CEN 202 Thermodynamics

Introduction to Chemical Engineering Thermodynamics

CHAPTER 2

2.8 Heat Capacity

Gases, liquids and solids have capacity for heat. A heat capacity might be defined as:

$$C \equiv \frac{dQ}{dT}$$

Heat Capacity at Constant Volume

Defined as: $C_V \equiv \left(\frac{\partial U}{\partial T}\right)_V$ → $dU = C_V dT$

For mechanically reversible, constant-volume process $Q = \Delta U = \int_{T_1}^{T_2} C_V dT$

Heat Capacity at Constant Pressure: $C_P \equiv \left(\frac{\partial H}{\partial T}\right)_P$ → $dH = C_P dT$

For mechanically reversible, constant-pressure process: $Q = \Delta H = \int_{T_1}^{T_2} C_P dT$

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CHAPTER 2

2.9 MASS AND ENERGY BALANCES FOR OPEN SYSTEMS

Open systems are characterised by flowing treams:

- Mass flow rate, $\dot{m}$
- Molar flow rate, $\dot{n}$
- Volumetric flow rate, q
- Velocity, u

The measures of flow are interrelated:

$\dot{m} = M\dot{n}$ and $q = uA$

M: molar mass; A: the cross sectional area for flow

$\dot{m} = uA\rho$; $\dot{n} = uA\rho$

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CHAPTER 2: Mass Balance for Open Systems

The mass balance is expressed mathematically by:

$$\frac{dm_{CV}}{dt} + \Delta(\dot{m})_{fs} = 0$$

The second term is:

$$\Delta(\dot{m})_{fs} = \dot{m}_3 - \dot{m}_1 - \dot{m}_2$$

Δ signifies the difference between exit and entrance flows, fs: all flowing streams.

$$\frac{dm_{CV}}{dt} + \Delta(\rho u A)_{fs} = 0$$

For steady-state flow processes, accumulation term of this equation is zero,

$$\Delta(\rho u A)_{fs} = 0$$

$$\dot{m} = const = \rho_2 u_2 A_2 = \rho_1 u_1 A_1$$

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CHAPTER 2: The General Energy Balance

Because energy, like mass, is conserved, the rate of change of energy within the control volume equals the net rate of energy transfer into the control volume. Each unit mass of a stream carries with it a total energy;

$$U + \frac{1}{2}u^2 + zg$$

where u is the average velocity of the stream, z is its elevation above a datum level, and g is the local acceleration of gravity. Thus, each stream transports energy at the rate;

$$\left(U + \frac{1}{2}u^2 + zg\right)\dot{m}$$

The net energy transported into the system by the flowing streams is therefore

$$-\Delta\left[\left(U + \frac{1}{2}u^2 + zg\right)\dot{m}\right]_{fs}$$

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CHAPTER 2: The General Energy Balance

Where the effect of the minus sign with "Δ" is to make the term read inlet-out.

$$\frac{d(mU)_{CV}}{dt} = -\Delta\left[\left(U + \frac{1}{2}u^2 + zg\right)\dot{m}\right]_{fs} + \dot{Q} + work\,rate$$

Including shaft work and work done on the system

$$\frac{d(mU)_{CV}}{dt} = -\Delta\left[\left(U + \frac{1}{2}u^2 + zg\right)\dot{m}\right]_{fs} + \dot{Q} - \Delta[(PV)\dot{m}]_{fs} + \dot{W}$$

Remember: H=U+PV

$$\frac{d(mU)_{CV}}{dt} = -\Delta\left[\left(H + \frac{1}{2}u^2 + zg\right)\dot{m}\right]_{fs} + \dot{Q} + \dot{W}$$

$$\frac{d(mU)_{CV}}{dt} + \Delta\left[\left(H + \frac{1}{2}u^2 + zg\right)\dot{m}\right]_{fs} = \dot{Q} + \dot{W}$$

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CHAPTER 2: The General Energy Balance

For many (but not all) applications, kinetic and potential energy changes in the flowing streams are negligible and the equation then simplifies to:

$$\frac{d(mU)_{CV}}{dt} + \Delta(H\dot{m})_{fs} = \dot{Q} + \dot{W}$$

$$\frac{d(mU)_{CV}}{dt} + \Delta\left[\left(H + \frac{1}{2}u^2 + zg\right)\dot{m}\right]_{fs} = \dot{Q} + \dot{W}$$

Accumulation term is zero, and the work of the process is only shaft work, $\dot{W}_s$;

$$\Delta\left[\left(\boldsymbol{H}+\frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{u}^{\mathbf{2}}+\boldsymbol{zg}\right)\dot{\boldsymbol{m}}\right]_{\boldsymbol{fs}}=\dot{\boldsymbol{Q}}+\dot{\boldsymbol{W}}_{\boldsymbol{s}}$$

For single stream;

$$\Delta\left(H+\frac{1}{2}u^2+zg\right)\dot{m}=\dot{Q}+\dot{W}_s$$

Division by $\dot{m}$ gives

$$\Delta\left(H+\frac{1}{2}u^2+zg\right)=\frac{\dot{Q}}{\dot{m}}+\frac{\dot{W}_s}{\dot{m}}=Q+W_s$$

$$\Delta H+\frac{1}{2}\Delta u^2+g\Delta z=Q+W_s$$

This equation is the mathematical expression of the first law for a steady state, steady flow process between one entrance and one exit. Omitting kinetic and potential energy terms;

$$\Delta H=Q+W_s$$