Review Sheet

Thursday, April 30, 2020 11:55 AM

Exergy

- energy available to do work
- can be used to produce work or be "wasted"/destroyed

Dead State (State of Environment)

- If something is at the dead state, you cannot use it to produce work

Exergy of a Closed System

$$X = (U-U_0) + P_0(V-V_0) - T_0(S-S_0)$$

Volume / Entropy at dead state T_0, P_0

In theory, KE and PE can be converted completely to work

$$X = (U-U_0) + P_0(V-V_0) - T_0(S-S_0) + m\frac{V^2}{2} + mgz$$

add KE and PE terms

Relationship to Entropy Generation

$$X_{des} = T_0 \cdot S_{gen}$$

– holds for any system

SSSF systems

Specific reversible work = change in flow exergy

$$\psi_1 - \psi_2 = (h_1 - h_2) - T_0(s_1 - s_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2)$$

- can be negative but just because formula assumes direction
- exergy as a concept must always be ≥ 0

Associated w/ Heat Flow

$$\Delta X = Q\left(1 - \frac{T_0}{T}\right)$$

[illegible]

Exergy Balance of SSSF or for a general system

$$\dot{X}_{in} = \underbrace{\dot{X}_{out}}_{T_0 \cdot S_{gen}} + \dot{X}_{destroyed} \qquad \dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroyed} = \Delta X_{system}$$

- can be referenced to as lost work / irreversibility

Second Law Efficiency

- performance of a device relative to its performance under fully reversible conditions

Fridges/Heat Pumps: $\eta_{II} = \frac{COP}{COP_{rev}} =$

Work Consuming: $\eta_{II} = \frac{W_{rev}}{W_a}$

Work Producing: $\eta_{II} = \frac{W_a}{W_{rev}}$

Heat engines: $\eta_{II} = \frac{\eta_{TH}}{\eta_{TH, rev}}$

$$\eta_{II} = 1 - \frac{\text{Exergy destroyed}}{\text{Exergy or Work Used}}$$

Gas Power Cycles

Otto Cycle, spark-ignition internal combustion engine

1) Intake of Air/Fuel mix
2) Compression
3) Ignition and Expansion
4) Exhaust State

Idealize cycle w/ isochoric heating, isentropic expansion/compression, isochoric cooling
Cold air standard (temp independent specific heat)
ignore combustion products

Efficiency of Cold air-standard Otto

$$\eta = 1 - \frac{1}{r^{k-1}}$$

$k = \frac{C_p}{C_v}$

$r =$ compression ratio $= \frac{V_{max}}{V_{min}}$

Vmin

Diesel Engine

- no spark, ignition due to high compression
- difference from Otto is heat is added at constant P not V

ICE Model: Dual Cycle (More Realistic)

- incorporates both isochoric and isobaric heating

Atkinson Cycle (More efficient, Prius)

- longer expansion

Stirling Engine

- external combustion engine

Brayton Cycle

Ideal Reversible Brayton Cycle

1-2 Isentropic Compression (compressor)
2-3 Constant Pressure heating
3-4 Isentropic expansion (turbine)
4-1 Constant Pressure heat rejection

— area in T-S diagram is heat interaction

Pressure Ratio $r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}$

Efficiency of Brayton Cycle: $\eta = \frac{W_{net}}{q_{in}} = 1 - \frac{1}{r_p^{(k-1)/k}}$

Gas → Electric Power Plants

- use Brayton cycle

Regeneration

- combustion products from exit of turbine heat compressed air before combustion chamber (less q_{in} required)

Intercooling / Reheating

- intercool between compressor, reheat between turbines

Airplanes

- mostly use a version of Brayton Cycle

Diffuser → compressor → Burner → Turbine → Nozzle

1→2 2→3 3→4 4→5 5→6

Turbojet, $\dot{W}_{compressor} = \dot{W}_{turbine}$ } turbine solely powers compressor

Turboprop engines

- extra energy from turbine used to drive a large fan
  - more efficient than turbojets at low speeds / altitudes

Turbofan

- combination of turbo prop and turbojet
- some thrust from nozzle, some from fan

Rankine Cycle

- model of steam engine

Ideal SSSF Rankine Cycle

① Pump $q = 0$ $w_{pump} = h_2 - h_1$] - Reversible pumping of an incompressible liquid is Δh or $(P_2 - P_1)v$

② Boiler $q_{in} = h_3 - h_2$ $w = 0$

③ Turbine $q = 0$ $w_{out} = h_3 - h_4$

④ Condenser $q_{out} = h_4 - h_1$ $w = 0$

Combined Cycles

- combine Rankine Cycle with Brayton Gas Cycle
- exhaust gas heat water in boiler
  - what modern natural gas power plants use (CCGT)

Cogeneration of H/P

- use excess heat for space heating

Utilization $\epsilon_u = \frac{\dot{W}_{net} + \dot{Q}_p}{\dot{Q}_{in}}$

Vapor-Compression Cycle (Inverse of Rankine)

- use throttling valve instead of turbine
- used in fridges, heat pumps, A/C units

$COP_{actual} = COP_{ideal} \cdot \eta_{isentropic\ compressor}$

Gas refridgerant

- reverse Brayton cycle
- lower COP but lighter (use gas not liquid refrigerant) so have some applications

Thermoelectric Fridges

- lower efficiency but can cool at a variety of temperatures, quiet, and low maintenance

Mixtures

- Volume of combined ideal gases? $V_{mix} = V_1 + V_2$
- Be careful of mass vs. molar fractions
- find average properties of mix using molar or mass fraction

$$R_m = \sum mf_i R_i \text{ or } = \frac{R_u}{M_m}$$

- Formulas w/ per unit mass use mass fractions (C_p, R)
  Others that depend on Kmols use molar fractions
- Partial Pressures $P_i = y_i \cdot P_m$
- Daltons law of added pressures: $P_{mix} = P_A + P_B$

Mixture not an ideal gas? Use Compressibility Factor w/ pseudocritical pressures and temperatures

When finding thermodynamic properties, use sum of properties of each component

Use partial pressures for change in entropy $\Delta s_i = C_{p,i} \ln\left(\frac{T_2}{T_1}\right) - R_i \ln\left(\frac{P_{i2}}{P_{i1}}\right)$

Entropy Generation during Mixture (P=const)

[illegible]

Entropy Generation during Mixture (P=const)

$\bar{s}_2-\bar{s}_1 = -R_u \sum y_i \ln(y_i)$ $\quad$ $s_2-s_1 = -R_m \sum_i y_i \ln(y_i)$

Exergy Destroyed $= T_0 \cdot \bar{S}_g = -R_u T_0 \sum y_i \ln(y_i) > 0$

Separation Work $\quad w = T_0 \bar{s}_g = -R_u T_0 \sum y_i \ln(y_i)$

Separation Work for one Component from Large Mixture

$\bar{w}_{sep,A} = -R_u T_0 \ln(y_A)$ per Kmol

or $\quad w_{sep,A} = -R_A T_0 \ln(y_A)$ per Kg