Calculate The Final Temperature, The Work Done, And The Change Of Internal Energy When Ammonia Is Used

Calculate The Final Temperature, The Work Done, And The Change Of Internal Energy When Ammonia Is Used

Understanding the thermodynamic behavior of ammonia during various processes is essential in fields such as refrigeration, chemical engineering, and thermodynamics education. When ammonia undergoes a thermodynamic process—such as compression, expansion, or heating—it experiences changes in temperature, internal energy, and performs work. Accurately calculating these parameters helps engineers design efficient systems and better understand ammonia's properties as a working fluid. This article provides a comprehensive guide to calculating the final temperature, work done, and change of internal energy when ammonia is involved in a thermodynamic process.

Understanding Ammonia's Thermodynamic Properties

Before diving into calculations, it is crucial to understand the basic properties of ammonia (NH_3), a common refrigerant and industrial chemical. Ammonia exhibits both gaseous and liquid behaviors depending on temperature and pressure, and its thermodynamic properties can be obtained from standard tables or property charts.

Key Properties of Ammonia

- Molecular weight: 17.03 g/mol
- Critical temperature: 132.4°C (405.5 K)
- Critical pressure: 11.3 MPa
- Normal boiling point: –33.3°C at 1 atm
- Specific heats:
- c_p (constant pressure): approximately 4.7 kJ/kg·K
- c_v (constant volume): approximately 3.8 kJ/kg·K

Note: These values vary slightly depending on temperature and pressure, so for precise calculations, refer to detailed ammonia thermodynamic tables.

Fundamental Concepts and Assumptions

When analyzing thermodynamic processes involving ammonia, several assumptions simplify the calculations:

- Ideal Gas Behavior: For many processes, ammonia can be approximated as an ideal gas, especially at high temperatures and low pressures.
- Constant Specific Heats: Assume c_p and c_v are constant over the temperature range.
- Process Type: The process could be isothermal, adiabatic, isobaric, or polytropic. The process type affects the calculations.
- Closed System: No mass enters or leaves the system during the process.

Calculating Final Temperature of Ammonia

The final temperature after a thermodynamic process depends on the initial conditions and the nature of the process.

1. Isobaric Process (Constant Pressure)

In an isobaric process, the pressure remains constant. The relationship between initial and final states is:

$$
Q = m c_p (T_{2} - T_{1})
$$

where:
- Q = heat added or removed
- m = mass of ammonia
- c_p = specific heat at constant pressure
- T_1 = initial temperature
- T_2 = final temperature

If heat transfer is known, compute T_2:

$$
T_2 = T_1 + \frac{Q}{m c_p}
$$

Example:

Suppose 1 kg of ammonia at 20°C (293 K) absorbs 50 kJ of heat at constant pressure:

$$
T_2 = 293 + \frac{50}{1 \times 4.7} \approx 293 + 10.64 \approx 303.64\, \text{K}
$$

---

2. Isothermal Process (Constant Temperature)

In an ideal gas, the temperature remains unchanged during an isothermal process:

$$
T_2 = T_1
$$

However, work and internal energy change depend on the process specifics.

---

3. Adiabatic Process (No Heat Transfer)

For an adiabatic process involving an ideal gas:

$$
T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\kappa - 1}{\kappa}}
$$

where:
- P_1, P_2 = initial and final pressures
- $\kappa = c_p / c_v$ = heat capacity ratio (~1.23 for ammonia)

Example:

If ammonia expands adiabatically from 10 MPa to 2 MPa, initial temperature 300 K:

$$
T_2 = 300 \times \left(\frac{2}{10} \right)^{\frac{1.23 - 1}{1.23}} \approx 300 \times (0.2)^{0.195} \approx 300 \times 0.659 \approx 197.7\, \text{K}
$$

Calculating Work Done During the Process

The work done by or on ammonia during a thermodynamic process is a critical parameter, especially in power cycles.

1. Work in an Isothermal Process

For an ideal gas undergoing an isothermal process:

$$
W = nRT \ln \left(\frac{P_1}{P_2} \right)
$$

Expressed per unit mass:

$$
W = c_v T \ln \left(\frac{P_1}{P_2} \right)
$$

Note: Negative work indicates work done on the fluid (compression), positive indicates work done by the fluid (expansion).

---

2. Work in an Adiabatic Process

For adiabatic processes:

$$
W = \frac{P_1 V_1 - P_2 V_2}{\kappa - 1}
$$

Expressed in terms of pressure and temperature:

$$
W = \frac{c_p}{\kappa - 1} (T_1 - T_2)
$$

Alternatively, using the ideal gas law:

$$
W = m R T_1 \frac{1 - \left(\frac{P_2}{P_1} \right)^{\frac{\kappa - 1}{\kappa}}}{\kappa - 1}
$$

---

3. General Approach for Work Calculation

- Determine the process type.
- Use appropriate formulas to calculate work.
- Ensure units are consistent (e.g., SI units).

Calculating Change of Internal Energy

The change in internal energy (ΔU) depends on the heat added or removed and the work done:

$$
\Delta U = Q - W
$$

For ideal gases:

$$
\Delta U = m c_v (T_2 - T_1)
$$

Example:

If 1 kg of ammonia heats from 293 K to 303 K:

$$
\Delta U = 1 \times 3.8\, \text{kJ/kg·K} \times (303 - 293) = 3.8 \times 10 = 38\, \text{kJ}
$$

Practical Calculation Example: Ammonia Compression Cycle

Suppose we analyze an ammonia compression process in a refrigeration cycle:

- Initial state: $P_1 = 2\, \text{MPa}$, $T_1 = 300\, \text{K}$
- Final state: $P_2 = 8\, \text{MPa}$
- Assume adiabatic compression.

Step 1: Calculate Final Temperature

$$
T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\kappa - 1}{\kappa}} = 300 \times \left(\frac{8}{2} \right)^{\frac{0.23}{1.23}} \approx 300 \times 4^{0.187} \approx 300 \times 1.66 \approx 498\, \text{K}
$$

Step 2: Calculate Work Done

$$
W = \frac{c_p}{\kappa - 1} (T_2 - T_1) = \frac{4.7}{0.23} \times (498 - 300) \approx 20.43 \times 198 \approx 4046\, \text{kJ}
$$

Step 3: Calculate Change of Internal Energy

$$
\Delta U = m c_v (T_2 - T_1) = 1 \times 3.8 \times 198 \approx 752\, \text{kJ}
$$

Interpretation:

- The work input to compress ammonia from 2 MPa to 8 MPa at constant entropy results in a significant increase in temperature and internal energy.
- These calculations inform equipment design, energy efficiency analysis, and safety considerations.

Additional Considerations for Accurate Calculations

- Use Accurate Property Data: Rely on detailed ammonia thermodynamic tables or software for precise property values at specific states.
- Account for Non-Ideal Behavior: At high pressures or low temperatures, ammonia deviates from ideal gas behavior; consider real gas equations of state.
- Process Irreversibilities: Real processes involve irreversibilities; adjustments may be necessary for real-world applications.
- Software Tools

Frequently Asked Questions

How do you determine the final temperature when

ammonia undergoes a thermodynamic process?

The final temperature can be calculated using the first law of thermodynamics, considering the initial temperature, heat transfer, work done, and the specific heat capacity of ammonia during the process.

What is the formula to calculate the work done when ammonia expands or compresses?

The work done (W) is calculated using $W = P\Delta V$ for constant pressure processes or $W = \int PdV$ for variable pressure, where P is pressure and V is volume change of ammonia.

How can the change in internal energy of ammonia be determined after a process?

The change in internal energy (ΔU) can be found using $\Delta U = Q - W$, where Q is the heat added or removed, and W is the work done by or on the system.

What thermodynamic data is necessary to accurately calculate the final temperature of ammonia?

You need the initial temperature, specific heat capacity at constant pressure or volume, initial state properties, and details of heat transfer or work involved during the process.

In what scenarios is the work done by ammonia considered positive or negative?

Work done by ammonia is positive during expansion (system does work on surroundings) and negative during compression (work is done on the system).

Can the change in internal energy be zero during an ammonia process? Under what conditions?

Yes, if the process is an ideal isothermal process where temperature remains constant, the internal energy change is zero because internal energy depends only on temperature.

What role do thermodynamic tables or equations of state play in calculating the properties of ammonia?

They provide essential data such as specific heats, enthalpy, and internal energy at various temperatures and pressures, enabling accurate calculation of temperature changes, work, and internal energy variations.

How does the phase of ammonia affect the calculations of temperature, work, and internal energy change?

The phase (liquid, vapor, or mixed) influences the thermodynamic properties used in calculations. For example, phase changes involve latent heat and require different approaches, such as using phase diagrams or specific data for each phase.

What assumptions are typically made when calculating thermodynamic changes in ammonia processes?

Common assumptions include ideal gas behavior, constant specific heats, no heat loss to surroundings, and reversible processes unless specified otherwise, to simplify calculations.

Additional Resources

Calculate The Final Temperature, The Work Done, And The Change Of Internal Energy When Ammonia Is Used

Understanding the thermodynamic behavior of ammonia during various processes is critical across industries, including refrigeration, heat pumps, and chemical manufacturing. When ammonia undergoes a thermodynamic process—be it expansion, compression, or phase change—key parameters such as final temperature, work done, and change in internal energy become essential for evaluating efficiency, safety, and design optimization. This article aims to provide a comprehensive analysis of these parameters, integrating fundamental principles with practical calculations to elucidate the thermodynamic characteristics of ammonia during such processes.

Introduction to Thermodynamic Properties of Ammonia

Ammonia (NH_3) is a widely used refrigerant and industrial chemical owing to its favorable thermodynamic properties. Its relatively high latent heat of vaporization, favorable pressure-temperature relationship, and environmental benefits make it a preferred choice in several applications. To analyze the thermodynamic changes during a process involving ammonia, one must understand its properties in various phases—liquid, vapor, or mixture—and how these properties vary with temperature and pressure.

Key properties of ammonia include:

- Critical temperature: approximately 132.4°C (405.5 K)
- Critical pressure: about 11.3 MPa
- Specific heats: varies with temperature and phase
- Vapor pressure curve: delineates the boiling point at different pressures
- Enthalpy of vaporization: approximately 1370 kJ/kg at boiling point

These properties are tabulated in refrigerant tables and thermodynamic data sources, which are indispensable for precise calculations.

Understanding the Thermodynamic Process Involving Ammonia

The process involving ammonia could be a simple idealized cycle, such as an idealized expansion or compression, or a more complex process involving phase change, heat transfer, and work interactions. For our analysis, we assume a typical process where ammonia undergoes a reversible expansion or compression between two states, with known initial conditions (pressure and temperature) and process parameters.

Common scenarios include:

- Isothermal expansion or compression
- Isochoric (constant volume) or isobaric (constant pressure) heating or cooling
- Isentropic (adiabatic and reversible) compression or expansion
- Non-ideal processes involving phase change

The key parameters to compute are:

1. Final temperature (T_2): The temperature after the process
2. Work done (W): The work exchanged with surroundings
3. Change in internal energy (ΔU): The internal energy difference between initial and final states

Each parameter depends on initial and final conditions, thermodynamic process path, and ammonia's properties.

Calculating the Final Temperature of Ammonia

Overview

The final temperature after a thermodynamic process involving ammonia can be derived from the principles of conservation of energy and the known process parameters. The specific approach depends on the process type (e.g., isentropic, isothermal, adiabatic).

1. Using Thermodynamic Tables and Data

Most accurate calculations involve referencing ammonia’s thermodynamic tables or software tools such as REFPROP or NIST databases. These tables provide enthalpy (h), entropy (s), specific volume (v), and internal energy (u) at various states.

2. For Idealized Processes

- Isentropic Process (reversible adiabatic expansion/compression):

The relation between initial and final states is based on entropy remaining constant:

$$
s_1 = s_2
$$

Using the initial state (pressure P_1, temperature T_1), find the entropy s_1. Then, at the final pressure P_2, locate the temperature T_2 where the entropy matches s_1. This often requires iterative lookup or interpolation within the tables.

- Constant Pressure or Volume Processes:

Use the respective enthalpy or internal energy data:

$$
T_2 = \text{interpolated from tables at } P_2 \text{ with known } h_2 \text{ or } u_2
$$

3. Example Calculation

Suppose ammonia initially at:

- $P_1 = 2\, \text{MPa}$
- $T_1 = 20^\circ C$ (293 K)

Under an idealized isentropic expansion to:

- $P_2 = 0.5\, \text{MPa}$

Using ammonia tables:

- Find s_1 at initial state.
- Locate the state at $P_2 = 0.5\, \text{MPa}$ with entropy $s_2 = s_1

\).

Interpolating from the tables gives the final temperature T_2.

Note: The actual numerical value depends on the specific data tables used.

Calculating the Work Done During the Process

Fundamental concept

The work done by or on ammonia during a thermodynamic process can be calculated using the first law of thermodynamics:

$$
W_{12} = \int_{1}^{2} P\, dV
$$

For practical purposes, especially with real gases, the work is often computed via:

$$
W_{12} = h_2 - h_1 - T_{avg}(s_2 - s_1)
$$

where:

- h_1, h_2: specific enthalpies at initial and final states
- s_1, s_2: specific entropies
- T_{avg}: average temperature during the process (for approximate calculations)

1. Work in Isentropic Processes

In a reversible adiabatic process:

$$
W_{12} = h_1 - h_2
$$

assuming the process is between two states with known enthalpies.

2. Work in Non-Isentropic Processes

For processes involving heat transfer or irreversibilities, additional data is required, including heat transfer rates and entropy production.

3. Numerical Calculation Example

Continuing the previous example, suppose:

- h_1 at initial state: 1.5 kJ/kg·K
- h_2 at final state: 1.2 kJ/kg·K

Then:

$$
W_{12} = h_1 - h_2 = 1.5 - 1.2 = 0.3\, \text{kJ/kg}
$$

This represents the work done during the process per unit mass of ammonia.

Calculating the Change of Internal Energy (ΔU)

The internal energy change is a core thermodynamic parameter reflecting the energy stored within the ammonia molecules due to their kinetic and potential energy.

$$
\Delta U = u_2 - u_1
$$

where u_1 and u_2 are the specific internal energies at initial and final states, respectively.

1. Using Tables

Similar to enthalpy, the internal energy values are obtained from thermodynamic tables:

- Find u_1 at the initial state.
- Find u_2 at the final state.

2. Relation to Work and Heat

From the first law:

$$
\Delta U = Q - W
$$

where:

- Q: heat exchanged with surroundings
- W: work done by the system

For adiabatic processes, $Q=0$, so:

$$
\Delta U = -W
$$

meaning the energy change equals the negative of work done.

3. Example Calculation

Suppose:

- $u_1 = 400\, \text{kJ/kg}$
- $u_2 = 350\, \text{kJ/kg}$

Then:

$$
\Delta U = 350 - 400 = -50\, \text{kJ/kg}
$$

indicating a decrease in internal energy, consistent with energy being converted into work or transferred as heat.

Impact of Phase Changes and Real-World Limitations

Real processes involving ammonia are often complicated by phase changes, especially in refrigeration cycles. During vaporization or condensation, the temperature remains nearly constant at the saturation temperature for the given pressure, and the enthalpy change corresponds to the latent heat.

Key considerations include:

- Phase equilibrium: Ensuring the process remains within the stable phase region
- Superheating or subcooling: Deviations from saturation temperature affecting energy calculations
- Irreversibilities: Real processes are not perfectly reversible, leading to entropy generation and efficiency losses

In practical applications, engineers use detailed cycle models incorporating real fluid properties, pressure drops, heat transfer efficiencies, and component characteristics.

Conclusion and Practical Significance

The calculation of the final temperature, work done, and internal energy change when ammonia is used in a thermodynamic process provides invaluable insights into system performance, efficiency, and design considerations. Accurate assessments rely heavily on detailed thermodynamic data and understanding the process path.

Implications for industry include:

- Design optimization: Minimizing energy consumption by understanding work interactions
- Safety considerations: Ensuring temperature and pressure stay within safe operational limits
- Environmental impact: Efficient cycles reduce energy use and greenhouse gas emissions

Calculate The Final Temperature The Work Done And The Change Of Internal Energy When Ammonia Is Used

Calculate The Final Temperature The Work Done And The Change Of Internal Energy When Ammonia Is Used

Related Articles

- Consider The Appearance And Meaning Of Various Symbols Used By The Early Christians. Why Did They Need
- Debugging Of Your Textbook Lists Three Possibilities To Consider If A Function Is Not Working.Describe
- Draw The Long Run Trade Off Between Inflation And Unemployment. Explain How The Short Run And Long Run

Back to Home