

CH365 Chemical Engineering Thermodynamics

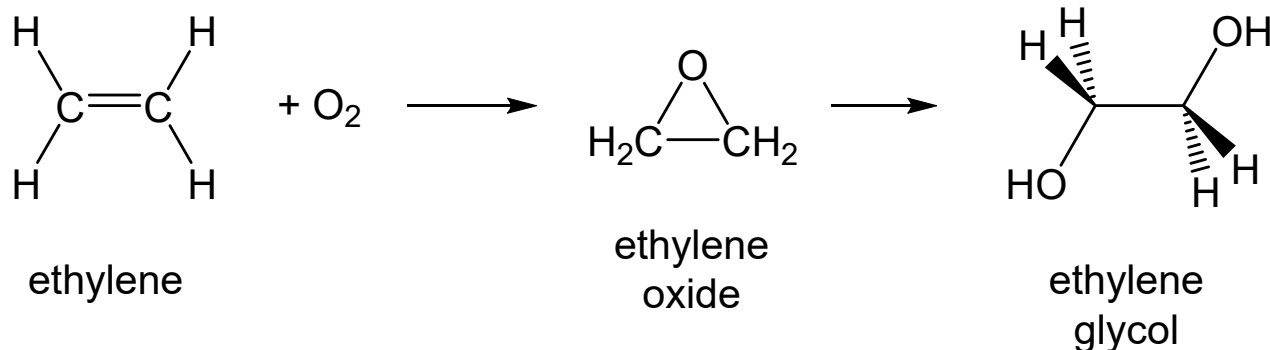
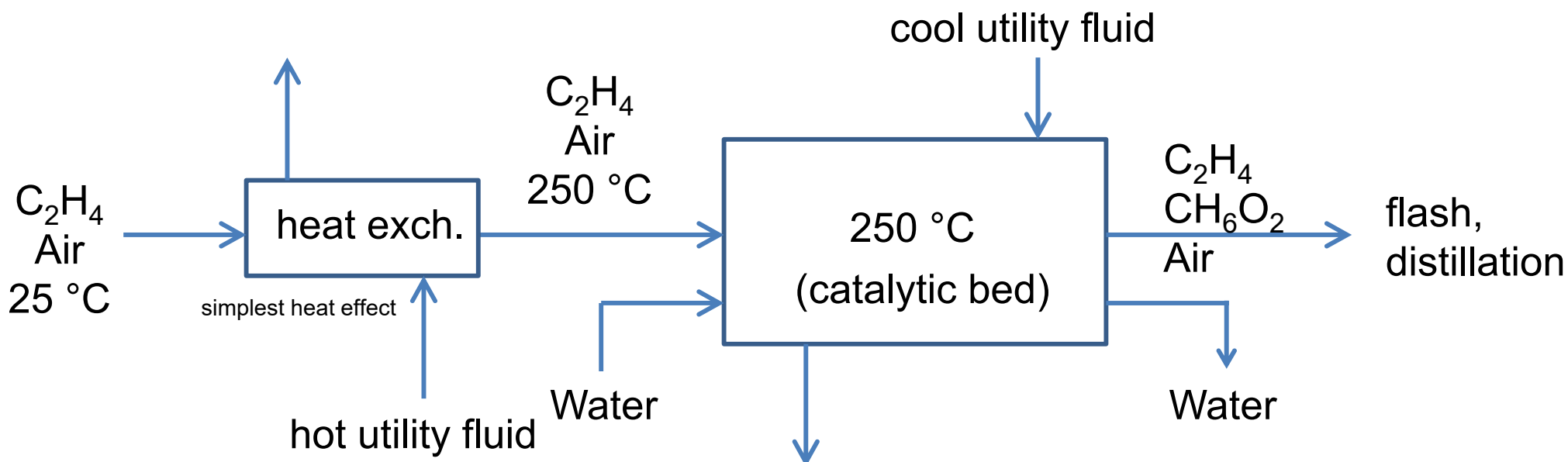
Lesson 16 Sensible Heat Effects

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Ethylene Glycol Process

- Sensible heat effects are associated with temperature change
- Latent heat (phase changes) – no temperature change
- Heat of Reaction
- Heat of Mixing

Example: Manufacture of Ethylene Glycol – Chapter 4 Intro



“Sensible” Heat Effects

Sensible = No phase transitions, no chemical reactions, and no change in composition.

$$U = U(T, V)$$

Total differential introduced
in L10, Slide 7, page 138

$$dU = \left(\frac{\partial U}{\partial T} \right)_V dT + \left(\frac{\partial U}{\partial V} \right)_T dV$$

0 for constant volume process,
ideal gases, or incompressible fluids

Departure of real gases
from “ig” above several
bars. Still good estimate.

$$\frac{C_V^{\text{ig}}}{R} = \frac{C_P^{\text{ig}}}{R} - 1 \quad \text{Eq. 4.6}$$

dimensionless

L11, Slide 8

$$dU = C_V dT$$

Eq. 4.1

$$Q = \Delta U = \int_{T_1}^{T_2} C_V dT$$

$Q = \Delta U$ for mechanically reversible, constant
volume process (why? $\Delta U = Q + W$)

$$H = H(T, P)$$

0 for constant pressure process,
ideal gases or approximately for real
gases at high T and low P

$$C_{P,\text{mixture}}^{\text{ig}} = y_A C_{P_A}^{\text{ig}} + y_B C_{P_B}^{\text{ig}} + \dots \quad \text{Eq. 4.7}$$

$$dH = \left(\frac{\partial H}{\partial T} \right)_P dT + \left(\frac{\partial H}{\partial P} \right)_T dP$$

Need $C_P(T)$

$$\frac{C_P^{\text{ig}}}{R} = A + BT + CT^2 + DT^{-2} \quad \text{Eq. 4.5}$$

(constitutive – CH485)
(dimensionless)

L11, Slide 3

$$dH = C_P dT$$

Eq. 4.2

$$Q = \Delta H = \int_{T_1}^{T_2} C_P dT \quad \text{Eq. 4.3}$$

steady-flow heat transfer

$Q = \Delta H$ for mechanically reversible, constant
pressure closed-system processes or when ΔE_K ,
 ΔE_P , and $W_s = 0$ in H-form of 1st Law eq 2.31

$$\Delta H + \frac{\Delta(u^2)}{2} + g\Delta z = Q + W_{\text{shaft}}$$

Mean Heat Capacity

Integral evaluated forms – “user-defined functions” – simplifies working with mixtures

These forms are used in later derivations in the textbook.

ICPH:
$$\int_{T_0}^T \frac{C_P}{R} dT = A(T - T_0) + \frac{B}{2}(T^2 - T_0^2) + \frac{C}{3}(T^3 - T_0^3) + D\left(\frac{T - T_0}{T \cdot T_0}\right) \quad \text{Eq. 4.8}$$

$$\Delta H = \text{ICPH} \cdot R$$

$$\int_{T_0}^T \frac{C_P}{R} dT = \left[A + \frac{B}{2}(T + T_0) + \frac{C}{3}(T^2 + T_0^2 + T \cdot T_0) + \frac{D}{T \cdot T_0} \right] (T - T_0)$$

MCPH:
$$\frac{\langle C_P \rangle_H}{R} = \left[A + \frac{B}{2}(T + T_0) + \frac{C}{3}(T^2 + T_0^2 + T \cdot T_0) + \frac{D}{T \cdot T_0} \right] \quad \text{Eq. 4.9}$$

$\langle C_P \rangle_H$ is the **mean heat capacity**.

$$\Delta H = \langle C_P \rangle_H (T - T_0) \quad \text{Eq. 4.9}$$

$$\Delta H = \text{MCPH} \cdot R \cdot (T - T_0)$$

Ideal Gas Heat Capacity in Simulators

Improved function – used in professional simulators such as CC and Aspen+

F. A. Aly and L. L. Lee, "Self-Consistent Equations for calculating the Ideal Gas Heat Capacity, Enthalpy, and Entropy," *Fluid Phase Equilibria*, 1981, Vol. 6, Issues 3-4, pp. 169-179.

a, b, c, d & e are constants published and maintained by DIPPr (link on course web site).

**Needed in Capstone
CHEMCAD**

$$C_p = C_p(T) = a + b \cdot \left(\frac{c/T}{\text{Sinh}[c/T]} \right)^2 + d \cdot \left(\frac{e/T}{\text{Cosh}[e/T]} \right)^2$$

hyperbolic sine hyperbolic cosine

The image shows a sequence of three software windows from the CC/DIPPr simulator:

- Component List:** A window showing a list of components. "1 (62) Water" is selected. A blue arrow points to the "View/Edit" button at the bottom.
- View/Edit Component Data:** A window with a sidebar menu. A blue arrow points to "Heat Capacity Data" in the sidebar.
- Library Heat Capacity Data:** A window for editing data for "Water" (Component ID: 62).
 - Ideal Gas Heat Capacity (J/kmol-K):** The "Equation No." field is circled in red and contains the value "107".
 - Liquid Heat Capacity (J/kmol-K):** The "Equation No." field contains the value "100".
 - Solid Heat Capacity (J/kmol-K):** The "Equation No." field contains the value "100".
 - Coefficients:** A red circle highlights the coefficient input fields for the Ideal Gas section (A: 33359, B: 26798, C: 2609.3, D: 8888, E: 1167.6).

CC/DIPPr eq 107 found here

Ideal Gas Heat Capacity in Simulators

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Needed in Capstone

Aspen+

$$C_p = C_p(T) = a + b \cdot \left(\frac{c/T}{\sinh[c/T]} \right)^2 + d \cdot \left(\frac{e/T}{\cosh[e/T]} \right)^2$$

hyperbolic sine
hyperbolic cosine

The screenshot shows the Aspen+ software interface. The top toolbar includes buttons for 'Retrieve Parameters' and 'Copy to Input'. The 'Results - Pure Components' window is open, showing the 'T-Dependent' tab. The 'CPIGDP-1' parameter is selected. A table of heat capacity values for Methane, Ethane, and Propane is displayed, with the values for Element 1 circled in red.

| Component | METHANE | ETHANE | PROPANE |
|-------------------|----------|----------|----------|
| Temperature units | K | K | K |
| Source | PURE37 | PURE37 | PURE37 |
| Property units | J/KMOL-K | J/KMOL-K | J/KMOL-K |
| Element 1 | 33298 | 44256 | 59474 |
| Element 2 | 79933 | 84737 | 126610 |
| Element 3 | 2086.9 | 872.24 | 844.31 |
| Element 4 | 41602 | 67130 | 86165 |
| Element 5 | 991.96 | 2430.4 | 2482.7 |
| Element 6 | 50 | 298.15 | 298.15 |
| Element 7 | 1500 | 1500 | 1500 |

Aspen+/DIPPr eq 107 found here

Homework

Problem 4.5

How much heat is required when 10,000 kg of CaCO_3 is heated at atmospheric pressure from 50 deg C to 880 deg C?

Solve by three methods: (a) direct integration of C_p polynomial, (b) ICPH, and (c) MCPH

Express all answers in MJ.

Submission in Mathematica Required

Problem 4.9

A process stream is heated as a gas from 25 deg C to 250 deg C at constant P. A quick estimate of the energy requirement is obtained from Eq. 4.3, with C_p taken as constant and equal to its value of 25 deg C. Is the estimate of Q likely to be low or high? Why?

Submission in Mathematica Required.

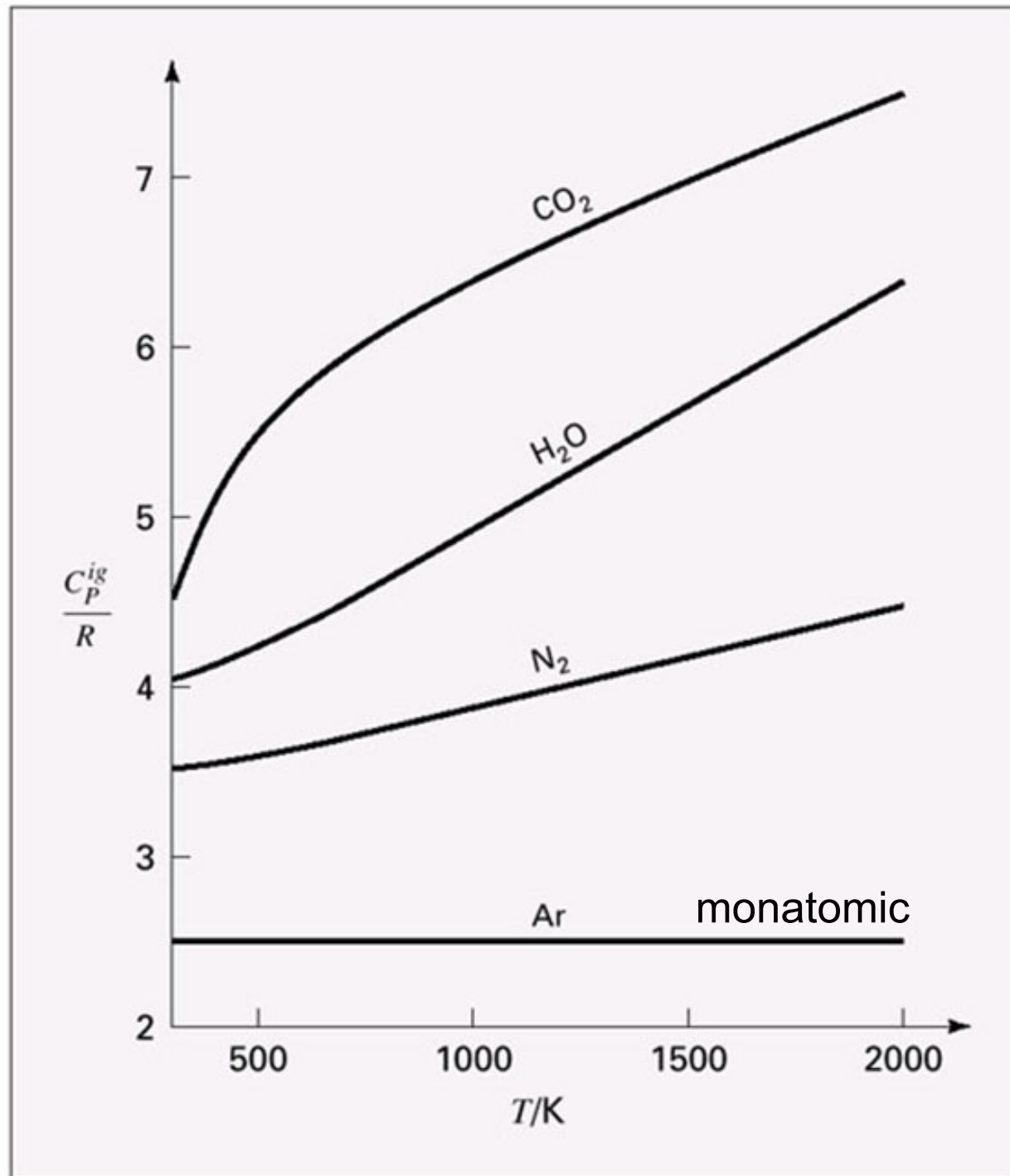


Figure 4.1. Ideal-gas heat capacities of argon, nitrogen, water, and carbon dioxide.