0-5-1 [UX] If a therm of heat costs $1.158 and a kWh of electricity costs $0.106, then prices of (a) heat and (b) electricity on the basis of GJ.

SOLUTION

Cost of heat

1 Therm $=105.5\ \text{MJ}=105.5\text{x}10^{-3}\text{GJ}$;

$$\text{Therefore, } \frac{\$1.158}{\text{Therm}} = \frac{\$1.158}{105.5\text{x}10^{-3}\text{GJ}} = \frac{\$10.976}{\text{GJ}}$$

Cost of electricity:

1 kWh $=1(3600)\ \text{kJ} =3.6\ \text{MJ}=3.6\text{x}10^{-3}\text{GJ}$;

$$\text{Therefore, } \frac{\$0.106}{\text{kWh}} = \frac{\$1.158}{3.6\text{x}10^{-3}\text{GJ}} = \frac{\$29.444}{\text{GJ}}$$

0-5-2 [UC] A power plant has an average annual load of 2000 MW (electrical). If the overall thermal efficiency is 38%, what is the annual cost of fuel for (a) natural gas (\$1.26/Therm) and (b) No. 2 fuel oil (\$9.40/MMBtu).

SOLUTION

(a)

$$W_{\text{out,el}} = \dot{W}_{\text{out,el}} t = (2000)(365)(24)(3600) = (2000)\left(3.1536\times10^{7}\right)\ \text{kJ}$$

$$\Rightarrow W_{\text{out,el}} = 6.307\times10^{10}\ \text{MJ}$$

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

$$\Rightarrow Q_{\text{in}} = \frac{6.307\times10^{10}}{0.38} = 1.6598\times10^{11}\ \text{MJ}$$

Cost of heat:

$$\Rightarrow \left(\frac{\$1.26}{\text{Therm}}\right)\left(\frac{\text{Therm}}{105.5\ \text{MJ}}\right)\left(1.6598\times10^{11}\ \text{MJ}\right) = \$1.98\ \text{billion}$$

(b)

$$\left(\frac{\$9.40}{\text{MMBtu}}\right)\left(\frac{1\ \text{MMBtu}}{1055\ \text{MJ}}\right)\left(1.6598\times10^{11}\ \text{MJ}\right) = \$1.48\ \text{billion}$$

0-5-3 [UH] A gas trapped inside a piston-cylinder device receives 20 kJ of heat (Q) while it expands performing a boundary work (W_B) of 5 kJ. At the same time 10 kJ of electrical work (W_{el}) is transferred into the system. Evaluate (a) Q and (b) W with appropriate signs.

SOLUTION

According to the WinHip sign convention heat in is positive and work out is positive.

(a)

$$Q = Q_{\text{in}} = \text{ 5 kJ}$$

(b)

$$W_{\text{ext}} = W_{\text{out,B}} - W_{\text{in,el}} = 5 - 10 = \text{ -5 kJ}$$

0-5-4 [QN] A gas station sells gasoline and diesel at $2.00/gallon and $1.75/gallon respectively. If the following data are known about the two fuels, compare the prices on the basis of MJ of energy: heating value: gasoline 47.3 MJ/kg, diesel 46.1 MJ/kg; density: gasoline 0.72 kg/L, diesel 0.78 kg/L.

SOLUTION

Price of gasoline:

To release 1 MJ of heat, gasoline required is:

$$\frac{1}{47.3}\text{ kg, or }\frac{1}{(0.72)(47.3)}\text{ L, or }\frac{1}{(3.785)(0.72)(47.3)}\text{ gallon}$$

which has a price of $\dfrac{\$2}{(3.785)(0.72)(47.3)} = \$\,0.0155$

Price per MJ = $ 0.0155

Price of diesel:

To release 1 MJ of heat, diesel required is:

$$\frac{1}{46.1}\text{ kg, or }\frac{1}{(0.78)(46.1)}\text{ L, or }\frac{1}{(3.785)(0.78)(47.3)}(46.1)\text{ gallon}$$

which has a price of $\dfrac{\$2}{(3.785)(0.78)(46.1)} = \$\,0.0129$

Price per MJ = $ 0.0129

0-5-5 [QE] A rigid cylindrical tank stores 100 kg of a substance at 500 kPa and 500 K while the outside temperature is 300 K. A paddle wheel stirs the system transferring shaft work at a rate of 0.5 kW. At the same time an internal electrical resistance heater transfers electricity at the rate of 1 kW. Determine Q necessary to ensure that no net energy enters or leaves the tank.

SOLUTION

$$\dot{Q}_{\text{out}} = \dot{W}_{\text{in,sh}} + \dot{W}_{\text{in,el}} = 0.5 + 1 = 1.5 \text{ kW};$$

Using the WinHip sign convention:

$$\Rightarrow \dot{Q} = \dot{Q}_{\text{in}} = -\dot{Q}_{\text{out}} = -1.5 \text{ kW}$$

0-5-6 [QI] The nutrition label on a snack bar, which costs \$1.00, reads - Serving size 42 g; Calories Per Serving 180. Determine (a) the heating value in MJ/kg, and (b) price in cents per MJ of heat release. (c) If gasoline with a heating value of 44 MJ/kg and a density of 750 kg/m^3 costs \$2.50 a gallon, what is the gasoline price in cents/MJ?

SOLUTION

(a)

1 Calorie = 1 kcal = 4.187 kJ

$$\text{Heat release per kg: } \frac{180}{0.042}\ \frac{\text{kcal}}{\text{kg}} = \frac{(180)(4.187)}{0.042}\ \frac{\text{kJ}}{\text{kg}} = \frac{(180)(4.187)}{(0.042)(1000)}\ \frac{\text{MJ}}{\text{kg}} = 17.95\,\frac{\text{MJ}}{\text{kg}}$$

(b)

$$\text{Heat release per bar: } (180\ \text{kcal})\left(\frac{4.187}{1000}\ \frac{\text{MJ}}{\text{kcal}}\right) = 0.7538\ \text{MJ}$$

$$\Rightarrow \frac{100\ \text{cents}}{0.7538\ \text{MJ}} = 132.667\,\frac{\text{cents}}{\text{MJ}}$$

(c)

$$\cancel{V} = (1\ \text{gallon})\left(\frac{0.003785\ \text{m}^3}{\text{gallon}}\right); \quad \Rightarrow \cancel{V} = 0.003785\ \text{m}^3$$

$$m = \rho \cancel{V}; \quad \Rightarrow m = \left(\frac{750\ \text{kg}}{\text{m}^3}\right)(0.003785\ \text{m}^3); \quad \Rightarrow m = 2.83875\ \text{kg}$$

$$Q = (2.83875\ \text{kg})\left(\frac{44\ \text{MJ}}{\text{kg}}\right); \quad \Rightarrow Q = 124.905\ \text{MJ}$$

$$\left(\frac{250\ \text{cents}}{124.905\ \text{MJ}}\right) = 2.00\ \frac{\text{cents}}{\text{MJ}}$$

0-5-7 [QL] A popular soda can contains 0.355 kg of soda, which can be considered to be composed of 0.039 kg of sugar and the rest water. If the calorific value is written as 140 Calorie (bio), (a) calculate the heating value (maximum heat that will be released by 1 kg of the food) of sugar in MJ/kg. (b) Compare the heating value of sugar with different fuels listed in Table G-2.

SOLUTION

(a)

Heat release from a can: $(140\ \text{kcal})\left(\frac{4.187}{1000}\frac{\text{MJ}}{\text{kcal}}\right) = 0.58626\ \text{MJ}$

Heating value of sugar: $\left(\frac{0.58626\ \text{MJ}}{0.039\ \text{kg}}\right) = 15.03\frac{\text{MJ}}{\text{kg}}$

(b) Consult Table G-2.

0-5-8 [QG] Consider three options for heating a house. Electric resistance heating with electricity priced at \$0.10/kWh, gas heating with gas priced at \$1.10/Therm and oil (density 0.8 kg/L, heating value 46.5 MJ/kg) heating with oil priced at \$1.50/gal. Energetic efficiencies are 100% for the electrical heating system, 85% for the gas heating system and 80% for the oil heating system. Determine the cost of delivering 1 GJ of energy by each system.

SOLUTION

Cost of delivering $1\text{ GJ} = 10^6\text{ kJ}$ of energy using electricity:

$$\frac{(\$0.1)(10^6)}{3600} = \frac{\$\,27.778}{\text{GJ}}$$

Cost of delivering $1\text{ GJ} = 10^6\text{ kJ}$ of energy using gas:

Cost of delivering $1\text{ GJ} = 10^6\text{ kJ}$ of energy using gas

$$\frac{(1.1)(10^6)}{(105500)(85\%)} = \frac{\$\,12.267}{\text{GJ}}$$

Cost of delivering 1 GJ of energy using oil

$$\frac{(1.5)(10^3)}{(3.785)(.8)(46.5)(80\%)} = \frac{\$\,13.317}{\text{GJ}}$$

0-5-9 [TO] In order to determine which is a cheaper fuel, a student collects the following data for gasoline and diesel respectively. Price per gallon: \$2.90 vs. \$3.10; Heating value: 44 MJ/kg vs. 43.2 MJ/kg; Density: 740 kg/m^3 vs. 820 kg/m^3; 1 Gallon = 3.78 L; 1 L = 10^{-3} m^3. Determine (a) the price of gasoline in cents per MJ of heat release, (b) the price of diesel per MJ of heat release.

SOLUTION

(a)

$$\mathcal{V}_g = (1\text{ gallon})\left(\frac{3.785\text{ L}}{\text{gallon}}\right)\left(\frac{10^{-3}\text{ m}^3}{\text{L}}\right); \qquad \Rightarrow \mathcal{V}_g = 3.785\times10^{-3}\text{m}^3$$

$$m_g = \rho_g \mathcal{V}_g; \qquad \Rightarrow m_g = \left(\frac{740\text{ kg}}{\text{m}^3}\right)\left(0.003785\text{ m}^3\right); \qquad \Rightarrow m_g = 2.801\text{ kg}$$

$$Q_g = (2.801\text{ kg})\left(\frac{44\text{ MJ}}{\text{kg}}\right); \qquad \Rightarrow Q_g = 123.25\text{ MJ}$$

$$\left(\frac{290\text{ cents}}{123.25\text{ MJ}}\right) = 2.35\ \frac{\text{cents}}{\text{MJ}}$$

(b)

$$\mathcal{V}_d = (1\text{ gallon})\left(\frac{3.785\text{ L}}{\text{gallon}}\right)\left(\frac{10^{-3}\text{ m}^3}{\text{L}}\right); \qquad \Rightarrow \mathcal{V}_d = 3.785\times10^{-3}\text{m}^3$$

$$m_d = \rho_d \mathcal{V}_d; \qquad \Rightarrow m_d = \left(\frac{820\text{ kg}}{\text{m}^3}\right)\left(0.003785\text{ m}^3\right); \qquad \Rightarrow m_d = 3.1037\text{ kg}$$

$$Q_d = (3.1037\text{ kg})\left(\frac{43.2\text{ MJ}}{\text{kg}}\right); \qquad \Rightarrow Q_d = 134.08\text{ MJ}$$

$$\left(\frac{310\text{ cents}}{134.08\text{ MJ}}\right) = 2.31\ \frac{\text{cents}}{\text{MJ}}$$

0-5-10 [TA] In 2003, the US consumed (a) 20 MMbd of crude oil, (b) 21.9 tcf (trillion cubic feet) of natural gas, and (c) 1 billion tons (short) of coal. The Btu equivalents are as follows: 1 bbl crude oil: 5.8 million Btu; 1 Mcf gas: 1.03 million Btu; 1 ton coal: 21 million Btu. Compare the energy consumption in the consistent unit of Quad (1 Quad = 10^{15} Btu).

SOLUTION

Energy consumption

Crude Oil per year:

$$\left(20\text{x}10^6\right)(365)\left(5.8\text{x}10^6\right)\left(\frac{1}{10^{15}}\right) = 42.34\text{ Quad} \qquad \left[\frac{\text{barrel}}{\text{day}}.\frac{\text{day}}{\text{year}}.\frac{\text{Btu}}{\text{ft}^3}.\frac{\text{Quad}}{\text{Btu}}\right]$$

Natural gas per year:

$$\left(21.9\text{x}10^{12}\right)\left(\frac{1.03\text{x}10^6}{1000}\right)\left(\frac{1}{10^{15}}\right) = 22.55\text{ Quad} \qquad \left[\text{ft}^3.\frac{\text{Btu}}{\text{ft}^3}.\frac{\text{Quad}}{\text{Btu}}\right]$$

Coal per year:

$$\left(10^9\right)\left(21\text{x}10^6\right)\left(\frac{1}{10^{15}}\right) = 21\text{ Quad} \qquad \left[\text{tons (short)}.\frac{\text{Btu}}{\text{tons (short)}}.\frac{\text{Quad}}{\text{Btu}}\right]$$

0-5-11 [TH] On Aug. 20, 2011, the prices for crude oil (heating value 43 MJ/kg) and natural gas were quoted as 82.26 USD/Bbl and 3.94 USD/MMBtu in the world market. Compare the prices on a comparable scale (USD/MJ). Use properties of heavy diesel to represent crude oil.

SOLUTION

Crude Oil:

One barrel has different measures depending on what it is supposed to hold. A barrel of oil is equivalent to 42 gallons (US), which is equal to 42* 3.785 L = 42*3.785/1000 = 0.15897 m^3.

Using data from Table G.2 (TEST>Tables), the density and higher heating values are 850 kg/m^3 and 45.5 MJ/kg respectively.

Maximum heat released by one barrel of crude, therefore, is equal to 850*0.15897*45.5 MJ = 6.148 GJ. This is also known as barrel of oil equivalent (BOE). So the price per MJ is 1.338 cents/MJ.

Natural Gas:

MMBtu means a million (M in Greek stands for a thousand; so MM means thousand thousand). 1 Btu = 1.055 kJ. Therefore, 1 MMBtu = 1.055 GJ = 1055 MJ.

The price per MJ is 0.373 cents/MJ.

0-5-12 [QZ] The USA consumed about 21 MMbd (million barrels per day) of crude oil (density 0.82 kg/L, heating value 47 MJ/kg), 67% of which is utilized in the transportation sector. Determine how many barrels of oil can be saved per year, if the fuel consumption in the transportation sector can be reduced by 20% through the use of hybrid technology.

SOLUTION

$$\text{Consumption of crude oil }\left(\text{per yr}\right) = (21)(365)\text{ MMbd} = 7665\text{ million barrel (MMb)}$$

$$\text{Consumption of crude oil in transportation sector} = \left(0.67\right)\left(7665\right) = 5135.55\text{ MMb}$$

$$\text{Fuel consumption in transportation }\left(\text{if hybrid used}\right) = \left(0.80\right)\left(5135.55\right) = 4108.44\text{ MMbd}$$

$$\text{Oil savings }\left(\text{year}\right) = 5135.55 - 4108.44$$
$$\Rightarrow \text{Oil savings }\left(\text{year}\right) = 1027.11\text{ MMb}$$
$$\Rightarrow \text{Oil savings }\left(\text{year}\right) = 1.027\text{ Billion barrels}$$