0-4-1 [UK] A bucket of concrete with a mass of 5000 kg is raised without any acceleration by a crane through a height of 20 m. (a) Determine the work transferred into the bucket. (b) Also determine the power delivered to the bucket if it is raised at a constant speed of 1 m/s. (c) What happens to the energy after it is transferred into the bucket?

SOLUTION

(a) The pull force of the cable from the crane is equal the weight of the load.

$$W_{\text{in}} = F\left(z_f - z_b\right); \qquad \Rightarrow W_{\text{in}} = \left(\frac{(5000)(9.81)}{1000}\right)(20-0);$$

$$\Rightarrow W_{\text{in}} = 981 \text{ kJ}$$

Note that while the work transferred into the bucket is positive, the external work for the bucket as a system is negative according to WinHip sign convention.

(b) Power is the rate of work:

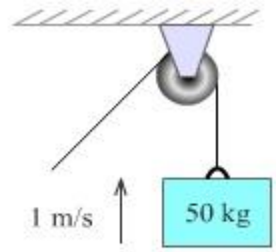
$$\dot{W}_{\text{in}} = FV;$$

$$\Rightarrow \dot{W}_{\text{in}} = \frac{mg}{1000}V; \qquad \Rightarrow \dot{W}_M = \left(\frac{(5000)(9.81)}{1000}\right)(1);$$

$$\Rightarrow \dot{W}_{\text{in}} = 49.05 \text{ kW}$$

It is stored as the increased potential energy of the bucket (the work done is exactly equal to the increase in potential energy).

0-4-2 [UP] The accompanying figure shows a body of mass 50 kg being lifted at a constant velocity of 1 m/s by the rope and pulley arrangement. Determine power delivered by the shaft.



SOLUTION

Only the absolute value of the power delivered by the shaft is required.

$$\dot{W}_{\text{delivered}} = FV; \qquad \Rightarrow \dot{W}_{\text{delivered}} = \frac{mg}{1000}V;$$

$$\Rightarrow \dot{W}_{\text{delivered}} = \frac{(50)(9.81)}{1000}(1);$$

$$\Rightarrow \dot{W}_{\text{delivered}} = 0.4905 \text{ kW}$$

0-4-3 [BEZ] An elevator with a total mass of 1500 kg is pulled upward using a cable (see Anim. 0-4-2) at a velocity of 5 m/s through a height of 300 m. (a) Determine the rate at which is work is transferred into the elevator(magnitude only, no sign). (b) What is the sign of W? Enter -1 (negative) or 1 (positive). (c) The change in stored E of the elevator assuming the KE and U to remain unchanged.

SOLUTION

(a) $\dot{W}_{\text{in}} = FV; \quad \Rightarrow \dot{W}_{\text{in}} = \dfrac{mg}{1000}V;$

$$\Rightarrow \dot{W}_{\text{in}} = \left(\frac{1500 \times 9.81}{1000}\right)(5);$$

$$\Rightarrow \dot{W}_{\text{in}} = 73.575 \text{ kW}$$

(b) Work is transferred into the system, so the sign of the work is negative: -1 by the WinHip convention.

(c) $\Delta E = \Delta KE + \Delta PE + \Delta U; \quad \Rightarrow \Delta E = \cancel{\Delta KE}^{0} + \Delta PE + \cancel{\Delta U}^{0};$

$$\Rightarrow \Delta E = \Delta PE; \quad \Rightarrow \Delta E = \frac{mg\Delta z}{1000}; \quad \Rightarrow \Delta E = \frac{(1500)(9.81)(300-0)}{1000};$$

$$\Rightarrow \Delta E = 4414.5 \text{ kJ}$$

0-4-4 [BEK] In problem 0-4-3[BEZ], assume the energetic efficiency (work transfer to the elevator (desired) to the electrical work transfer (required) to the motor), η, of the system to be 80%, (a) determine the power consumption rate by the motor (magnitude only). (b) Assuming electricity rate is 20 cents per kWh, determine the energy cost of operation in cents.

SOLUTION

(a) $\eta_M = \dfrac{\dot{W}_{\text{desired}}}{\dot{W}_{\text{required}}};$

$$\Rightarrow \dot{W}_{\text{required}} = \frac{73.55}{0.80};$$

$$\Rightarrow \dot{W}_{\text{required}} = 91.97 \text{ kW}$$

(b) $\eta_M = \dfrac{\dot{W}_{\text{desired}}}{\dot{W}_{\text{required}}};$

$$\Rightarrow \dot{W}_{\text{required}} = \frac{73.55}{0.80};$$

$$\Rightarrow \dot{W}_{\text{required}} = 91.97 \text{ kW}$$

(c) $W_{\text{required}} = \dot{W}_{\text{required}} t; \qquad \Rightarrow W_{\text{required}} = 91.97\left(\dfrac{300}{5}\right);$

$$\Rightarrow W_{\text{required}} = 5518.1 \text{ kJ};$$

$$\Rightarrow W_{\text{required}} = \frac{5518.1}{3600}; \qquad \Rightarrow W_{\text{required}} = 1.53 \text{ kWh};$$

Therefore, the cost is

$$(1.53)(\$0.20) = \$0.31 = 31 \text{ cents}$$

0-4-5 [UU] (a) Determine the constant force necessary to accelerate a car of mass 1000 kg from 0 to 100 km/h in 6 seconds. (b) Also calculate the work done by the force. (c) Verify that the work done by the force equals the change in kinetic energy of the car. Neglect friction. (d) **What-if Scenario:** What would the work be if the acceleration were achieved in 5 seconds?

SOLUTION

(a) $F = \frac{ma}{1000}; \quad \Rightarrow F = \frac{m}{1000}\frac{V}{\Delta t}; \quad \Rightarrow F = \frac{(1000)(100000)}{(1000)(6)(3600)};$

$\Rightarrow F = 4.63 \text{ kN}$

(b) $W_M = F\bar{V}\Delta t; \quad \Rightarrow W_M = (4.63)\left(\frac{100000}{2}\right)\left(\frac{6}{3600}\right); \quad \Rightarrow W_M = 385.8 \text{ kJ}$

(c) $\Delta \text{KE} = \frac{mV_f^2}{2000} - \frac{mV_b^2}{2000};$

$\Rightarrow \Delta \text{KE} = \frac{1000}{2000}\left(\frac{100000}{3600}\right)^2 - 0;$

$\Rightarrow \Delta \text{KE} = 385.8 \text{ kJ}$

(d) The answers depend on the beginning and final velocities of the car. So the time of acceleration does not affect the answers.

0-4-6 [CV] A driver locks the brake of a car traveling at 140 km/h. Without anti-lock-brakes, the tires immediately start skidding. If the total mass of the car, including the driver is 1200 kg, determine (a) the deceleration and (b) the stopping distance for the car and (c) the work transfer (include sign) treating the car as the system. Assume the friction coefficient between rubber and pavement to be 0.9. Neglect viscous drag.

SOLUTION

(a) $F = \dfrac{ma}{1000}; \quad \Rightarrow F = \dfrac{\mu mg}{1000};$

$$\Rightarrow a = \mu g; \quad \Rightarrow a = (0.9)(9.81); \quad \Rightarrow a = 8.829\ \frac{\text{m}}{\text{s}^2}$$

(b) The initial velocity

$$V_b = \frac{140000}{3600}; \quad \Rightarrow V_b = 38.89\ \frac{\text{m}}{\text{s}};$$

Therefore, $t = \dfrac{V_b}{a}; \quad \Rightarrow t = \dfrac{38.89}{8.829}; \quad \Rightarrow t = 4.405\text{s};$

The skid distance can be obtained from the average velocity and time

$$x_f - x_b = \frac{(38.89+0)}{2}\frac{1}{4.405}; \quad \Rightarrow x_f - x_b = 4.41\ \text{m}$$

(c) $W_f = F_f\left(x_f - x_b\right); \quad \Rightarrow W_f = \mu\left(\dfrac{mg}{1000}\right)\left(x_f - x_b\right);$

$$\Rightarrow W_f = \frac{(0.9)(1200)(9.81)}{1000}(4.41-0); \quad \Rightarrow W_f = 10.59\ \text{kJ};$$

The external work transfer for the car as the system is positive

$$W_{\text{ext}} = W_f; \quad \Rightarrow W_{\text{ext}} = 10.59\ \text{kJ}$$

0-4-7 [CQ] A car delivers 200 hp to a winch used to raise a load of 1000 kg. Determine the maximum speed of lift.

SOLUTION

The maximum speed is achieved when the entire power delivered by the winch goes into raising the load.

$$\dot{W}_{\text{winch}} = 200 \text{ hp}; \quad \Rightarrow \dot{W}_{\text{winch}} = 149.13889 \text{ kW};$$

$$\dot{W}_{\text{winch}} = FV; \quad \Rightarrow \dot{W}_{\text{winch}} = \left(\frac{mg}{1000}\right)V;$$

$$\Rightarrow V = \frac{149.13889(1000)}{(1000)(9.81)};$$

$$\Rightarrow V = 15.20 \ \frac{\text{m}}{\text{s}}$$

0-4-8 [CT] A block of mass 100 kg is dragged on a horizontal surface with static and kinetic friction coefficients of 0.15 and 0.09 respectively. Determine (a) the pull force necessary to initiate motion (b) the work done by the pull force and (c) the work done against the frictional force as the block is dragged over a distance of 5 m. (d) What is the net work transfer between the block and its surroundings?

SOLUTION

(a) $F = \frac{\mu_s mg}{1000}; \quad \Rightarrow F = \frac{(0.15)(100)(9.81)}{1000};$

$\Rightarrow F = 0.147 \text{ kN}$

(b) $W_{\text{pull}} = F\left(x_f - x_b\right); \quad \Rightarrow W_{\text{pull}} = \left(\frac{\mu_k mg}{1000}\right)\left(x_f - x_b\right);$

$\Rightarrow W_{\text{pull}} = \left(\frac{(0.09)(100)(9.81)}{1000}\right)(5-0); \quad \Rightarrow W_{\text{pull}} = 0.441 \text{ kJ}$

(c) $W_f = F\left(x_f - x_b\right); \quad \Rightarrow W_f = \left(\frac{\mu_k mg}{1000}\right)\left(x_f - x_b\right);$

$\Rightarrow W_f = \left(\frac{(0.09)(100)(9.81)}{1000}\right)(5-0); \quad \Rightarrow W_f = 0.441 \text{ kJ}$

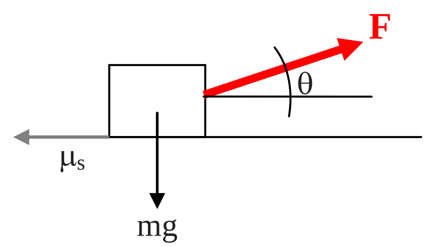
(d) The worked transferred by the pull force into the system (body) is exactly equal to the work transferred by the body as it does work to overcome friction.

$W_{\text{ext}} = 0.441 - 0.441; \quad \Rightarrow W_{\text{ext}} = 0 \text{ kJ}$

0-4-9 [CY] In the accompanying figure, determine (a) the work done by the force F acting at an angle of $\theta = 20^o$ in moving the block of mass 10 kg by a distance of 3 m if $\mu_s = 0.5$. (b) What is the sign of the work transfer if the block were treated as a system (1:positive; 2:negative)? (c) If the block comes to rest at the end of the process, describe what happens to the work done by the force?

SOLUTION

(a) Assuming no acceleration



$$\mu_k\left(\frac{mg}{1000} - F\sin\theta\right) = F\cos\theta;$$

$$\Rightarrow F = \frac{\mu_k\left(\frac{mg}{1000}\right)}{\cos\theta + \mu_k\sin\theta};$$

$$\Rightarrow F = \frac{(0.5)\left(\frac{10g}{1000}\right)}{\cos 20 + (0.5)\sin 20}; \qquad \Rightarrow F = 0.846\text{kN};$$

$$\Rightarrow W = F\cos\theta\left(x_f - x_b\right); \qquad \Rightarrow W = (0.846)(\cos 20)(3); \qquad \Rightarrow W = 2.385 \text{ kJ}$$

(b) Negative: 2 as the work is transferred into the system.

(c) Work done by the force is completely used to overcome the frictional force. The frictional work is transferred into internal energy of the block and the surface (making them warmer).

0-4-10 [CF] Twenty 50 kg suitcases are carried by a horizontal conveyor belt at a velocity of 0.5 m/s without any slippage. If μ_s = 0.9, (a) determine the power required to drive the conveyor. Assume no friction loss on the pulleys. (b) **What-if Scenario:** What would the power required be if the belt were inclined upward at an angle of 10^o?

SOLUTION

(a) Since the belt (suitcases are attached to the belt by friction) is moving horizontally and there is no friction at the pulleys, no work is being done.

$$\Rightarrow \dot{W}_{\text{conveyor}} = 0 \text{ kW}$$

(b) When the belt moves at an angle, the pull force is:

$$F = \frac{mg}{1000}\sin 10; \quad \Rightarrow F = \frac{(20)(50)(9.81)}{1000}\sin 10; \quad \Rightarrow F = 1.7035 \text{ N};$$

$$\dot{W}_{\text{conveyor}} = FV; \quad \Rightarrow \dot{W}_{\text{conveyor}} = (0.5)(1.7035); \quad \Rightarrow \dot{W}_{\text{conveyor}} = 0.852 \text{ kW}$$

0-4-11 [CJ] A person with a mass of 70 kg climbs the stairs of a 50 m tall building. (a) What is the minimum work transfer if you treat the person as a system? Assume standard gravity. (b) If the energetic efficiency (work output/heat released by food) of the body is 30%, how many Calories are burned during this climbing process?

SOLUTION

(a) Work done

$$F\left(z_f - z_b\right) = \frac{(70)(9.81)}{1000}(50); \qquad \Rightarrow F\left(z_f - z_b\right) = 34.335 \text{ kJ}$$

(b) $\eta = \dfrac{34.335}{Q_{\text{food}}}; \qquad \Rightarrow \eta = 30\%;$

$$\Rightarrow Q_{\text{food}} = \frac{34.335}{0.3}; \qquad \Rightarrow Q_{\text{food}} = 114.45 \text{ kJ}; \qquad \Rightarrow Q_{\text{food}} = 27.354 \text{ kcal}$$

0-4-12 [CD] A person with a mass of 50 kg and an energetic efficiency of 35% decides to burn all the calories consumed from a can of soda (140 Calories) by climbing stairs of a tall building. Determine the maximum height of the building necessary to ensure that all the calories from the soda can is expended in the work performed in climbing.

SOLUTION

$$\eta = \frac{mgz}{(1000)\times Q_{\text{food}}}; \qquad \Rightarrow \eta = 0.35;$$

$$\Rightarrow z = \frac{(0.35)(1000)(140)(4.187)}{(50)(9.81)};$$

$$\Rightarrow z = 418 \text{ m}$$

0-4-13 [CM] The aerodynamic drag force F_d in kN on an automobile is given as $F_d = 1/2000\ c_d\, A\, \rho\, V^2$ [kN], Where c_d is the non-dimensional drag coefficient, A is the frontal area in m^2, ρ is the density of the surrounding air in kg/m^3, and V is the velocity of air with respect to the automobile in m/s. Determine the power required to overcome the aerodynamic drag for a car with $c_d = 0.4$ and $A = 7$ m^2, traveling at a velocity of 100 km/h. Assume the density of air to be $\rho = 1.2$ kg/m^3.

SOLUTION

$$F_d = \frac{1}{2000} c_d A \rho V^2;$$

$$\dot{W}_d = F_d V; \quad \Rightarrow \dot{W}_d = \frac{1}{2000} c_d A \rho V^3;$$

$$\Rightarrow \dot{W}_d = \frac{1}{2000}(0.4)(7)(1.2)\left(\frac{100000}{3600}\right)^3;$$

$$\Rightarrow \dot{W}_d = 36.0 \text{ kW}$$

0-4-14 [VO] The rolling resistance of the tires is the second major opposing force (next to aerodynamic drag) on a moving vehicle and is given by $F_r = f\ W$ [kN] where f is the rolling resistance coefficient and W is the weight of the vehicle in kN. Determine the power required to overcome the rolling resistance for a 2000 kg car traveling at a velocity of 100 km/h, if $f = 0.007$.

SOLUTION

$$\dot{W}_r = F_r V; \quad \Rightarrow \dot{W}_r = \frac{fmg}{1000} V;$$

$$\Rightarrow \dot{W}_r = \frac{(0.007)(2000)(9.81)}{1000}\left(\frac{100000}{3600}\right);$$

$$\Rightarrow \dot{W}_r = 3.815 \text{ kW}$$

0-4-15 [CW] Determine (a) the power required to overcome the aerodynamic drag and (b) rolling resistance for a truck traveling at a velocity of 120 km/h, if $c_d = 0.8$, $A = 10\ \text{m}^2$, $\rho = 1.2\ \text{kg/m}^3$, $f = 0.01$, and $m = 20{,}000$ kg. Plot the power requirement - aerodynamic, rolling friction and total - against velocity within the range from 0 to 200 km/h.

SOLUTION

(a) $\dot{W}_d = F_d V; \qquad \Rightarrow \dot{W}_d = \dfrac{1}{2000} c_d A \rho V^3;$

$$\Rightarrow \dot{W}_d = \frac{1}{2000}(0.8)(10)(1.2)\left(\frac{120000}{3600}\right)^3;$$

$$\Rightarrow \dot{W}_d = 177.78\ \text{kW}$$

(b) $\dot{W}_r = F_r V; \qquad \Rightarrow \dot{W}_r = \dfrac{fmg}{1000} V;$

$$\Rightarrow \dot{W}_r = \frac{(0.01)(20000)(9.81)}{1000}\left(\frac{120000}{3600}\right);$$

$$\Rightarrow \dot{W}_r = 65.4\ \text{kW}$$

0-4-16 [VR] Determine (a) the power required to overcome the aerodynamic drag and (b) rolling resistance for a bicyclist traveling at a velocity of 21 km/h, if c_d = 0.8, A = 1.5 m^2, ρ = 1.2 kg/m^3, f = 0.01 and m = 100 kg. Also determine (c) the metabolic energetic efficiency (work output/energy input) for the bicyclist if the rate at which calories are burned is measured at 650 Calories/h.

SOLUTION

(a) $\dot{W}_d = F_d V; \quad \Rightarrow \dot{W}_d = \frac{1}{2000} c_d A \rho V^3;$

$$\Rightarrow \dot{W}_d = \frac{1}{2000}(0.8)(1.5)(1.2)\left(\frac{21000}{3600}\right)^3;$$

$$\Rightarrow \dot{W}_d = 0.143 \text{ kW}$$

(b) $\dot{W}_r = F_r V; \quad \Rightarrow \dot{W}_r = \frac{fmg}{1000} V;$

$$\Rightarrow \dot{W}_r = \frac{(0.01)(100)(9.81)}{1000}\left(\frac{21000}{3600}\right);$$

$$\Rightarrow \dot{W}_r = 0.057 \text{ kW}$$

(c) $\eta = \frac{\dot{W}_d + \dot{W}_r}{\dot{W}_{\text{input}}}; \quad \Rightarrow \eta = \frac{(0.143 + 0.057)}{650 \text{ Cal/h}}; \quad \Rightarrow \eta = \frac{(0.2)}{0.756 \text{ kW}}; \quad \Rightarrow \eta = 0.265;$

$$\Rightarrow \eta = 26.5\%$$

0-4-17 [VB] Determine (a) the work transfer involved in compressing a spring with a spring constant of 150 kN/m from its rest position by 10 cm. (b) What is the work done in compressing it further by another 10 cm?

SOLUTION

(a) $W_{10\text{ cm}} = \dfrac{kx^2}{2}; \quad \Rightarrow W_{10\text{ cm}} = \dfrac{(150)(0.1)^2}{2}; \quad \Rightarrow W_{10\text{ cm}} = 0.75\text{ kJ}$

(b) $W_{20\text{ cm}} = \dfrac{kx^2}{2}; \quad \Rightarrow W_{20\text{ cm}} = \dfrac{(150)(0.2)^2}{2}; \quad \Rightarrow W_{20\text{ cm}} = 3\text{ kJ};$

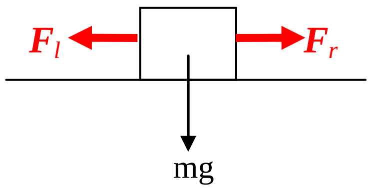
Extra work needed:

$3 - 0.75 = 2.25\text{ kJ}$

0-4-18 [VS] An object with a mass of 200 kg is acted upon by two forces, 0.1 kN to the right and 0.101 kN to the left. Determine (a & b) the work done by the two faces and (c) the net work transfer as the system (the object) is moved a distance of 10 m.

SOLUTION

(a) The body moves towards left.



$$W_{\text{right}} = F_l\left(x_f - x_b\right); \quad \Rightarrow W_{\text{right}} = 0.1(0-10);$$
$$\Rightarrow W_{\text{right}} = -1 \text{ kJ}$$

(b)
$$W_{\text{right}} = F_r\left(x_f - x_b\right); \quad \Rightarrow W_{\text{right}} = 0.101(10-0);$$
$$\Rightarrow W_{\text{right}} = 1.01 \text{ kJ}$$

(c) With the object as the system, use of WinHip sign convention produces:

$$W_{\text{ext}} = -\left(W_{\text{left}} + W_{\text{right}}\right) = -(1.01-1) = -0.01 \text{ kJ}$$

The work done by the external forces is the negative of the work produced (external work transfer) by the system.

0-4-19 [QA] A rigid chamber contains 100 kg of water at 500 kPa, 100°C. A paddle wheel stirs the water at 1000 rpm while an internal electrical resistance heater heats the water while consuming 10 amps of current at 110 Volts. At steady state, the chamber looses heat to the atmosphere at 27°C at a rate of 1.2 kW. Determine (a) W_{sh} in kW, (b) the torque in the shaft in N-m.

SOLUTION

(a) At steady state, the energy entering the system through shaft and electrical work must be equal to the heat loss.

$$\dot{Q}_{\text{loss}} = \dot{W}_{\text{in,el}} + \dot{W}_{\text{in,sh}}$$

$$\Rightarrow \dot{W}_{\text{in,sh}} = \dot{Q}_{\text{loss}} - \dot{W}_{\text{in,el}} = 1.2 - \left(\frac{(10)(110)}{1000}\right)$$

$$\Rightarrow \dot{W}_{\text{in,sh}} = 0.1 \text{ kW}$$

(b)

$$\dot{W}_{\text{in,sh}} = T\omega = T\frac{2\pi N}{60}$$

$$\Rightarrow T = \frac{(0.1)(60)}{2\pi(1000)} = 0.000955 \text{ kN}\cdot\text{m}$$

$$\Rightarrow T = 0.955 \text{ N}\cdot\text{m}$$

0-4-20 [VA] A piston-cylinder device containing a fluid is fitted with a paddle wheel stirring device operated by the fall of an external weight of mass 50 kg. As the mass drops by a height of 5 m, the paddle wheel makes 10,000 revolutions. Meanwhile the free moving piston (frictionless and weightless) of 0.5 m diameter moves out by a distance of 0.7 m. Find the W_{net} for the system if the pressure outside is 101 kPa.

SOLUTION

The loss of potential energy of the hanging weight must be equal to the work transferred by the paddle wheel.

$$W_{\text{in,sh}} = (50)(9.81)(5) = -2.4525 \text{ kJ}$$

The work transferred by boundary work is

$$W_{\text{out},B} = p\left(\cancel{V}_f - \cancel{V}_b\right) = 101 \text{ kPa}\left(\pi \frac{(0.5)^2}{4}\right)(0.7) = 13.88 \text{ kJ}$$

$$W_{\text{ext}} = W_{\text{out},B} - W_{\text{in,sh}} = 13.88 - 2.4525 = 11.429 \text{ kJ}$$

0-4-21 [VH] An insulated piston-cylinder device contains steam at 300 kPa, 200°C, occupying a volume of 1 m^3, and having a specific volume of 0.716 m^3/kg. It is heated by an internal electrical heater until the volume of steam doubles due to an increase in temperature.

(a) Determine the final specific volume of steam.

(b) If the diameter of the piston is 20 cm and the outside pressure is 100 kPa, determine the mass of the weight placed on the piston to maintain a 300 kPa internal pressure.

(c) Calculate the W_B (magnitude only) done by the steam in kJ.

(d) Calculate the amount of W_M (magnitude only) transferred into the weight in kJ.

(e) If you are asked to choose one of the three values - 1300 kJ, 300 kJ, 200 kJ - as the magnitude of W_{el}, which one will be your educated guess? Why?

SOLUTION

(a)

$$v_2 = \frac{\cancel{V}_2}{m} = \frac{2\cancel{V}_1}{m} = 2v_1 = 2(0.716) = 1.432\ \frac{\text{m}^3}{\text{kg}}$$

(b)

$$Ap_i = \frac{mg}{1000} + Ap_0;$$

$$\Rightarrow m = \frac{A(p_i - p_0)(1000)}{g} = \left(\frac{\pi}{4}\right)(0.2^2)(300-100)\frac{1000}{9.81} = 640.5\text{ kg}$$

(c)

$$W_B = p_i(\cancel{V}_f - \cancel{V}_b); \qquad \Rightarrow W_B = (300)(2-1); \qquad \Rightarrow W_B = 300\,\text{kJ}$$

(d)

$$\cancel{V}_1 = A_1 z_1; \qquad \Rightarrow 1 = \left(\pi/4\right)(0.2^2)z_1; \qquad \Rightarrow z_1 = 31.83\,\text{m}$$

$$\cancel{V}_2 = A_1 z_2; \qquad \Rightarrow 2 = \left(\pi/4\right)(0.2^2)z_2; \qquad \Rightarrow z_2 = 63.66\,\text{m}$$

$$W_M = \frac{mg\Delta z}{1000}; \qquad \Rightarrow W_M = \frac{(640.5)(9.81)(63.66-31.83)}{1000}$$

$$\Rightarrow W_M = 200\,\text{kJ}$$

(e)

The system does 300 kJ of boundary work (200 kJ of that goes into lifting the weight and 100 kJ to lift the atmosphere). An increase in temperature requires additional energy. Therefore, 1300 kJ would be the correct choice.

0-4-22 [VN] A gas in a vertical piston-cylinder device has a volume of 0.5 m^3 and a temperature of 400 K. The piston has a mass of 50 kg and a cross-sectional area of 0.2 m^2. As the gas cools down to atmospheric temperature the volume decreases to 0.375 m^3. Neglect friction and assume atmospheric pressure to be 100 kPa. Determine (a) the work transfer during the process. (b) **What-if Scenario:** What would the work transfer be if the piston weight were considered negligible?

SOLUTION

(a)

$$Ap_i = \frac{mg}{1000} + Ap_0;$$

$$\Rightarrow p_i = \frac{mg}{(1000)A} + p_0 = \frac{(50)(9.81)}{1000(0.2)} + 100 = 102.45 \text{ kPa}$$

$$W_B = p_i\left(\cancel{V}_f - \cancel{V}_b\right);$$

$$\Rightarrow W_B = 102.45(0.375 - 0.5); \quad \Rightarrow W_B = -12.8 \text{ kJ}$$

(b) $p_i = p_0 = 100$ kPa

$$W_B = p_i\left(\cancel{V}_f - \cancel{V}_b\right); \quad \Rightarrow W_B = (100)(0.375 - 0.5); \quad \Rightarrow W_B = -12.5 \text{ kJ}$$

The negative sign indicates that work is transferred into the system as the gas shrinks in volume.

0-4-23 [VE] A man weighing 100 kg is standing on the piston head of a vertical piston-cylinder device containing nitrogen. The gas is now heated by an electrical heater until the man is slowly lifted by a height of 1 m. The piston is weightless and has an area of 1 m^2. The outside pressure is 100 kPa. Determine (a) the initial pressure inside the cylinder, (b) the final pressure inside, (c) the boundary work (magnitude only)performed by the piston-cylinder device (nitrogen is the system) assuming an average pressure of 101 kPa inside the cylinder during the heating process, and (d) the work (magnitude only) transferred to the man (man as the system). Assume the acceleration due to gravity to be 9.81 m/s^2.

SOLUTION

(a)

$$Ap_i = \frac{mg}{1000} + Ap_0;$$

$$\Rightarrow p_i = \frac{mg}{(1000)A} + p_0 = \frac{(100)(9.81)}{1000(1)} + 100 = 101\,\text{kPa}$$

(b)

The outside force on the piston is the same in the new position. Therefore, the gas pressure does not change during expansion.

$$p_i = 101\,\text{kPa}$$

(c)

$$W_B = p_i \Delta V = p_i A \Delta z = (101)(1)(1)$$

$$\Rightarrow W_B = 101\,\text{kJ}$$

(d)

$$W_M = \frac{mg\Delta z}{1000}; \quad \Rightarrow W_M = \frac{(100)(9.81)(1)}{(1000)}; \quad \Rightarrow W_M = 0.981\,\text{kJ}$$

The difference between the boundary work performed by the gas and the work transferred to the man is the work that goes into the atmosphere (in lifting it).

0-4-24 [VI] A 10 m^3 insulated rigid tank contains 20 kg of air at 25^{o}C. An electrical heater within the tank is turned on which consumes a current of 5 Amps for 30 min from a 110 V source. Determine the work transfer in kJ.

SOLUTION

$$W_{\text{in,el}} = \dot{W}_{\text{in,el}}\Delta t = \frac{VI}{1000}\Delta t = \frac{(110)(5)}{1000}(1800) = 990 \text{ kJ};$$

$$\Rightarrow\ W_{\text{ext}} = -W_{\text{in,el}} = -990 \text{ kJ}$$

0-4-25 [VL] A paddle wheel stirs a water tank at 500 rpm. The torque transmitted by the shaft is 20 N-m. At the same time an internal electric resistance heater draws 2 Amps of current from a 110 V source as it heats the water. Determine (a) W in kW. (b) What is the total W in one hour?

SOLUTION

(a)

$$\dot{W}_{\text{in,sh}} = 2\pi n T = 2\pi\left(\frac{500}{60}\right)\left(\frac{20}{1000}\right) = 1.047 \text{ kW}$$

$$\dot{W}_{\text{in,el}} = \frac{VI}{1000} = \frac{(110)(2)}{1000} = 0.22 \text{ kW}$$

$$\dot{W}_{\text{ext}} = -\dot{W}_{\text{in,sh}} - \dot{W}_{\text{in,el}} = -1.047 - 0.22 = -1.267 \text{ kW}$$

(b)

$$W_{\text{ext}} = \dot{W}_{\text{ext}}\Delta t = (-1.267)(3600) = -4561 \text{ kJ}$$

0-4-26 [VK] Determine the power transmitted by the crankshaft of a car transmitting a torque of 0.25 kN-m at 3000 rpm.

SOLUTION

$$\dot{W}_{\text{out,sh}} = 2\pi nT = 2\pi\left(\frac{3000}{60}\right)(0.25) = 78.54\ \text{kW}$$

0-4-27 [VG] An electric motor draws a current of 16 amp at 110 V. The output shaft delivers a torque of 10 N-m at a speed of 1500 RPM. Determine (a) the electric power transferred, (b) shaft power, and (c) the rate of heat transfer if the motor operates at steady state.

SOLUTION

(a)

$$\dot{W}_{\mathrm{el}} = -\frac{VA}{1000} = -\frac{(110)(16)}{(1000)} = -1.76\ \mathrm{kW}$$

(b)

$$\dot{W}_{sh} = 2\pi\frac{NT}{60}; \qquad \Rightarrow \dot{W}_{sh} = \frac{(2\pi)(1500)(10)}{(60)(1000)} = 1.57\ \mathrm{kW}$$

(c)

$$\dot{W}_{\mathrm{ext}} = \dot{W}_{\mathrm{el}} + \dot{W}_{\mathrm{sh}} = (-1.76) + (1.57) = -0.19\ \mathrm{kW}$$

There is a net negative external work transfer, which means the system gains energy (more work coming in than going out) at the rate of 0.19 kW. To maintain steady state, heat must be rejected at the same rate.

Therefore, $\dot{Q} = -0.19\ \mathrm{kW}$

0-4-28 [VZ] Determine the boundary work transfer in blowing up a balloon to a volume of 0.01 m^3. Assume that the pressure inside the balloon is equal to the surrounding atmospheric pressure, 100 kPa.

SOLUTION

$$W_B = p\left(\cancel{V}_f - \cancel{V}_b\right); \quad \Rightarrow W_B = 100(0.01-0); \quad \Rightarrow W_B = 1\text{ kJ}$$

0-4-29 [VP] Air in a horizontal piston-cylinder assembly expands from an initial volume of 0.25 m^3 to a final volume of 0.5 m^3 as the gas is heated for 90 seconds by an electrical resistance heater consuming 1 kW of electric power. If the atmospheric pressure is 100 kPa, determine (a) W_B and (b) W_{net}. (c) **What-if Scenario:** How would the answers change if the cylinder contained oxygen instead? (0:no change; 1:increase; -1:decrease)

SOLUTION

(a)

$$W_B = p\left(\cancel{V}_f - \cancel{V}_b\right) = 100(0.5 - 0.25) = 25 \text{ kJ}$$

(b)

$$W_{\text{el}} = -\dot{W}_{\text{el}}\Delta t = -(1)(90) = -90 \text{ kJ}$$

$$W_{\text{ext}} = W_B + W_{\text{el}} = 25 + (-90) = -65 \text{ kJ}$$

(c) No change.

0-4-30 [VU] A vertical piston-cylinder assembly (see figure) contains 10 L of air at 20°C. The cylinder has an internal diameter of 20 cm. The piston is 2 cm thick and is made of steel of density ρ = 7830 kg/m^3. If the atmospheric pressure outside is 101 kPa, (a) determine the pressure of air inside the cylinder. The air is now heated until its volume doubles. (b) Determine the boundary work transfer during the process. **What-if Scenario:** What would the (c) pressure and (d) work be if the piston weight were neglected?

SOLUTION

(a)

$$p_i = p_0 + \frac{m_p g}{(1000)A_p} = p_0 + \frac{\rho_p \cancel{V}_p g}{(1000)A_p} = p_0 + \frac{\rho_p A_p t g}{(1000)A_p}$$

$$\Rightarrow\ p_i = 101\ \text{kPa} + \frac{(7830)(0.02)(9.81)}{1000} = 102.54\ \text{kPa}$$

(b)

$$W_B = p_i\left(\cancel{V}_f - \cancel{V}_b\right) = p_i\left(2\cancel{V}_b - \cancel{V}_b\right) = 102.54\left(0.01\ \text{m}^3\right);$$

$$\Rightarrow\ W_B = 1.0254\ \text{kJ}$$

(c)

$$p_i = p_0; \qquad \Rightarrow\ p_i = 101\ \text{kPa}$$

(d)

$$W_B = p_i\left(2\cancel{V}_b - \cancel{V}_b\right) = 101\left(0.01\ \text{m}^3\right);$$

$$\Rightarrow\ W_B = 1.01\ \text{kJ}$$

0-4-31 [VX] Air in the accompanying piston-cylinder device is initially in equilibrium at 200°C. The mass of the hanging weight is 10 kg and the piston diameter is 10 cm. As air cools due to heat transfer to the surroundings, the piston moves to the left, pulling the weight up. Determine (a) the boundary work and (b) the work done in raising the weight for a piston displacement of 37 cm. (c) Explain why the two are different.

SOLUTION

(a)

$$p_i = p_0 - \frac{m_{\text{hang}} g}{(1000) A_{\text{piston}}} = 100 - \frac{(10)(9.81)}{(1000)\left(\pi \frac{0.10^2}{4}\right)} = 87.5 \text{ kPa}$$

$$W_B = p_i \left(\cancel{V}_f - \cancel{V}_b \right) = p_i (A \Delta x);$$

$$\Rightarrow W_B = -(87.5)\left(\pi \frac{0.10^2}{4}\right)(0.37) = -0.254 \text{ kJ}$$

(the negative sign indicates that work is transferred into the system)

(b)

$$W_r = F\left(z_f - z_b\right) = \frac{mg\Delta z}{1000} = \frac{(10)(9.81)(0.37)}{1000} = 0.0363 \text{ kJ}$$

(this work is done by the string on the weight and is transferred into the weight)

(c)

The atmospheric pressure is actually doing work in this case, some of it going toward lifting the weight, and the rest toward compressing the contents of the cylinder. Note that, the work done by the atmosphere $p_0\left(\cancel{V}_b - \cancel{V}_f\right)$ is exactly equal to the sum of the work transferred into the system and the weight.

0-4-32 [VC] A horizontal piston-cylinder device contains air at 90 kPa while the outside pressure is 100 kPa. This is made possible by pulling the piston with a hanging weight through a string and pulley arrangement (see accompanying figure). If the piston has a diameter of 20 cm,

(a) determine the mass of the hanging weight in kg.

(b) The gas is now heated using an electrical heater and the piston moves out by a distance of 20 cm. Determine the boundary work (include sign) in kJ.

(c) What fraction of the boundary work performed by the gas goes into the hanging weight?

(d) How do you account for the loss of stored energy (in the form of PE) by the hanging weight?

SOLUTION

(a)

$$p_i = p_0 - \frac{m_{\text{hang}}\, g}{(1000)\, A_{\text{piston}}}$$

$$\Rightarrow m_{\text{hang}} = \frac{\pi}{4} \frac{(100-90)(1000)\left(0.2^2\right)}{g} = 32 \text{ kg}$$

(b)

$$W_B = p_i \Delta V = p_i A \Delta x = (90)\left(\frac{\pi}{4}\right)\left(0.2^2\right)(0.2) = 0.565 \text{ kJ}$$

(c)

The boundary work goes into displacing the atmosphere, so 0.

(d)

Only part of the work of displacing the outside atmosphere is done by the expanding gas inside the cylinder. The rest is done by the descending weight.

0-4-33 [VV] An insulated, vertical piston-cylinder assembly (see figure) contains 50 L of steam at 105°C. The outside pressure is 101 kPa. The piston has a diameter of 20 cm and the combined mass of the piston and the load is 75 kg. The electrical heater and the paddle wheel are turned on and the piston rises slowly by 25 cm. Determine (a) the pressure of air inside the cylinder during the process (b) the boundary work performed by the gas and (c) the combined work transfer by the shaft and electricity if the net energy transfer into the cylinder is 3.109 kJ.

SOLUTION

(a) Pressure remains constant during the expansion of the gas. This can be verified by a free body diagram of the piston.

$$p_i = p_0 + \frac{m_{\text{piston}} g}{1000 A_{\text{piston}}}$$

$$\Rightarrow\ p_i = 101 + \frac{(75)(9.81)}{1000\left(\pi \dfrac{0.20^2}{4}\right)}; \qquad \Rightarrow\ p_i = 124.42 \text{ kPa}$$

(b)

$$W_B = p_i\left(\mathcal{V}_f - \mathcal{V}_b\right)$$

$$\Rightarrow\ W_B = p_i\left(\mathcal{V}_b + \frac{\pi}{4}(0.20)^2(0.25) - \mathcal{V}_b\right)$$

$$\Rightarrow\ W_B = (124.42)\left(7.854\times10^{-3}\right) = 0.977 \text{ kJ}$$

(c) The total energy transfer into the cylinder is due to boundary, shaft, and electrical work since heat transfer is absent (due to insulation).

$$W_{\text{in,sh}} + W_{\text{in,el}} - W_{\text{out},B} = 3.109$$

$$\Rightarrow\ W_{\text{in,sh}} + W_{\text{in,el}} = 3.109 + W_{\text{out},B}$$

$$\Rightarrow\ W_{\text{in,sh}} + W_{\text{in,el}} = 3.109 + 0.977 = 4.086 \text{ kJ}$$

$$\text{Therefore, } W_{\text{sh}} + W_{\text{el}} = -4.086 \text{ kJ}$$

Note that symbols with subscripts in and out are absolute values.

0-4-34 [VQ] Steam is compressed from p_1 = 100 kPa, Vol_1 = 1 m^3 to p_2 = 200 kPa, Vol_2 = 0.6 m^3. The external force exerted on the piston is such that pressure increases linearly with a decrease in volume. Determine (a) the boundary work transfer (b) Show the work by shaded areas in a *p*-*v* diagram.

SOLUTION

(a)
$$W_B = \int_b^f p\,d\cancel{V}; \quad \Rightarrow W_B = \int_b^f (aV + b)\,d\cancel{V}; \quad \Rightarrow W_B = a\frac{\cancel{V}_2^2 - \cancel{V}_1^2}{2} + b\left(\cancel{V}_2 - \cancel{V}_1\right)$$

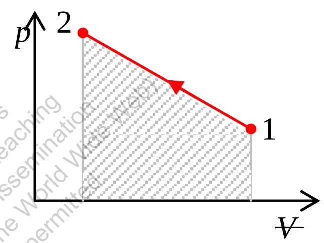
$$\Rightarrow W_B = \left(-250\ \frac{\text{kPa}}{\text{m}^3}\right)\left(\frac{\left((0.6)^2 - (1)^2\right)m^6}{2}\right) + (350\ \text{kPa})(0.6 - 1)\ \text{m}^3$$

$$\Rightarrow W_B = -60\ \text{kJ}$$

(b)
$$W_B = Area = \left(\frac{p_1 + p_2}{2}\right)\left(\cancel{V}_2 - \cancel{V}_1\right)$$

$$\Rightarrow W_B = \left(\frac{(100) + (200)}{2}\right)(0.6 - 1)$$

$$\Rightarrow W_B = -60\ \text{kJ}$$



0-4-35 [VT] A gas in a piston-cylinder assembly is compressed (through a combination of external force on the piston and cooling) in such a manner that the pressure and volume are related by pV^n = constant. Given an initial state of 100 kPa and 1 m^3 and a final volume of 0.5 m^3. Evaluate the work transfer if (a) n = 0 (b) n = 1 and (c) n = 1.4 and (d) plot a p-V diagram for each process and show the work by shaded areas.

SOLUTION

(a) $$p_2 = p_1\left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)^n; \quad \Rightarrow p_2 = (100)\left(\frac{1}{0.5}\right)^0; \quad \Rightarrow p_2 = 100 \text{ kPa}$$

$$W_B = \int_b^f p\,d\cancel{V}; \quad \Rightarrow W_B = \frac{p_2\cancel{V}_2 - p_1\cancel{V}_1}{1-n}; \quad \Rightarrow W_B = \frac{(100)(0.5)-(100)(1)}{1-(0)}$$

$$\Rightarrow W_B = -50 \text{ kJ}$$

(b) $$p_2 = p_1\left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)^n; \quad \Rightarrow p_2 = (100)\left(\frac{1}{0.5}\right)^1; \quad \Rightarrow p_2 = 200 \text{ kPa}$$

For special case of $n = 1$, the formula will be:

$$W_B = \int_b^f p\,d\cancel{V}; \quad \Rightarrow W_B = p_1\cancel{V}_1 \ln\left(\frac{\cancel{V}_2}{\cancel{V}_1}\right); \quad \Rightarrow W_B = (100)(1)\ln\left(\frac{0.5}{1}\right)$$

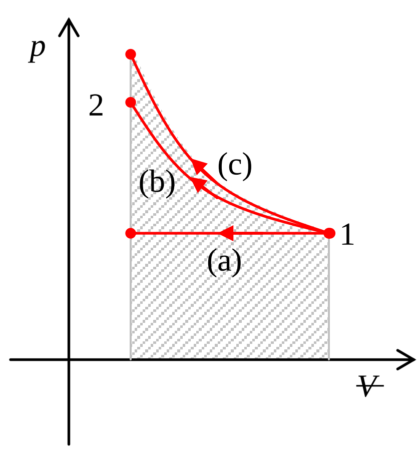
$$\Rightarrow W_B = -69.31 \text{ kJ}$$

(c) $$p_2 = p_1\left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)^n; \quad \Rightarrow p_2 = (100)\left(\frac{1}{0.5}\right)^{1.4}; \quad \Rightarrow p_2 = 263.9 \text{ kPa}$$

$$W_B = \int_b^f p\,d\cancel{V}; \quad \Rightarrow W_B = \frac{p_2\cancel{V}_2 - p_1\cancel{V}_1}{1-n}; \quad \Rightarrow W_B = \frac{(263.9)(0.5)-(100)(1)}{1-(1.4)}$$

$$\Rightarrow W_B = -79.88 \text{ kJ}$$

(d)



0-4-36 [VY] In the preceding problem the piston has a cross-sectional area of 0.05 m^2. If the atmospheric pressure is 100 kPa and the weight of the piston and friction are negligible, plot how the external force applied by the connecting rod on the piston varies with the gas volume for (a) $n = 0$ (b) $n = 1$ and (c) $n = 1.4$.

SOLUTION

(a)

$$p_2 = p_1\left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)^n; \quad \Rightarrow p_2 = (100)\left(\frac{1}{0.5}\right)^0; \quad \Rightarrow p_2 = 100 \text{ kPa}$$

$$F_{\text{ext-1}} = F_{\text{ext-2}} = F_{\text{total}} - F_0; \quad \Rightarrow F_{\text{ext-1}} = \frac{p_1}{A_{\text{piston}}} - \frac{p_0}{A_{\text{piston}}}; \quad \Rightarrow F_{\text{ext-1}} = \frac{100}{0.05} - \frac{100}{0.05}; \quad \Rightarrow F_{\text{ext-1}} = 0 \text{ kN}$$

(b)

$$p_2 = p_1\left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)^n; \quad \Rightarrow p_2 = (100)\left(\frac{1}{0.5}\right)^1; \quad \Rightarrow p_2 = 200 \text{ kPa}$$

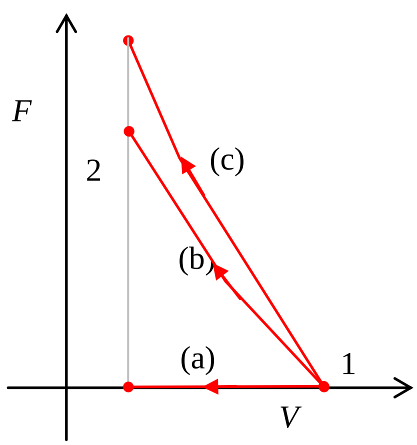
$$F_{\text{ext-2}} = F_{\text{total}} - F_0; \quad \Rightarrow F_{\text{ext-2}} = \frac{p_2}{A_{\text{piston}}} - \frac{p_0}{A_{\text{piston}}}; \quad \Rightarrow F_{\text{ext-2}} = \frac{200}{0.05} - \frac{100}{0.05}; \quad \Rightarrow F_{\text{ext-2}} = 2000 \text{ kN}$$

(c)

$$p_2 = p_1\left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)^n; \quad \Rightarrow p_2 = (100)\left(\frac{1}{0.5}\right)^{1.4}; \quad \Rightarrow p_2 = 263.9 \text{ kPa}$$

$$F_{\text{ext-2}} = F_{\text{total}} - F_0; \quad \Rightarrow F_{\text{ext-2}} = \frac{p_2}{A_{\text{piston}}} - \frac{p_0}{A_{\text{piston}}}; \quad \Rightarrow F_{\text{ext-2}} = \frac{263.9}{0.05} - \frac{100}{0.05}; \quad \Rightarrow F_{\text{ext-2}} = 3278 \text{ kN}$$

Plot:



0-4-37 [VF] A piston-cylinder device contains 0.03 m^3 of nitrogen at a pressure of 300 kPa. The atmospheric pressure is 100 kPa and the spring pressed against the piston has a spring constant of 256.7 kN/m. Heat is now transferred to the gas until the volume doubles. If the piston has a diameter of 0.5 m, determine (a) the final pressure of nitrogen, (b) the work transfer from nitrogen to the surroundings, and (c) the fraction of work that goes into the atmosphere.

SOLUTION

(a)

$$\mathcal{V}_2 = 2\mathcal{V}_1; \quad \Rightarrow \mathcal{V}_2 = (2)(0.03); \quad \Rightarrow \mathcal{V}_2 = 0.06 \text{ m}^3$$

$$p_2 = p_1 + \frac{k\Delta\mathcal{V}}{A_{\text{piston}}^2}; \quad \Rightarrow p_2 = 300 + \frac{(256.7)(0.06-0.03)}{\left(\pi\frac{(0.5)^2}{4}\right)^2}; \quad \Rightarrow p_2 = 499.75 \text{ kPa}$$

(b)

$$W_B = \frac{(p_1+p_2)}{2}(\mathcal{V}_2 - \mathcal{V}_1); \quad \Rightarrow W_B = \frac{(300+499.75)}{2}(0.06-0.03);$$

$$\Rightarrow W_B = 11.996 \text{ kJ}$$

(c)

$$W_{B-\text{atm}} = (100)(0.03); \quad \Rightarrow W_{B-\text{atm}} = 3 \text{ kJ}$$

Fraction of works that goes to the atmosphere:

$$f = \frac{3}{11.996}; \quad \Rightarrow f = 0.25; \quad \Rightarrow f = 25\%$$

0-4-38 [VD] Same as 0-4-32

0-4-38/39 [VJ] A 100 kg block of solid is moved upward by an external force F as shown in the accompanying figure. After a displacement of 10 cm, the upper surface of the block reaches a linear spring at its rest position. The external force is adjusted so that the displacement continues for another 10 cm. If the spring constant is 100 kN/m and acceleration due to gravity is 9.81 m/s^2, determine (a) the work done by the external force. (b) What fraction of the energy transferred is stored in the spring?

SOLUTION

(a) $$W_M = \frac{mg}{1000}(x_1 + x_2) + \frac{kx_2^2}{2000}; \quad \Rightarrow W_M = \frac{(100)(9.81)}{1000}(0.1+0.1) + \frac{(100000)(0.1)^2}{2000}$$

$$W_M = 0.1962 + 0.5 = 0.6962 \text{ kJ}$$

(b) $$\text{Percent stored in spring} = \frac{0.5}{0.6962}(100) = 71.8\%$$

0-4-39/40 [VW] Nitrogen in a horizontal piston-cylinder assembly expands from an initial volume of 0.10 m^3 to a final volume of 0.5 m^3 as the gas is heated for 5 minutes by an electrical resistance heater consuming 1 kW of electric power. If the pressure remains constant at 150 kPa, and 70 kJ of heat is lost from the cylinder during the expansion process, determine (a) W_B (include sign), (b) W_{el} (include sign), and (c) W_{net} (absolute value) into the system through heat and work.

SOLUTION

(a) $W_B = p(\cancel{V}_f - \cancel{V}_b)$; $\Rightarrow W_B = (150)(0.5 - 0.1) = 60$ kJ

(b) $W_{el} = -\dot{W}_{el}\Delta t$; $\Rightarrow W_{el} = -(1)(300) = -300$ kJ

(c) $\Delta E_{net} = W_{\text{in,el}} - W_{\text{out,B}} - Q_{\text{out}} = 300 - 60 - 70 = 170$ kJ

0-4-40/41 [QO] Water enters a system, operating at steady state, at 100 kPa, 25°C, and 10 m/s at a mass flow rate of 200 kg/s. It leaves the system at 15 m/s, 1 MPa, 25°C. If the density (ρ) of water is 1000 kg/m^3, determine (a) the rate of flow work ($\dot{W}_F$) at the inlet (magnitude only) and (b) the diameter of the pipe at the inlet.

SOLUTION

(a)

$$\dot{\mathcal{V}} = \frac{\dot{m}}{\rho}; \qquad \Rightarrow \dot{\mathcal{V}} = \frac{200}{1000}; \qquad \Rightarrow \dot{\mathcal{V}} = 0.2 \text{ m}^3/\text{s}$$

$$\dot{W}_{F,i} = p_i \dot{\mathcal{V}}_i = (100)(0.2) = 20 \text{ kW}$$

(b)

$$\dot{m} = \rho A V; \qquad \Rightarrow A = \frac{200}{(1000)(10)} \text{ m}^2$$

$$\Rightarrow \frac{\pi}{4} d^2 = 0.02 \text{ m}^2;$$

$$\Rightarrow d = 0.1596 \text{ m} = 15.96 \text{ cm}$$

0-4-41/42 [QR] The rate of energy transfer due to flow work at a particular cross-section is 20 kW. If the volume flow rate is 0.2 m^3/min, determine the pressure at that location.

SOLUTION

$$\dot{W}_{F,e} = p_e A_e V_e$$

$$\Rightarrow p_e = \frac{\dot{W}_{F,e}}{A_e V_e}; \qquad \Rightarrow p_e = \frac{20}{\left(\frac{0.2}{60}\right)}; \qquad \Rightarrow p_e = 6000 \text{ kPa} = 6 \text{ MPa}$$

0-4-42/43 [QB] Water enters a pump at 100 kPa with a mass flow rate of 20 kg/s and exits at 500 kPa with the same mass flow rate. If the density (ρ) of water is 1000 kg/m^3, determine (a) the net rate of flow work transfer in kW.

SOLUTION

$$\dot{W}_F = \dot{W}_{Fe} - \dot{W}_{Fi} = (p_e \dot{V}_e) - (p_i \dot{V}_i) = (p_e - p_i)\dot{V}$$

$$\Rightarrow \dot{W}_F = (500 - 100)\left(\frac{20}{1000}\right) \text{ kW} = 8 \text{ kW}$$

0-4-43/44 [BEG] Water (ρ = 1000 kg/m^3) flows steadily into a hydraulic turbine through an inlet with a mass flow rate of 500 kg/s. The conditions at the inlet are measured as 500 kPa and 25^{o}C. (a) Determine the magnitude of the rate of flow work transfer in kW and (b) the sign of the work transfer (-1 if negative, 1 if positive) treating the turbine as the system.

Analysis

(a)

$$\dot{W}_F = pAV = \rho AV\frac{p}{\rho} = \dot{m}\frac{p}{\rho}$$

$$\Rightarrow \dot{W}_F = p\left(\frac{\dot{m}}{\rho}\right) = (500)\left(\frac{500}{1000}\right) = 250 \text{ kW}$$

(b)

The work is being done at the inlet (work is transferred into the system); therefore, according to the WinHip sign convention, the work is negative.