CHAPTER 2: THE NATURE OF ENERGY

2.1) A 5.00-kg light fixture is suspended above a theater's stage 15.0 meters above the ground. The local acceleration due to gravity is 9.75 m/s^2. Determine the potential energy of the light fixture.

Given: m = 5.00 kg, z = 15.0 m; g = 9.75 m/s^2

Solution:

PE = mgz = (5.00 kg)(9.75 m/s^2)(15.0 m) = **731 J**

2.2) In 1908, Charles Street of the Washington, D.C., baseball team caught a baseball thrown from the top of the Washington Monument. If the height of the ball before it was thrown was 165 m, and the mass of the baseball was 0.145 kg, what was the potential energy of the baseball before it was thrown? Assume that the acceleration due to gravity was 9.81 m/s^2.

Given: m = 0.145 kg, z = 165 m; g = 9.81 m/s^2

Solution:

PE = mgz = (0.145 kg)(9.81 m/s^2)(165 m) = **235 J**

2.3) 10.0 kg of water is about to fall over a cliff in a waterfall. The height of the cliff is 115 m. Determine the potential energy of the mass of water considering standard gravity on Earth.

Given: m = 10.0 kg; g = 9.81 m/s^2; z = 115 m

Solution:

PE = mgz = (10.0 kg)(9.81 m/s^2)(115 m) = 11,280 J **= 11.3 kJ**

2.4) A jet airplane is flying at a height of 10,300 m at a velocity of 240 m/s. If the mass of the airplane is 85,000 kg, and if the acceleration due to gravity is 9.70 m/s^2, determine the potential energy and the kinetic energy of the airplane.

Given: m = 85,000 kg; g = 9.70 m/s^2; z = 10,300 m; V = 240 m/s

Solution:

PE = mgz = (85,000 kg)(9.70 m/s^2)(10,300 m) = **8.49 x 10^9 J = 8,490 MJ**

$KE = \frac{1}{2} mV^2 = \frac{1}{2} (85{,}000 \text{ kg})(240 \text{ m/s})^2 =$ **2.45×10^9J = 2,450 MJ**

2.5) A piece of space debris with a mass of 15 lbm is falling through the atmosphere towards earth at a height of 15,000 ft with a velocity of 750 ft/s. Determine the potential and kinetic energy of the object.

Given: m = 15.0 lbm; z = 15,000 ft; V = 750 ft/s
Assume: $g = 32.1$ ft/s^2 (Acceleration due to gravity at 15,000 ft)

Solution:

$PE = mgz/g_c = (15.0 \text{ lbm})(32.1 \text{ ft/s}^2)(15{,}000 \text{ ft}) / (32.174 \text{ lbm-ft/lbf-s}^2) =$ **244,500 ft-lbf = 288 Btu**
$KE = \frac{1}{2} mV^2/g_c = \frac{1}{2} (15.0 \text{ lbm})(750 \text{ ft/s})^2 / (32.174 \text{ lbm-ft/lbf-s}^2) =$ **131,000 ft-lbf = 169 Btu**

2.6) A baseball with a mass of 0.145 kg is thrown by a pitcher at a velocity of 42.0 m/s. Determine the kinetic energy of the baseball.

Given: m = 0.145 kg; V = 42.0 m/s

Solution:

$KE = \frac{1}{2} mV^2 = \frac{1}{2} (0.145 \text{ kg}) (42.0 \text{ m/s})^2 =$ **128 J**

2.7) A brick with a mass of 2.50 kg, which was dropped from the roof of a building, is about to hit the ground at a velocity of 27.0 m/s. Determine the kinetic energy of the brick.

Given: m = 2.50 kg; V = 27.0 m/s

Solution:

$KE = \frac{1}{2} mV^2 = \frac{1}{2} (2.50 \text{ kg}) (27.0 \text{ m/s})^2 =$ **911J**

2.8) An 80.0-kg rock that was hurled by a catapult is about to hit a wall while traveling at 7.50 m/s. What is the kinetic energy of the rock just before contacting the wall?

Given: m = 80.0 kg; V = 7.50 m/s

Solution:

$KE = ½\ mV^2 = ½\ (80.0\ kg)\ (7.50\ m/s)^2 =$ **2250 J = 2.25 kJ**

2.9) Steam flows through a pipe located 4 m above the ground. The velocity of the steam in the pipe is 80.0 m/s. If the specific internal energy of the steam is 2765 kJ/kg, determine the total internal energy, the kinetic energy, and the potential energy of 1.50 kg of steam in the pipe.

Given: m = 1.50 kg; z = 4 m; V = 80.0 m/s; u = 2765 kJ/kg
Assume: $g = 9.81\ m/s^2$

Solution:

U = mu = (1.50 kg) (2765 kJ/kg) = **4,150 kJ**
$KE = ½\ mV^2 = ½\ (1.50\ kg)(80.0\ m/s)^2 = 4{,}800\ J =$ **4.80 kJ**
$PE = mgz = (1.50\ kg)(9.81\ m/s^2)(4\ m) = 58.9\ J$ **= 0.0589 kJ**

2.10) Now, for problem 2.9 replace the steam with liquid water. If the specific internal energy of the liquid water is 120 kJ/kg, determine the total internal energy, the kinetic energy, and the potential energy of 1.50 kg of water in the pipe.

Given: m = 1.50 kg; z = 4 m; V = 80.0 m/s; u = 120 kJ/kg
Assume: $g = 9.81\ m/s^2$

Solution:

U = mu = (1.50 kg) (120 kJ/kg) = **180 kJ**
$KE = ½\ mV^2 = ½\ (1.50\ kg)(80.0\ m/s)^2 = 4{,}800\ J =$ **4.80 kJ**
$PE = mgz = (1.50\ kg)(9.81\ m/s^2)(4\ m) = 58.9\ J$ **= 0.0589 kJ**

2.11) Steam, with a specific internal energy of 1205 Btu/lbm, is flowing through a pipe located 15 ft above the ground. The velocity of the steam in the pipe is 200 ft/s. Determine the total internal energy, the kinetic energy, and the potential energy of 2.50 lbm of steam in the pipe.

Given: m = 2.50 lbm; z = 15ft; V = 200 ft/s; u = 1205 Btu/lbm
Assume: $g = 32.174\ ft/s^2$

Solution:

U = mu = (2.50 lbm) (1205 Btu/lbm) = **3130 Btu**
$KE = ½\ mV^2/g_c = ½\ (2.50\ lbm)(200\ ft/s)^2/(32.174\ lbm\text{-}ft/lbf\text{-}s^2) = 1550\ ft\text{-}lbf =$ 2**.00 Btu**

$PE = mgz/g_c$ = (2.50 lbm)(32.174 ft/s^2)(15 ft)/(32.174 lbm-ft/lbf-s^2) = 37.5 ft-lbf **= 0.0482 Btu**

2.12) Replace the steam in Problem 2.11 with liquid water. If the specific internal energy of the liquid qater is 45 Btu/lbm, determine the total internal energy, the kinetic energy, and the potential energy of 2.50 lbm of water in the pipe.

Given: m = 2.50 lbm; z = 15ft; V = 200 ft/s; u = 45 Btu/lbm
Assume: g = 32.174 ft/s^2

Solution:

U = mu = (2.50 lbm) (45 Btu/lbm) = **113 Btu**
KE = ½ mV^2/g_c = ½ (2.50 lbm)(200 ft/s)^2/(32.174 lbm-ft/lbf-s^2) = 1550 ft-lbf = 2**.00 Btu**
$PE = mgz/g_c$ = (2.50 lbm)(32.174 ft/s^2)(15 ft)/(32.174 lbm-ft/lbf-s^2) = 37.5 ft-lbf **= 0.0482 Btu**

2.13) Determine the specific energy of air at 25^{o}C, traveling at 35.0 m/s at a height of 10.0 m. Consider the specific internal energy of the air to be 212.6 kJ/kg.

Given: T= 25^{o}C ; z = 10.0 m; V = 35.0 m/s; u = 212.6 kJ/kg
Assume: g = 9.81 m/s^2

Solution:

e = u + ½ V^2 = gz = 212.6 kJ/kg + ½ (35.0 m/s)^2/(1000 J/kJ) + (10.0 m)(9.81 m/s^2) / (1000 J/kJ)
e = 213.3 kJ/kg

2.14) Determine the total energy of water vapor with a mass of 2.50 kg, a specific internal energy of 2780 kJ/kg, traveling at a velocity of 56.0 m/s at a height of 3.50 m.

Given: m = 2.50 kg ; z = 3.50 m; V = 56.0 m/s; u = 2780 kJ/kg
Assume: g = 9.81 m/s^2

Solution:

E = mu + ½ mV^2 + mgz
= (2.50 kg)[2780 kJ/kg + ½ (56.0 m/s)^2/(1000 J/kJ) + (9.81 m/s^2)(3.50 m)/(1000 J/kJ)]
E = **6950 kJ (6954 kJ)**

2.15) A house has outside walls made of brick with a thermal conductivity of 1.20 W/m-K. The wall thickness is 0.20 m. (a) If the inside temperature of the wall is 20.0°C and the outside temperature of the wall is -10.0°C, determine the heat transfer rate per unit area from conduction (the conductive heat flux) for the wall. (b) For an inside wall temperature of 20.0°C, plot the conductive heat flux through the wall for outside wall temperatures ranging from 30.0°C to -15.0°C. (c) For an outside wall temperature of -10.0°C, plot the conductive heat flux for inside wall temperatures ranging from 15.0°C to 25.0°C. Discuss how this relates to gaining cost savings by heating a home to a lower temperature in the winter.

Given: κ = 1.20 W/m-K; Δx = 0.20 m

Solution:

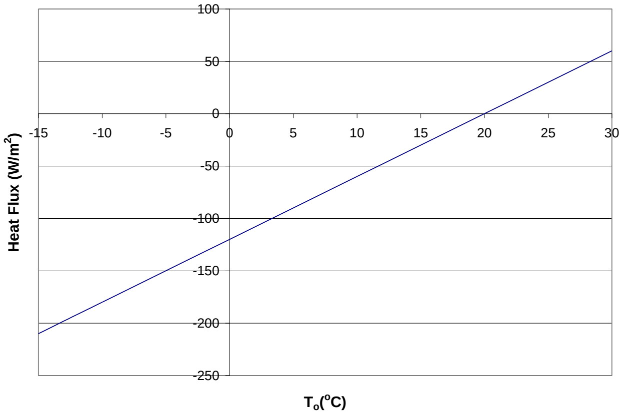
(a) T_o = -10.0°C, T_i = 20.0°C

$$\dot{Q}_{cond} = -\kappa A \frac{dT}{dx}$$

For the wall, approximate: $\frac{dT}{dx} = \frac{T_i - T_o}{\Delta x} = 150$ °C/m = 150 K/m

$\frac{\dot{Q}_{cond}}{A}$ =-(1.20 W/m-K)(150 K/m) = **-180 W/m²**

(b)



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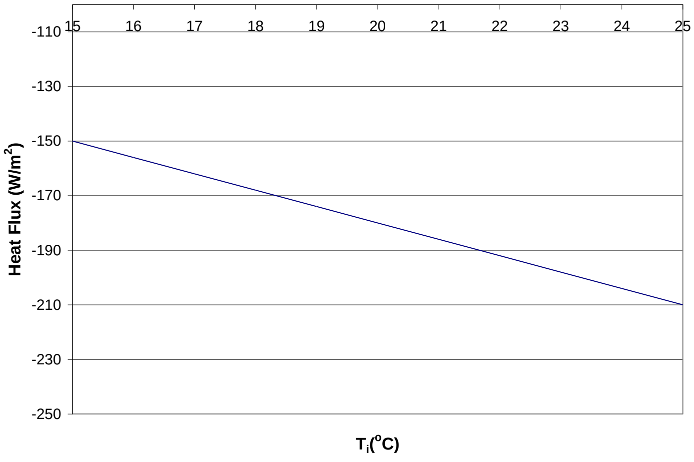


2.16) To reduce heat transfer losses through a glass window, you consider replacing the window with one of three alternatives: a sheet of tin 0.50-cm thick, a layer of brick 8.0-cm thick, and a combination of wood and insulation 4.0-cm thick. The original thickness of the glass is 1.0-cm. Consider the thermal conductivities of each to be the following: glass – 1.40 W/m-K; tin – 66.6 W/m-K; brick – 1.20 W/m-K; wood/insulation combination – 0.09 W/m-K. Considering the inside temperature of the surface to be 20.0^{o}C, and the outside temperature to be -5.0^{o}C, determine the heat conduction rate per unit area for the glass and the three alternatives, and discuss the relative merits of the three alternatives (ignoring material and installation costs).

Given: T_i = 20.0^{o}C; T_o = -5.0^{o}C

Solution:

For the each material, approximate: $\frac{dT}{dx} = \frac{T_i - T_o}{\Delta x}$

For Glass: κ = 1.40 W/m-K; Δx = 1.0 cm = 0.01 m

$\frac{\dot{Q}_{cond}}{A} = -\kappa \frac{T_i - T_o}{\Delta x}$ **= -3,500 W/m^2**

Tin: κ = 66.6 W/m-K; Δx = 0.5 cm = 0.005 m

$\frac{\dot{Q}_{cond}}{A} = -\kappa \frac{T_i - T_o}{\Delta x}$ **= -266,400 W/m^2**

Brick: κ = 1.20 W/m-K; Δx = 8.0 cm = 0.08 m

$\frac{\dot{Q}_{cond}}{A} = -\kappa \frac{T_i - T_o}{\Delta x}$ **= -375 W/m^2**

Wood/Insulation:

κ = 0.09 W/m-K; Δx = 4.0 cm = 0.04 m

$\frac{\dot{Q}_{cond}}{A} = -\kappa\frac{T_i - T_o}{\Delta x}$= **-56.3 W/m²**

The wood/insulation combination will offer the most resistance to heat flow, followed by the brick. The tin is a worse option than the original glass.

2.17) A factory has a sheet metal wall with a thermal conductivity of 105 Btu/h-ft-°F. The wall thickness is 1 inch. (a) If the inside temperature of the wall is 80.0°F and the outside temperature of the wall is 10.0°F, determine the heat transfer rate per unit area from conduction (the conductive heat flux) for the wall. (b) For an inside wall temperature of 80.0°F, plot the conductive heat flux through the wall for outside wall temperatures ranging from 90.0°F to 0.0°F. (c) For an outside wall temperature of 10.0°F, plot the conductive heat flux for inside wall temperatures ranging from 50.0°F to 85.0°F. Discuss how this relates to gaining cost savings by heating a building to a lower temperature in the winter.

Given: κ = 105 Btu/h-ft-°F; Δx = 1 in = 0.0833 ft

Solution:

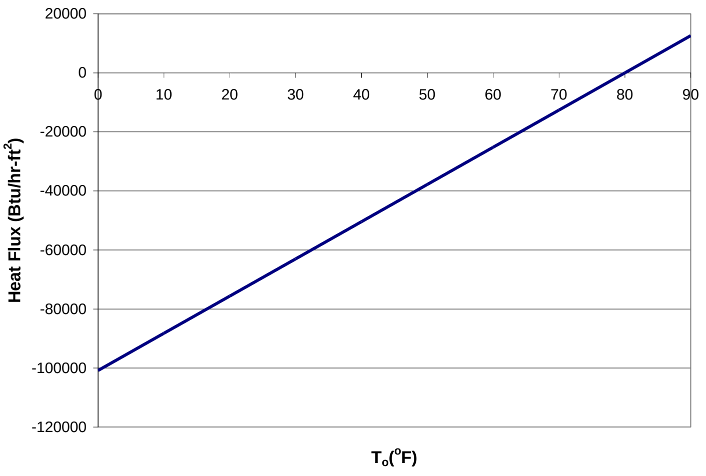
(a) T_o = 10.0°F, T_i = 80.0°F

$$\dot{Q}_{cond} = -\kappa A\frac{dT}{dx}$$

For the wall, approximate: $\frac{dT}{dx} = \frac{T_i - T_o}{\Delta x} = 840.3\ ^{o}\text{F/ft}$

$\frac{\dot{Q}_{cond}}{A}$ =-(105 Btu/hr-ft-°F)(840.3 °F/ft) = **-88,200 Btu/hr-ft²**

(b)



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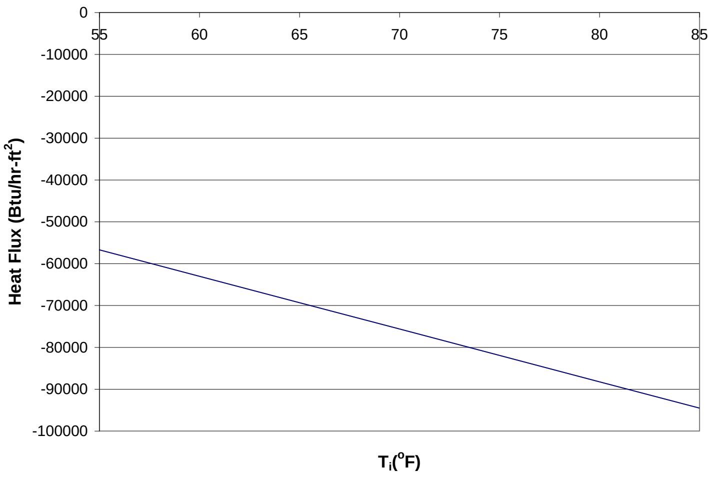


2.18) You are stoking a fire in a furnace, and leave the stoker inside the furnace for several minutes. The end of the stoker inside the furnace reaches a temperature of 300°C, while the other end of the stoker in the air is cooled sufficiently to maintain a temperature of 60°C. The length of the stoker between these two ends is 2.0 m. If the cross-sectional area of the stoker is 0.0010 m^2, determine the rate of heat transfer that occurs if (a) the stoker is made of aluminum (κ = 237 W/m-K), (b) iron (κ = 80.2 W/m-K), and (c) granite (κ = 2.79 W/m-K).

Given: T_1 = 300°C; T_2 = 60°C; Δx = 2.0 m; A = 0.0010 m^2

Solution:

For the each material, approximate: $\frac{dT}{dx} = \frac{T_2 - T_1}{\Delta x}$

$$\dot{Q}_{cond} = -\kappa A \frac{dT}{dx} = -\kappa A \frac{T_2 - T_1}{\Delta x}$$

(a) Aluminum: κ = 237 W/m-K

$\dot{Q}_{cond}$ = -(237 W/m-K)(0.0010 m^2)(60^{o}C-300^{o}C)/2.0m = **28.4 W**

(b) Iron: κ = 80.2 W/m-K

$\dot{Q}_{cond}$ = - (80.2 W/m-K)(0.0010 m^2)(60^{o}C-300^{o}C)/2.0m = **9.62 W**

(c) Granite: κ = 2.79 W/m-K

$\dot{Q}_{cond}$ = - (2.79 W/m-K)(0.0010 m^2)(60^{o}C-300^{o}C)/2.0m = **0.335 W**

2.19) A conductive heat transfer of 15 W is applied to a metal bar whose length is 0.50-m. The hot end of the bar is at 80^{o}C. Determine the temperature at the other end of the bar for (a) a copper bar (κ = 401 W/m-K) with a cross-sectional area of 0.0005 m^2, (b) a copper bar (κ = 401 W/m-K) with a cross-sectional area of 0.005 m^2, and (c) a zinc bar (κ = 116 W/m-K) with a cross-sectional area of 0.005 m^2.

Given: $\dot{Q}_{cond}$=150 W; Δx = 0.50 m; T_1 = 80^{o}C

Solution:

From $\dot{Q}_{cond} = -\kappa A \frac{dT}{dx} = -\kappa A \frac{T_2 - T_1}{\Delta x}$

$$T_2 = \frac{\dot{Q}_{cond}}{-kA}\Delta x + T_1$$

(a) Copper, κ = 401 W/m-K, A = 0.0005 m^2

$T_2 = \frac{15W}{-\left(\frac{401W}{m-K}\right)(0.0005m^2)}(0.50m) + 80^oC$ **= 42.6^{o}C**

(b) Copper, κ = 401 W/m-K, A = 0.005 m^2

T_2 = 76.3^{o}C

(c) Zinc, κ = 116 W/m-K, A = 0.005 m^2

T_2 = 54.1^{o}C

Note: A material with a higher thermal conductivity will allow the same amount of heat flow with a smaller temperature difference than a material with a lower thermal conductivity.

2.20) A wind blows over the face of a person on a cold winter day. The temperature of the air is -5.0°C, while the person's skin temperature is 35.0°C. If the convective heat transfer coefficient is 10.0 W/m^2-K, and the exposed surface area of the face is 0.008 m^2, determine the rate of heat loss from the skin via convection.

Given: T_f = -5.0°C; T_s = 35.0°C; h = 10.0 W/m^2-K; A= 0.008 m^2

Solution:

$\dot{Q}_{conv} = hA(T_f - T_s)$ = (10.0 W/m^2-K)(0.008 m^2)(-5°C - 35.0°C) = **-3.2 W**

The heat transfer is from the person to the air.

2.21) Cooling water flows over a hot metal plate with a surface area of 0.5 m^2 in a manufacturing process. The temperature of the cooling water is 15°C, while the metal plate's surface temperature is maintained at 200°C. If the convective heat transfer rate is 68.0 W/m^2-K, determine the rate of convective heat transfer from the plate.

Given: A = 0.5 m^2; T_f = 15°C; T_s = 200°C; h = 68.0 W/m^2-K

Solution:

$\dot{Q}_{conv} = hA(T_f - T_s)$ = (68.0 W/m^2-K)(0.5 m^2)(15°C - 200°C) = **-6,290 W = -6.29 kW**

The heat is transferred from the plate to the water.

2.22) Air passes over a hot metal bar which has a surface area of 2.5 ft^2. The temperature of the air is 70°F, while the bar has a temperature maintained at 280°F. If the convective heat transfer coefficient is 4 Btu/h-ft^2-°F, determine the rate of convective heat transfer from the plate.

Given: A = 2.5 ft^2; T_f = 70°C; T_s = 280°C; h = 4 Btu/h-ft^2-°F

Solution:

$\dot{Q}_{conv} = hA(T_f - T_s)$ = (4 Btu/h-ft^2-°F)(2.5 ft^2)(70°F - 280°F) = **-2,100 Btu/h**

The heat is transferred from the bar to the air.

2.23) A cool early spring breeze passes over the roof of a poorly-insulated home. The surface area of the roof is 250 m^2, and the temperature of the roof is maintained at 20°C from heat escaping the house. The air temperature is 5.0°C, and the convective heat transfer coefficient is 12.0 W/m^2-K. Determine the rate of convective heat transfer from the roof.

Given: $A = 250\ m^2$; $T_f = 5.0^oC$; $T_s = 20^oC$; $h = 12.0\ W/m^2\text{-}K$

Solution:

$\dot{Q}_{conv} = hA(T_f - T_s) =$ (12.0 W/m^2-K)(250 m^2)(5^{o}C - 20^{o}C) = **-45,000 W = -45.0 kW**
Heat is lost from the roof to the air.

2.24) An electric space heater has a metal coil at a temperature of 250^{o}C, and is used to heat a space with an air temperature of 15^{o}C. If the surface area of the space heater is 0.02 m^2, and the emissivity of the heating element is 0.95, what is the rate of radiation heat transfer between the heater and the air?

Given: $T_s = 250^oC = 523\ K$; $T_{surr} = 15^oC = 288\ K$; $A = 0.02\ m^2$; $\varepsilon = 0.95$

Solution:

$\dot{Q}_{rad} = -\varepsilon\sigma A\left(T_s^4 - T_{surr}^4\right)$ = - (0.95)(5.67x10^{-8} W/m^2-K^4)(0.02m^2)[(523 K)^4 – (288 K)^4] = **-73.2 W**
Heat is transferred from the heater to the air.

2.25) An electrical resistance heater is placed inside a hollow cylinder. The heater has a surface temperature of 500^{o}F, while the inside of the cylinder is maintained at 80^{o}F. If the surface area of the heater is 1.25 ft^2, and the emissivity of the heater is 0.90, what is the net rate of radiation heat transfer from the heater?

Given: $T_s = 500^oF = 960\ R$; $T_{surr} = 80^oF = 540\ R$; $A = 1.25\ ft^2$; $\varepsilon = 0.90$

Solution:

$\dot{Q}_{rad} = -\varepsilon\sigma A\left(T_s^4 - T_{surr}^4\right)$ = - (0.90)(0.1714x10^{-8} Btu/h-ft^2-R^4)(1.25ft^2)[(960 R)^4 – (540 R)^4]
= **- 1470 Btu/h**

2.26) A baker has developed a marvelous cookie recipe that works best if the cookie is cooled in a vacuum chamber through radiation heat transfer alone. The cookie is placed inside the chamber with a surface temperature of 125^{o}C. Assume that the cookie is thin enough so that the temperature is uniform throughout during the cooling process. The walls of the chamber are maintained at 10.0^{o}C. If the surface area of the cookie is 0.005 m^2, and if the emissivity of the cookie is 0.80, determine the initial radiation heat transfer rate from the cookie to the walls of the chamber.

Given: $T_s = 125^oC = 398\ K$; $T_{surr} = 10^oC = 283\ K$; $A = 0.005\ m^2$; $\varepsilon = 0.80$

Solution:

$\dot{Q}_{rad} = -\varepsilon\sigma A\left(T_s^4 - T_{surr}^4\right)$ = - (0.80)(5.67x10^{-8} W/m^2-K^4)(0.005m^2)[(398 K)^4 – (283 K)^4] = - **4.24 W**
Heat is transferred from the cookie to the walls.

2.27) A building is losing heat to the surrounding air. The inside walls of the building are maintained at 22.0°C, and the walls have a thermal conductivity of 0.50 W/m-K. The wall thickness is 0.10 m, and the outside wall temperature is held at 2.0°C. The air temperature is -10.0°C. Consider the emissivity of the outside of the walls to be 0.85. Calculate the conductive heat flux and the radiative heat flux. Considering that the heat flux entering the outside of the wall from the inside must balance the heat flux leaving the outside of the wall via convection and radiation, determine the necessary convective heat transfer coefficient of the air passing over the outside wall.

Given: $T_o = T_s$ = 2°C = 275 K; T_{surr} = -10°C = 263 K; T_i = 22.0°C = 295 K; Δx = 0.10 m; ε = 0.85; κ = 0.50 W/m-K

Solution:

Conduction: $\frac{\dot{Q}_{cond}}{A} = -\kappa\frac{T_i - T_o}{\Delta x} =$ - (0.50W/m-K)(295 K – 275 K)/(0.10 m) = **-100 W/m^2**
Radiation:
$\frac{\dot{Q}_{rad}}{A} = -\varepsilon\sigma\left(T_s^4 - T_{surr}^4\right)$ = - (0.85)(5.67x10^{-8} W/m^2-K^4)[(275 K)^4 – (263 K)^4] = **- 45.1 W/m^2**
Convection:
The difference between the conduction and radiation is the convective heat flux:
$\frac{\dot{Q}_{conv}}{A} = \frac{\dot{Q}_{cond}}{A} - \frac{\dot{Q}_{rad}}{A}$ = -100 W/m^2 – (-45.1 W/m^2) = **-54.9 W/m^2**

2.28) A long cylindrical rod with a diameter of 3.0 cm is placed in the air. The rod is heated by an electrical current so that the surface temperature is maintained at 200°C. The air temperature is 21°C. Air flows over the rod with a convective heat transfer coefficient of 5.0 W/m^2-K. Consider the emissivity of the rod to be 0.92. Ignoring the end effects of the rod, determine the heat transfer rate per unit length of the rod (a) via convection and (b) via radiation.

Given: T_s = 200°C = 473 K; $T_f = T_{surr}$ = 21°C = 294 K; h = 5.0 W/m^2-K; ε =0.92; D = 3.0 cm = 0.03 m

Solution:

The surface area of the cylinder is A = πDL = 0.09425L m^2 , where L is the length of the rod.

Convection:

$\frac{\dot{Q}_{conv}}{L} = h\frac{A}{L}(T_f - T_s)$ = (5.0 W/m^2-K)(0.09425 m)(21ºC - 200ºC) = **-84.4 W/m**

Radiation:

$\frac{\dot{Q}_{rad}}{L} = -\varepsilon\frac{A}{L}\sigma\left(T_s^4 - T_{surr}^4\right)$ = -(0.92)(0.09425 m)(5.67x10^{-8} W/m^2-K^4)[(473 K)^4 – (294 K)^4]

= **-209 W/m**

2.29) A weight is attached to a horizontal load through a frictionless pulley. The weight has a mass of 25.0 kg, and the acceleration due to gravity is 9.80 m/s^2. The weight is allowed to fall 2.35 m. What is the work done by the falling weight as it pulls the load on a horizontal plane?

Given: m = 25.0 kg; g = 9.80 m/s^2; Δx = 2.35 m

Solution:

$W = \int_{x_1}^{x_2} F \cdot dx$ = W Δx = (mg) Δx = (25.0 kg)(9.80 m/s^2) (2.35 m) = **576 J**

2.30) How much work is needed to lift a rock with a mass of 58.0 kg a distance of 15.0 m, where the acceleration due to gravity is 9.81 m/s^2?

Given: m = 58.0 kg; Δx = 15.0 m; g = 9.81 m/s^2

Solution:

$W = \int_{x_1}^{x_2} F \cdot dx$ = W Δx = (mg) Δx = (58.0 kg)(9.81 m/s^2) (15.0 m) = **8,530 J = 8.53 kJ**

2.31) How much work is needed to lift a 310 lbm rock a distance of 25.0 ft, where the acceleration due to gravity is 32.16 ft/s^2?

Given: m = 310 lbm; Δx = 25.0 ft; g = 32.16 ft/s^2

Solution:

$W = \int_{x_1}^{x_2} F \cdot dx$ = W Δx = [(mg)/g_c] Δx = [(310 lbm)(32.16 ft/s^2)/(32.174 lbm-ft/lbf-s^2)] (25.0 ft) = **7,750 ft-lbf**

2.32) A piston-cylinder device is filled with air. Initially, the piston is stabilized such that the length of the cylinder beneath the piston is 0.15 m. The piston has a diameter of 0.10 m. A weight with mass of 17.5 kg is placed on top of the piston, and the piston moves 0.030 m, such that the new length of the air-filled cylinder beneath the piston is 0.12 m. Determine the work done by the newly-added mass.

Given: x_1 = 0.15 m; x_2 = 0.12 m; D = 0.10 m; m = 17.5 kg

Assume: g = 9.81 m/s^2

Solution:

The force exerted by the mass equals the weight of the mass: W= mg = (17.5 kg)(9.81 m/s^2) = 171.7 N

$W = \int_{x_1}^{x_2} F \cdot dx$ = F (x_2 – x_1) = (171.7 N) (0.12 m – 0.15 m) = **- 5.15 J**

The negative sign indicates that this is work that is adding energy to the system – the air under the piston in the cylinder.

2.33) 250 kPa of pressure is applied to a piston in a piston-cylinder device. This pressure causes the piston to move 0.025 m. The diameter of the piston is 0.20 m. Determine the work done on the gas inside the piston.

Given: Δx = -0.025 m; P = 250 kPa; D = 0.20 m

Solution:

$W_{mb} = \int_{\forall_1}^{\forall_2} P \cdot d\forall$ = P ΔV

ΔV = (πD^2/4)Δx = -0.000785 m^3

W_{mb} = (250 kPa) (-0.000785 m^3) = -0.196 kN-m = -0.196 kJ = **-196 J**

2.34) A piston-cylinder device is filled with 5 kg of liquid water at 150°C. The specific volume of the liquid water is 0.0010905 m^3/kg. Heat is added to the water until some of the water boils, giving a liquid-vapor mixture with a specific volume of 0.120 m^3/kg . The pressure of the water is 475.8 kPa. How much work was done by the expanding water vapor?

Given: m = 5 kg; v_1 = 0.0010905 m^3/kg; v_2 = 0.120 m^3/kg; P = 475.8 kPa

Solution:

The water boils at constant pressure

$W_{mb} = \int_{V_1}^{V_2} P \cdot dV$ = mP ($v_2 - v_1$) = (5 kg)(475.8 kPa)(0.120 m^3/kg – 0.0010905 m^3/kg)

= **283 kJ**

In this case, work is being done on the surroundings by the expanding water, so the work represents energy out of the system.

2.35) Air at 100 psi and 75°F fills a piston-cylinder assembly to a volume of 0.55 ft^3. The air expands, in a constant-temperature process, until the pressure is 30 psi. (The constant-temperature process with a gas can be modeled as a polytropic process with n=1.) Determine the work done by the air as it expands.

Given: P_1 = 100 psi; V_1 = 0.55 ft^3; P_2 = 30 psi

Solution:

PV^1 = constant, so $P_1V_1 = P_2V_2$

$V_2/V_1 = P_1/P_2$

$W_{mb} = P_1V_1 \ln\frac{V_2}{V_1}$ = $P_1V_1\ln(P_1/P_2)$ = (100 lbf/in^2)(144 in^2/ft^2) (0.55 ft^3) ln ((100 psi/30 psi))

= **9,540 ft-lbf**

2.36) Air at 450 kPa and 20°C fills a piston-cylinder assembly to a volume of 0.075 m^3. The air expands, in a constant-temperature process, until the pressure is 150 kPa. (The constant-temperature process with a gas can be modeled as a polytropic process with n=1.) Determine the work done by the air as it expands.

Given: P_1 = 450 kPa; V_1 = 0.075 m^3; P_2 = 150 kPa

Solution:

PV^1 = constant, so $P_1V_1 = P_2V_2$

$V_2/V_1 = P_1/P_2$

$W_{mb} = P_1 V_1 \ln \frac{V_2}{V_1}$ = $P_1V_1\ln(P_1/P_2)$ = (450 kPa) (0.075 m^3) ln ((450 kPa/150 kPa)) = **37.1 kJ**

2.37) 1.5 kg of water vapor at 500 kPa fills a balloon. The specific volume of the water vapor is 0.3749 m^3/kg. The water vapor condenses at constant pressure until a liquid-vapor mixture with a specific volume of 0.0938 m^3/kg is present. Determine the work done in the process.

Given: m = 1.5 kg; P = 500 kPa; v_1 = 0.3749 m^3/kg; v_2 = 0.0938 m^3/kg

Solution:

The water condenses at constant pressure

$W_{mb} = \int_{V_1}^{V_2} P \cdot dV$ = mP ($v_2 - v_1$) = (1.5 kg)(500 kPa)(0.0938 m^3/kg – 0.3749 m^3/kg)
= **-211 kJ**

2.38) Air at 1200 kPa and 250ºC fills a balloon with a volume of 2.85 m^3. The balloon cools and expands until the pressure is 400 kPa. The pressure and volume follow a relationship given by $PV^{1.3}$ = constant. Determine the work done by the air as it expands, and the final temperature of the air.

Given: P_1 = 1200 kPa; T_1 = 250ºC = 523 K; V_1 = 2.85 m^3; P_2 = 400 kPa; $PV^{1.3}$ = constant

Solution:

From the ideal gas law, m = P_1V_1/RT_1
For air, R = 0.287 kJ/kg-K, so m = 22.78 kg

$V_2 = V_1 \sqrt[1.3]{\frac{P_1}{P_2}}$ = 6.635 m^3

The moving boundary work for a polytropic process with n ≠ 1:

$W_{mb} = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{(400kPa)(6.635m^3) - (1200kPa)(2.85m^3)}{1-1.3}$ = **2550 kJ**

From the ideal gas law:
$T_2 = P_2V_2/mR$ = **406 K = 133ºC**

2.39) Oxygen gas expands in a flexible container following a relationship of $PV^{1.15}$ = constant. The mass of the oxygen is 1.75 lbm, and initially the pressure and temperature of the oxygen is 150 psi and 150°F, respectively. The expansion continues until the volume is double the original volume. Determine the final pressure and temperature of the oxygen, and the work done by the oxygen during the expansion.

Given: m = 1.75 lbm; T_1 = 150°F = 610 R; P_1 = 150 psi = 21,600 lbf/ft^2; $V_2 = 2V_1$; $PV^{1.15}$ = constant.

Solution:

$P_2 = P_1(V_1/V_2)^{1.15}$ = (21,600 lbf/ft^2)$(1/2)^{1.15}$ = **9,730 lbf/ft² = 67.6 psi**

For O_2, R = 48.29 ft-lbf/lbm-R

From the ideal gas law: $V_1 = mRT_1/P_1$ = 2.387 ft^3

Then, $V_2 = 2\ V_1$ = 4.773 ft^3

From the ideal gas law: $T_2 = P_2V_2/mR$ = **550 R**

For the moving boundary work:

$$W_{mb} = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{(9730\,psf)(4.773\,ft^3) - (21{,}600\,psf)(2.387\,ft^3)}{1-1.15} = 34{,}100 \text{ ft-lbf}$$

2.40) Nitrogen gas is compressed in a flexible container following a relationship of $PV^{1.2}$ = constant. The mass of the nitrogen is 1.5 kg, and initially the pressure and temperature of the nitrogen is 120 kPa and 15°C, respectively. The compression continues until the volume reaches 0.10 m^3. Determine the final pressure and temperature of the nitrogen, and the work done on the nitrogen in the process.

Given: m = 1.5 kg; P_1 =120 kPa; T_1 = 15°C = 288 K; $PV^{1.2}$ = constant; V_2 = 0.10 m^3

Solution:

For N_2, R = 0.2968 kJ/kg-K

Using the ideal gas law: $V_1 = mRT_1/P_1$ = 1.068 m^3

For a polytropic process with n = 1.2: $P_1V_1^{1.2} = P_2V_2^{1.2}$

So, **P_2 = 2060 kPa**

From the ideal gas law, $T_2 = P_2V_2/mR$ = **462 K = 189 °C**

For the moving boundary work:

$$W_{mb} = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{(2058kPa)(0.1m^3) - (120kPa)(1.068m^3)}{1-1.20} = \mathbf{-388\ kJ}$$

2.41) Air expands in an isothermal process from a volume of 0.5 m^3 and a pressure of 850 kPa, to a volume of 1.2 m^3. The temperature of the air is 25°C. Determine the work done by the air in this expansion process.

Given: $T_1 = T_2 = 25^oC$; $V_1 = 0.5\ m^3$; $P_1 = 850$ kPa; $V_2 = 1.2\ m^3$

Solution:

An isothermal process involving an ideal gas can be modeled as a polytropic process with n = 1.

Therefore,

$W_{mb} = P_1V_1\ln\frac{V_2}{V_1}$ = (850 kPa)(0.5 m^3) ln (1.2 m^3 / 0.5 m^3) = **372 kJ**

2.42) 3.0 kg of air is initially at 200 kPa and 10°C. The air is compressed in a polytropic process, following the relationship PV^n = constant. The air is compressed until the volume is 0.40 m^3. Determine the work done and the final temperature of the air for values of n of 1.0, 1.1, 1.2, 1.3, and 1.4, and plot the work as a function of n.

Given: m = 3.0 kg; P_1 = 200 kPa; $T_1 = 10^oC = 283$ K; $V_2 = 0.40\ m^3$

Solution:

For air, R = 0.287 kJ/kg-K

From the ideal gas law, $V_1 = mRT_1/P_1 = 1.218\ m^3$

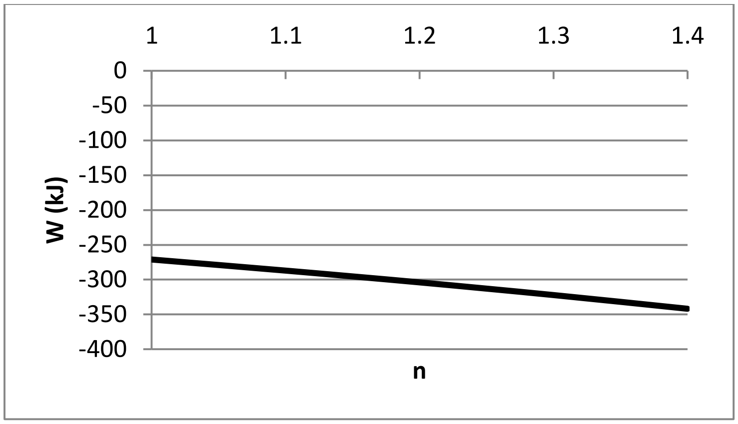
For a polytropic process with n = 1: $W_{mb} = P_1V_1\ln\frac{V_2}{V_1}$ = **- 271 kJ**

For a polytropic process with n ≠ 1: $W_{mb} = \frac{P_2V_2 - P_1V_1}{1-n}$

To solve for P_2, use $P_2 = P_1 (V_1/V_2)^n$

The following values can be found from these two equations:

n	P_2 (kPa)	W_{mb} (kJ)
1.1	681	-287
1.2	761	-304
1.3	851	-322
1.4	951	-342



2.43) A torque of 250 N-m is applied to a rotating shaft. Determine the work delivered for one revolution of the shaft.

Given: T = 250 N-m

Solution:

1 revolution involves a rotation through 2π radians. So, the rotating shaft work is

$W_{rs} = \int_{\theta_1}^{\theta_2} T \cdot d\theta$ = 2πT = 1571 J = **1.57 kJ**

2.44) A torque of 510 N-m is applied to a rotating shaft. Determine the power used if the shaft rotates at 1500 revolutions per minute.

Given: T = 510 N-m, $\dot{N}$ = 1500 rpm = 25 rps

Solution:

The rotating shaft power can be found from

$\dot{W}_{rs} = \int_{\theta_1}^{\theta_2} T \cdot d\dot{\theta}$=2πT $\dot{N}$ = 80,100 J/s = **80.1 kW**

2.45) An engine delivers 75 hp of power to a rotating shaft. If the shaft rotates at 2500 revolutions per minute, determine the torque exerted on the shaft by the engine.

Given: $\dot{W}_{rs} = 75\ \text{hp} = 41{,}250\,\frac{\text{ft}-\text{lbf}}{\text{s}};\ \dot{N} = 2500\ \text{rpm} = 41.67\ \text{rps}$

Solution:

From Problem 2.44, $T = \frac{\dot{W}_{rs}}{2\pi\dot{N}}$ = **158 ft-lbf**

2.46) A steam turbine operates at 1800 revolutions per minute (rpm). The turbine delivers 65.0 MW of power to the shaft of an electrical generator. Determine the torque on the steam turbine's shaft.

Given: $\dot{W}_{rs} = 65.0 \text{ MW} = 65{,}000{,}000 \text{ W}; \dot{N} = 1800 \text{ rpm} = 30 \text{ rps}$

Solution:

From Problem 2.44, $T = \frac{\dot{W}_{rs}}{2\pi\dot{N}}$ = 345,000 N-m = **345 kN-m**

2.47) A room fan operates on 120-volts and draws a current of 1.5 amps. What is the power used by the fan?

Given: E = 120 V; I = 1.5 A

Solution:

$\dot{W}_e = -\text{E}I$ = **-180 W**

2.48) A 23-Watt CFL bulb is plugged into a 120-volt source. What is the current drawn by the bulb?

Given: $\dot{W}_e$ = -23 W; E = 120 V

Solution:

$I = -\frac{\dot{W}_e}{E}$ = **0.192 A**

2.49) An air compressor is plugged into a 208-volt outlet, and requires 10 kW of power to complete its compression process. What is the current drawn by the air compressor?

Given: $\dot{W}_e$ = -10 kW = -10,000 W; E = 208 V

Solution:

$\mathrm{I} = -\frac{\dot{W}_e}{E}$ = **48.1 A**

2.50) You are placed in an unfamiliar environment, with many odd pieces of electrical equipment using non-standard plugs. You need to determine the voltage of a particular outlet. The information on the machine plugged into the outlet reveals that the machine uses 2.50 kW of power and draws a current of 20.8 amps. What is the voltage of the outlet?

Given: $\dot{W}_e$ = -2.50 kW = -2,500 W; I = 20.8 A

Solution:

$E = -\frac{\dot{W}_e}{I}$ = **120 V**

2.51) A linear elastic spring with a spring constant of 250 N/m is compressed from a length of 0.25 m to a length of 0.17 m. Determine the work done in this compression process.

Given: k = 250 N/m; x_1 = 0.25m ; x_2 = 0.17 m

Solution:

For a spring with a constant spring constant:

$W_{spring} = \int_{x_1}^{x_2} F \cdot dx = \int_{x_1}^{x_2} kx \cdot dx = \frac{1}{2}k(x_2^2 - x_1{}^2)$ = ½ (250 N/m) [(0.17 m)^2 – (0.25 m)^2] = **- 4.2 J**

2.52) A linear elastic spring has a spring constant of 21 lbf/ft is compressed from a length of 1.5 ft to a length of 1.3 ft. Determine the work done in this compression process.

Given: k = 21 lbf/ft; x_1 = 1.5 ft ; x_2 = 1.3 ft

Solution:

For a spring with a constant spring constant:

$W_{spring} = \int_{x_1}^{x_2} F \cdot dx = \int_{x_1}^{x_2} kx \cdot dx = \frac{1}{2}k(x_2^2 - x_1{}^2)$ = ½ (21 lbf/ft) [(1.3 ft)^2 – (1.5 ft)^2] = **- 5.89 ft-lbf**

2.53) A linear elastic spring with a spring constant of 1.25 kN/m is initially at a length of 0.25 m. The spring expands, doing 40 J of work in the process. What is the final length of the spring?

Given: k = 1,250 N/m; x_1 = 0.25m ; W_{spring} = 40 J

Solution:

For a spring with a constant spring constant:

$$W_{spring} = \int_{x_1}^{x_2} F \cdot dx = \int_{x_1}^{x_2} kx \cdot dx = \frac{1}{2}k(x_2^2 - x_1{}^2)$$

$$x_2 = \sqrt{\frac{2W_{spring}}{k} + x_1^2} = \mathbf{0.356\ m}$$

2.54) Air, with a mass flow rate of 8.0 kg/s, enters a gas turbine. The enthalpy of the air entering the turbine is 825 kJ/kg, the velocity of the air is 325 m/s, and the height of the air above the ground is 2.5 m. The acceleration due to gravity is 9.81 m/s^2. Determine the rate at which energy is being transferred into the gas turbine via mass flow by this air.

Given: $\dot{m}$ = 8.0 kg/s; h = 825 kJ/kg; V = 325 m/s; z = 2.5 m; g = 9.81 m/s^2

Solution:

$$\dot{E}_{massflow} = \dot{m}\left(h + \frac{1}{2}V^2 + gz\right)$$

= (8.0 kg/s)[825 kJ/kg + ½ (325 m/s)^2/(1000 J/kJ) + (9.81 m/s^2)(2.5 m)/(1000 J/kJ)] = **7,023 kW = 7.02 MW**

2.55) A jet of liquid water with a velocity of 42 m/s and an enthalpy of 62 kJ/kg enters a system at a mass flow rate of 210 kg/s. The potential energy of the water is negligible. What is the rate of energy transfer to the system via mass flow for the water jet?

Given: $\dot{m}$ = 210 kg/s; h = 62 kJ/kg; V = 42 m/s; z = 0 m;

Solution:

$$\dot{E}_{massflow} = \dot{m}\left(h + \frac{1}{2}V^2 + gz\right)$$

= (210 kg/s)[62 kJ/kg + ½ (42 m/s)^2/(1000 J/kJ) + 0] = **13,210 kW = 13.2 MW**

2.56) Steam enters a steam turbine at a volumetric flow rate of 110 ft^3/s. The enthalpy of the steam is 1320 Btu/lbm, and the specific volume of the steam is 2.43 ft^3/lbm. The velocity of the steam as it enters the steam turbine is 250 ft/s, and the height of the entrance above the ground is 10 ft. The acceleration due to gravity is 32.17 ft/s^2. Determine the rate at which energy is being transferred via mass flow for the steam.

Given: $\dot{V}$ = 110 ft^3/s; h = 1320 Btu/lbm; v = 2.43 ft^3/lbm; V = 250 ft/s; z = 10 ft;

g = 32.17 ft/s^2

Solution:

First, finding the mass flow: $\dot{m} = \frac{\dot{V}}{v}$ = 45.27 lbm/s

$$\dot{E}_{massflow} = \dot{m}\left(h + \frac{1}{2g_c}V^2 + \frac{gz}{g_c}\right)$$

=(45.27 lbm/s)[1320 Btu/lbm + ½ [(250 ft/s)^2/(32.174 lbm-ft/lbf-s^2)][1 Btu/778.169 ft-lbf] + [(32.17 ft/s^2)(10 ft)/(32.174 lbm-ft/lbf-s^2)][1 Btu/778.169 ft-lbf]] = **59,810 Btu/s = 16.6 Btu/h**

2.57) You have steam available to add energy to a system via mass flow. The enthalpy of the steam is 2750 kJ/kg, and the velocity of the steam is 120 m/s. The potential energy of the steam is negligible. If you must add 33.1 MW of energy to the system with this steam, what is the required mass flow rate of steam entering the system?

Given: $\dot{E}_{massflow}$ = 33,100 kW; h = 2750 kJ/kg; V = 120 m/s; z = 0 m;

Solution:

$$\dot{E}_{massflow} = \dot{m}\left(h + \frac{1}{2}V^2 + gz\right), \text{ so}$$

$$\dot{m} = \frac{\dot{E}_{massflow}}{h+\frac{1}{2}V^2+gz} = \frac{33{,}100 \text{ kW}}{2750\frac{kJ}{kg}+\frac{(\frac{120\text{ m}}{s})^2}{2(1000\frac{J}{kJ})}+0} = \mathbf{12.0\ kg/s}$$