Calculate The % Relative Humidity Of Air-water Vapor Mixturehaving A Humidity Of 0.0157 At 30 OC And

Calculate The % Relative Humidity Of Air-water Vapor Mixturehaving A Humidity Of 0.0157 At 30 OC And understanding the concept of relative humidity is crucial in various fields such as meteorology, HVAC (heating, ventilation, and air conditioning), agriculture, and environmental science. Relative humidity (RH) indicates how saturated the air is with water vapor relative to the maximum amount it can hold at a specific temperature. In this article, we will explore how to calculate the % relative humidity of an air-water vapor mixture given a specific humidity value at 30°C, providing a comprehensive understanding of the process, relevant formulas, and practical applications.

Understanding Humidity and Its Types

What Is Humidity?

Humidity refers to the amount of water vapor present in the air. It influences weather patterns, comfort levels, and various industrial processes. Humidity can be expressed in several ways:

- **Absolute humidity**: The mass of water vapor per unit volume of air (g/m³).
- **Specific humidity**: The ratio of the mass of water vapor to the total mass of the moist air (kg of vapor / kg of air).
- **Relative humidity**: The ratio of the current vapor pressure to the saturation vapor pressure at a given temperature, expressed as a percentage (%).

What Is Specific Humidity?

Specific humidity (often denoted as q) is particularly relevant here. It is defined as:

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

where:
- $m_{water\,vapor}$ is the mass of water vapor
- $m_{dry\,air}$ is the mass of dry air

Given the specific humidity, we can determine the relative humidity if we know the saturation vapor pressure at the temperature of interest.

Key Concepts and Constants

Before delving into calculations, it’s important to familiarize oneself with certain key concepts:

Saturation Vapor Pressure (P_{vs})

The maximum vapor pressure that air can hold at a specific temperature. It varies with temperature and can be calculated using empirical equations like the Antoine equation or the Tetens equation.

Actual Vapor Pressure (P_{v})

The vapor pressure of water vapor present in the air, which is proportional to the actual humidity.

Temperature at 30°C

Given as the temperature at which the calculations are performed, which influences the saturation vapor pressure.

Constants and Data

For calculations at 30°C, some useful constants are:
- Saturation vapor pressure at 30°C, P_{vs}: approximately 4.24 kPa (or 42.4 mb)
- Universal gas constant and other empirical data may be used for precise calculations if needed.

Calculating the Saturation Vapor Pressure at 30°C

The first step involves determining the saturation vapor pressure (P_{vs}) at 30°C. Various empirical formulas exist; one common approximation is the Tetens equation:

$$
P_{vs} = 0.6108 \times \exp \left(\frac{17.27 \times T}{T + 237.3} \right)
$$

where:
- P_{vs} is in kilopascals (kPa),
- T is in °C.

Applying at $T = 30°C$:

$$
P_{vs} = 0.6108 \times \exp \left(\frac{17.27 \times 30}{30 + 237.3} \right)
$$

Calculating numerator:

$$
17.27 \times 30 = 518.1
$$

Calculating denominator:

$$
30 + 237.3 = 267.3
$$

Now,

$$
\frac{518.1}{267.3} \approx 1.936
$$

Compute exponential:

$$
\exp(1.936) \approx 6.928
$$

Finally,

$$
P_{vs} = 0.6108 \times 6.928 \approx 4.23\, \text{kPa}
$$

This confirms that the saturation vapor pressure at 30°C is approximately 4.23 kPa.

Note: The value aligns with standard data indicating P_{vs} around 4.24 kPa.

Understanding Specific Humidity and Its Relationship to Vapor Pressure

Given a specific humidity ($q = 0.0157$), we need to relate this to vapor pressure. The relationship between specific humidity and vapor pressure is derived from the ideal gas law and the properties of water vapor.

The formula connecting specific humidity q to vapor pressure P_v is:

$$
q = \frac{0.622 \times P_v}{P_{total} - P_v}
$$

where:

- P_{total} is the total atmospheric pressure (usually assumed standard; approximately 101.3 kPa at sea level),
- P_v is the vapor pressure of water vapor.

Rearranged to solve for P_v:

$$
P_v = \frac{q \times P_{total}}{0.622 + q}
$$

Assuming standard atmospheric pressure:

$$
P_{total} = 101.3\, \text{kPa}
$$

Calculate P_v:

$$
P_v = \frac{0.0157 \times 101.3}{0.622 + 0.0157}
$$

Numerator:

$$
0.0157 \times 101.3 \approx 1.59
$$

Denominator:

$$
0.622 + 0.0157 \approx 0.6377
$$

Therefore:

$$
P_v \approx \frac{1.59}{0.6377} \approx 2.49\, \text{kPa}
$$

This is the actual vapor pressure of water vapor in the mixture.

Summary so far:

- Saturation vapor pressure at 30°C, $P_{vs} \approx 4.23\, \text{kPa}$
- Actual vapor pressure, $P_v \approx 2.49\, \text{kPa}$

Calculating the Relative Humidity

Finally, the relative humidity (RH) is given by:

$$
\text{RH} = \frac{P_v}{P_{vs}} \times 100\%
$$

Substituting the values:

$$
\text{RH} = \frac{2.49}{4.23} \times 100\% \approx 58.9\%
$$

Therefore, the % relative humidity of the air-water vapor mixture with a specific humidity of 0.0157 at 30°C is approximately 59%.

Practical Applications and Significance

Understanding how to calculate relative humidity from specific humidity and temperature is vital in numerous practical contexts:

- **Climate Control:** Ensuring indoor environments maintain comfortable humidity levels for health and comfort.
- **Agriculture:** Monitoring humidity to optimize crop growth and prevent diseases caused by overly humid conditions.
- **Weather Forecasting:** Assessing humidity levels helps predict weather patterns, fog formation, and precipitation.
- **Industrial Processes:** Many manufacturing processes require precise humidity control to ensure product quality.
- **HVAC Design:** Engineers use humidity calculations to design systems that regulate indoor air quality effectively.

Conclusion

Calculating the % relative humidity of an air-water vapor mixture involves understanding the relationship between specific humidity, vapor pressure, and saturation vapor pressure at a given temperature. By applying empirical formulas and understanding the thermodynamic principles, one can accurately assess the moisture content of the air. In the specific case of an air-water vapor mixture with a specific humidity of 0.0157 at 30°C, the relative humidity is approximately 59%, indicating the air is somewhat moist but not saturated. Mastery of this calculation is essential for professionals working in meteorology, environmental science, HVAC, and related fields, facilitating better control and understanding of atmospheric and indoor air conditions.

Frequently Asked Questions

What is the formula to calculate the % relative humidity of an air-water vapor mixture?

The % relative humidity is calculated using the formula: (Actual vapor pressure / Saturation vapor pressure) × 100%. Alternatively, if given humidity ratio, temperature, and vapor pressures, you can use these to determine the relative humidity.

How does the given humidity of 0.0157 relate to the vapor pressure in the air-water mixture at 30°C?

The humidity of 0.0157 (humidity ratio) indicates the ratio of the mass of water vapor to dry air. To find vapor pressure, you can use this ratio along with air pressure and temperature data, typically through psychrometric relations.

What is the typical saturation vapor pressure of water at 30°C?

The saturation vapor pressure of water at 30°C is approximately 4.24 kPa (or about 31.8 mm Hg). This value is used as the maximum vapor pressure at that temperature.

How do you calculate the % relative humidity given humidity ratio and temperature?

First, determine the actual vapor pressure from the humidity ratio, then divide it by the saturation vapor pressure at 30°C, and multiply by 100%. This gives the % relative humidity.

What is the significance of knowing the relative humidity in air-water vapor mixtures?

Knowing the relative humidity helps assess comfort levels, predict condensation, and design HVAC systems by understanding moisture content in the air at specific temperatures.

Can the given humidity of 0.0157 be converted directly into % relative humidity at 30°C?

Yes, by calculating the actual vapor pressure from the humidity ratio and dividing it by the saturation vapor pressure at 30°C, then multiplying by 100%, you can determine the % relative humidity.

Additional Resources

Calculate The % Relative Humidity Of Air-Water Vapor Mixture Having A Humidity Of 0.0157 At 30°C And

Understanding the intricacies of humidity measurement is essential across various scientific and industrial applications—from meteorology and HVAC systems to environmental monitoring and process engineering. In this article, we delve into the calculation of the percentage relative humidity of an air-water vapor mixture with a given humidity of 0.0157 at a temperature of 30°C. By exploring the fundamental principles, the necessary formulas, and practical computation steps, we aim to clarify this vital aspect of atmospheric physics in a clear, accessible manner.

What Is Relative Humidity? An Overview

Before we jump into calculations, it's crucial to understand what relative humidity (RH) actually signifies and why it matters.

Definition of Relative Humidity

Relative humidity is the ratio of the current partial pressure of water vapor in the air to the saturation vapor pressure at a given temperature, expressed as a percentage:

$$\text{RH} = \frac{p_{v}}{p_{vs}} \times 100\%$$

Where:
- p_{v} = partial pressure of water vapor in the air
- p_{vs} = saturation vapor pressure at the same temperature

In essence, RH indicates how close the air is to being fully saturated with water vapor. When RH reaches 100%, the air is saturated, and condensation can occur, leading to dew or fog formation.

Significance of Relative Humidity

Understanding RH is vital because:
- It influences weather patterns and climate.
- It affects human comfort and health.
- It impacts industrial processes, such as drying, printing, and manufacturing.
- It determines the likelihood of condensation and corrosion.

Understanding Humidity and Its Measurement

In our scenario, the "humidity" is given as 0.0157. It's important to clarify what this value represents.

Absolute vs. Specific Humidity

- Absolute humidity refers to the mass of water vapor per unit volume of air.
- Specific humidity is the ratio of the mass of water vapor to the total mass of the moist air mixture.
- Humidity ratio (or mixing ratio) indicates the mass of water vapor per unit mass of dry air.

Given the context, the value 0.0157 is most likely the humidity ratio (or mixing ratio), expressed as a unitless ratio or in grams of water vapor per kilogram of dry air.

Note: In many thermodynamic calculations, the humidity ratio ω is used, which is defined as:

$$\omega = \frac{m_{v}}{m_{a}}$$

where:
- m_{v} = mass of water vapor
- m_{a} = mass of dry air

For clarity, we will assume the given value of 0.0157 is the humidity ratio ω.

Key Concepts and Formulas for Calculation

To calculate the relative humidity from the humidity ratio, we need to understand the relationship between these quantities and the vapor pressure.

Relationship Between Humidity Ratio and Vapor Pressure

The humidity ratio ω relates to the partial vapor pressure p_{v} by:

$$\omega = 0.622 \times \frac{p_{v}}{p_{a}}$$

where:
- p_{a} = partial pressure of dry air
- p_{v} = partial pressure of water vapor

Since the total pressure P is the sum of dry air and water vapor pressures:

$$P = p_{a} + p_{v}$$

In typical atmospheric conditions, the partial pressure of dry air p_{a} can be approximated as:

$$p_{a} = P - p_{v}$$

However, for the purpose of calculating relative humidity, it’s more straightforward to relate humidity ratio directly to vapor pressure and saturation vapor pressure.

Saturation Vapor Pressure at 30°C

The saturation vapor pressure p_{vs} at a specific temperature can be obtained using empirical equations. The Antoine equation or the Tetens formula are common choices.

Tetens Equation for p_{vs} (in hPa):

$$p_{vs} = 6.1078 \times 10^{\left(\frac{7.5 T}{T + 237.3}\right)}$$

where T is in °C.

Calculating p_{vs} at 30°C provides the maximum vapor pressure the air can hold before saturation.

Step-by-Step Calculation of Relative Humidity

Let's now proceed through the calculation process systematically.

1. Determine Saturation Vapor Pressure at 30°C

Using the Tetens formula:

$$p_{vs} = 6.1078 \times 10^{\left(\frac{7.5 \times 30}{30 + 237.3}\right)}$$

Calculate the exponent:

$$\frac{7.5 \times 30}{267.3} \approx \frac{225}{267.3} \approx 0.8418$$

Calculate $10^{0.8418}$:

$$10^{0.8418} \approx 6.96$$

Now, compute p_{vs}:

$$p_{vs} = 6.1078 \times 6.96 \approx 42.56 \, \text{hPa}$$

Thus, the saturation vapor pressure at 30°C is approximately 42.56 hPa.

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2. Convert Humidity Ratio to Vapor Pressure

Given $\omega = 0.0157$, and assuming standard atmospheric pressure P is 1013 hPa:

The relation between humidity ratio ω and vapor pressure p_{v}:

$$\omega = 0.622 \times \frac{p_{v}}{p_{a}}$$

Since $p_{a} = P - p_{v}$, rearranged:

$$\omega = 0.622 \times \frac{p_{v}}{P - p_{v}}$$

Solve for p_{v}:

$$p_{v} = \frac{\omega \times P}{0.622 + \omega}$$

Plugging in the values:

$$p_{v} = \frac{0.0157 \times 1013}{0.622 + 0.0157}$$

Calculate denominator:

$$0.622 + 0.0157 = 0.6377$$

Calculate numerator:

$$0.0157 \times 1013 \approx 15.91$$

Now, compute p_{v}:

$$p_{v} = \frac{15.91}{0.6377} \approx 24.97 \, \text{hPa}$$

The partial vapor pressure of water vapor in the mixture is approximately 24.97 hPa.

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3. Calculate Relative Humidity

Now, using the definition:

$$\text{RH} = \frac{p_{v}}{p_{vs}} \times 100\%$$

Substitute the known values:

$$ \text{RH} = \frac{24.97}{42.56} \times 100\% $$

Calculate the ratio:

$$ \frac{24.97}{42.56} \approx 0.587 $$

Finally:

$$ \text{RH} \approx 0.587 \times 100\% = 58.7\% $$

Therefore, the relative humidity of the air-water vapor mixture at 30°C with a humidity ratio of 0.0157 is approximately 58.7%.

Implications and Practical Significance

Understanding that the relative humidity is roughly 59% at 30°C provides valuable insight into the atmospheric conditions. Such a humidity level suggests fairly moist air, which can influence various processes:

- Weather Prediction: Humidity levels contribute to cloud formation and precipitation forecasts.
- Indoor Air Quality: Maintaining optimal humidity (typically 30-50%) is crucial for comfort and health; knowing the current RH helps in managing humidifiers or dehumidifiers.
- Industrial Processes: Moisture content affects drying times, chemical reactions, and equipment longevity.

Additional Considerations and Assumptions

While the above calculations are robust, some assumptions are inherent:

- The total atmospheric pressure is assumed to be 1013 hPa, standard sea-level pressure.
- The humidity ratio provided (0.0157) is interpreted as the mixing ratio.
- The empirical formulas used for vapor pressure estimation are approximate; more precise methods or tables can improve accuracy.
- Temperature stability is assumed; fluctuations can affect vapor pressure and humidity.

Conclusion

Calculating the relative humidity of an air-water vapor mixture involves understanding the relationship between vapor pressure, saturation vapor pressure, and humidity ratio. Using standard formulas like the Tetens equation and simple algebraic rearrangements, we find that a mixture with a humidity ratio of 0.0157 at 30°C has an approximate relative humidity of 59%. This

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