Water At 40 Oc Is Pumped From An Open Tank Through 200 M Of 50-mm-diameter Smooth Horizontal Pipe. The

Water At 40 Oc Is Pumped From An Open Tank Through 200 M Of 50-mm-diameter Smooth Horizontal Pipe. The process of transporting water through piping systems is fundamental in various engineering applications, from municipal water supplies to industrial processes. Understanding the flow characteristics, pressure losses, and the factors influencing efficient pumping is crucial for designing effective piping systems. This article explores the detailed aspects of pumping water at 40°C from an open tank through a 200-meter-long, smooth, horizontal pipe with a 50-mm diameter.

Overview of the Pumping System

The scenario involves several key parameters:

- Fluid: Water at 40°C
- Source: Open tank
- Pipe Length: 200 meters
- Pipe Diameter: 50 mm (0.05 meters)
- Pipe Type: Smooth, horizontal pipe
- Flow Direction: From the open tank, through the pipe, to the discharge point

Understanding this setup is essential for calculating flow rates, pressure drops, and pump requirements.

Physical Properties of Water at 40°C

Before diving into flow calculations, it’s important to understand the physical properties of water at this temperature:

- Density (□): Approximately 992 kg/m^3
- Dynamic Viscosity (μ): Around 0.653 mPa·s or 0.000653 Pa·s
- Kinematic Viscosity (□): Calculated as μ/□ □ 0.659 × 10□□ m^2/s

These properties influence the flow regime and pressure losses within the pipe.

Flow Regimes and Reynolds Number

Flow in pipes can be classified as laminar or turbulent based on the Reynolds number (Re):

Calculating Reynolds Number

Re = (□ × V × D) / μ

Where:

- V = average velocity of water in the pipe
- D = diameter of the pipe (0.05 m)

To determine the flow regime, we need to estimate the velocity, which depends on the flow rate. Assuming an initial flow rate (Q), the velocity V = Q / A, where A is the cross-sectional area of the pipe.

Cross-Sectional Area of the Pipe

$A = (\pi/4) \times D^2 = (3.1416/4) \times (0.05)^2 \approx 1.9635 \times 10^{-3}\ m^2$

Pressure Losses in Horizontal Pipe

Transporting water over 200 meters involves overcoming various pressure losses, primarily due to:

- Frictional resistance of the pipe
- Minor losses at fittings (not applicable here as the pipe is smooth and straight)
- Elevation changes (assumed negligible for a horizontal pipe)

Frictional Head Loss: Darcy-Weisbach Equation

The head loss (h_f) due to friction is calculated as:

$h_f = (4f \times L \times V^2) / (2g \times D)$

Where:
- f = Darcy friction factor
- L = length of pipe (200 m)

- V = flow velocity
- g = acceleration due to gravity (9.81 m/s^2)

The friction factor f depends on the flow regime:

- For laminar flow (Re < 2000): f = 64 / Re
- For turbulent flow (Re > 2000): f can be estimated using the Colebrook-White equation or approximated via the Swamee-Jain equation for smooth pipes:

f = 0.25 / [log10((□ / (3.7D)) + (5.74 / Re^0.9))]^2

Where □ is the pipe roughness height. For a smooth pipe, □ □ 0.000005 meters.

Calculating Flow Rate and Head Loss

To proceed, assume a target flow rate (Q) or flow velocity. For example, let's analyze at a flow velocity of 1 m/s.

Calculating Velocity and Reynolds Number at V=1 m/s

V = 1 m/s

Re = (992 kg/m^3 × 1 m/s × 0.05 m) / 0.000653 Pa·s □ 75,978

Since Re > 2000, the flow is turbulent, and we can use the Colebrook-White equation to find f.

Estimating Friction Factor f

Using the Swamee-Jain approximation:

$f = 0.25 / [\log_{10}((\varepsilon / (3.7D)) + (5.74 / Re^{0.9}))]^2$

Plugging in the values:

$\varepsilon / (3.7D) = 0.000005 / (3.7 \times 0.05) \approx 2.70 \times 10^{-5}$

$Re^{0.9} \approx 75{,}978^{0.9} \approx 33{,}275$

$5.74 / Re^{0.9} \approx 0.000172$

Sum inside the log: $2.70 \times 10^{-5} + 0.000172 \approx 0.000199$

$\log_{10}(0.000199) \approx -3.702$

$f \approx 0.25 / (-3.702)^2 \approx 0.25 / 13.69 \approx 0.0183$

Calculating Head Loss

$h_f = (4 \times 0.0183 \times 200 \times 1^2) / (2 \times 9.81 \times 0.05) \approx (14.64) / (0.981) \approx 14.93$ meters

This head loss indicates the energy loss due to friction over the 200-meter pipe at a flow velocity of 1 m/s.

Pump Selection and Pressure Requirements

To determine the pump capacity, consider the total head the pump must overcome, including:

- Frictional head loss (h_f)
- Elevation head (assumed zero for horizontal pipe)
- Any additional minor losses (negligible here)
- Velocity head (if increasing flow rate)

Assuming the desired flow rate (Q):

$Q = V \times A = 1\ m/s \times 1.9635 \times 10^{-3}\ m^2 \approx 1.96\ L/s$

The pump must provide enough pressure to overcome approximately 15 meters of head (from the head loss) plus a safety margin.

Factors Influencing Flow and Pressure Losses

Several factors can affect the efficiency and performance of the piping system:

- **Pipe Material and Surface Finish:** Smooth pipes reduce frictional losses.
- **Flow Velocity:** Higher velocities increase head loss exponentially, so optimizing velocity is key.
- **Pipe Diameter:** Larger diameters decrease velocity and head loss.

- **Pipe Length:** Longer pipes increase frictional losses.
- **Temperature Variations:** Water at higher temperatures has lower viscosity, affecting flow behavior.

Design Considerations for Efficient Pumping

When designing a pumping system for this scenario, consider the following:

1. **Flow Rate Optimization:** Balance between desired flow rate and energy consumption.
2. **Pump Selection:** Choose a pump capable of providing the calculated head at the required flow rate.
3. **Pipe Siping and Material Choice:** Use smooth, corrosion-resistant materials like PVC or HDPE for reduced friction.
4. **Energy Efficiency:** Minimize head losses through proper pipe sizing and flow management.
5. **Maintenance and Inspection:** Regularly check for blockages, leaks, and pipe integrity.

Conclusion

Transporting water at 40°C from an open tank through a 200-meter-long, 50-mm-diameter smooth horizontal pipe involves careful consideration of flow regimes, pressure losses, and pump capabilities. By understanding the physical properties of water at this temperature, calculating Reynolds number, and estimating head losses via the Darcy-Weisbach equation and the Colebrook-White approximation, engineers can design efficient systems that meet flow and pressure requirements.

Proper system design ensures minimal energy consumption, reliable operation, and longevity of the piping infrastructure. Whether for municipal water supply, industrial processes, or irrigation, a thorough understanding of fluid dynamics principles is essential for optimizing pumping systems in real-world applications.

Keywords: Water pumping, open tank, horizontal pipe, pressure loss, Darcy-Weisbach, Reynolds number, flow rate, head loss, pump selection, fluid dynamics, pipe design, energy efficiency

Frequently Asked Questions

What is the significance of pumping water at 40°C through a horizontal pipe?

Pumping water at 40°C affects its viscosity and density, which in turn influence flow characteristics and pressure losses in the pipe system.

How does the pipe diameter of 50 mm impact the flow rate of water

pumped through it?

A 50 mm diameter pipe constrains the flow, and the flow rate depends on the pressure head and the friction losses in the pipe; larger diameters reduce flow resistance.

What are the major factors contributing to pressure loss in this pipe system?

Major factors include pipe friction (due to pipe length and roughness), water velocity, and minor losses at fittings or bends (though none specified here).

How can we calculate the head loss due to friction in this setup?

The Darcy-Weisbach equation is typically used, which requires pipe length, diameter, flow velocity, and a friction factor based on pipe smoothness and flow regime.

What is the effect of temperature on water flow in this pipe system?

Higher temperatures decrease water viscosity, which can reduce friction losses and potentially increase flow rate for a given pressure head.

How does the length of 200 meters influence the pumping requirements?

Longer pipe length increases head loss due to friction, requiring more pump power to maintain the desired flow rate.

What are the typical methods to reduce head loss in such a pipeline system?

Methods include increasing pipe diameter, reducing pipe length, smoothening the pipe interior, or installing pumps with higher head capacity.

Would the flow be laminar or turbulent in this scenario, and how can we determine it?

Flow is likely turbulent given the pipe size and typical flow velocities; it can be determined using the Reynolds number, which exceeds 2000 in turbulent flow.

What safety considerations should be taken when pumping hot water at 40°C through this pipeline?

Ensure the pipe material can withstand the temperature, prevent leaks or bursts, and implement proper insulation and pressure regulation to prevent accidents.

Additional Resources

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Introduction

Pumping water from an open tank through a horizontal pipe is a fundamental process in fluid mechanics, with applications spanning industrial processes, municipal water supply, irrigation, and HVAC systems. When the water is at an elevated temperature of 40°C and is transported over a significant length of 200 meters through a smooth pipe of 50-mm diameter, several complex phenomena influence the flow characteristics, energy requirements, and system design considerations. This review provides an exhaustive analysis of the key factors involved, including fluid properties, flow regimes, pressure losses, pump selection, and practical implications.

Fluid Properties at 40°C

Understanding the physical properties of water at 40°C is essential for accurate analysis:

- Density (□): Approximately 992 kg/m^3
- Dynamic Viscosity (μ): About 0.653 mPa·s (or 0.000653 Pa·s)
- Kinematic Viscosity (□): Approximately 0.658×10^{-6} m^2/s
- Specific Weight (□): 9.81 kN/m^3 (since □ = □ × g)
- Thermal Effects: Slightly reduced surface tension and increased thermal expansion compared to water at room temperature, which may influence cavitation and vapor pressure considerations.

These properties influence flow behavior, head losses, and pump performance.

Pipe and System Description

- Pipe Characteristics:
- Diameter (D): 50 mm = 0.05 m
- Length (L): 200 meters
- Material: Smooth, which minimizes pipe friction but does not eliminate it.
- Orientation: Horizontal, implying gravitational head effects are minimal unless elevation varies.

- Flow Conditions:
- Open tank feeding system suggests the water level in the tank influences the initial pressure.
- Pumping from the open tank introduces a free surface condition at the inlet, with atmospheric pressure acting on the water surface.
- The system is likely designed to deliver a specific flow rate or head, which influences pump selection.

Flow Regime Analysis

Reynolds Number Calculation

The Reynolds number (Re) determines whether the flow is laminar or turbulent:

$$
Re = \frac{\rho V D}{\mu}
$$

Where:

- V: Mean flow velocity
- D: Pipe diameter
- ρ: Water density
- μ: Dynamic viscosity

Expressed in terms of volumetric flow rate Q:

$$
V = \frac{Q}{A} = \frac{4Q}{\pi D^2}
$$

For example, assuming a flow rate Q:

- $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} \times (0.05)^2 \approx 1.9635 \times 10^{-3} \, \text{m}^2$

Suppose the desired flow rate is 0.01 m^3/s:

$$
V = \frac{0.01}{1.9635 \times 10^{-3}} \approx 5.09 \, \text{m/s}

\]

Calculating Re:

$$
Re = \frac{992 \times 5.09 \times 0.05}{0.000653} \approx \frac{252.7}{0.000653} \approx 386,900
$$

Since Re > 4000, the flow is turbulent.

Implications:

- Turbulent flow predominates, leading to higher frictional head losses.
- Turbulence increases energy dissipation, requiring appropriately rated pumps.

Head Losses in the Pipe

Frictional Head Losses

The Darcy-Weisbach equation governs head loss h_f:

$$
h_f = \frac{4fL V^2}{2gD}
$$

Where:

- f: Darcy friction factor
- L: Pipe length

- V: Velocity
- D: Diameter
- g: Acceleration due to gravity

Friction Factor Determination

- For turbulent flow in smooth pipes, the Colebrook-White equation simplifies to the Swamee-Jain approximation:

$$
f = \frac{0.25}{\left[\log_{10}\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}
$$

Where:

- ε: Absolute roughness of the pipe (for smooth pipes, typically $\varepsilon \approx 0.0000015 \, \text{m}$)
- D: Pipe diameter

Calculating f:

$$
f \approx \frac{0.25}{\left[\log_{10}\left(\frac{1.5 \times 10^{-6}}{3.7 \times 0.05} + \frac{5.74}{(3.87 \times 10^5)^{0.9}}\right)\right]^2}
$$

This yields approximately $f \approx 0.017$ for high Re in smooth pipes.

Calculated Head Loss

Using the earlier velocity $V \approx 5.09 \, \text{m/s}$:

$$
h_f = \frac{4 \times 0.017 \times 200 \times (5.09)^2}{2 \times 9.81 \times 0.05}
$$

$$
h_f \approx \frac{4 \times 0.017 \times 200 \times 25.9}{2 \times 9.81 \times 0.05}
$$

$$
h_f \approx \frac{4 \times 0.017 \times 200 \times 25.9}{0.981}
$$

$$
h_f \approx \frac{4 \times 0.017 \times 200 \times 25.9}{0.981} \approx \frac{4 \times 0.017 \times 200 \times 25.9}{0.981}
$$

Calculating numerator:

$$
4 \times 0.017 = 0.068
$$

$$
0.068 \times 200 = 13.6
$$

$$
13.6 \times 25.9 \approx 352.24
$$

Final head loss:

$$
h_f \approx \frac{352.24}{0.981} \approx 359.4 \, \text{meters}
$$

This indicates significant head loss at these flow conditions, emphasizing the need for a powerful pump.

Minor Losses

In addition to frictional losses, minor losses due to fittings, bends, or entry/exit effects are typically less significant in straight, smooth pipes but should still be considered for accurate system design.

Pump Selection and System Head

Total Dynamic Head (TDH)

The pump must overcome:

- Frictional head losses (h_f)
- Any additional elevation head (if present)
- Losses due to fittings (if applicable)
- The pressure head at the outlet

Assuming the tank is at a known elevation and negligible fittings, the primary concern is overcoming h_f.

Pump Performance Curve

Choosing an appropriate pump involves matching the required flow rate Q with a pump curve that delivers the corresponding head. Given the high head loss (~359 meters at 0.01 m³/s), the pump must be capable of providing at least this head at the desired flow rate.

Pump Efficiency and Power

The power P required:

$$
P = \frac{\rho g Q H}{\eta}
$$

Where:

- H: Total head (meters)
- η: Pump efficiency (assumed between 70% and 90%)

Assuming $H \approx 359 \, \text{m}$, $Q = 0.01 \, \text{m}^3/\text{s}$:

$$
P = \frac{992 \times 9.81 \times 0.01 \times 359}{0.8} \approx \frac{992 \times 9.81 \times 3.59}{0.8}
$$

Calculating numerator:

$$
992 \times 9.81 \approx 9735 \, \text{N}
$$

$$
9735 \times 0.01 \times 359 \approx 9735 \times 3.59 \approx 34,938 \, \text{J/s}
$$

Power:

$$
P \approx \frac{34,938}{0.8} \approx 43,673 \, \text{W} \approx 43.7 \, \text{kW}
$$

This substantial power requirement underlines the necessity for a high-capacity, industrial-grade pump.

Practical Considerations

Open Tank Dynamics

- Tank Pressure: The water surface in the open tank is at atmospheric pressure, and the initial pressure head is determined by the water level height h.

- Hydrostatic Pressure: The static pressure at the pipe inlet depends on the water height in the tank:

$$
P_{static} = \rho g h
$$

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