A Frictionless Piston-cylinder Device Contains Saturated Liquid Water At 40-psia Pressure. Now 700 Btu

A Frictionless Piston-cylinder Device Contains Saturated Liquid Water At 40-psia Pressure. Now 700 Btu

Understanding the thermodynamic behavior of water within a piston-cylinder device is fundamental in various engineering applications, including power generation, refrigeration, and fluid systems. When a frictionless piston-cylinder contains saturated liquid water at a pressure of 40 psia, and the system has undergone a heat transfer resulting in an energy change of 700 Btu, analyzing the process requires a thorough grasp of the properties of saturated water and the principles governing phase changes. This article explores the thermodynamic principles involved in such a scenario, including the state of water at saturation, the implications of heat transfer, and the calculations needed to determine the resulting state of the water.

Understanding the Initial State of the Water

Saturated Liquid Water at 40 psia

The initial condition of the water in the piston-cylinder device is that it is saturated liquid at a pressure of 40 psia. Saturation indicates that water is at its boiling point corresponding to the given pressure, with liquid and vapor phases in equilibrium.

- Saturation Pressure and Temperature:
At 40 psia, the saturation temperature of water is approximately 212°F (100°C). This is a standard reference point where water exists just at the brink of boiling at this pressure.

- Properties of Saturated Liquid Water:
Saturated liquid water has specific thermodynamic properties such as specific volume, enthalpy, and entropy. For instance, at 40 psia, the specific volume of saturated liquid water is approximately 0.0179 ft^3/lb, and the enthalpy is around 1050 Btu/lb.

- Initial State Parameters:
- Pressure (P_1): 40 psia
- Temperature (T_1): ~212°F
- Enthalpy (h_1): ~1050 Btu/lb
- Specific volume (v_1): ~0.0179 ft^3/lb

Having this initial state allows us to analyze how heat transfer affects the water's phase and energy content.

Energy Transfer and Its Effects on the System

Heat Addition of 700 Btu

When 700 Btu of heat is added to the saturated liquid water within the piston-cylinder, several possible outcomes depend on the extent of energy added and the system's constraints.

- Frictionless and Quasi-Static Conditions:
Because the piston is frictionless, the process is idealized as quasi-static, meaning the system passes through equilibrium states, allowing us to apply thermodynamic property tables directly.

- Work Interaction:
As heat is added, the water may undergo a phase change from saturated liquid to wet mixture or even become superheated vapor if enough energy is supplied.

- Energy Balance:
The energy added (Q) relates to changes in internal energy, work done, and phase change. Since the piston is frictionless and assumed to be thermally insulated from external forces other than heat transfer, the first law applies as:

$$
Q = \Delta U + W
$$

For a piston with negligible external work (assuming the process occurs at constant pressure), the work done can be expressed as:

$$
W = P \Delta V
$$

However, in many cases, particularly at constant pressure, the focus simplifies to analyzing enthalpy changes.

Analyzing the Process Step-by-Step

Step 1: Determine the Final State of the Water

Given the initial conditions and the heat added, the first step is to determine whether the water remains saturated, becomes a mixture, or transitions to vapor.

- Calculate the Mass of Water:
Suppose the initial volume of water is known or arbitrarily considered. Alternatively, analyze per unit mass for simplicity.

- Calculate the Change in Enthalpy:
The specific enthalpy change per unit mass is:

$$
\Delta h = \frac{Q}{m}
$$

where m is the mass of water.

- Estimate the Final Enthalpy:
The new enthalpy:

$$
h_2 = h_1 + \Delta h
$$

For example, if 1 lb of water receives 700 Btu:

$$
h_2 = 1050 \text{ Btu/lb} + 700 \text{ Btu/lb} = 1750 \text{ Btu/lb}
$$

This value indicates that the water has gained enough energy to transition into a superheated vapor state.

- Identify the Final State from Tables:
Using steam tables, find the state corresponding to 40 psia with an enthalpy of approximately 1750 Btu/lb. This corresponds to superheated water vapor, as saturated vapor at 40 psia has a higher enthalpy (~1150 Btu/lb), so the system is superheated.

Step 2: Determine the Final Temperature and Specific Volume

- Superheated Steam Region:
At a given pressure of 40 psia, superheated steam properties are tabulated for various temperature points.

- Estimate the Final Temperature:
Interpolating from superheated steam tables, an enthalpy of 1750 Btu/lb corresponds to a temperature of approximately 350°F–400°F.

- Final Specific Volume:
The specific volume of superheated vapor at 40 psia and 350°F is roughly 2.7 ft^3/lb, significantly larger than the initial specific volume of saturated liquid.

Implications of the Process and Practical Applications

Phase Change and Energy Transfer

The addition of 700 Btu to the saturated liquid water at 40 psia results in the water transitioning into a superheated vapor state. This process exemplifies how energy input can induce phase change and temperature increase in a controlled manner.

- Phase Transition Analysis:
- Initial state: saturated liquid at 40 psia (~212°F)
- Final state: superheated vapor at approximately 350°F–400°F

- Energy Requirements:
The energy needed to convert the liquid into superheated vapor exceeds the latent heat of vaporization (roughly 970 Btu/lb at 40 psia), indicating that after boiling, additional heat raises the vapor's temperature.

Design and Engineering Considerations

Understanding such thermodynamic processes is essential in designing efficient boilers, turbines, and heat exchangers.

- Efficiency Optimization:
By knowing how much heat input results in phase change and temperature rise, engineers can optimize energy transfer processes.

- Safety and Material Selection:
High-temperature, high-pressure vapor states require materials that withstand extreme conditions, influencing system design.

- Control of Phase and Pressure:
Maintaining desired states involves careful control of pressure, temperature, and heat flow to prevent unwanted phase transitions or system failure.

Conclusion

Analyzing the scenario of a frictionless piston-cylinder containing saturated liquid water at 40 psia with an added 700 Btu of heat illustrates fundamental principles of thermodynamics. The process showcases how energy input leads to phase change from saturated liquid to superheated vapor, with properties such as temperature, specific volume, and enthalpy shifting accordingly. Engineers and thermodynamicists utilize steam tables and property charts to predict these changes accurately, enabling the design of efficient thermal systems. Whether in power plants, refrigeration cycles, or industrial processes, understanding these principles ensures optimized performance and safety in systems involving water and steam under various conditions.

Frequently Asked Questions

What is the initial state of the water in the piston-cylinder device?

The initial state contains saturated liquid water at a pressure of 40 psia.

What does the 700 Btu represent in this process?

The 700 Btu indicates the amount of heat added to or removed from the system during the process.

How can we determine the change in water's state after adding 700 Btu?

By using steam tables or thermodynamic property charts to track the initial state and the heat transfer, we can find the new state of the water.

What phase change occurs if heat is added to saturated liquid water at constant pressure?

The water will begin to vaporize, transitioning from saturated liquid to a mixture of liquid and vapor, or possibly to saturated vapor if enough heat is added.

How does the pressure of 40 psia influence the boiling point of water?

At 40 psia, the saturation temperature of water is approximately 251°F, so boiling occurs at this temperature during the phase change.

What is the significance of the piston being frictionless in this process?

A frictionless piston implies that the process is idealized, with no work losses due to friction, making the analysis based purely on thermodynamic principles more straightforward.

Additional Resources

Piston-Cylinder Device: An In-Depth Analysis of Saturated Liquid Water at 40-psia and 700 Btu

---

Introduction

In the realm of thermodynamics and engineering, piston-cylinder devices stand as fundamental components used for various applications — from testing material properties to simulating real-world processes. Today, we delve into a specific scenario involving a frictionless piston-cylinder system containing saturated liquid water at 40 psia, with an energy transfer of 700 Btu. This case offers rich insights into phase change phenomena, energy interactions, and the behavior of water under controlled conditions.

Understanding this scenario is crucial for engineers, students, and professionals involved in power plant design, refrigeration, and thermal system analysis. It exemplifies core principles such as the first law of thermodynamics, phase equilibrium, and the thermodynamic properties of water.

The System Overview

Frictionless Piston-Cylinder Device

A piston-cylinder device is a closed system where the piston can move freely without friction, allowing for idealized analysis. The key features include:

- Frictionless motion: Ensures that the only forces acting on the piston are pressure forces and gravity (which is often neglected in ideal cases).
- Rigid boundary: The cylinder’s walls are rigid, leading to a fixed volume unless the piston moves.
- Containment of water: The working fluid (water) initially exists as a saturated liquid at a specific pressure.

This setup allows us to analyze how energy transfer influences the phase and state of the water, especially when heat is added or removed.

Initial Conditions: Saturated Liquid Water at 40 psia

Understanding Saturation at 40 psia

- Saturation pressure: The pressure at which water exists as a saturated liquid-vapor mixture at equilibrium.
- At 40 psia (pounds per square inch absolute), the properties of water are well-documented in thermodynamic tables.

Key properties at saturation (approximate):

Property	Value at 40 psia (approximate)
Saturation Temperature	211.9 °F (about 99.9°C)
Specific Enthalpy of Saturated Liquid (hf)	102.0 Btu/lb
Specific Enthalpy of Saturated Vapor (hg)	1152.0 Btu/lb
Specific Volume of Saturated Liquid (vf)	0.01604 ft^3/lb
Specific Volume of Saturated Vapor (vg)	3.23 ft^3/lb

Note: These values are approximate and based on standard steam tables.

The Energy Addition: 700 Btu

The system receives 700 Btu of energy. This energy transfer could be in the form of heat transfer (Q), work transfer (W), or a combination of both, but in a typical piston-cylinder context with a fixed boundary, we often analyze heat transfer into or out of the system.

Assumption: Since the problem specifies an energy transfer amount without explicitly stating the process type, the most common scenario is heat addition at constant pressure, or a process where energy is added as heat, causing phase change or temperature increase.

Thermodynamic Analysis

Step 1: Initial State

- Mass of water (m): The initial state is saturated liquid at 40 psia.
- Initial specific volume (vf): 0.01604 ft^3/lb.
- Initial specific enthalpy (hf): 102.0 Btu/lb.

The initial total internal energy (U) and enthalpy (H) can be expressed as:

- $U_{initial} = m \times u_f$
- $H_{initial} = m \times h_f$

where u_f and h_f are specific internal energy and enthalpy of saturated liquid water.

Step 2: Energy Addition and Its Implications

The key question is: What is the final state of the water after adding 700 Btu?

- Energy per unit mass:

$$
\frac{700\, \text{Btu}}{m} = \Delta h
$$

- The total energy added per unit mass depends on the initial mass, which can be determined if the initial volume or mass is known.

Assumption for simplicity: Let's consider the entire process on a per-pound basis, analyzing what happens when 700 Btu is added to 1 lb of saturated liquid water.

$$
\Delta h = 700\, \text{Btu}
$$

- The initial enthalpy is 102 Btu/lb, so the final specific enthalpy:

$$
h_{final} = h_f + \Delta h = 102 + 700 = 802\, \text{Btu/lb}
$$

Step 3: State Post Energy Addition

Given the final specific enthalpy (h_final), we need to determine the new state:

- Is the water still saturated? Or has it become a mixture or vapor?

- To answer this, compare h_{final} to the saturated enthalpy of vaporization at 40 psia.

From steam tables:

Property	Value at 40 psia
h_f	102.0 Btu/lb
h_g	1152.0 Btu/lb
$h_{fg} = h_g - h_f$	1050 Btu/lb

Since $h_{final} = 802\, \text{Btu/lb}$, it is between h_f and h_g. This indicates that the water has transitioned into a wet mixture, i.e., a mixture of saturated liquid and vapor, with quality x given by:

$$
h_{final} = h_f + x \times h_{fg}
$$

Solving for x:

$$
x = \frac{h_{final} - h_f}{h_{fg}} = \frac{802 - 102}{1050} \approx \frac{700}{1050} \approx 0.6667
$$

This means the final state is approximately 66.67% vapor by mass.

Physical Interpretation of the Process

- The addition of 700 Btu increases the internal energy and enthalpy of the water, causing the liquid to evaporate partially.
- The system transitions from a saturated liquid to a wet vapor mixture.
- The piston responds to pressure and temperature changes, but since the process occurs in a frictionless environment, the pressure remains approximately at saturation pressure (assuming a quasi-static process).

The Final State: Key Properties

Using the quality x, we can now determine other properties:

Property	Calculation / Approximate Value
Specific volume (v)	$v = v_f + x \times v_{fg}$

Where:

- $v_f = 0.01604\, \text{ft}^3/\text{lb}$
- $v_{fg} = v_g - v_f = 3.23 - 0.01604 \approx 3.21396\, \text{ft}^3/\text{lb}$

Thus,

$$
v = 0.01604 + 0.6667 \times 3.21396 \approx 0.01604 + 2.1426 \approx 2.1586\,
\text{ft}^3/\text{lb}
$$

The piston would expand slightly to accommodate the increased volume, assuming the pressure remains constant (or adjusts slightly due to the process).

Practical Implications and Insights

1. Phase Change Dynamics

The analysis highlights how energy input can induce phase change in saturated liquids. In this case, adding 700 Btu to 1 lb of saturated water at 40 psia leads to a two-thirds vapor quality, indicating significant vaporization.

2. Pressure-Temperature Relationship

The system remains at saturation pressure during the process, assuming quasi-static conditions. The temperature corresponds to the saturation temperature at 40 psia (~211.9 °F), unaffected by the phase change unless the pressure varies.

3. Work and Energy Interactions

In a frictionless piston-cylinder:

- Work done by the system: The piston moves outward as vapor quality increases.
- Work done on the system: If the piston is fixed, then no boundary work occurs, and the energy transfer is purely as heat.

If the process allows piston movement:

$$
W_{boundary} = P \times \Delta V
$$

\]

which can be calculated from the change in volume and pressure.

Broader Applications and Significance

This scenario is not just academic; it mirrors real-world systems like:

- Boilers and condensers in power plants, where water undergoes phase changes at controlled pressures.
- Refrigeration cycles, involving saturated liquids and vapors.
- Thermal energy storage, where phase change materials absorb or release heat.

Understanding the thermodynamics of such processes aids in designing efficient systems, optimizing energy transfer, and predicting system behavior under varying operational conditions.

Concluding Remarks

The analysis of a frictionless piston-cylinder containing saturated liquid water at 40 psia with an energy addition of 700 Btu exemplifies core thermodynamic principles. It demonstrates how energy

A Frictionless Piston Cylinder Device Contains Saturated Liquid Water At 40 Psia Pressure Now 700 Btu

A Frictionless Piston Cylinder Device Contains Saturated Liquid Water At 40 Psia Pressure Now 700 Btu

Related Articles

- A Triangle Has Vertices At B(3, 0), C(2, 1), D(1, 2). Which Transformation Would Produce An Image With
- A Flywheel Is Turned On And Attains An Angular Speed Of 45 Revolutions Per Minute In Just 4.10 S. Find
- A Square Is Inscribed In A Circle As Shown Below. The Radius Of The Circle Is Decreasing At A Constant

Back to Home