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Understanding the behavior of humid air is fundamental in fields such as meteorology, environmental science, HVAC engineering, and many industrial processes. When analyzing a sample of air saturated with water vapor at a specific temperature, it's essential to comprehend the partial pressures, humidity ratios, and other thermodynamic properties involved. This article explores the scenario where a sample of air is saturated with water vapor at 65°C, with a total pressure of 850.0 Torr. We will delve into the concepts of partial pressure, saturation vapor pressure, humidity ratio, and related calculations to provide a comprehensive understanding of this system.

Understanding the Basics of Humidity and Air Composition

Before analyzing the specific conditions, it is crucial to grasp the fundamental concepts involved in moist air systems:

What Is Saturated Air?

- Saturated air contains the maximum amount of water vapor it can hold at a given temperature.
- Any additional water vapor will condense into liquid water if the air remains at the same temperature.
- Saturation is characterized by the relative humidity being at 100%.

Partial Pressure and Dalton's Law

- The total pressure of a gas mixture is the sum of the partial pressures of each component.
- Dalton's Law states: \(P_{total} = P_{water vapor} + P_{dry\ air} \).

- Understanding partial pressures helps determine the humidity content of the air sample.

Water Vapor Saturation Pressure

- Saturation vapor pressure is the maximum vapor pressure exerted by water at a specific temperature.

- It increases with temperature, meaning warmer air can hold more water vapor.

- At 65°C, the saturation vapor pressure is known from empirical data or Antoine equations.

Analyzing the Given Conditions

The problem states:
- The air is saturated with water vapor at 65°C.
- The total pressure of the mixture is 850.0 Torr.

From this information, we aim to determine several properties:
- The partial pressure of water vapor.
- The partial pressure of dry air.
- The humidity ratio.
- The dew point (if relevant).
- The implications for real-world applications such as HVAC systems.

Calculating the Saturation Vapor Pressure at 65°C

The saturation vapor pressure at a given temperature is critical for understanding the moisture content in the air.

Empirical Data for Saturation Vapor Pressure

At 65°C, the saturation vapor pressure of water is approximately:

- Using standard tables or Antoine equation: $P_{sat} \approx 197.5$ Torr.

- This value indicates the maximum vapor pressure water can exert at 65°C.

Note: Different data sources may give slightly varying values, but 197.5 Torr is a typical approximation.

Determining Partial Pressures in the Mixture

Since the air is saturated at 65°C, the partial pressure of water vapor is equal to the saturation vapor pressure at that temperature.

Partial Pressure of Water Vapor (P_{water})

- $P_{water} = P_{sat} = 197.5$ Torr

Partial Pressure of Dry Air (P_{dry})

Using Dalton’s Law:

$$
P_{total} = P_{water} + P_{dry}
$$

$$
P_{dry} = P_{total} - P_{water} = 850.0\, \text{Torr} - 197.5\, \text{Torr} = 652.5\, \text{Torr}
$$

This indicates the partial pressure of dry air within the mixture.

Calculating the Humidity Ratio

The humidity ratio (also called mixing ratio) describes the mass of water vapor per unit mass of dry air.

Definition of Humidity Ratio (ω)

$$
\omega = \frac{m_{water\, vapor}}{m_{dry\, air}}
$$

Alternatively, it can be calculated from partial pressures:

$$
\omega = 0.622 \times \frac{P_{water}}{P_{dry}}
$$

\]

Where:
- 0.622 is the ratio of the molecular weight of water vapor (18.015 g/mol) to dry air (28.97 g/mol).

Calculating ω for the Sample

$$
\omega = 0.622 \times \frac{197.5}{652.5} \approx 0.622 \times 0.303 \approx 0.188 \text{ kg water vapor per kg dry air}
$$

This ratio indicates the moisture content relative to dry air in the sample.

Implications of Saturation at 65°C

Understanding the properties of saturated air at this temperature has practical applications:

Relative Humidity

Since the air is saturated:
- Relative humidity (RH) = 100%
- Any cooling of this air below 65°C will cause condensation if the moisture content remains constant.

Potential for Condensation

- If this air cools to a temperature below 65°C, the vapor pressure exceeds the saturation vapor pressure, leading to condensation.
- This principle underpins cloud formation and dew point phenomena.

Application in HVAC and Environmental Control

- Engineers can use these calculations to design dehumidifiers or humidifiers.
- Controlling humidity at specific temperatures ensures comfort, prevents mold growth, and optimizes processes.

Additional Considerations

While the above calculations assume ideal behavior, real-world scenarios may involve deviations:

Non-Ideal Gas Behavior

- At high pressures or specific conditions, real gases deviate from ideality.
- Corrections using Virial equations or other models may be necessary.

Impacts of Pressure Changes

- Elevation and pressure variations alter vapor pressures and humidity ratios.
- Understanding local atmospheric conditions is vital for accurate predictions.

Measurement and Instrumentation

- Devices like hygrometers measure humidity.
- Accurate measurement of partial pressures enables precise control of environmental conditions.

Summary

To summarize:
- A sample of air saturated with water vapor at 65°C and a total pressure of 850.0 Torr contains a water vapor partial pressure of approximately 197.5 Torr.
- The partial pressure of dry air in the mixture is around 652.5 Torr.
- The humidity ratio for this sample is approximately 0.188 kg of water vapor per kg of dry air.
- Recognizing the saturation vapor pressure at specific temperatures allows engineers and scientists to predict condensation, design environmental controls, and understand atmospheric phenomena.

Conclusion

Analyzing saturated air samples involves understanding the interplay between temperature, pressure, and humidity. By calculating the partial pressures and humidity ratios, professionals can make informed decisions in designing systems, predicting weather patterns, or managing environments. The scenario of an air sample saturated at 65°C with a total pressure of 850 Torr exemplifies these principles, illustrating the importance of thermodynamics in real-world applications.

Remember: Precise data and calculations are essential for accurate environmental control and scientific analysis. Always refer to up-to-date vapor pressure tables or empirical equations for the most accurate information in your specific context.

Frequently Asked Questions

What is the significance of air being saturated with water vapor at 65°C?

When air is saturated with water vapor at 65°C, it contains the maximum amount of water vapor possible at that temperature, indicating the relative humidity is 100%, which can lead to condensation if conditions change.

How can we determine the partial pressure of water vapor in the mixture?

The partial pressure of water vapor can be found using the vapor pressure of water at 65°C, which is approximately 20.7 Torr, assuming the air is saturated at that temperature.

What is the partial pressure of dry air in the mixture?

The partial pressure of dry air is the total pressure minus the partial pressure of water vapor: 850.0 Torr - 20.7 Torr = 829.3 Torr.

How does temperature affect the saturation vapor pressure of water?

As temperature increases, the saturation vapor pressure of water also increases, allowing more water vapor to be held in the air before condensation occurs.

Can we determine the humidity ratio from the given data?

Yes, the humidity ratio (mass of water vapor per unit mass of dry air) can be calculated if the vapor pressure and the molecular weights are known, using the formula: (0.622 × vapor pressure) / (total pressure - vapor pressure).

What practical applications relate to understanding saturated air at a specific temperature and pressure?

This knowledge is vital in meteorology, HVAC system design, industrial processes involving humidity control, and predicting condensation or dew formation.

Additional Resources

Understanding the Saturation of Air With Water Vapor at 65°C and Total Pressure of 850.0 Torr

In the realm of thermodynamics and atmospheric sciences, the behavior of water vapor in air is a subject of immense importance. The scenario where a sample of air is saturated with water vapor at a temperature of 65°C and a total pressure of 850.0 Torr provides a rich context to explore concepts like vapor pressure, humidity, and the thermodynamic properties of moist air. This detailed review delves into the fundamental principles involved, calculations, implications, and practical applications associated with such a system.

Fundamental Concepts Involved

Before analyzing the specific scenario, it is essential to understand the core concepts:

1. Saturation and Vapor Pressure

- Saturation refers to the state where the air contains the maximum amount of water vapor it can hold at a given temperature.
- Vapor pressure is the partial pressure exerted by water vapor in the air when the air is saturated.
- At a specific temperature, the vapor pressure of water reaches a characteristic value called the saturation vapor pressure (SVP), which increases with temperature.

2. Partial Pressure and Total Pressure

- The partial pressure of a component is the pressure it would exert if it alone occupied the entire volume at the same temperature.
- The total pressure of a mixture is the sum of the partial pressures of all components, as per Dalton's Law.

3. Humidity and Relative Humidity

- Absolute humidity: The mass of water vapor per unit volume of air.
- Relative humidity (RH): The ratio of the actual vapor pressure to the saturation vapor pressure at a given temperature, expressed as a percentage.
- At saturation, RH = 100%.

Analyzing the Scenario

The scenario specifies:
- The air is saturated with water vapor at 65°C.
- The total pressure of the mixture is 850.0 Torr.

Our goal is to understand what these conditions imply in terms of vapor pressure, partial pressures, humidity, and other thermodynamic quantities.

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1. Vapor Pressure of Water at 65°C

The first step is to determine the saturation vapor pressure of water at 65°C.

- Based on standard reference data (e.g., Antoine equation, steam tables), the saturation vapor pressure of water at 65°C is approximately:

$$
\text{SVP at 65°C} \approx 20.8 \text{ Torr}
$$

This value indicates that when water vapor is at this pressure, the air is saturated at 65°C.

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2. Partial Pressure of Water Vapor in Saturated Air

Since the air is saturated:

$$
P_{water vapor} = \text{SVP at 65°C} = 20.8 \text{ Torr}
$$

Remaining partial pressure is attributable to dry air:

$$
P_{dry\ air} = P_{total} - P_{water vapor} = 850.0 \text{ Torr} - 20.8 \text{ Torr} = 829.2 \text{ Torr}
$$

This partitioning underscores that water vapor constitutes a small fraction of the total pressure, but its thermodynamic impact is significant.

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3. Partial Pressures and Composition

- Percentage of water vapor in the mixture:

$$

\text{Mass or molar fraction depends on partial pressures and molar volumes, but for initial estimation:}
\]

\[
\text{Mole fraction of water vapor } (x_{water}) = \frac{P_{water vapor}}{P_{total}} = \frac{20.8}{850.0} \approx 0.0245 \text{ or } 2.45\%
\]

This indicates that water vapor makes up approximately 2.45% of the molar composition of the moist air.

Implications of Saturation at 65°C

Understanding the equilibrium state at this temperature involves exploring the thermodynamic and psychrometric properties.

1. Humidity and Relative Humidity

- Since the air is saturated, relative humidity is 100%.
- Any cooling below 65°C (without removing water vapor) would cause condensation.
- Conversely, heating the air at this humidity level would decrease relative humidity until it drops below saturation.

2. Dew Point Calculation

- The dew point is the temperature at which water vapor begins to condense.
- Given the vapor pressure is 20.8 Torr at 65°C, the dew point temperature is exactly 65°C.
- Therefore, if this moist air is cooled to below 65°C, condensation will occur.

3. Specific Humidity and Mixing Ratios

- Specific humidity (q): The ratio of the mass of water vapor to the total mass of moist air.
- Mixing ratio (r): The ratio of the mass of water vapor to dry air.

Calculations:

- Molar mass of water vapor \(M_{water} = 18.015 g/mol \)
- Molar mass of dry air \(M_{dry} \approx 29 g/mol \)

Number of moles of water vapor in 1 mol of moist air:

\[

$$
n_{water} = x_{water} \times n_{total} \approx 0.0245 \text{ mol}
$$

Mass of water vapor per mol of moist air:

$$
m_{water} = n_{water} \times M_{water} \approx 0.0245 \times 18.015 \approx 0.441 \text{ g}
$$

Mass of dry air per mol:

$$
m_{dry} = (1 - x_{water}) \times M_{dry} \approx (1 - 0.0245) \times 29 \approx 28.3 \text{ g}
$$

- Specific humidity (q):

$$
q = \frac{m_{water}}{m_{dry} + m_{water}} \approx \frac{0.441}{28.3 + 0.441} \approx 0.0152 \text{ (or 1.52\%)}
$$

- Mixing ratio (r):

$$
r = \frac{m_{water}}{m_{dry}} \approx \frac{0.441}{28.3} \approx 0.0156 \text{ kg water / kg dry air}
$$

This data is vital in HVAC, atmospheric modeling, and meteorology.

Thermodynamic and Psychrometric Considerations

Understanding the thermodynamic behavior of moist air in this scenario involves several key principles.

1. Enthalpy of Moist Air

- The enthalpy of moist air combines the sensible heat of dry air and the latent heat of water vapor:

\[

$$
h = c_{pa} T + r \times L_v
$$

Where:
- c_{pa} = specific heat capacity of dry air (~0.24 kcal/kg·°C),
- T = temperature in °C,
- r = mixing ratio,
- L_v = latent heat of vaporization (~600 kcal/kg at 65°C).

Calculations at 65°C:

$$
h \approx 0.24 \times 65 + 0.0156 \times 600 \approx 15.6 + 9.36 = 24.96 \text{ kcal/kg}
$$

This enthalpy value is crucial in understanding energy transfer processes.

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2. Dew Point and Condensation Risks

- If the moist air cools below 65°C, condensation occurs.
- The dew point temperature can be derived from vapor pressure data using empirical formulas or steam tables.
- At a water vapor pressure of 20.8 Torr, the dew point is roughly 65°C, consistent with the initial temperature.

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3. Psychrometric Charts and Practical Applications

- Psychrometric charts graphically depict relationships among dry bulb temperature, wet bulb temperature, humidity ratio, and enthalpy.
- For this scenario, the point on the chart would be at:
- Dry bulb temperature: 65°C,
- Relative humidity: 100%,
- Specific humidity: approximately 1.52%.

This information guides HVAC engineers in designing systems for humidification, dehumidification, and climate control.

Real-World Applications and Significance

The principles elucidated here are applied across various fields:

1. Meteorology and Climate Science

- Accurate modeling of atmospheric moisture content is essential for weather prediction.
- Understanding saturation points aids in predicting fog formation, cloud development, and precipitation.

2. HVAC and Indoor Air Quality

- Managing indoor humidity levels is critical for comfort and health.
- Systems are designed to prevent condensation and mold growth by controlling temperature and moisture.

3. Industrial Processes

- In industries like pharmaceuticals, food processing, and textiles, controlling humidity ensures product quality.
- Steam generation and humidification processes often operate near saturation conditions.