (2) main factors in determining the size of the pump:

- ✓ **Flow rate,** the quantity of fluid (or volume) that goes through the pump in a specific unit of time.
- ✓ **Hydraulic head of a pump,** the actual energy that the pump can deliver to the fluid.

Source: https://www.debem.com/wp-content/uploads/2022/03/img-1.jpg

Calculating pump head

H1 + Hm = H2 H1 = Inlet energy

Hm = Energy delivered by the pump

H2 = Outlet energy

The calculation of pump pressure head depends on various factors, including the pump characteristics, system requirements, and fluid properties

Example 1

Given that:

- ✓Pipe diameter: 0.4 meters
- ✓Fluid velocity: 5 m/s
- ✓Elevation at point 1: 10 meters
- ✓Elevation at point 2: 5 meters

Question:

Calculate the pump head.

To calculate the pump head, we can use the equation:

Pump Head = (V2^2 - V1^2) / (2 * g) + (Z2 - Z1)

Substituting the given values:

Pump Head = ((5^2) - (0^2)) / (2 * 9.81) + (5 - 10)

Pump Head = 1.27 meters

Example 2

Given that:

- ✓Pipe diameter: 0.3 meters
- ✓Fluid velocity: 8 m/s
- ✓Elevation at point 1: 15 meters
- ✓Elevation at point 2: 10 meters

Using the same equation:

Pump Head = (V2^2 - V1^2) / (2 * g) + (Z2 - Z1)

Substituting the given values:

Pump Head = ((8^2) - (0^2)) / (2 * 9.81) + (10 - 15)

Pump Head = 3.24 meters

The pump head required is approximately 3.24 meters.

Example 3

Let's consider a centrifugal pump operating at a flow rate of 10 cubic meters per hour (m^3/h) and delivering water. The pump's total dynamic head (TDH) is 30 meters, which includes both the pressure head and the friction losses in the system. Calculate the pump pressure head

Solution

Determine the friction losses in the system:

These can be calculated using empirical formulas or by conducting a detailed hydraulic analysis of the system. Let's assume the friction losses in this example are 5 meters.

Subtract the friction losses from the total dynamic head:

Pump pressure head = Total dynamic head - Friction losses Pump pressure head = 30 meters - 5 meters Pump pressure head = 25 meters

Therefore, the pump pressure head in this example is 25 meters.

Example 4

Consider a positive displacement pump operating at a flow rate of 500 liters per minute (l/min) and pumping oil. The pump's rated differential pressure is 4 bar (absolute). Calculate the pump pressure head.

Solution:

Step 1. Convert the flow rate to cubic meters per second (m^3/s): Flow rate = 500 l/min = 0.5 m^3/min = (0.5/60) m^3/s = 0.00833 m^3/s.

Step 2. Convert the differential pressure to pascals (Pa): Pressure = 4 bar = 4×10^5 Pa.

Step 3. Divide the pressure by the fluid density to get the pressure head:

Pump pressure head = Pressure / (fluid density × gravitational acceleration).

Note: The density of oil can vary, so you'll need to know the specific density value for your oil.

Let's assume the oil density is 850 kilograms per cubic meter (kg/m^3):

Pump pressure head = (4×10^5 Pa) / (850 kg/m^3 × 9.81 m/s^2) Pump pressure head ≈ 47.9 meters.

Therefore, the pump pressure head in this example is approximately 47.9 meters.

When working with real-world pump systems, it's important to consider additional factors such as:

- ✓Friction losses,
- ✓Pipe fittings,
- ✓and losses due to valves or bends in the piping system.

These factors can be incorporated into the calculation using additional terms in the Bernoulli's equation or by using the energy equation, also known as the Darcy-Weisbach equation.

Example

Let's say that we have a water pumping system where water is being pumped from a lower reservoir to a higher reservoir. We want to calculate the pump head required to achieve the desired flow rate. Here are the given parameters:

- ✓The elevation of the lower reservoir surface: 100 meters
- ✓The elevation of the higher reservoir surface: 150 meters
- ✓The pipe diameter: 0.2 meters
- ✓The pipe length: 50 meters
- ✓The flow rate: 2 cubic meters per second
- ✓The fluid density: 1000 kilograms per cubic meter
- ✓The acceleration due to gravity: 9.81 meters per second squared

To calculate the pump head, we can apply Bernoulli's equation between the two reservoirs. Bernoulli's equation states that the total energy per unit mass of a fluid remains constant along a streamline. The equation is given as:

$P/\rho + V^2/2g + Z = \text{constant}$

where:

- ✓P is the pressure of the fluid
- ✓ρ is the density of the fluid
- ✓V is the velocity of the fluid
- ✓g is the acceleration due to gravity
- ✓Z is the elevation of the fluid

In this case, we can ignore the pressure term since the pipe is open to the atmosphere at both ends. Therefore, the equation simplifies to:

V^2/2g + Z = constant

Now let's calculate the pump head:

1. Convert the flow rate to velocity:

- Q = A * V
- V = Q / A
- V = 2 / (π * (0.2/2)^2) V ≈ 79.58 m/s

2. Calculate the lower reservoir energy per unit mass:

- E1 = V^2 / (2 * g) + Z1
- E1 = (79.58^2) / (2 * 9.81) + 100
- E1 ≈ 617.04 m

3. Calculate the higher reservoir energy per unit mass:

E2 = V^2 / (2 * g) + Z2

E2 = (79.58^2) / (2 * 9.81) + 150

E2 ≈ 667.04 m

Calculate the pump head:

Pump Head = E2 - E1

Pump Head ≈ 667.04 - 617.04

Pump Head ≈ 50 meters.

Therefore, the pump head required to achieve the desired flow rate is approximately 50 meters.

THANK YOU!!!!!!!!!!

QUESTIONS AND ANSWERS

References

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