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## Problem Set 2 - Solutions

### 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  $C_p = 4.18 \frac{kJ}{kg \cdot degC}$ .
- (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.

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

1715. J

The work done on the water is 1715 J. //ANS

#### Part (b)

“Nonconducting” means well-insulated, which means  $Q=0$ . The change in internal energy is equal to the amount of work done on the system, since  $\Delta U = Q + W = W$ .

$$(\Delta U = Q + W = W = 1715 \text{ J} = 1.715 \text{ kJ} \quad *)$$

The internal energy change of the water is +1715 J. //ANS

#### Part (c)

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

Solve [eq1, T2]

{ { T2 → 20.01641 degC } }

The final temperature of the water is 20.0164 degC. //ANS

### Part (d)

$$(*Q = -W = -1715.J = -1.715 \text{ kJ}*)$$

The amount of heat that must be removed from the water is 1.715 kJ. //ANS

### Part (e)

Energy is conserved in all cases. The total energy change of the universe is zero. //ANS

## 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  $\Delta U = Q + P_{\text{electrical}} + W$ . Assume  $\Delta U = 0$  at steady state since the temperature of the motor is not changing, so  $0 = Q + P_{\text{electrical}} + W$ .

$$\begin{aligned} \text{In[*]} &:= (*P_{\text{electrical}} = \text{voltage} * \text{current} *) \\ P_{\text{electrical}} &= 9.7 \text{ amp} * 110 \text{ volt} * \frac{1 \text{ W}}{1 \text{ amp} * \text{volt}} * \frac{1 \text{ kW}}{1000 \text{ W}} \end{aligned}$$

$$\text{Out[*]} = 1.067 \text{ kW}$$

Work, as in work delivered, is -1.25 hp leaving the motor. Convert this to kW:

$$W = -1.25 \text{ hp} * \frac{1 \text{ kW}}{1.34102 \text{ hp}}$$

$$\text{Out[*]} = -0.9321263 \text{ kW}$$

$$\text{In[*]} := \text{eq1} = 0 == Q + P_{\text{electrical}} + W;$$

$$\text{In[*]} := \text{Solve}[\text{eq1}, Q]$$

$$\text{Out[*]} = \{ \{ Q \rightarrow -0.1348737 \text{ kW} \} \}$$

The rate of heat transfer from the motor is  $Q = -0.135 \text{ kW}$ . //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  $\Delta U = Q + W$ , with  $\Delta U$  and  $Q$  given, to solve for  $W$ .

$$Q = 7.5; (*kJ*)$$

$$\Delta U = -12; (*kJ*)$$

$$W = \Delta U - Q (*kJ*)$$

Out[\*]=

$$-19.5$$

-19.5 kJ of energy is transferred as work out of the system (19.5 kJ of energy is transferred to the surroundings). //ANS

#### Part (b)

Use the first law for closed systems in the form  $\Delta U = Q + W$  with  $\Delta U$  and  $W$  given to solve for  $Q$ . Since  $W=0$ , the amount of heat transferred is equal to the change in internal energy.

$$\Delta U = -12; (*kJ*)$$

$$W = 0; (*kJ*)$$

$$Q = \Delta U - W (*kJ*)$$

Out[\*]=

$$-12$$

-12 kJ of energy is transferred out of the system as heat. //ANS

## Problem 2.11

An incompressible fluid ( $\rho = \text{constant}$ ) 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  $P_1$  to  $P_2$ ?

### SOLUTION

If the fluid density is constant, then this is a constant-volume process for which the work must be zero. //ANS Since the cylinder is insulated, assume no heat is transferred, so  $Q=0$ . 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

For an electrical motor, the first law is  $\Delta U = Q + P_{\text{electrical}} + W$ . Electrical power  $P_{\text{electrical}}$  can be converted into either heat or work. Adding insulation increases the temperature of the motor by reducing the heat transfer to the surroundings. The internal irreversibilities referred to in the problem statement are frictional and electrical resistance losses. The increase in temperature causes the electrical resistance of the motor’s windings to increase, since resistance increases with temperature. Increased resistance means additional electrical power is converted into heat rather than mechanical work.

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.

Question to ChatGPT:

Does adding insulation to the outside of an electrical motor increase performance?



Adding insulation to the outside of an electrical motor does not increase its performance and can actually have negative effects. Here's why:

1. **Heat Dissipation:** Electrical motors generate heat during operation, and this heat needs to be dissipated to prevent overheating. The motor's casing often serves as a means for this heat to escape. If you add insulation to the outside of the motor, you could trap heat inside, causing the motor to overheat. Overheating can lead to a decrease in performance, reduced efficiency, and potentially damage the motor.
2. **Cooling Efficiency:** Many motors rely on external airflow or cooling systems to maintain optimal operating temperatures. Insulating the outside of the motor could obstruct airflow, reducing the effectiveness of these cooling methods and leading to higher operating temperatures.
3. **Material Stress:** Overheating due to poor heat dissipation can cause thermal stress on the motor's materials, leading to a shorter lifespan and increased maintenance needs.

In summary, adding insulation to the outside of an electrical motor is generally not recommended and can decrease performance by hindering heat dissipation, potentially leading to overheating and motor damage. The motor's design typically accounts for proper cooling, and additional external insulation would disrupt this balance.

