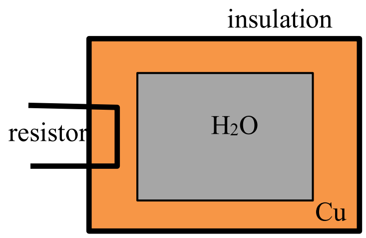
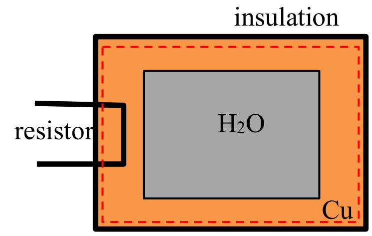
A system consists of a copper tank with a mass of 13 kg, 4 kg of liquid water, and an electrical resistor of negligible mass. The system is insulated on its outer surface. Initially, the temperature of the copper is 27 °C and the temperature of the water is 50 °C. The electrical resistor transfers 100 kJ of energy to the system. Eventually the system comes to equilibrium. Determine the final equilibrium temperature in °C.





SOLUTION:
Apply the First Law to a system consisting of the copper, water, and resistor,

$$\Delta E_{sys} = Q_{\substack{into\\sys}} + W_{\substack{into\\sys}} \Rightarrow \Delta U_{sys} = Q_{\substack{into\\sys}} + W_{\substack{into\\sys}}\ , \tag{1}$$

where the change in total energy in the system consists only of the change in internal energy. There is no heat transfer into or out of the system since the copper tank is insulated, i.e., $Q_{into\ sys} = 0$. The work into the system is the electrical work into the resistor, $W_{into\ sys} = 100$ kJ. The change in internal energy is,

$$\Delta U_{sys} = m_{Cu}\Delta u_{Cu} + m_{H_2O}\Delta u_{H_2O}\ . \text{ (The resistor mass is negligible.)} \tag{2}$$

Treating the copper and water as incompressible substances,

$$\Delta u_{Cu} = c_{Cu}\Delta T_{Cu} = c_{Cu}\left(T_{2,Cu} - T_{1,Cu}\right), \tag{3}$$

$$\Delta u_{H_2O} = c_{H_2O}\Delta T_{H_2O} = c_{H_2O}\left(T_{2,H_2O} - T_{1,H_2O}\right). \tag{4}$$

Note that the final temperatures of the water and copper will be the same, i.e., $T_{2,Cu} = T_{2,H2O} = T_2$.

Simplifying Eq. (1), making use of Eqs. (2) - (4),

$$m_{Cu}c_{Cu}\left(T_2 - T_{1,Cu}\right) + m_{H_2O}c_{H_2O}\left(T_2 - T_{1,H_2O}\right) = W_{\substack{into\\sys}}\ , \tag{5}$$

$$\left(m_{Cu}c_{Cu} + m_{H_2O}c_{H_2O}\right)T_2 = W_{\substack{into\\sys}} + m_{Cu}c_{Cu}T_{1,Cu} + m_{H_2O}c_{H_2O}T_{1,H_2O}\ , \tag{6}$$

$$T_2 = \frac{W_{\substack{into\\sys}} + m_{Cu}c_{Cu}T_{1,Cu} + m_{H_2O}c_{H_2O}T_{1,H_2O}}{m_{Cu}c_{Cu} + m_{H_2O}c_{H_2O}}\ . \tag{7}$$

Substitute the given values,

$W_{into\ sys}$ = 100 kJ
$c_{Cu,300\ K}$ = 0.385 kJ/(kg.K) (from thermodynamic table, e.g., Table A-19 of Moran et al., 7^{th} ed.)
$c_{H2O,300\ K}$ = 4.179 kJ/(kg.K) (from thermodynamic table, e.g., Table A-19 of Moran et al., 7^{th} ed.)
m_{Cu} = 13 kg
m_{H2O} = 4 kg
$T_{1,Cu}$ = 27 °C = 300 K
$T_{1,H2O}$ = 50 °C = 323 K
$\Rightarrow \boxed{T_2 = 322\text{ K} = 49.3°\text{C}}$

TABLE A-19

Properties of Selected Solids and Liquids: c_p, ρ, and κ

Substance	Specific Heat, c_p (kJ/kg · K)	Density, ρ (kg/m^3)	Thermal Conductivity, κ (W/m · K)
Selected Solids, 300K			
Aluminum	0.903	2700	237
Coal, anthracite	1.260	1350	0.26
Copper	0.385	8930	401
Granite	0.775	2630	2.79
Iron	0.447	7870	80.2
Lead	0.129	11300	35.3
Sand	0.800	1520	0.27
Silver	0.235	10500	429
Soil	1.840	2050	0.52
Steel (AISI 302)	0.480	8060	15.1
Tin	0.227	7310	66.6
Building Materials, 300K			
Brick, common	0.835	1920	0.72
Concrete (stone mix)	0.880	2300	1.4
Glass, plate	0.750	2500	1.4
Hardboard, siding	1.170	640	0.094
Limestone	0.810	2320	2.15
Plywood	1.220	545	0.12
Softwoods (fir, pine)	1.380	510	0.12
Insulating Materials, 300K			
Blanket (glass fiber)	—	16	0.046
Cork	1.800	120	0.039
Duct liner (glass fiber, coated)	0.835	32	0.038
Polystyrene (extruded)	1.210	55	0.027
Vermiculite fill (flakes)	0.835	80	0.068
Saturated Liquids			
Ammonia, 300K	4.818	599.8	0.465
Mercury, 300K	0.139	13529	8.540
Refrigerant 22, 300K	1.267	1183.1	0.085
Refrigerant 134a, 300K	1.434	1199.7	0.081
Unused Engine Oil, 300K	1.909	884.1	0.145
Water, 275K	4.211	999.9	0.574
300K	4.179	996.5	0.613
325K	4.182	987.1	0.645
350K	4.195	973.5	0.668
375K	4.220	956.8	0.681
400K	4.256	937.4	0.688

Sources: Drawn from several sources, these data are only representative. Values can vary depending on temperature, purity, moisture content, and other factors.

Table from Moran et al., 7th ed.