0-6-1 [BEL] During charging, a battery pack loses heat at a rate of 0.2 kW. The electric current flowing into the battery from a 220 V source is measured as 10 amp. Determine (a) Q, (b) W_{el}, and (c) W_{ext}. Include sign.

SOLUTION

(a)

(a)

$$\dot{Q} = -0.2 \text{ kW} \qquad [\text{out of the system}]$$

(b)

$$\dot{W}_{el} = -\left(\frac{220 \times 10}{1000}\right); \qquad \Rightarrow \dot{W}_{el} = -2.2 \text{ kW} \qquad [\text{into the system}]$$

(c)

$$\dot{W}_{ext} = \dot{W}_{el}; \qquad \Rightarrow \dot{W}_{ext} = -2.2 \text{ kW} \qquad [\text{into the system}]$$

0-6-2 [UV] A car delivers its power to a winch, which is used to raise a load of 1000 kg at a vertical speed of 2 m/s. Determine (a) the work delivered by the engine to the winch in kW, and (b) the rate (g/s) at which fuel is consumed by the engine. Assume the engine to be 35% efficient with the heating value of fuel to be 40 MJ/kg.

SOLUTION

(a) Power delivered by the engine:

$$\dot{W}_{\text{engine}} = FV = \frac{mg}{1000}V = \left(\frac{1000 \times 9.81}{1000}\right)(2)$$
$$\Rightarrow \dot{W}_{\text{engine}} = 19.62 \text{ kW}$$

(b) Heat input required by the engine:

$$\dot{Q}_{\text{in}} = \frac{\dot{W}_{\text{engine}}}{0.35} = \frac{19.62}{0.35} = 56.06 \text{ kW}$$

Heat released by 1 kg of fuel is 40000 kJ. Therefore, the fuel consumption rate is:

$$\frac{56.06 \text{ (kJ/s)}}{40000 \text{ (kJ/kg)}} = 0.0014 \frac{\text{kg}}{\text{s}} = 1.4 \frac{\text{g}}{\text{s}}$$

0-6-3 [QS] A car delivers 96.24 kW to a winch, which is used to raise a load of 1000 kg. (a) Determine the maximum velocity in m/s with which the load can be raised. (b) If the heating value of the fuel used is 45 MJ/kg and the engine has an overall efficiency of 35%, determine the rate of fuel consumption in kg/h.

SOLUTION

(a)

$$\dot{W}_{\text{engine}} = FV = \frac{mg}{1000}V;$$

$$\Rightarrow\ V = \left(\frac{1000 \times \dot{W}_{\text{engine}}}{1000 \times 9.81}\right) = 9.81 \text{ m/s}$$

(b) Heat input required by the engine:

$$\dot{Q} = \frac{\dot{W}_M}{0.35} = \frac{96.24}{0.35} = 274.97 \ \text{kW}$$

Heat released by 1 kg of fuel is 45000 kJ. Therefore, fuel consumption rate is:

$$\frac{274.97 \text{ (kJ/s)}}{45000 \text{ (kJ/kg)}} = 0.00611 \ \frac{\text{kg}}{\text{s}} = 22 \ \frac{\text{kg}}{\text{h}}$$

0-6-4 [UT] A semi-truck of mass 25,000 lb (1 kg = 2.2 lb) enters a highway ramp at 10 mph (1 m/h = 0.447 m/s). It accelerates to 75 mph while merging with the highway at the end of the ramp at an elevation of 15 m. (a) Determine the change in mechanical energy of the truck. (b) If the heating value of diesel is 40 MJ/kg and the truck engine is 30% efficient (in converting heat to mechanical energy), determine the mass of diesel (in kg) burned on the ramp.

SOLUTION

(a)

$$m_t = (25000)\left(\frac{1}{2.2}\right) = 11363.6363 \text{ kg}$$

$$V_b = (10)(0.447) = 4.47 \ \frac{\text{m}}{\text{s}}$$

$$V_f = (75)(0.447) = 33.525 \ \frac{\text{m}}{\text{s}}$$

$$\Delta E = \Delta KE + \Delta PE + \Delta U; \qquad \Rightarrow \Delta E = \frac{m_t \Delta V^2}{2000} + \frac{m_t g \Delta z}{1000} + \cancel{\Delta U}^{\,0}$$

$$\Rightarrow \Delta E = \frac{m_t\left(V_f^{\,2} - V_b^{\,2}\right)}{2000} + \frac{m_t g\left(z_f - z_b\right)}{1000}$$

$$\Rightarrow \Delta E = \left[\frac{(11363.6363)\left(33.525^2 - 4.47^2\right)}{2000}\right] + \left[\frac{(11363.6363)(9.81)(15-0)}{1000}\right]$$

$$\Rightarrow \Delta E = 6272.413 + 1672.159 = 7945 \text{ kJ}$$

$$\Rightarrow \Delta E = 7.945 \text{ MJ}$$

(b)

$$\eta_{th} = \frac{W_{out}}{Q_{in}}; \qquad \Rightarrow 0.30 = \frac{7.945}{Q_{in}}; \qquad \Rightarrow Q_{in} = \frac{7.945}{0.30}; \qquad \Rightarrow Q_{in} = 26.48 \text{ MJ}$$

$$m_d = \frac{26.48 \text{ MJ}}{\left(40 \text{ MJ}/\text{kg}\right)}; \qquad \Rightarrow m_d = 0.66 \text{ kg}$$

0-6-5 [UY] We are interested in the amount of gasoline consumed to accelerate a car of mass 5000 kg from 5 to 30 m/s (about 60 mph) on a freeway ramp. The ramp has a height of 15 m. Assuming the internal energy of the car to remain constant, (a) determine the change in stored energy *E* of the car. (b) If the heating value of gasoline is 44 MJ/kg and the engine has a thermal efficiency of 30%, determine the amount of gasoline (in kg) that will be consumed as the car moves through the ramp. Assume all the engine power goes into the kientic and potential energies of the car.

SOLUTION

(a)

$$\begin{aligned}\Delta E &= \Delta KE + \Delta PE + \cancel{\Delta U}^{0} \\ &= \frac{m\left(V_f^{\,2} - V_b^{\,2}\right)}{2000} + \frac{mg\left(z_f - z_b\right)}{1000} \\ &= 2923 \text{ kJ}\end{aligned}$$

(b) Heat required to produce this work is 2923/0.3 = 9743 kJ. Therefore, the fuel consumed is:

$$= \frac{9743 \text{ kJ}}{44000 \ (\text{kJ/kg})} = 0.221 \text{ kg}$$

0-6-6 [QK] A jumbo jet with a mass of 5 million kg requires a speed of 175 mph for take off. Assuming an overall efficiency of 20% (from heat release to kinetic energy of the aircraft), determine the amount of jet fuel (heating value: 44 MJ/kg) consumed during the take off.

SOLUTION

$$V_f = (175)(0.447) = 78.225 \ \frac{\text{m}}{\text{s}}$$

$$\Delta E = \Delta KE + \Delta PE + \Delta U = \Delta KE + \cancel{\Delta PE}^{0} + \cancel{\Delta U}^{0}$$

$$\Rightarrow \Delta E = \frac{m\left(V_f^{\ 2} - V_b^{\ 2}\right)}{2000} = \frac{m\left(V_f^{\ 2} - V_b^{\ 2}\right)}{2000}$$

$$\Rightarrow \Delta E = \frac{\left(5\times10^6\right)\left(78.225^2 - 0^2\right)}{2000}; \qquad \Rightarrow \Delta E = 15.298 \text{ GJ}$$

$$\eta_{th} = \frac{W_{out}}{Q_{in}};$$

$$\Rightarrow Q_{in} = \frac{15.298}{0.20} = 76.489 \text{ GJ} = 76489 \text{ MJ}$$

$$m_f = \frac{76489 \text{ MJ}}{\left(44 \text{ MJ}/\text{kg}\right)} = 1738 \text{ kg}$$

0-6-7 [QP] A 0.1 kg projectile travelling with a velocity of 200 m/s (represented by State-1) hits a stationary block of solid (represented by State-2) of mass 1 kg and becomes embedded (combined system is represented by State-3). Assuming momentum is conserved (there are no external forces, including gravity, on any system), (a) determine the velocity of the combined system (V_3) in m/s. (b) If the stored energy of the systems before and after the collision are same (that is, $E_1 = E_2 = E_3$), determine the change in internal energy after the collision ($U_3 - U_1 - U_2$) in kJ.

SOLUTION

(a) Mass conservation:

$$m_3 = m_1 + m_2; \qquad \Rightarrow m_3 = 0.1 + 1; \qquad \Rightarrow m_3 = 1.1 \text{ kg}$$

Momentum conservation:

$$m_1V_1 + m_2V_2 = m_3V_3; \qquad \Rightarrow \quad (0.1)(200) = (1.1)V_3 \qquad (V_2 = 0)$$
$$\Rightarrow V_3 = 18.18 \text{ m/s}$$

(b)As stored energy is the same,

Change in Kinetic Energy = Change in Internal Energy

$$\Delta E = 0;$$
$$\Rightarrow \Delta U + \Delta \text{KE} + \cancel{\Delta \text{PE}}^{0} = 0;$$
$$\Rightarrow \Delta U = -\Delta \text{KE} = -\left(\frac{1}{2000}m_3V_3^2 - \frac{1}{2000}m_1V_1^2 - \frac{1}{2000}m_2V_2^2\right); \qquad [\text{kJ}]$$
$$\Rightarrow \Delta U = -\left[\frac{1}{2000}(1.1)(18.18)^2 - \frac{1}{2000}(0.1)(200)^2 - \frac{1}{2000}(1)(0)^2\right];$$
$$\Rightarrow \Delta U = 1.81 \text{ kJ}$$

0-6-8 [QC] A semi-truck of mass 20,000 lb accelerates from 0 to 75 mph (1 mph = 0.447 m/s) in 10 seconds. (a) What is the change in kinetic energy of the truck in 10 seconds? (b) If *PE* and *U* of the truck can be assumed constant, what is the average value of *dE/dt* of the truck during this period? (c) If 30% of the heat released from the combustion of diesel (heating value of diesel is 40 MJ/kg) is converted to kinetic energy, determine the average rate of fuel consumption in kg/s.

SOLUTION

(a)

$$\Delta KE = \frac{1}{2000} m(V_2^2 - V_1^2) = \frac{1}{2000}(20000)(0.4536)\big((75)(0.447)\big)^2 = 5100 \text{ kJ}$$

$$\Rightarrow \ \Delta KE = 5.1 \text{ MJ}$$

(b)

$$\frac{dE}{dt} = \frac{\Delta KE}{\Delta t} = \frac{5.1}{10} = 0.51 \text{ MW}$$

(c)

Heat release required $= \frac{dE}{dt}\frac{1}{0.30}$ (as only 30% is utilised)

$$\dot{Q} = \frac{0.51}{0.3}; \qquad \Rightarrow \ \dot{Q} = 1.7 \text{ MW}$$

Rate of fuel consumption $= \dfrac{\dot{Q}}{\text{Heating value}}$

$$\dot{m} = \frac{1.7}{40} = 0.0425 \text{ kg/s}$$

0-6-9 [QU] A gas trapped in a piston-cylinder device is subjected to the energy interactions shown in the accompanying figure for 30 seconds: the electric resistance heater draws 0.1 amp from a 100 V source, the paddle wheel turns at 60 rpm with the shaft transmitting a torque of 5 N-m and 1 kJ of heat is transferred into the gas from the candle. The volume of the gas increases by 6 L during the process. If the atmospheric pressure is 100 kPa and the piston can be considered weightless, determine (a) W_B, (b) W_{sh}, (c) W_{el}, (d) W_{net}, (e) E_{net} that is added to the system.

SOLUTION

(a) Boundary work (positive: work out)

$$W_B = p_i \Delta \cancel{V} = p_0 \Delta \cancel{V} = (100)(6\times10^{-3})\text{ kJ} = 0.6\text{ kJ}$$

(b) Shaft work = $-T\omega t$ (negative: work in)

$$W_{\text{sh}} = -T\omega t = -T\frac{2\pi N}{60}t = -\frac{5}{1000}\left(\frac{(2\pi)(60)}{60}\right)30 = -0.94\text{ kJ}$$

(c) Electrical Work $= -VIt$ (negative: work in)

$$W_{\text{el}} = -\frac{(100)(0.1)(30)}{1000} = -0.3\text{ kJ}$$

(d)

$$W_{\text{ext}} = W_{\text{el}} + W_{\text{sh}} + W_B$$
$$\Rightarrow \quad W_{\text{ext}} = -0.3 - 0.94 + 0.6 = -0.64\text{ kJ}$$

(e)

$$\text{Net energy added} = Q - W_{\text{ext}}$$
$$\Rightarrow \quad \Delta E = 1 - (-0.64) = 1.64\text{ kJ}$$

0-6-10 [QX] A gas trapped inside a piston-cylinder device receives 20 kJ of heat while it expands performing a boundary work of 5 kJ. At the same time 10 kJ of electrical work is transferred into the system. Evaluate (a) Q and (b) W with appropriate signs.

SOLUTION

(a) Q (heat input) = 20 kJ

(b) $W_{\text{ext}} = 5 - 10 = -5$ kJ

0-6-11 [QQ] A gas at 300 kPa is trapped inside a piston-cylinder device. It receives 20 kJ of heat while it expands performing a boundary work of 5 kJ. At the same time 10 kJ of electrical work is transferred into the system. Evaluate (a) Q (b) W_{el}, (c) W_B, (d) W_{ext} with appropriate signs. (e)What is the net change in stored energy E of the system (magnitude only in kJ)? Neglect KE and PE.

SOLUTION

(a) Q = 20 kJ (WinHip: positive as heat is received)

(b) W_{el}= -10 kJ (WinHip: negative as work is transferred into the system)

(c) W_B = 5 kJ (WinHip: positive as work is done by the system)

(d) W_{ext} = -10 +5 = -5 kJ

(e) $\Delta E = Q - W_{\text{ext}} = 20 - (-5) = 25$ kJ

0-6-12 [QV] An iron block of 20 kg undergoes a process during which there is a heat loss from the block at 4 kJ/kg, an elevation increase of 50 m, and an increase in velocity from 10 m/s to 50 m/s. During the process, which also involves work transfer, the internal energy of the block decreases by 100 kJ. Determine the work transfer during the process in kJ if the total energy remains constant. Include sign.

SOLUTION

$$\Delta E = \Delta KE + \Delta PE + \Delta U = \frac{20\left(50^2 - 10^2\right)}{2000} + \frac{20(9.81)(50-0)}{1000} + (-100) = -66.19 \text{ kJ}$$

Also, $\Delta E = Q - W_{\text{ext}}$;

$$\Rightarrow W_{\text{ext}} = Q - \Delta E = -(20)(4) - 66.19 = -146.19 \text{ kJ}$$

0-6-13 [QT] A person turns on a 100-W fan before he leaves the warm room at 100 kPa, 30°C, hoping that the room will be cooler when he comes back after 5 hours. Heat transfer from the room to the surroundings occur at a rate of 5*t* (*t* in minutes) watts. Plot the change in energy of the air in the room, in kJ.

SOLUTION

(a)

$$E(t) = E(0) + \frac{100}{1000}t - 5\frac{t}{60} = E(0) + 0.0167t \quad [\mathrm{kJ}]$$

Any plotting routine can be used to show that the energy increases linearly with time.

0-6-14 [QF] A fully charged battery supplies power to an electric car of mass 3000 kg. Determine the amount of energy depleted (in kJ) from the battery as the car accelerates from 0 to 140 km/h.

SOLUTION

140 km/h = 38.89 m/s

Energy supplied by the battery is equal to the increase in kinetic energy (neglecting frictional and other thermodynamic losses).

The increase in KE of the car is:

$$\begin{aligned}\Delta E &= \cancel{\Delta U}^{0} + \Delta \mathrm{KE} + \cancel{\Delta \mathrm{PE}}^{0} \\ &= \frac{1}{2(1000)} m\left(V_2^{\,2} - V_1^{\,2}\right) = \frac{mV_2^{\,2}}{2(1000)} \\ &= 2269 \text{ kJ}\end{aligned}$$

Therefore, the energy of the battery must deplete by the amount:

2269 kJ

0-6-15 [QD] A photovoltaic array produces an average electric power output of 20 kW. The power is used to charge a storage battery. Heat transfer from the battery to the surroundings occurs at 1.5 kW. Determine the total amount of energy stored in the battery (in MJ) in 5 hours of operation.

SOLUTION

$$t = (5)(3600) = 18000\,\mathrm{s}$$

$$\Delta E = W_{\mathrm{in}} - Q_{\mathrm{loss}} = (20)(18000) - (1.5)(18000) = 333\ \mathrm{MJ}$$

0-6-16 [QW] The heating value (maximum heat released as a fuel is burned with atmospheric air) of diesel is 43 MJ/kg. Determine the minimum fuel consumption necessary to accelerate a 20 ton (short ton) truck from 0 to 70 mph speed. Assume that all the work done by the engine is used to raise the kinetic energy of the truck and the efficiency of the engine is 35%.

SOLUTION

1 short ton = 907.18474 kg
20 short ton = 18143.6948 kg

$$\Delta KE = \frac{m(V_2^2 - V_1^2)}{2000} = \frac{(18143.6948)(31.2928^2)}{2000} = 8.884 \text{ MJ}$$

$$Q = \frac{8.884}{0.35} = 25.38 \text{ MJ}$$

$$\text{Fuel consumption}\,(m) = \frac{\text{Heat required}}{\text{Heating value}}$$

$$m = \frac{25.38}{43} = 0.59 \text{ kg}$$

0-6-17 [TS] In 2002, the US produced 3.88 trillion kWh of electricity. If coal (heating value 24.4 MJ/kg) accounted for 51% of the electricity production at an average thermal efficiency (electrical work output/heat input) of 40%, determine the total amount of coal (in short tons) consumed by the power plants in 2002.

SOLUTION

Total amount of coal consumed per year:

$$m_{coal} = \frac{(3.88\times10^{12})(3600)(51\%)}{(24.4\times10^{3})(907.185)(40\%)} = 8.0456\times10^{8} \text{ short tons}$$

$$\Rightarrow m_{coal} = 0.805 \text{ billion short tons}$$