A 0.18-m Rigid Tank Is Filled With Saturated Liquid Water At 120C. A Valve At The Bottom Of The Tank

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Understanding the thermodynamic behavior of water in storage tanks is essential in various engineering applications, including power plants, refrigeration systems, and process industries. This article explores the scenario of a rigid tank with a specific volume filled with saturated liquid water at a given temperature, focusing on the implications of opening a valve at the bottom of the tank. We will analyze the thermodynamic principles involved, the potential outcomes, and the calculations necessary to evaluate the system's behavior.

Introduction to the Problem Scenario

Imagine a rigid, closed tank with a volume of 0.18 meters (which refers to the internal volume) that is completely filled with saturated liquid water at 120°C. The tank has a valve positioned at its bottom, which can be opened to allow water to flow out. The primary questions are:

- What is the thermodynamic state of the water within the tank?
- What happens when the valve is opened?
- How much water exits, and what is the resulting state of the remaining water?
- What energy considerations come into play?

This scenario is common in thermal systems where water is stored under specific conditions and manipulated via controlled outlets.

Thermodynamic Properties at 120°C

To analyze the situation accurately, it is essential to understand the properties of saturated water at 120°C.

Saturation Properties of Water at 120°C

Property	Value at 120°C (from standard steam tables)
Saturation Pressure	approximately 2.02 MPa (Megapascals)
Specific Volume of Saturated Liquid, vf	approximately 0.001059 m^3/kg
Specific Volume of Saturated Vapor, vg	approximately 0.8904 m^3/kg
Enthalpy of Saturated Liquid, hf	approximately 504.7 kJ/kg

| Enthalpy of Vaporization, hfg | approximately 206.4 kJ/kg |

Note: These values are approximate and can vary slightly depending on the source.

Determining the Mass of Water in the Tank

Given the volume of the tank (V = 0.18 m^3) and the specific volume of saturated liquid water at 120°C (vf ≈ 0.001059 m^3/kg), the mass of water initially in the tank can be calculated as:

$$ m_{initial} = \frac{V}{v_f} = \frac{0.18 \, \text{m}^3}{0.001059 \, \text{m}^3/\text{kg}} \approx 170 \, \text{kg} $$

This large mass indicates that the tank is filled with saturated liquid water at this temperature and volume.

Initial State of the Water in the Tank

The initial state is characterized by:

- Temperature: 120°C
- Pressure: approximately 2.02 MPa (saturation pressure at 120°C)
- State: Saturated liquid water
- Volume: 0.18 m^3
- Mass: approximately 170 kg

Because the water is saturated liquid, it exists at the boundary between liquid and vapor, but it is entirely in the liquid phase.

Opening the Valve at the Bottom: Thermodynamic Implications

When the valve at the bottom is opened, several phenomena occur depending on the nature of the valve (whether it is fully open or partially opened), the duration of opening, and the system's environment.

Idealized Assumptions for Analysis

- The tank is perfectly rigid; its volume remains constant.
- The process occurs quasi-statically or rapidly enough that the process can be approximated as adiabatic.
- No heat transfer occurs during the process (insulated tank).
- The outlet is at atmospheric pressure (or a known pressure), which is significantly lower than the

saturation pressure at 120°C.
- The flow is steady during the opening (or can be approximated as such during a small time interval).

Possible Outcomes Upon Opening the Valve

1. Flow of Water Out of the Tank

If the outlet pressure is lower than the saturation pressure, water will flow out, possibly as a mixture of liquid and vapor depending on the pressure and temperature conditions.

2. Pressure and Temperature Changes

As water drains, the pressure inside the tank may decrease, leading to phase change if the pressure drops below saturation pressure at the current temperature. Conversely, if the pressure remains above the vapor pressure, only liquid outflow occurs.

3. Remaining Water State

The residual water in the tank may experience a pressure decrease, potentially leading to boiling or vaporization if the pressure drops below saturation pressure at the constant temperature.

Analyzing the Outflow Process

To understand the process quantitatively, let's consider the scenario where the tank is open to atmospheric pressure (approximately 0.101 MPa). Since the initial saturation pressure is about 2.02 MPa, opening the valve leads to a rapid depressurization.

Step 1: Determine the Final State of the Remaining Water

- The pressure inside the tank drops from 2.02 MPa to atmospheric pressure (0.101 MPa).
- Because the initial water is saturated liquid at 120°C and the pressure drops significantly, the water may become a mixture of saturated liquid and vapor at the lower pressure/temperature.

Step 2: Isenthalpic Flash Calculation

Assuming an isenthalpic (constant enthalpy) process during depressurization (a common approximation in rapid expansion processes), we analyze the state change of the water.

- Initial enthalpy per unit mass: $h_{initial} = h_f \approx 504.7\, \text{kJ/kg}$.
- During depressurization to 0.101 MPa, find the specific enthalpy of saturated water at that pressure:

From saturation tables at 0.101 MPa:

Property	Value at 0.101 MPa (saturation)
Saturation temperature	approximately 100°C
Specific enthalpy of saturated liquid, hf, atm	approximately 419 kJ/kg
Specific enthalpy of saturated vapor, hg, atm	approximately 2676 kJ/kg

Since the process is rapid and approximated as isenthalpic, the final state of the water in the tank is a saturated mixture at 0.101 MPa with an enthalpy:

$$ h_{final} = h_{initial} = 504.7\, \text{kJ/kg} $$

Because h_f at 0.101 MPa is 419 kJ/kg, and $h_{initial}$ is 504.7 kJ/kg, the mixture's quality (vapor fraction, x) is:

$$ h_{final} = h_f + x \times h_{fg} $$
$$ 504.7 = 419 + x \times (2676 - 419) $$
$$ 504.7 - 419 = x \times 2257 $$
$$ 85.7 = x \times 2257 $$
$$ x \approx \frac{85.7}{2257} \approx 0.0379 $$

This indicates approximately 3.79% vapor quality in the remaining water.

Step 3: Mass of Water Exiting

Since the total initial mass is approximately 170 kg, the mass of water that remains in the tank after depressurization is:

$$ m_{remaining} = m_{initial} \times (1 - x) $$
$$ m_{remaining} \approx 170 \times (1 - 0.0379) \approx 163.5\, \text{kg} $$

The mass that has exited is approximately:

$$ m_{exit} = 170 - 163.5 \approx 6.5\, \text{kg} $$

Note: This is an idealized calculation assuming all the water that leaves is at the initial state and the process is purely isenthalpic.

Energy Considerations and Work Done

Opening the valve involves energy transfer. If the process is adiabatic and no heat transfer occurs, the energy carried away with the outgoing water can be calculated.

Energy of Outflow

The kinetic energy of water exiting the valve depends on the pressure difference:

$$ KE = \frac{1}{2} v^2 $$

where \(v \) is the velocity of water at the outlet, calculated via Bernoulli's equation:

\[v = \sqrt{2 \times g \times h_{pressure}} \]

with

\[h_{pressure} = \frac{P_{initial} - P_{outlet}}{\rho} \]

Assuming:

- \(P_{initial} \approx 2.02\, \text{MPa} \)
- \(P_{outlet} = 0.101\, \text{MPa} \)
- \(\rho \approx 1000\, \text{kg/m}^3 \)

then:

\[\

Frequently Asked Questions

What is the initial state of the water in the tank at 120°C?

The water is in a saturated liquid state at 120°C, meaning it exists entirely as liquid with no vapor present.

How does the pressure inside the tank relate to the saturation temperature of 120°C?

The pressure inside the tank corresponds to the saturation pressure of water at 120°C, approximately 2.02 MPa (20.2 bar).

What happens when the valve at the bottom of the tank is opened?

Opening the valve allows water to flow out, potentially causing a decrease in pressure and temperature depending on the flow rate and conditions outside the tank.

What thermodynamic processes can occur in the tank as water is released?

The process can involve boiling or flashing if pressure drops significantly, or simply depressurization if the tank is open to the atmosphere, leading to phase change or temperature changes.

How can the amount of water remaining in the tank be

calculated after some water is released?

By applying mass conservation and using steam tables to determine the specific volume and enthalpy, you can calculate the remaining water mass and volume after flow.

What safety considerations are important when dealing with a pressurized saturated water tank at 120°C?

Proper pressure relief devices, regular maintenance, and ensuring the tank materials can withstand the temperature and pressure are critical to prevent accidents or failures.

Additional Resources

A 0.18-m Rigid Tank Is Filled With Saturated Liquid Water At 120°C is a classic scenario often encountered in thermodynamics and fluid mechanics coursework, as well as in practical engineering applications involving pressurized water systems. This situation provides a fundamental basis for understanding phase change, pressure-volume relationships, and the behavior of saturated liquids under confined conditions. Analyzing such a setup involves multiple aspects, including the properties of water at the given temperature, the implications of a rigid (fixed volume) tank, and the effects of opening or closing the valve at the bottom. In this comprehensive review, we will explore these elements in detail, breaking down the core concepts, the thermodynamic principles at play, and the potential applications and limitations of such a configuration.

Understanding the Basic Setup

The scenario involves a 0.18-meter (or 180 mm) rigid tank, which means the tank's volume is fixed and does not change regardless of internal pressure or temperature variations. The tank is filled with saturated liquid water at 120°C, a state where the water exists precisely at the boundary between its liquid and vapor phases under equilibrium conditions. The inclusion of a valve at the bottom introduces the possibility of fluid flow, pressure changes, and phase transition dynamics depending on whether the valve is opened or closed.

This setup exemplifies a fundamental thermodynamic problem often used to illustrate concepts such as:

- Saturation properties of water
- Pressure and temperature relationships
- Phase change behavior
- Effects of confinement on fluid states
- Valve operation and flow considerations in sealed systems

Properties of Saturated Liquid Water at 120°C

Understanding the thermodynamic properties of water at 120°C is crucial for analyzing the behavior within the tank. Water's saturation temperature corresponds to specific saturation pressure, which can be obtained from standard steam tables.

Saturation Pressure at 120°C

- Approximately 2.02 MPa (20.2 bar)
- The pressure at which water is at its saturated liquid state at this temperature.

Saturation Properties

- Specific Volume (v_f): About 0.00106 m^3/kg, indicating a relatively dense liquid.
- Enthalpy of saturated liquid (h_f): Approximately 504.7 kJ/kg.
- Quality (x): Zero, since the water is saturated liquid, meaning no vapor is present initially.

Implications of Saturation State

- The water is at a high-pressure, high-temperature state.
- Any change in pressure or temperature could induce phase change, especially if the conditions deviate from equilibrium.

Behavior of a Rigid Tank Containing Saturated Liquid Water

The rigidity of the tank imposes a constant volume constraint, which has several implications:

Volume and Mass Relations

- The volume (V) of the tank is fixed: V = 0.18 m.
- The mass of water inside can vary depending on whether the water undergoes phase change or pressure variations.
- The specific volume of saturated liquid at 120°C is known, so the total mass can be calculated as:

$$
m = \frac{V}{v_f} = \frac{0.18\, \text{m}^3}{0.00106\, \text{m}^3/\text{kg}} \approx 169.81\, \text{kg}
$$

- This indicates that, initially, approximately 169.81 kg of saturated liquid water at 120°C occupy the tank.

Initial State

- The water is entirely in the saturated liquid phase, occupying a volume consistent with the specific volume at that temperature.
- The system is at equilibrium, with pressure corresponding to saturation pressure at 120°C (~2.02 MPa).

Valve Operation at the Bottom of the Tank

The presence of a valve introduces dynamic possibilities:

Valve Closed Scenario

- The system remains sealed.
- No mass transfer occurs.
- The pressure, temperature, and phase distribution stay constant unless there are heat exchanges or other external influences.

Valve Opened Scenario

- Fluid can flow out or in, depending on pressure and temperature gradients.
- If the valve opens at the bottom, the behavior depends on the initial conditions and the properties of the water.

Possible outcomes include:
- Flow of saturated liquid water out of the tank if the pressure inside exceeds atmospheric or external pressure.
- Vaporization or condensation depending on external conditions and heat transfer.
- Pressure and temperature changes inside the tank due to the sudden release or intake of water or vapor.

Flow Characteristics and Thermodynamic Implications

- The flow rate depends on the valve's opening size, pressure difference, and fluid properties.
- Rapid depressurization could lead to flashing, where liquid water vaporizes suddenly, potentially causing safety concerns or structural stress.
- Conversely, closing the valve after some flow can cause pressure build-up or cooling effects.

Thermodynamic Analysis and Key Concepts

Analyzing this scenario involves applying fundamental thermodynamic principles:

Energy Conservation

- The first law of thermodynamics for a closed rigid tank states that:

$$
\Delta U = Q - W
$$

- Since the volume is fixed, work done (W) associated with volume change is zero.
- Heat transfer (Q) affecting the internal energy (U) can cause phase change or temperature variation.

Pressure-Volume-Temperature Relationship

- For saturated water at 120°C, the pressure is fixed by the saturation pressure.
- If the system is perfectly insulated, the internal energy remains constant unless phase change occurs.
- Opening the valve allows for mass and energy transfer, changing the internal pressure and temperature.

Phase Change Dynamics

- If the water evaporates (flashing), vapor forms within the tank, increasing internal pressure.
- Conversely, condensation can occur if vapor cools or pressure drops.
- The phase change process can be modeled using the Clapeyron equation or steam tables.

Practical Applications and Considerations

Such a setup is relevant in various engineering applications:

Steam Generation and Storage

- Pressurized water tanks at high temperature are used in power plants.
- Understanding the behavior of saturated water helps in designing safety systems and control mechanisms.

Pressurized Water Reactors (PWRs)

- Similar principles apply to reactor coolant systems, where water at high pressure and temperature is stored and circulated.

Safety and Design Aspects

- Pressure relief valves are critical to prevent over-pressurization.
- Material strength considerations are vital due to high internal pressures.
- Rapid phase change can cause mechanical stresses or safety hazards.

Features, Pros, and Cons of the System

Features:
- Fixed volume allows for straightforward thermodynamic calculations.
- Saturated liquid state simplifies initial property determination.
- Valve introduces dynamic control over fluid flow and pressure.

Pros:
- Clear understanding of phase change phenomena.
- Useful for educational purposes to illustrate thermodynamic principles.
- Can be employed in practical designs of safety valves and pressurized storage.

Cons:
- Real systems may have heat transfer, heat loss, or external influences not accounted for in ideal models.
- Rapid phase change can cause structural or safety issues.
- The assumption of pure saturation at 120°C might be oversimplified in real-world conditions with impurities or non-ideal behavior.

Conclusion

The analysis of a 0.18-m rigid tank filled with saturated liquid water at 120°C with a valve at the bottom offers rich insights into thermodynamic behavior, phase change phenomena, and system control. The fixed volume constraints combined with water's saturation properties create a complex environment where pressure, temperature, and phase states are tightly coupled. Understanding these interactions is essential in designing safe, efficient, and reliable pressurized water systems, especially in thermal power generation, industrial processes, and safety-critical applications. While idealized models provide a foundation for analysis, real-world considerations such as heat transfer, material strength, and transient dynamics must also be incorporated for comprehensive system design and safety assessment.

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