Determine The Vapor Pressure Of An Aqueous Ethylene Glycol (C2H6O2) Solution That Is 14.8 % C2H6O2 By

Determine The Vapor Pressure Of An Aqueous Ethylene Glycol (C2H6O2) Solution That Is 14.8 % C2H6O2 By composition involves understanding the principles of vapor pressure, Raoult’s law, and the properties of the solvent and solute involved. Ethylene glycol (C2H6O2), a common antifreeze agent, forms solutions with water that exhibit vapor pressures deviating from that of pure water. Calculating the vapor pressure of such a solution requires a detailed analysis of the molar composition, the vapor pressures of the pure components, and the application of colligative property principles. This article provides an in-depth explanation of the steps and concepts involved in determining this vapor pressure.

Understanding Vapor Pressure and Its Significance

What Is Vapor Pressure?

Vapor pressure is the pressure exerted by a vapor in thermodynamic equilibrium with its condensed phases (liquid or solid) at a given temperature. It reflects the tendency of molecules to escape from the liquid phase into the vapor phase. When a liquid is exposed to its vapor, molecules continuously evaporate and condense, and the vapor pressure is the steady-state pressure exerted by the vapor.

Factors Affecting Vapor Pressure

- Temperature: As temperature increases, vapor pressure rises exponentially.
- Nature of the solvent: Different liquids have characteristic vapor pressures.
- Presence of solutes: Non-volatile solutes lower vapor pressure; volatile solutes can increase it.

Raoult’s Law and Its Role

Raoult’s law states that the vapor pressure of a solvent in a solution (P_solution) is proportional to the mole fraction of the solvent (X_solvent) and the vapor pressure of the pure solvent (P°_solvent):

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P_solution = X_solvent P°_solvent
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For solutions involving a volatile solute, modifications are necessary, but for dilute solutions involving non-volatile solutes like ethylene glycol, Raoult’s law provides a solid foundation.

Properties of Ethylene Glycol and Water

Vapor Pressure of Pure Components

At a standard temperature (e.g., 25°C), the vapor pressures are approximately:
- Pure Water: P°_water ≈ 23.8 mm Hg
- Pure Ethylene Glycol: P°_ethylene glycol ≈ 0.06 mm Hg

These values are temperature-dependent, so accurate calculations require the vapor pressure data at the specific temperature of interest.

Molecular Weights and Molar Masses

- Water (H_2O): 18.015 g/mol
- Ethylene Glycol ($C_2H_6O_2$): 62.068 g/mol

Knowing the molar masses helps convert mass percentages to mole fractions, which are essential in applying Raoult’s law.

Calculating the Composition of the Solution

Mass Percent to Molar Fractions

Given:
- Ethylene glycol: 14.8%
- Water: 85.2% (since total is 100%)

Assuming 100 g of solution:
- Mass of ethylene glycol = 14.8 g
- Mass of water = 85.2 g

Calculate moles of each component:
- Moles of ethylene glycol:

```plaintext
n_EG = 14.8 g / 62.068 g/mol ≈ 0.2385 mol
```

- Moles of water:
```plaintext
n_water = 85.2 g / 18.015 g/mol ≈ 4.727 mol
```

Total moles in the solution:
```plaintext
n_total = 0.2385 + 4.727 ≈ 4.9655 mol
```

Mole fraction of ethylene glycol:
```plaintext
X_EG = n_EG / n_total ≈ 0.2385 / 4.9655 ≈ 0.048
```

Mole fraction of water:
```plaintext
X_water = 1 - X_EG ≈ 0.952
```

Applying Raoult’s Law to Calculate Vapor Pressure

Vapor Pressure of the Solution

Using Raoult’s law:
```plaintext
P_solution = X_water P°_water + X_EG P°_ethylene_glycol
```

Since ethylene glycol has a negligible vapor pressure at room temperature, its contribution is minimal, but for completeness, include it:
```plaintext
P_solution ≈ 0.952 23.8 mm Hg + 0.048 0.06 mm Hg
```

Calculations:
```plaintext
P_solution ≈ (0.952 23.8) + (0.048 0.06)
P_solution ≈ 22.66 + 0.0029 ≈ 22.66 mm Hg
```

Therefore, the vapor pressure of the aqueous solution is approximately 22.66 mm Hg at 25°C.

Factors Influencing the Accuracy of the Calculation

Temperature Dependence

Vapor pressures are highly temperature-dependent. The values used here are at 25°C; for other temperatures, vapor pressures of pure water and ethylene glycol need to be adjusted using empirical data or Antoine equations.

Non-Ideal Solution Behavior

Ethylene glycol and water form nearly ideal solutions, but deviations can occur due to intermolecular interactions, hydrogen bonding, or specific solution behavior. Activity coefficients (γ) may be introduced to correct for non-ideality:

```plaintext
P_solution = γ_water X_water P°_water
```

In dilute solutions, γ is often close to 1, but for more precise calculations, activity coefficients should be considered.

Impact of Ethylene Glycol’s Low Vapor Pressure

Given that ethylene glycol’s vapor pressure is extremely low, its influence on the total vapor pressure is minimal. However, in solutions with higher glycol concentrations, its contribution becomes more significant and requires more complex models.

Advanced Considerations and Corrections

Using Activity Coefficients for Non-Ideal Solutions

To refine the vapor pressure calculation, experimental data or models such as Margules, Van Laar, or Wilson equations can be used to estimate activity coefficients:

- Activity (a): $a_i = \gamma_i X_i$
- Modified Raoult’s Law:
```plaintext
P_solution = a_water P°_water
```

Applying these corrections allows for more accurate predictions, especially at higher solute concentrations.

Temperature Adjustment Using Antoine Equation

The Antoine equation relates vapor pressure to temperature:

```plaintext
log P° = A - (B / (C + T))
```

Where:
- P° is vapor pressure in mm Hg
- T is temperature in °C
- A, B, and C are substance-specific constants

Using this equation, vapor pressures at different temperatures can be accurately calculated, allowing for temperature-dependent analyses.

Summary and Final Remarks

Calculating the vapor pressure of an aqueous ethylene glycol solution involves understanding the solution’s composition, applying Raoult’s law, and considering the properties of the individual components. For a solution with 14.8% ethylene glycol by mass at 25°C, the approximate vapor pressure is around 22.66 mm Hg, primarily dictated by the water vapor pressure and the mole fraction of water.

This process underscores the importance of:
- Accurate measurement of component vapor pressures
- Precise calculation of mole fractions
- Considering solution non-ideality for refined results
- Adjusting calculations for temperature variations

By mastering these principles, scientists and engineers can predict and manipulate vapor pressures in various industrial and scientific applications, including cooling systems, antifreeze formulations, and chemical process design.

In conclusion, understanding and calculating vapor pressure in complex solutions like aqueous ethylene glycol solutions is essential for optimizing their performance and ensuring safety in practical applications.

Frequently Asked Questions

How do you determine the vapor pressure of an aqueous ethylene glycol solution that is 14.8% C2H6O2 by weight?

To determine the vapor pressure, first find the mole fraction of ethylene glycol using its mass percentage and molar mass, then apply Raoult's Law by multiplying the mole fraction by the vapor pressure of pure water at the given temperature.

What is the significance of the 14.8% C2H6O2 by weight in calculating vapor pressure?

The 14.8% by weight indicates the concentration of ethylene glycol in the solution, which is essential for calculating the mole fraction of each component, a key step in determining the vapor pressure via Raoult's Law.

How do temperature variations affect the vapor pressure of an aqueous ethylene glycol solution?

Vapor pressure increases with temperature for any solution. To accurately determine vapor pressure, the temperature at which the measurement is taken must be specified, as it influences the vapor pressure of water and the solution's overall vapor pressure.

What is Raoult's Law and how is it used in calculating the vapor pressure of the solution?

Raoult's Law states that the vapor pressure of a solvent in an ideal solution is proportional to its mole fraction and the vapor pressure of the pure solvent. It is used by multiplying the mole fraction of water by the vapor pressure of pure water at the given temperature to find the solution's vapor pressure.

How do you calculate the mole fraction of ethylene glycol in the solution?

Calculate moles of ethylene glycol and water using their masses and molar masses, then divide the moles of ethylene glycol by the total moles of both components to find its mole fraction.

What are typical vapor pressure values of pure water at common temperatures, and how do they influence the calculation?

For example, pure water has a vapor pressure of approximately 23.8 mmHg at 20°C and 760 mmHg at 100°C. These values are used in Raoult's Law to determine the vapor pressure of the solution based on water's mole fraction.

Why is it important to consider deviations from ideality when calculating vapor pressure for this solution?

Ethylene glycol and water form near-ideal solutions over certain concentration ranges, but deviations can occur, affecting vapor pressure calculations. If significant deviations are expected, activity coefficients should be used to obtain more accurate results.

Additional Resources

Determine The Vapor Pressure Of An Aqueous Ethylene Glycol (C2H6O2) Solution That Is 14.8% C2H6O2 By

Understanding the vapor pressure of solutions, particularly aqueous mixtures like ethylene glycol and water, is fundamental in chemical engineering, environmental science, and industrial applications. Ethylene glycol ($C_2H_6O_2$) is widely used as an antifreeze agent, coolant, and in various manufacturing processes. Calculating its vapor pressure when mixed with water at specific concentrations provides insights into its volatility, evaporation rate, and thermodynamic properties. In this article, we will delve into the methods for determining the vapor pressure of a 14.8% ethylene glycol solution, exploring the theoretical background, practical calculation steps, and the implications of these values.

Introduction to Vapor Pressure and Its Significance

Vapor pressure is a fundamental property indicating how readily a liquid evaporates into the vapor phase at a given temperature. It is influenced by molecular interactions, temperature, and the composition of the solution. For mixtures like ethylene glycol and water, the vapor pressure depends on the individual vapor pressures of each component and their interactions within the solution.

Knowing the vapor pressure helps in designing cooling systems, predicting evaporation losses, assessing environmental impacts, and understanding phase equilibria. When dealing with solutions of ethylene glycol in water, the vapor pressure determines how much vapor is generated at a certain temperature, which is essential for safety and efficiency in industrial processes.

Understanding the Composition of the Solution

The problem specifies a solution that is 14.8% ethylene glycol by weight. To analyze this solution, it’s crucial to understand its composition in terms of molar ratios, which directly influence vapor pressure calculations.

Calculating Masses and Moles

Suppose we take 100 g of the solution:

- Mass of ethylene glycol ($C_2H_6O_2$): 14.8 g
- Mass of water: 85.2 g

Molar masses:

- Ethylene glycol: approximately 62.07 g/mol
- Water: approximately 18.015 g/mol

Number of moles:

- Ethylene glycol: 14.8 g / 62.07 g/mol ≈ 0.2387 mol
- Water: 85.2 g / 18.015 g/mol ≈ 4.727 mol

Total moles: ≈ 0.2387 + 4.727 ≈ 4.966 mol

Mole fraction of ethylene glycol:

- $X_{C_2H_6O_2} = \frac{0.2387}{4.966} \approx 0.048$

Mole fraction of water:

- $X_{H_2O} = 1 - 0.048 = 0.952$

This mole fraction will be used in Raoult’s law calculations.

Raoult’s Law and Ideal Solution Assumption

To estimate vapor pressure, Raoult’s law is often employed, which states:

$$P_{solution} = X_{component} \times P_{pure\, component}$$

Where:

- $P_{solution}$: vapor pressure of the component in the solution
- $X_{component}$: mole fraction of the component
- $P_{pure\, component}$: vapor pressure of the pure component at the same temperature

For the aqueous ethylene glycol solution, the total vapor pressure is primarily influenced by water’s vapor pressure and the extent to which ethylene glycol suppresses it.

Features of Raoult’s Law:

- Assumes ideal solution behavior (no significant interactions beyond those in pure components)
- Valid at low to moderate concentrations
- Easier to apply at standard laboratory conditions

Limitations:

- Deviations occur at high concentrations or with strong intermolecular interactions
- Ethylene glycol-water mixtures often show non-ideal behavior, requiring correction factors

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Vapor Pressure Data for Pure Components

To proceed, we need the vapor pressures of pure water and pure ethylene glycol at the temperature of interest. Assuming standard room temperature (25°C):

- Vapour pressure of water at 25°C: approximately 23.8 mm Hg
- Vapour pressure of ethylene glycol at 25°C: approximately 0.06 mm Hg

These values highlight significant differences in volatility; water is much more volatile than ethylene glycol.

Calculating the Vapor Pressure of the Mixture

Based on Raoult’s law, the vapor pressure over the solution primarily depends on water, as ethylene glycol's vapor pressure is negligible at room temperature.

Step-by-step Calculation:

1. Estimate the partial vapor pressure of water:

$$ P_{H_2O} = X_{H_2O} \times P_{H_2O}^{pure} $$

$$ P_{H_2O} = 0.952 \times 23.8\, \text{mm Hg} \approx 22.66\, \text{mm Hg} $$

2. Account for non-idealities:

Since ethylene glycol interacts with water, the activity coefficients might differ from unity, especially at higher concentrations. For dilute solutions (~14.8%), Raoult’s law is a reasonable approximation.

3. Total vapor pressure:

Given the negligible vapor pressure of ethylene glycol at 25°C, the total vapor pressure is approximately equal to the vapor pressure of water in the mixture:

$$ P_{total} \approx P_{H_2O} \approx 22.66\, \text{mm Hg} $$

Temperature Dependence and Corrections

Vapor pressure is strongly temperature-dependent, following the Antoine equation:

$$ \log_{10} P^{pure} = A - \frac{B}{C + T} $$

Where:

- P^{pure}: vapor pressure in mm Hg
- T: temperature in °C
- A, B, C: Antoine constants specific to each component

For water at 25°C:

- $A = 8.07131$
- $B = 1730.63$
- $C = 233.426$

Using these constants, the vapor pressure can be calculated more precisely at temperatures other than 25°C.

Note: For ethylene glycol, similar constants exist but are less commonly used due to its low vapor pressure.

Implications of the Vapor Pressure Calculation

Calculating the vapor pressure informs various industrial and safety considerations:

- Evaporation Rate: Lower vapor pressures mean slower evaporation, which is desirable in cooling applications.
- Boiling Point Adjustment: The presence of ethylene glycol elevates boiling points, affecting heat transfer processes.
- Vapor-Liquid Equilibrium: Understanding the vapor pressure helps in designing distillation or separation processes.
- Environmental Impact: Lower volatility reduces emissions, an essential factor in environmental safety.

Pros and Cons of Using Raoult’s Law for this Calculation

Pros:

- Simplicity: Easy to apply with readily available data
- Suitable for dilute solutions where non-ideal effects are minimal
- Provides quick estimates essential in preliminary analyses

Cons:

- Ignores non-ideal interactions, which can be significant at higher concentrations
- Less accurate for solutions with strong intermolecular forces or complex compositions
- Assumes complete miscibility and ideal mixing behavior

Conclusion and Final Remarks

Determining the vapor pressure of an aqueous ethylene glycol solution at 14.8% concentration involves understanding the solution composition, applying Raoult’s law, and considering temperature effects. At standard room temperature, the vapor pressure is approximately 22.66 mm Hg, primarily dictated by water’s volatility and suppressed by the presence of ethylene

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glycol. For more precise and application-specific calculations, incorporating
activity coefficients and temperature-dependent vapor pressure data through
Antoine equations or experimental measurements is recommended.

The knowledge gained from such calculations is vital in optimizing industrial
processes, ensuring safety standards, and minimizing environmental impacts.
While simplified models like Raoult’s law provide valuable initial estimates,
real-world systems often require more detailed thermodynamic modeling to
account for non-idealities and complex interactions within the solution.

Additional Resources:
- Antoine constants for water and ethylene glycol
- Experimental vapor pressure data at various temperatures
- Advanced thermodynamic models for non-ideal solutions

In summary, understanding and calculating vapor pressure for ethylene glycol-
water mixtures is essential for practical applications, and the approach
outlined here offers a solid foundation for further exploration and detailed
analysis.
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