Problem 2.1

A nonconducting container filled with 25 kg of water at 20 deg C is fitted with a stirrer which is made to turn by gravity acting on a weight of mass 35 kg. The weight falls slowly through a distance of 5 m in driving the stirrer. Assuming that all work done on the weight is transferred to the water and that the local acceleration of gravity is 9.8 $\frac{m}{s^2}$, determine:

(a) The amount of work done on the water.

(b) The internal energy change of the water.

(c) The final temperature of the water, for which Cp=4.18 $\frac{\text{kJ}}{\text{kg*degC}}$.

(d) The amount of heat that must be removed from the water to return it to its initial temperature.

(e) The total energy change of the universe because of (1) the process of lowering the weight, (2) the process of cooling the water back to its initial temperature, and (3) both processes together.

Solution

Part (a)

```
(*The work done on the water is due to elevation change of weight.*)
```

$$35\ \text{kg} * 9.8\ \frac{\text{m}}{\text{s}^2} * 5\ \text{m} * \frac{1\ \text{J}}{\frac{1\ \text{kg}*\text{m}^2}{\text{s}^2}}$$

```
1715. J

(*//ANS part a*)
```

Part (b)

```
(*The change in internal energy is equal to the amount of work done on the system*)
(*ΔU = Q+W = W = 1715.J = 1.715kJ*)(*//ANS part b*)
```

Part (c)

$$\text{eq1} = 1.715\ \text{kJ} == 25\ \text{kg} * \frac{4.18\ \text{kJ}}{\text{kg} * \text{degC}} * (\text{T2} - 20\ \text{degC});$$

```
Solve[eq1, T2]
{{T2 → 20.0164 degC}}

(*//ANS part c*)
```

Part (d)

```
(*Q = -W = -1715.J = -1.715kJ*)

(*//ANS part d*)
```

Part (e)

```
(*Energy is conserved in all cases.  The total energy change of the universe is zero.*)

(*//ANS part e*)
```

Problem 2.4

An electric motor under steady load draws 9.7 amperes at 110 volts, delivering 1.25 hp of mechanical energy. What is the rate of heat transfer from the motor, in kW?

Solution

For a closed system, the first law of thermodynamics is $\Delta U = Q + W$. For an electrical motor, this looks a little different $\Delta U = Q + P_{electrical} + W$. Assume $\Delta U=0$ at steady state since the temperature of the motor is not changing, so $0 = Q + P_{electrical} + W$.

In[6]:=
```
(*P_electrical = voltage * current *)
```
$$P_{electrical} = 9.7\,\text{amp} * 110\,\text{volt} * \frac{1\,\text{W}}{1\,\text{amp} * \text{volt}} * \frac{1\,\text{kW}}{1000\,\text{W}}$$

Out[6]= 1.067 kW

In[7]:=
```
(*work, as in work delivered, is -1.25 hp leaving the motor*)
```
$$W = -1.25\,\text{hp} * \frac{1\,\text{kW}}{1.34102\,\text{hp}}$$

Out[7]= −0.932126 kW

In[8]:=
```
eq1 = 0 == Q + P_electrical + W;
```

In[9]:=
```
Solve[eq1, Q]
```

Out[9]= {{Q → −0.134874 kW}}

```
(*Q=-.135 kW  //ANS *)
```

Problem 2.9

Heat in the amount of 7.5 kJ is added to a closed system while its internal energy decreases by 12 kJ. How much energy is transferred as work? For a process causing the same change of state but for which the work is zero, how much heat is transferred?

Solution

Part (a)

```
(*Use the first law for closed systems in the form ΔU=Q+W*)
Q = 7.5; (*kJ*)
ΔU = -12; (*kJ*)
W = ΔU - Q (*kJ*)
```

Out[3]= -19.5

```
(*//ANS part a*)
```

Part (b)

```
(*The change in internal energy is equal to the amount of work done on the system*)
ΔU = -12; (*kJ*)
W = 0; (*kJ*)
Q = ΔU - W (*kJ*)
```

Out[6]= -12

```
(*//ANS part b*)
```

Problem 2.11

An incompressible fluid (ρ = constant) is contained in an insulated cylinder fitted with a frictionless piston. Can energy as work be transferred to the fluid? What is the change in internal energy of the fluid when the pressure is increased from P1 to P2?

Solution

If the fluid density is constant, then the compression is a constant-V process for which the work must be zero. Since the cylinder is insulated, we can presume that no heat is transferred. From the first Law, $\Delta U = Q + W = 0$.

(*//ANS*)

Problem 2.13

An electric motor runs “hot” under load, owing to internal irreversibilities. It has been suggested that the associated energy loss can be minimized by thermally insulating the motor casing. Comment critically on this suggestion.

Solution

Assume that the energy loss shows up as heat transfer from the motor (which is why it feels “hot.”), with rate of heat loss Q. Also assume that the first law applies, so $\Delta U = Q + P_{\text{electrical}} + W$. The rate of heat loss Q is reduced by adding insulation, so the reduction in Q must show up in either ΔU or $P_{\text{electrical}} + W$. If we assume $P_{\text{electrical}} + W$ unchanged, which could be controlled with a dynamometer, then the difference must show up as an increase in ΔU, which means higher temperature of the motor and possible damage to the bearings and windings. On the other hand, if we assume ΔU is unchanged, then $P_{\text{electrical}} + W$ must go down. Additional work can be drawn from the motor if electrical power is increased to compensate. If we could keep electrical power constant, then work removed would go down (W would be more negative).

The actual answer is somewhere between these two limits, but either case is undesirable. Also, since increasing internal energy is manifested by an elevated temperature of the motor, higher internal energy means higher motor temperature. The increased motor temperature could lead to damge to the bearings and electrical coils.

(*//ANS*)

Alternate Solution

Electrical and mechanical irreversibilities cause an increase in the internal energy of the motor, manifested by an elevated temperature of the motor. The temperature of the motor rises until a dynamic steady-state is established between the heat generated inside the motor and the rate of heat transfer to the surroundings. At steady state, the rate of heat transfer from the motor to the surroundings exactly matches the heat generated by the irreversibilities.

Insulating the motor decreases the rate of heat transfer to the surroundings. Since the insulation is at the system boundary, it does nothing to decrease the irreversibilities inside the motor. With the insulation and the accompanying decrease in rate of heat transfer, the steady-state temperature of the motor will increase until heat-transfer steady state with the surroundings is re-established.

Adding insulation could be a catastrophic error. With insulation added, the motor temperature could rise to a level high enough to cause damage to the motor.

(*//ANS*)