Thermodynamics

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Chapter 8
EXERGY: A MEASURE OF WORK POTENTIAL
The objectives:

• Examine the performance of engineering devices in light of the second law of thermodynamics.
• Define *exergy*, which is the maximum useful work that could be obtained from the system at a given state in a specified environment.
• Define *reversible work*, which is the maximum useful work that can be obtained as a system undergoes a process between two specified states.
• Define the *exergy destruction*, which is the wasted work potential during a process as a result of irreversibilities.
• Define the *second-law efficiency*.
• Develop the *exergy balance* relation.
EXERGY: WORK POTENTIAL OF ENERGY

AIR
25°C
101 kPa
V = 0
z = 0

$T_0 = 25°C$
$P_0 = 101$ kPa
EXERGY: WORK POTENTIAL OF ENERGY

Immediate surroundings

HOT POTATO

25°C

70°C

25°C

Environment
REVERSIBLE WORK AND IRREVERSIBILITY

Atmospheric air

$P_0$

SYSTEM $V_1$

Atmospheric air

$P_0$

SYSTEM $V_2$
REVERSIBLE WORK AND IRREVERSIBILITY

Cyclic devices

Steady-flow devices

Rigid tanks
REVERSIBLE WORK AND IRREVERSIBILITY

Initial state

Reversible process $W_{\text{rev}}$

Actual process $W_u < W_{\text{rev}}$

Final state

$I = W_{\text{rev}} - W_u$
REVERSIBLE WORK AND IRREVERSIBILITY

Source 1200 K

\[ \dot{Q}_{\text{in}} = 500 \text{ kJ/s} \]

HE

\[ \dot{W} = 180 \text{ kW} \]

Sink 300 K
REVERSIBLE WORK AND IRREVERSIBILITY

Surrounding air

Heat

IRON

$T_0 = 27^\circ C$

$200^\circ C$  $27^\circ C$
REVERSIBLE WORK AND IRREVERSIBILITY

IRON
200°C → 27°C

\( Q_{\text{in}} \)

Rev. HE

\( W_{\text{rev}} \)

Surroundings
27°C
SECOND-LAW EFFICIENCY

Source
600 K

\( \eta_{th} = 30\% \)
\( \eta_{th,\text{max}} = 50\% \)

Sink
300 K

Source
1000 K

\( \eta_{th} = 30\% \)
\( \eta_{th,\text{max}} = 70\% \)
SECOND-LAW EFFICIENCY
SECONDLAW EFFICIENCY

Source
1000 K

\[ \eta_{\text{th}} = 70\% \]
\[ \eta_{\text{rev}} = 70\% \]

Sink
300 K

100%
SECOND-LAW EFFICIENCY

- Hot water
  - 80°C

- Heat

- Atmosphere
  - 25°C
Exergy of a Fixed Mass
Exergy of a Fixed Mass

Atmosphere
$T_0 = 25^\circ\text{C}$

HEAT ENGINE

Work output

Cold medium
$T = 3^\circ\text{C}$
Exergy of a Flow Stream

\[ P \nu = P_0 \nu + w_{\text{shaft}} \]
Exergy of a Flow Stream

COMPRESSED AIR
1 MPa
300 K
Exergy of a Flow Stream

\[ T_0 = 20^\circ\text{C} \]
\[ T_2 = 50^\circ\text{C} \]
\[ P_2 = 0.8 \text{ MPa} \]
\[ P_1 = 0.14 \text{ MPa} \]
\[ T_1 = -10^\circ\text{C} \]
Exergy by Heat Transfer

\[ Q \]

\[ \frac{Q}{T_1} \]

\[ \frac{Q}{T_2} \]

\[ (1 - \frac{T_0}{T_1})Q \]

\[ (1 - \frac{T_0}{T_2})Q \]
Exergy by Mass

\[ h \quad s \quad \psi \quad \dot{m} \quad \dot{m}_h \quad \dot{m}_s \quad \dot{m}_\psi \]

Control volume
THE DECREASE OF EXERGy

No heat, work  
or mass transfer

Isolated system

\[ \Delta X_{\text{isolated}} \leq 0 \]

(or \( X_{\text{destroyed}} \geq 0 \))
EXERGY BALANCE

\[ X_{in} \rightarrow \text{Mass} \rightarrow System \rightarrow \Delta X_{system} \rightarrow \text{Work} \rightarrow X_{destroyed} \rightarrow \text{Heat} \rightarrow \text{Mass} \rightarrow X_{out} \rightarrow \text{Work} \]
EXERGY BALANCE

\[ P_0 = 100 \text{ kPa} \]
\[ T_0 = 25^\circ \text{C} \]

State 1

\[ P_1 = 1 \text{ MP} \]
\[ T_1 = 300^\circ \text{C} \]

State 2

Steam

\[ P_2 = 200 \text{ kPa} \]
\[ T_2 = 150^\circ \text{C} \]

2 kJ
EXERGY BALANCE

Furnace
$T_R = 1200 \, \text{K}$

Argon
$T_0 = 300 \, \text{K}$
$P_0 = 100 \, \text{kPa}$

$Q_R$

$400 \, \text{K}$
$350 \, \text{kPa}$
EXERGY BALANCE
EXERGY BALANCE
Second-Law Efficiency of Steady-Flow Devices
Second-Law Efficiency of Steady-Flow Devices

3 MPa
450°C

300 kW

T₀ = 25°C
P₀ = 100 kPa

0.2 MPa
150°C

STEAM TURBINE