

Advanced Thermodynamics in Mechanical

Advanced Thermodynamics in Mechanical Plants

Plants

Focused on concepts, equations, and practical applications for engineers and technicians

1. Overview

Aspect	Description
Purpose	Optimize energy conversion, improve plant efficiency, and ensure safe operation of high-temperature/pressure equipment.
Key Areas	1. Real-gas behavior 2. Irreversibility & entropy generation 3. Exergy analysis 4. Multi-stage cycles 5. Heat-transfer augmentation
Typical Systems	Gas turbines, combined-cycle plants, steam power plants, refrigeration/heat-pump loops, cogeneration (CHP) units.

2. Fundamental Relations (Re-examined)

Relation	Symbol	Typical Form (per unit mass)	Remarks
First Law (Energy balance)	$e = q - w$	$u + ke + pe = q - w$	Include kinetic & potential terms for high-speed flows.
Second Law (Entropy)	$s = ??$ $q_{rev}/T + s_{gen}$	$s = q/T_b + s_{gen}$ (for constant-T heat addition)	$s_{gen} \geq 0$; zero for reversible processes.
Enthalpy-Entropy (h-s) diagram	–	Useful for visualizing turbine/ compressor stages.	
Gibbs Equation	$T ds = du + p dv - \sum \mu_i dn_i$	Links property changes to measurable variables.	

3. Real-Gas Thermodynamics

3.1 Equations of State (EOS)

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EOS	Equation	Typical Use
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Peng–Robinson	$\left(p = \frac{RT}{v-b} - \frac{a\alpha}{v(v+b)+b(v-b)} \right)$	Hydrocarbon pipelines, refrigerants.
Redlich–Kwong	$\left(p = \frac{RT}{v-b} - \frac{a}{v(v+b)\sqrt{T}} \right)$	High-temperature gas turbines.
Virial	$\left(Z = 1 + \frac{B(T)}{v} + \frac{C(T)}{v^2} + \dots \right)$	Low-pressure steam and combustion gases.

Implementation tip: Use tabulated departure functions to convert ideal gas properties to real gas properties.

3.2 Compressibility Factor (Z)

- $Z = pv/RT$; deviation from 1 indicates non-ideal behavior.
- For design of compressors/turbines, compute Z at inlet/outlet to correct work and heat transfer calculations.

4. Irreversibility & Entropy Generation

4.1 Sources of Entropy Generation

1. Heat transfer across finite ΔT

$$[\dot{S}_{gen}]_{heat} = \dot{Q} \left(\frac{1}{T_c} - \frac{1}{T_h} \right)$$

2. Fluid friction (pressure drop)

$$[\dot{S}_{gen}]_{fric} = \frac{\dot{W}_{loss}}{T_{avg}}$$

3. Mixing of streams with different T, p, composition

4. Chemical reactions (combustion)

4.2 Minimization Strategies

Technique Effect

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