ESO 201A: Thermodynamics

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Energy Analysis of Closed Systems: part 5

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Learning objective

- Examine the moving boundary work or $P\,dV$ work commonly encountered in reciprocating devices such as automotive engines and compressors.
- Identify the first law of thermodynamics as simply a statement of the conservation of energy principle for closed (fixed mass) systems.
- Develop the general energy balance applied to closed systems.
- Define the specific heat at constant volume and the specific heat at constant pressure.
- Relate the specific heats to the calculation of the changes in internal energy and enthalpy of ideal gases.
- Describe incompressible substances and determine the changes in their internal energy and enthalpy.
- Solve energy balance problems for closed (fixed mass) systems that involve heat and work interactions for general pure substances, ideal gases, and incompressible substances.

Specific heat relation of ideal gases

$$h = u + RT$$

$$dh = du + R\,dT$$

$dh = c_p dT$ and $du = c_v dT$

The relationship between c_p, c_v and R

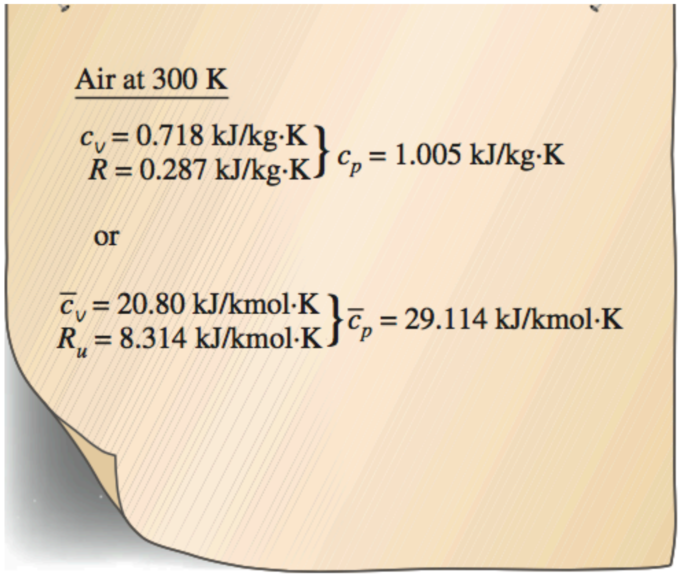
$$c_p = c_v + R \quad \text{(kJ/kg·K)}$$

On a molar basis

$$\bar{c}_p = \bar{c}_v + R_u \quad \text{(kJ/kmol·K)}$$

$$k = \frac{c_p}{c_v}$$

Specific heat ratio



The c_p of an ideal gas can be determined from a knowledge of c_v and R.

- The specific ratio varies with temperature, but this variation is very mild.
- For monatomic gases (helium, argon, etc.), its value is essentially constant at 1.667.
- Many diatomic gases, including air, have a specific heat ratio of about 1.4 at room temperature.

Example

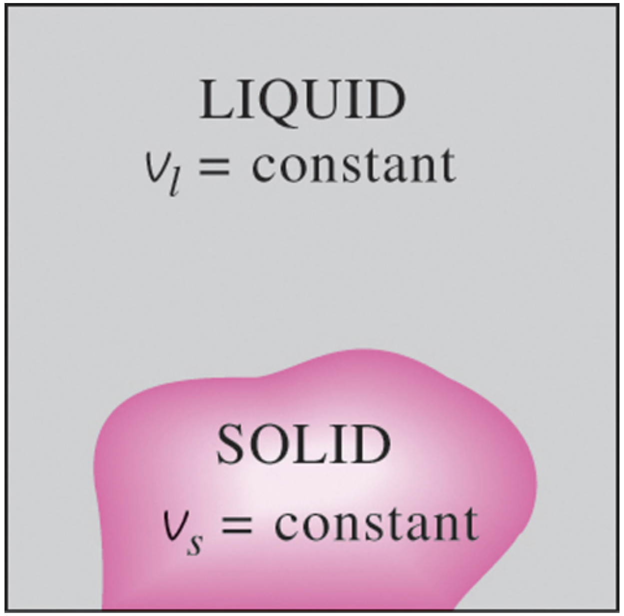
Calculate the change of enthalpy as 1 kg of oxygen is heated from 300 to 1500 K. Assume ideal-gas behavior.

Example

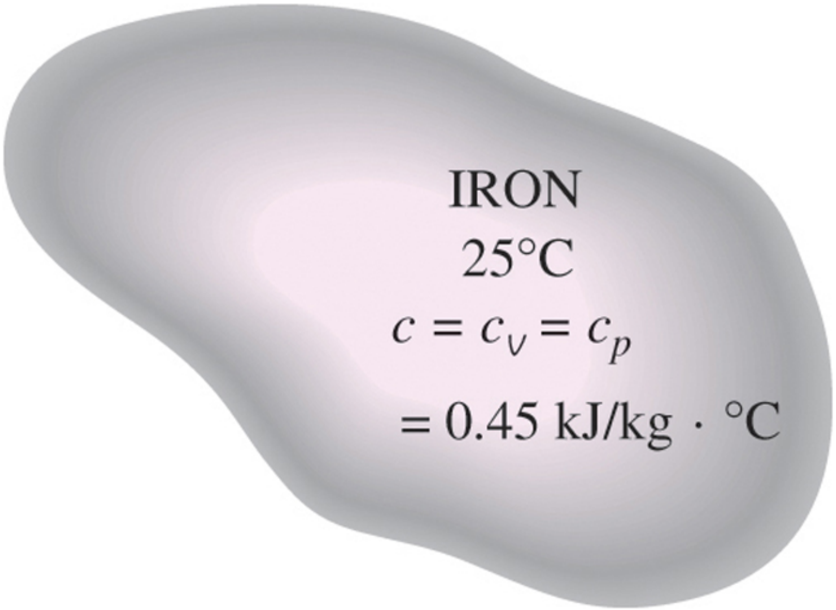
A cylinder fitted with a piston has an initial volume of 0.1 m^3 and contains nitrogen at 150 kPa, 25 ^oC. The piston is moved, compressing the nitrogen until the pressure is 1 MPa and the temperature is 150 ^oC. During this compression process heat is transferred from the nitrogen, and the work done on the nitrogen is 20 kJ. Determine the amount of this heat transfer.

Internal energy, enthalpy and specific heats of solids and liquids

Incompressible substance: A substance whose specific volume (or density) is constant. Solids and liquids are incompressible substances.



The specific volumes of incompressible substances remain constant during a process.



The c_v and c_p values of incompressible substances are identical and are denoted by c.

Internal energy changes for incompressible substance

$$du = c_v\, dT = c(T)\, dT$$

Depends on T only

$$\Delta u = u_2 - u_1 = \int_1^2 c(T)\, dT \quad \text{(kJ/kg)}$$

$$\Delta u \cong c_{avg}(T_2 - T_1)$$

Enthalpy Changes

$$h = u + Pv$$

$$dh = du + v\, dP + P\, d\overset{0}{v} = du + v\, dP$$

$$\Delta h = \Delta u + v\, \Delta P \cong c_{avg}\, \Delta T + v\, \Delta P \quad \text{(kJ/kg)}$$

For solids

$v\ \Delta P$ is insignificant and thus $\Delta h = \Delta u \cong c_{avg} \Delta T.$

Internal energy changes for incompressible substance

Enthalpy Changes for liquid

$$\Delta h = \Delta u + v\,\Delta P \cong c_{avg}\,\Delta T + v\,\Delta P \qquad (\text{kJ/kg})$$

For liquids, two special cases are commonly encountered:

1. Constant-pressure processes, as in heaters ($\Delta P = 0$): $\Delta h = \Delta u \cong c_{avg}\Delta T$
2. Constant-temperature processes, as in pumps ($\Delta T = 0$): $\Delta h = v\,\Delta P$

$$h_{@\,P,T} \cong h_{f\,@\,T}$$

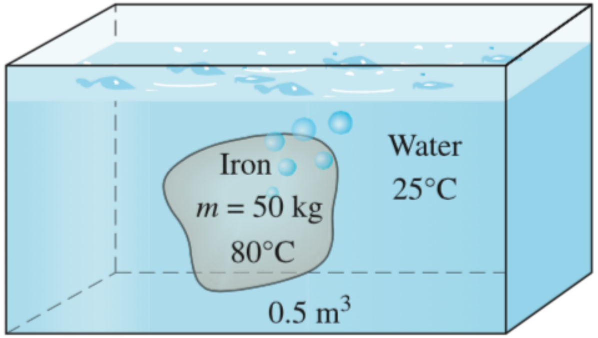
The enthalpy of a compressed liquid

$$h_{@P,T} \cong h_{f\,@\,T} + v_{f\,@\,T}(P - P_{sat\,@\,T})$$

A more accurate relation than

Example

A 50-kg iron block at 80°C is dropped into an insulated tank that contains 0.5 m^3 of liquid water at 25°C. Determine the temperature when thermal equilibrium is reached.



Example

Summary

- Moving boundary work
  - W_b for an isothermal process
  - W_b for a constant-pressure process
  - W_b for a polytropic process
- Energy balance for closed systems
  - Energy balance for a constant-pressure expansion or compression process
- Specific heats
  - Constant-pressure specific heat, c_p
  - Constant-volume specific heat, c_v
- Internal energy, enthalpy, and specific heats of ideal gases
  - Specific heat relations of ideal gases
- Internal energy, enthalpy, and specific heats of incompressible substances (solids and liquids)