EXERGY

Problem 1 (ME436s14q3)

A coal-fired furnace is used in a power plant. It delivers 5000 kW at 1000 K. The environment is at 300 K. What is the exergy of the added heat? You can use two steps to solve this problem.

(a) Determine the maximum percentage of the heat that can be converted to work.

(b) Using your answer from the first part, determine the maximum work possible.

Answer: (a) η_{Carnot} = 70 %

(b) $W_{rev,useful}$ = 3500 kW

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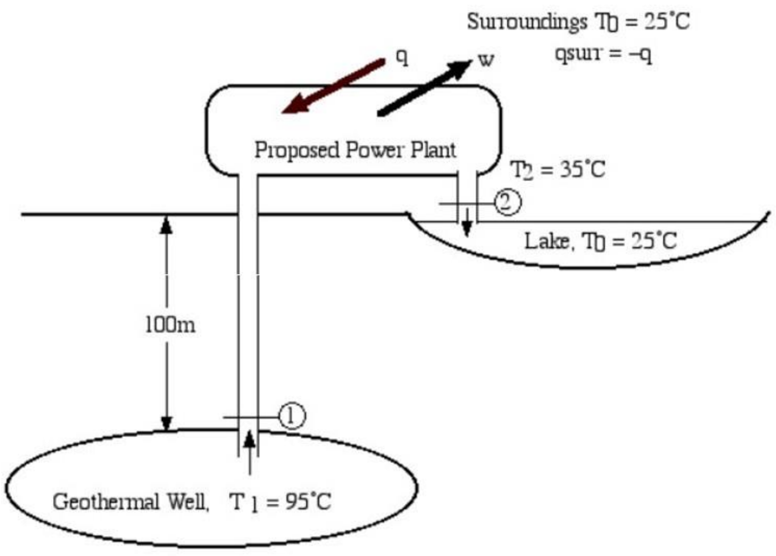
Problem 2 (ME436s14h4)

Assume that a village has discovered an underground geothermal well containing water at 95 °C, 100 m below the surface. They are evaluating the option of using the water from this well to provide power to the village. Determine the maximum available work [in kJ/kg] that could be obtained from a power plant that will pump water from the well, extract energy from the water, and discharge the water to a lake at the surrounding temperature T_0 = 25 °C. Assume that the water temperature can be reduced to 35 °C at the outlet of the power plant.



Answer: w_{rev} = 28.1 kJ/kg

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Problem 3 (ME436s14m1-2)

A piston-cylinder device contains 0.05 kg of steam at 1 MPa and 300 °C. Steam now expands to a final state of 200 kPa and 150 °C, doing work. Heat losses from the system to the surroundings are estimated to be Q_{out} = 2 kJ during this process. Assuming the surroundings to be at T_0 = 25 °C and P_0 = 100 kPa, determine

(a) the exergy of the steam at the initial and final states,

(b) the exergy change of the steam,

(c) the exergy destroyed during the process, and

(d) the second-law efficiency for the process.

The properties of the steam at the initial and final states are:

State 1	P_1 = 1 MPa	u_1 = 2793.7 kJ/kg
	T_1 = 300 °C	v_1 = 0.25799 m^3/kg
		s_1 = 7.1246 kJ/kg.K
State 2	P_2 = 200 kPa	u_2 = 2577.1 kJ/kg
	T_2 = 150 °C	v_2 = 0.95986 m^3/kg
		s_2 = 7.2810 kJ/kg.K
Dead State	P_2 = 100 kPa	$u_0 \approx u_f$ = 104.83 kJ/kg
	T_2 = 25 °C	$v_0 \approx v_f$ = 0.00103 m^3/kg
		$s_0 \approx s_f$ = 0.3672 kJ/kg.K

Assumptions: Kinetic and potential energies are negligible.

Exergy: $X = m\left[(u - u_0) - T_0(s - s_0) + P_0(v - v_0)\right]$

Exergy balance: $X_{in} - X_{out} - X_{destroyed} = \Delta X_{system}$

Exergy destroyed: $X_{destroyed} = T_0\, S_{gen} = T_0\left[m(s_2 - s_1) + \dfrac{Q_{surr}}{T_0}\right]$ or

$$X_{destroyed} = X_{in} - X_{out} - W_u = X_1 - X_2 - W_u$$

Energy balance: $E_{in} - E_{out} = \Delta E_{system}$ => Total boundary work: $W_b = -Q_{out} - m(u_2 - u_1)$

Useful work: $W_u = W_b - W_{surr}$

Surrounding work: $W_{surr} = P_0\, m\, (v_2 - v_1)$ Second-law efficiency: $\eta_{II} = \dfrac{W_u}{X_1 - X_2}$

Answer: (a) $X_1 = 35.0$ kJ ; $X_2 = 25.4$ kJ

(b) $\Delta X = -9.6$ kJ

(c) $X_{destroyed} = 4.3$ kJ

(d) $\eta_{II} = 55.2$ %

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Problem 4 (ME436s14mu1-2)

A geothermal well has water at 100 °C, 100 m below the surface. Determine the maximum available work [in kJ/kg] that could be obtained from a power plant that will pump water from the well, extract energy from the water, and discharge the water to a nearby lake at the surrounding temperature T_0 = 25 °C. Assume that the water temperature can be reduced to 35 °C at the outlet of the power plant.

For liquid water: $\Delta h = c_p \Delta T$ and $\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right)$

Mass flow rate is not given. So, use specific quantities.

First Law: $q - w = \Delta h + g\,\Delta z$ (If kinetic energy change is zero)

Entropy generation: $s_{gen} = \Delta s - \frac{q}{T_0}$ => $q = T_0\,\Delta s - T_0\,s_{gen}$

Note that entropy generation is zero for a reversible process.

Answer: $w_{rev} = 32.2$ kJ/kg

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Problem 5

A 500-kg iron block (c = 0.45 kJ/kg.K) is initially at 200 °C and is allowed to cool to 27 °C by transferring heat to the surrounding air at 27 °C.

Determine the reversible work and the irreversibility for this process.

Assumptions:

1) the kinetic potential energies are negligible.

2) the process involves no work interactions.

Answer: (a) $W_{rev} = 8191$ kJ

(b) I = 0

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Problem 6 (ME405f15q3 / ME436s16q3 / ME436s21m-3 / ME405s21m-3)

A freezer is maintained at - 6 °C by removing heat from it at a rate of 75 kJ/min. The power input to the freezer is 0.70 hp (1 hp = 735 W), and the surrounding air is at 25 °C. Determine

a) The reversible power;

b) The irreversibility; and

c) The second-law efficiency of this freezer.

Answer: (a) $\dot{W}_{rev,in}$ = 130 W

(b) I = 384.5 W

(c) η_{II} = 25.3 %

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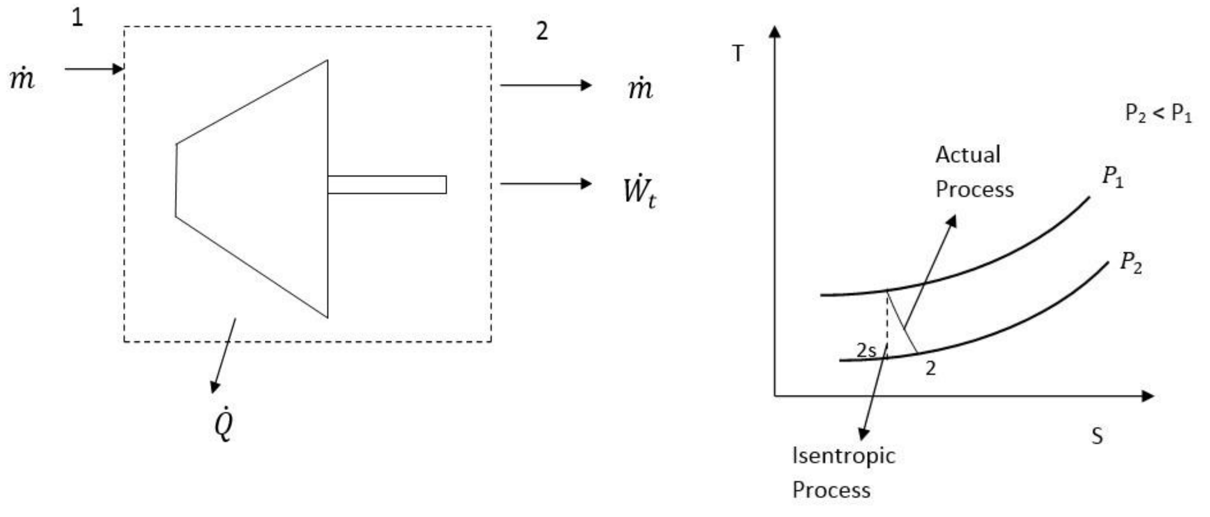
Problem 7 (ME436s15h3)

Air enters a turbine at 150 psia and 2000 °F and expands to 14.7 psia and 1000 °F. The heat loss from the turbine is approximately 2 % of the turbine power. The ambient temperature is 77 °F. Calculate the actual work and the available work for this turbine process.



Answer: w_T = 550 kJ/kg; w_a = 600 kJ/kg

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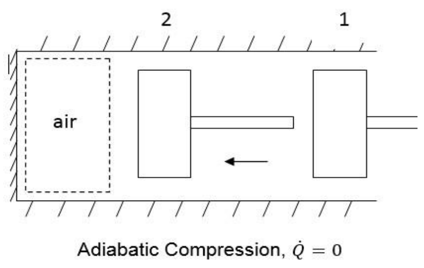
Problem 8



Air is compressed adiabatically in a piston cylinder process. For initial conditions of 20 psia and 100 °F and final conditions of 50 psia and 297.5 °F, calculate the actual work and available work in the process. The ambient temperature is 77 °F.

Answer: w_p = - 33.6 Btu/lbm; w_a = - 28.3 Btu/lbm

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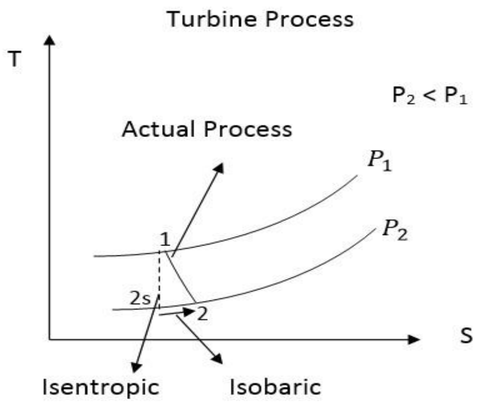
Problem 9



For the turbine operation in Problem 7, it is assumed that the air first expands isentropically to 14.7 psia and then changes to the final state by a reversible isobaric process. Calculate for this entire turbine process (a) the reversible work, (b) the Carnot work, (c) the lost work, and (d) the unavailable work.

Actual expansion: 1 → 2

Idealized expansion: 1 → 2s, 2s → 2

Assume air is an ideal gas, c_p = 0.24 Btu/lbm.R, and constant ambient temperature is 77 F.

Answer: (a) w_{rev} = 286.6 Btu/lbm

(b) w_{Carnot} = - 28.2 Btu/lbm

(c) w_{lost} = 51.3 Btu/lbm

(d) $w_{unavailabe}$ = 22.9 Btu/lbm

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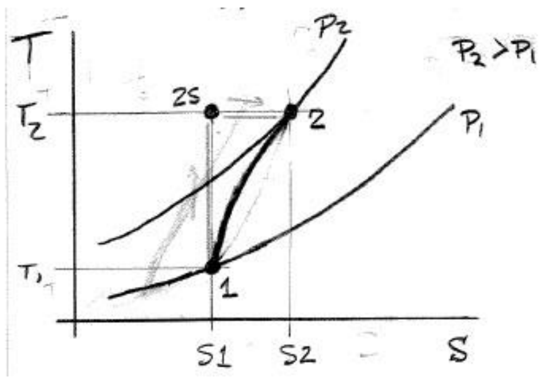
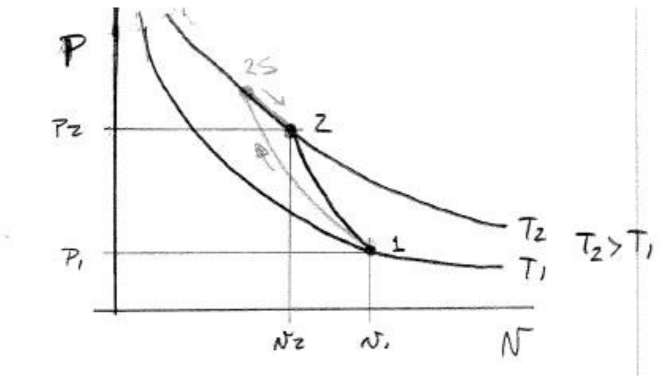
Problem 10

For the compressor specified in the previous example, it is assumed that the air is first compressed isentropically, then expanded reversibly and isothermally to the final state. For this entire process calculate (a) the reversible work, (b) the lost work, (c) the Carnot work, and (d) the unavailable work.





Answer: (a) w_{rev} = - 26.23 Btu/lbm

(b) w_{Carnot} = - 2.14 Btu/lbm

(c) w_{lost} = 7.35 Btu/lbm

(d) $w_{unavailabe}$ = 5.21 Btu/lbm

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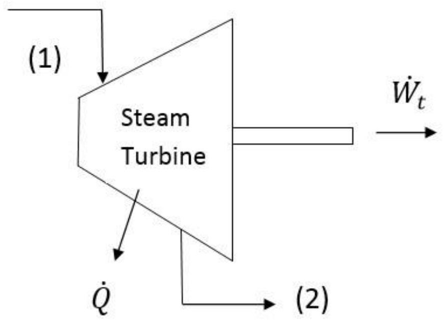
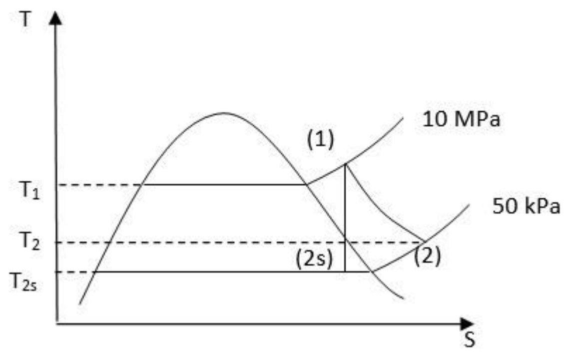
Problem 11

Steam enters a well-insulated turbine at 800 °C and 10 MPa at a flow rate of 2.5 kg/s. The steam exits at 50 kPa. The isentropic efficiency of the turbine is 0.9332. The surroundings are at 25 °C and 1 atm.

(a) Determine the rate at which availability enters the turbine; and

(b) Determine the rate of availability destruction.





State 1: T_1 = 800 °C, P_1 = 10 MPa

State 2: P_2 = 50 kPa

State ∞:   T = 25 °C, P = 1 atm

Assumptions: Steady state; Steady flow; Adiabatic; Negligible changes in KE and PE

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Problem 12

Consider a steam throttling process through an expansion valve. Steam enters the valve at 1900 psia and 1000 °F and leaves at 1800 psia. Calculate the flow availability per unit mass of steam at the inlet and exit.

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Problem 13 (ME405f15h4)

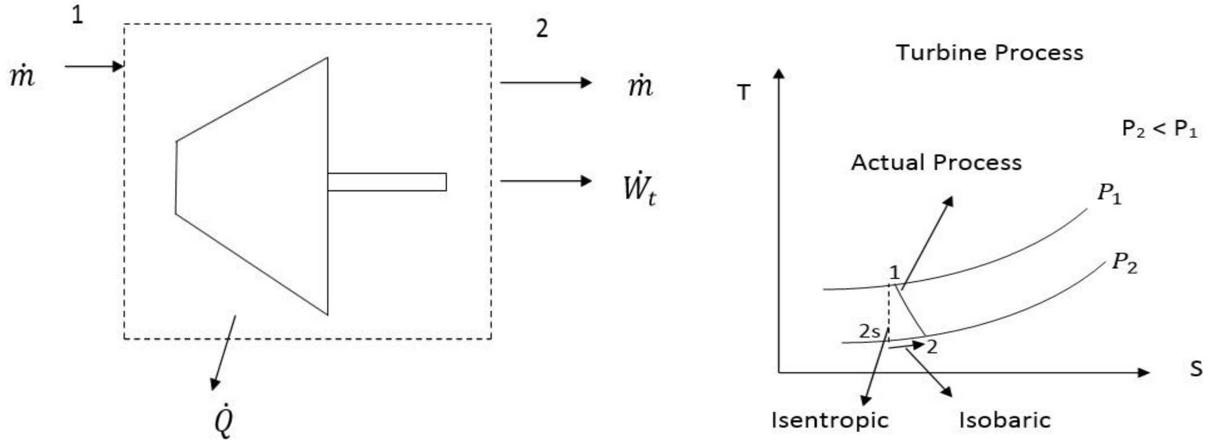
Air enters a turbine at 1 MPa and 1100 °C, expands isentropically to 100 kPa and changes to the final state at 100 kPa and 540 °C by a reversible isobaric process. The heat loss from the turbine is approximately 2 % of the turbine power. The ambient temperature is 25 °C. Calculate for this entire turbine process

(a) The reversible work;

(b) The Carnot work;

(c) The lost work; and

(d) The unavailable work.



Actual expansion: 1 → 2

Idealized expansion: 1 → 2s, 2s → 2

Assume air is an ideal gas, c_p = 1 kJ/kg.K, and constant ambient temperature is 25 °C.

For Isentropic ideal gas expansion: $T_{2s} = T_1 \left(\frac{P_{2s}}{P_1}\right)^{\frac{k-1}{k}}$

For Carnot work: $w_C = c_p \left[- (T_2 - T_{2s}) + T_\infty \ln\left(\frac{T_2}{T_{2s}}\right)\right]$

Answer: (a) w_{rev} = 662 kJ/kg

(b) w_{Carnot} = - 62 kJ/kg

(c) w_{lost} = 112 kJ/kg

(d) $w_{Unavailablet}$ = 50 kJ/kg

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Problem 14 (ME405f15m1-2)

Through combustion of a fossil fuel at 3500 °R, a plant receives energy at a rate of 3000 Btu/s to heat steam to 1500°R. There is no energy loss in the combustion process. The steam, in turn, produces 1000 Btu/s of work and rejects the remaining energy to the surroundings at 500 °R.

(a) What is the thermal efficiency of the plant?

(b) What are the reversible work and the Carnot efficiency corresponding to the source and sink temperatures?

(c) What is the irreversibility?

(d) What is the second-law efficiency?

Formulas:

$$\eta_{th} = \frac{W_{act}}{Q_{in}} \qquad \eta_C = 1 - \frac{T_L}{T_H} \qquad W_{rev} = \eta_C\, Q_{in} \qquad I = W_{rev} - W_{act} \qquad \eta_{II} = \frac{\eta_{th}}{\eta_C} = \frac{W_{act}}{W_{rev}}$$

Answer: (a) η_{th} = 33.3 %

(b) η_{Carnot} = 85.7 %; W_{rev} = 2571 Btu/s

(c) I = 1571 Btu/s

(d) η_{II} = 38.9 %

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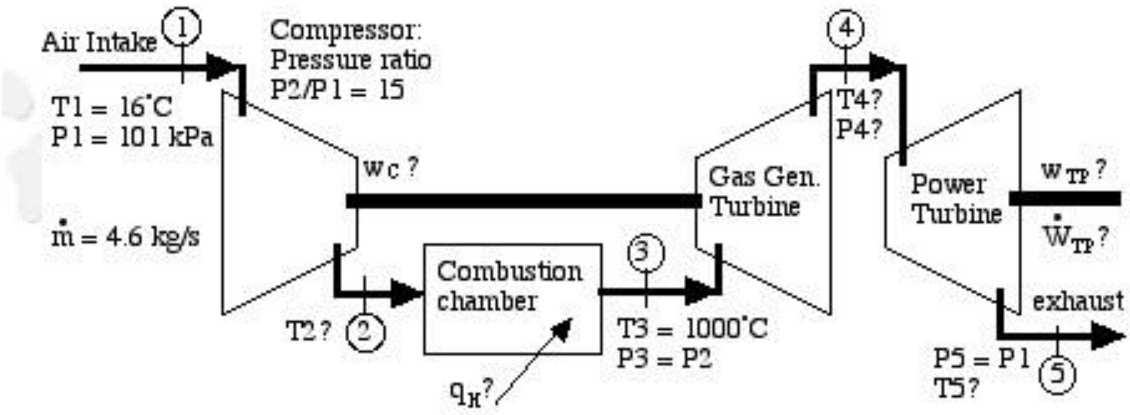
Problem 15 (ME436s16m1-3 / ME436s18f-4)

Consider the same helicopter engine of the previous problem.



Assume that the gas leaving the combustion chamber enters the gas turbine that derives the compressor at 1500 kPa and 927°C and exits at 400 kPa and 627°C, with 50 kJ/kg of heat loss transferred to the surroundings at 25°C. Assuming that the gas is pure air, determine

a) The actual work output (from the energy equation);
b) The entropy generated by this process;
c) The available reversible work output (from an exergy analysis); and
d) The Second Law efficiency (η_{II}) of this turbine.

Use the following:

$c_p = 1.142$ kJ/kg.K ; $R = 0.287$ kJ/kg.K

First law: $q - w_{act} = \Delta h$

For an ideal gas: $\Delta h = c_p \Delta T$; $\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$

$$s_{gen} = \Delta s + \frac{q_{surr}}{T_0} = \Delta s - \frac{q}{T_0}$$

$$w_{rev} = w_{act} + T_0 \Delta s$$

$$\eta_{II} = \frac{w_{act}}{w_{rev}} \quad \text{or} \quad \eta_{II} = \frac{w_{rev}}{w_{act}}$$

Answer: (a) $w_{act} = 292.6$ kJ/kg

(b) $s_{gen} = 0.2189$ kJ/kg.K

(c) $w_{rev} = 357.83$ kJ/kg

(d) $\eta_{II} = 82$ %

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Problem 16 (Me436s21q6 / ME405s21q6)

Ideally, which fluid can do more work: air at 4 MPa and 300 °C or steam at 4 MPa and 300 °C?

Assume that the system is closed and the dead state is STP, i.e., 25 °C and 100 kPa.

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Problem 17 (ME405f16h3 / ME436s17h4)

Before the widespread use of mechanical refrigeration, cooling was provided by ice, which was delivered by iceman and stored in an icebox. In a current application, blocks of ice at T_{ice} = 0 °C with a total mass of m_{ice} = 250 kg are placed in a large food-storage icebox that is used to keep the food at T_{food} = 7 °C on a day in which the outdoor temperature is T_{amb} = 25 °C. The rate of heat loss through the walls of the icebox is Q = 2900 Btu/hr.

(a) Estimate the amount of time it will take the ice to melt.

(b) Compare the rate of cooling provided in ton units to the mass of ice in tons.

(c) Define and calculate an efficiency for this process

(d) Determine the change in exergy of the ice in this process.

(e) Calculate the second-law efficiency for this process.

Answer: (a) Δt = 27 hours and 15 minutes

(b) 0.254 short tons in 24 hours

(c) Over 100 %?

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Problem 18 (ME405f16m1-3 / ME436s17m1-3 / ME405f22m-3 / ME405f24m-3)

The pressure of water is increased by the use of a pump from 100 kPa to 275 kPa. A rise in the water temperature from 15 °C to 15.1 °C is observed. Determine

(a) the irreversibility;

(b) the second law efficiency; and

(c) the isentropic efficiency of the pump.

Data for water: v = 0.001 m^3/kg c_p = 4.1855 kJ/kg.K

Irreversibility: $i = T_\infty \, c_p \, (s_2 - s_1) - q = T_\infty \, c_p \, \ln\left(\frac{T_2}{T_1}\right) - q$

Actual work: $w_{act} = h_1 - h_2 + q = c_p \, (T_1 - T_2) + v\,(P_1 - P_2) - q$

Reversible work: $w_{rev} = i + w_{act}$ Ideal work: $w_{ideal} = v\,(P_1 - P_2)$

Second-law efficiency: $\eta_{II} = \frac{w_{rev}}{w_{act}}$ Isentropic efficiency: $\eta_s = \frac{w_{ideal}}{w_{act}}$

Answer: (a) $i = 0.4333$ kJ/kg ; (b) $\eta_{II} = 0.27$; (c) $\eta_s = 0.295$

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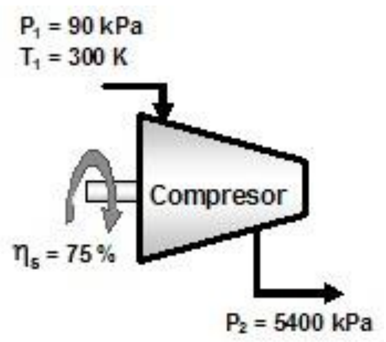
Problem 19 (ME405f16f-4 / ME436s17f-4)



A compressor with an isentropic efficiency of 75 % takes in air at T_1 = 300 K and P_1 = 90 kPa and discharges at P_2 = 5400 kPa. The air flow rate is 0.45 kg/s. Determine

(a) the actual work in kW;

(b) the lost work in kW;

(c) the reversible work in kW;

(d) the second law efficiency of the compressor.

Assume that air behaves as an ideal gas, the compressor is adiabatic and that the temperature of the surroundings is 300 K.

Isentropic efficiency for a compressor: $\eta = \frac{h_{2s} - h_1}{h_2 - h_1}$

Actual work: $w_{act} = h_1 - h_2 = \frac{h_1 - h_{2s}}{\eta}$

$$\text{Lost work} = \dot{m}\, T_{surr} \left(s_2 - s_1 - \frac{8.314}{29.0} \ln\left(\frac{P_2}{P_1}\right)\right)$$

Reversible work: $\dot{W}_{rev} = \dot{W}_{act} + \dot{W}_{lost}$

Second law efficiency: $\eta_{II} = \frac{\dot{W}_{rev}}{\dot{W}_{act}}$

Ideal gas relation: $\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$, k = 1.374 for air

The following properties are taken from the thermodynamic table for air:

Temperature, K	Enthalpy, kJ/kg	Entropy, kJ/kg.K
300	87.41	0.0061681
910	736.58	1.1744
920	747.82	1.1867
1100	952.79	1.3901

1200	975.88	1.4109

Answer: (a) – 392.56 kW

(b) 29.2 kW

(c) – 363.34 kW

(d) 92.5 %

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Problem 20 (ME405s23h5)

Two kilograms of air at 700 kPa and 800 C are constrained in a stationary piston cylinder arrangement. The air expands adiabatically to 150 kPa and 350 C.

(a) Determine the exergy of the air in kJ at the initial state.

(b) Determine the exergy of the air in kJ after expansion.

(c) Determine the change of exergy for the process.

(d) If 125 kJ of work are produced determine the effectiveness of this process.

(e) Determine the loss of exergy (the irreversibility).

Answer: (a) X_1 = 661.76 kJ ; (b) X_2 = 167.3 kJ ; (c) – 494.45 kJ ; (d) ε = 0.253 ; (e) 369.45 kJ

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Problem 21a (ME405s23q5)

Three kilograms of water at 400 C and 4 MPa are contained in stationary a piston cylinder arrangement. The water expands adiabatically to 200 C and 200 kPa.

a. Determine the exergy of the water in both kJ/kg and kJ at the initial state.

b. Determine the exergy of the water in kJ/kg and kJ after expansion.

c. Determine the change of exergy for the process.

Answers: (a) 2745 kJ ; (b) 1588 kJ ; (c) - 1157 kJ

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Problem 22

A large iron block at 500 C is removed from a furnace and cools to 200 C.

a. Determine the exergy of the block in both kJ/kg and kJ at the initial state.

b. Determine the exergy of the block in kJ/kg and kJ after expansion.

c. Determine the change of exergy for the cooling process.

d. Determine the effectiveness of this cooling process.

e. Determine the loss of exergy (the irreversibility).

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Problem 23

Nitrogen at 600 kPa and 400 C flows into a small turbine and exits at 120 kPa and 100 C. The mass flow rate of the nitrogen is 5 kg/s. Neglect the kinetic and potential energy of the flow.

a. Determine the exergy of the Nitrogen in both kJ/kg and kJ/s at the initial state.

b. Determine the exergy of the Nitrogen in kJ/kg and kJ/s after expansion.

c. Determine the change of exergy for the expansion process.

d. Determine the effectiveness of this expansion process if 200 kJ/s of work is produced.

e. Determine the loss of exergy (the irreversibility).

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Problem 24

Water at 8 MPa and 600 C flows into a steam turbine with a mass flow rate of 20 kg/s and exits at 140 kPa and 150 C. Neglect the kinetic and potential energy of the flow.

a. Determine the exergy of the water in both kJ/kg and kJ/s at the initial state.

b. Determine the exergy of the water in kJ/kg and kJ/s after expansion.

c. Determine the change of exergy for the expansion process.

d. Determine the effectiveness of this expansion process if 200 kJ/s of work is produced.

e. Determine the loss of exergy (the irreversibility).

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Problem 25

The driver of a 2000 kg automobile traveling at 100 km/h applies the brakes slowing the auto down to a dead stop. During this process the brake lining temperature abruptly reaches a maximum value of 200 °C.

a. Determine the exergy of the automobile in both kJ/kg and kJ/s at the initial state.

b. Determine the exergy of the automobile in kJ/kg and kJ/s after braking to zero velocity.

c. Determine the change of exergy for the process.

d. Determine the effectiveness of this process if the braking energy is discarded to the atmosphere.

e. Determine the effectiveness of this process if the braking energy is stored in batteries by a braking generator instead of friction brakes.

f. Determine the effectiveness of this process if the braking energy is transferred to a Carnot cycle.

g. Determine the loss of exergy (the irreversibility) for all three cases above.

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Problem 26 (ME436s18q5 / ME405s18q5)

Find the exergy (availability) of 2 kg of air (ideal gas), P = 7.5 MPa, T = 475 °C. Assume that the environment pressure and temperature are P_0 = 100 kPa and T_0 = 25 °C, respectively.

Answer: 683.3 kJ

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Problem 27 (ME436s18h3 / ME405s18h3 / ME436s19m1-3 / ME405s19m1-3 / ME436s20f-1 ME436s22h6 / ME405s22h5)

Air flows through an adiabatic compressor at 2 kg/s. The inlet conditions are 1 bar and 310 K and the exit conditions are 7 bar and 560 K. Determine the net rate of exergy transfer and the irreversibility. The ambient temperature can be taken as 298 K, the specific heat at constant pressure for air is 1.005 kJ/kg.K and the gas constant for air is 0.287 kJ/kg.K.

Answer: Net rate of exergy change: 481.16 kW

Irreversibility: I = 21.3 kW

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Problem 28 (ME436s18m1-3 / ME405s18m1-3)

There is 1 kg of water at T_1 = 20 °C and P_1 = 150 kPa (state 1) in a piston-cylinder arrangement. A linear spring is placed above the piston such that the pressure changes linearly with the volume. By transferring heat from a source at 600 °C, water is heated until P_2 = 1 MPa and T_2 = 500 °C (state 2). The environment is at P_0 = 100 kPa and T_0 = 25 °C.

The thermodynamic tables for water give the following properties:

	v, m^3/kg	u, kJ/kg	s, kJ/kg.K
At T_0 = 25 °C and P_0 = 100 kPa	0.001003	**104.86**	0.3673
At T_1 = 20 °C and P_1 = 150 kPa	0.001	83.94	0.2966
At T_2 = 500 °C and P_2 = 1 MPa	0.354	3124.3	7.7621

(a) Draw P-v and T-s diagrams of the process, 1 -> 2;

(b) Find the exergies of the water at states 1 and 2;

(c) Find the work done, ${}_1W_2$;

(d) Find the heat flow, ${}_1Q_2$;

(e) Find the irreversibility in the process, ${}_1I_2$.

Hints:

$X = m\,[(u - u_0) - T_0\,(s - s_0) + P_0\,(v - v_0)]$

$${}_1W_2 = \int_1^2 P(\forall)\, d\forall \quad , \quad {}_1Q_2 = m\,(u_2 - u_1) + {}_1W_2$$

$$\left(1 - \frac{T_0}{T}\right) {}_1Q_2 = X_2 - X_1 + \left[{}_1W_2 - P_0\,(\forall_2 - \forall_1)\right] + {}_1I_2$$

Answer: (b) X_1 = 0.159 kJ X_2 = 850 kJ

(c) ${}_1W_2$ = 203 kJ   (d) ${}_1Q_2$ = 3243.4 kJ   (e) ${}_1I_2$ = 1118.4 kJ

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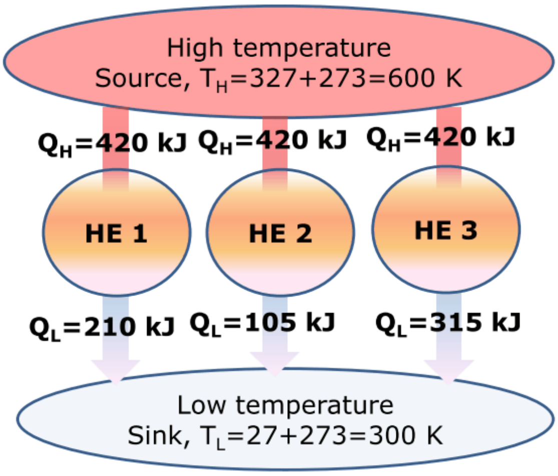
Problem 29 (ME436s19q5 / ME405s19q5)

A heat engine receives reversibly 420 kJ/cycle of heat from a source at 327 C and rejects heat reversibly to a sink at 27 C. There are no other heat transfers. Consider three different rates of heat rejection (a) 210 kJ (b) 105 kJ and (c) 315 kJ. For each of these cases show which cycle is reversible, irreversible and impossible.



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Problem 30 (ME436s20h4)

Air enters an adiabatic non-ideal nozzle at 9 m/s, 300 K, and 120 kPa and exits at 100 m/s and 100 kPa. Determine the irreversibility and the reversible work on a per mass basis.

Answer: Reversible work = Irreversibility = 15.71 kJ/kg

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Problem 31 (ME436s21h6 / ME405s21h6)

Carbon dioxide undergoes an isothermal reversible process from 250 kPa and 300 °C to 500 kPa. Determine the heat transfer per mass by using the first law and evaluating the boundary work from $\int P\,dv$. Compare this to the heat transfer per mass calculated from the entropy change and the second law.

CO_2 is an ideal gas

Closed system

Isothermal, reversible process

Properies:

State 1	State 2
T_1 = 300 °C = 573 K	$T_2 = T_1$ = 573 K
P_1 = 250 kPa	P_2 = 500 kPa
u_1 = 369.23 kJ/kg	u_2 = 369.23 kJ/kg
v_1 = 0.433 m^3/kg	v_2 = 0.2165 m^3/kg

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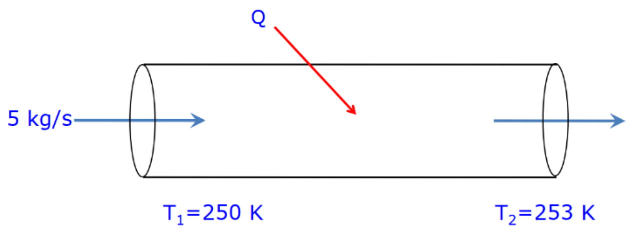
Problem 32 (ME436s22q5 / ME405s22q5)



A pipe carries a stream of a liquid with a mass flow rate of 5 kg/s. Because of poor insulation, the liquid temperature increases from 250 K at the pipe inlet to 253 K at the exit. Neglecting pressure losses, calculate the irreversibility rate associated with the heat leakage. Take T_0 as 293 K and specific heat for the liquid as 2.85 kJ/kg K.

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Problem 33 (ME436s22m-3 / ME405s22m-3)

An iron block of unknown mass at 85 °C is dropped into an insulated tank that contains 100 L of water at 20 °C. At the same time, a paddle wheel driven by a 200-W motor is activated to stir the water. It is observed that thermal equilibrium is established after 20 min with a final temperature of 24 °C. Assuming the surroundings to be at 20 °C, determine

(a) the mass of the iron block; and

(b) the exergy destroyed during this process.

For water: $c_w = 4.18$ kJ/kg.K $\rho_w = 1000$ kg/m^3

For iron: $c_i = 0.45$ kJ/kg.K

First law: $Q - W = U_2 - U_1 = m\ c\ \Delta T$

$$\Delta X = T_0\ S_{gen} = m\ c\ \ln\left(\frac{T_2}{T_1}\right)$$

Answers: $m_i = 52$ kg ; Exergy destroyed = 375 kJ

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Problem 34 (ME436s22f-3 / ME405s22f-3)

Air enters a nozzle steadily at 300 kPa and 87°C with a velocity of 50 m/s and exits at 95 kPa and 300 m/s. The heat loss from the nozzle to the surrounding medium at 17°C is estimated to be 4 kJ/kg. Determine

(a) the exit temperature of the air; and

(b) the exergy destroyed during this process.

For air: c_p = 1.004 kJ/kg.K R_{air} = 0.287 kJ/kg.K

$$\Delta s_{air} = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right) \qquad X_{dest} = T_0 S_{gen} \qquad S_{gen} = \Delta S_{air} + \Delta S_{surr}$$

Answers: T_2 = 39.44 C ; X_{dest} = 58.46 kJ/kg

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Problem 35 (ME405f22q6)

Find the specific exergy of saturated steam at 100 °C. The dead state is 25 °C and 100 kPa. Hint: Use the steam table for the properties.

Answer: x = 487.7 kJ/kg

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Problem 36 (ME405f22h6)

Steam at 260 °C and 1 MPa, mass flow rate 20 kg/s, is mixed adiabatically with liquid water at 93 °C and 1 MPa, mass flow rate 120 kg/s. Assume there is no pressure drop during mixing. Find the mixture temperature at steady state, and irreversibility of the mixing process.

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Problem 37 (ME405f23q5)

Geologists have discovered a solid "pocket" of impermeable rock at 3 km beneath the surface, with dimensions 2.5 x 3 x 6 km and almost uniform temperature 235 °C (508 K). The average density of the rock is 2700 kg/m^3 and its specific heat capacity 0.84 kJ/kg K. It is proposed that several wells be drilled to circulate water and transfer the heat of the rock to thermal engines that would produce power. Calculate the maximum amount of work (exergy) that may be extracted from this project. The temperature of the environment is 300 K.

Answer: $w_{max} = 5.1\ 10^{15}$ kJ

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Problem 38 (ME405f23h5)

A geothermal field has 12 production wells. Each geothermal well produces 58 kg/s of a steam-water mixture at T_1 = 190 °C, and dryness fraction (quality) of x_1 = 0.22. Because water recirculates in the down-hole aquifer, the temperature and mass flow rates of the wells are constant. Calculate the maximum electric power the field may produce. The environment is at T_0 = 300 K and P_0 = 1 atm.

Answer: $\dot{W}_{max}$ = 205 953 kW

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Problem 39

Define the following:

(a) Effectiveness of a heat exchanger;

(b) First-law efficiency of a heat exchanger;

(c) Second-law efficiency of a heat exchanger.

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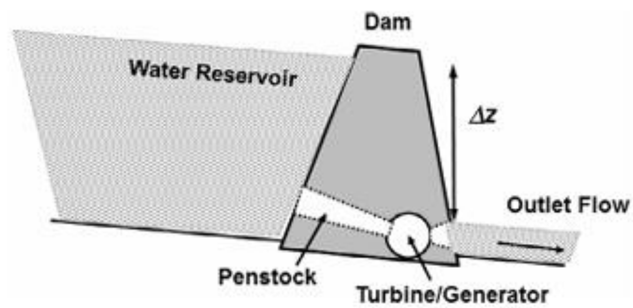
Problem 40 (ME405f24q5)



A small river passes through the outskirts of a town carrying on average 45 m^3/s of water. The river has a small waterfall downstream and the town is considering building a dam and a hydroelectric power plant. The dam will increase the height of the fall to 9.5 m.

(a) Determine the maximum power of this small hydroelectric project.

(b) Calculate what the generated power will be, if all the irreversibilities amount to 22 % of the total exergy of the water.

Answers: (a) Maximum power = 4.29 10^6 W; (b) Generated power = 3.27 10^6 W

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Problem 41 (ME405f24h5)

A small electric power plant produces 150 MW of power and operates with a Rankine cycle with superheat. Steam enters the turbine at 8 MPa and 520 ºC, and exits at 40 ºC. Cooling water enters the condenser at 27 ºC and exits at 37 ºC. The fuel is coal, for which carbon is the only combustible material. The isentropic efficiencies of the pump and the turbine are 80 % and 82 %, respectively. Determine the lost power (rate of exergy destruction) in each of the components of this power plant.

Answers:

Pump : 274 kW; Burner: 253 663 kW; Turbine: 31 438 kW; Condenser: 7 681 kW.

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