Estimate the enthalpy change of 1 kg of water from ice at 0°C to vapor at 110°C and pressure of 100 kPa. Express your answer in kJ/kg.

Data

$$\Delta \hat{H}_f = 335\ J/g \text{ at } 0°C,\ 101.3\ kPa$$

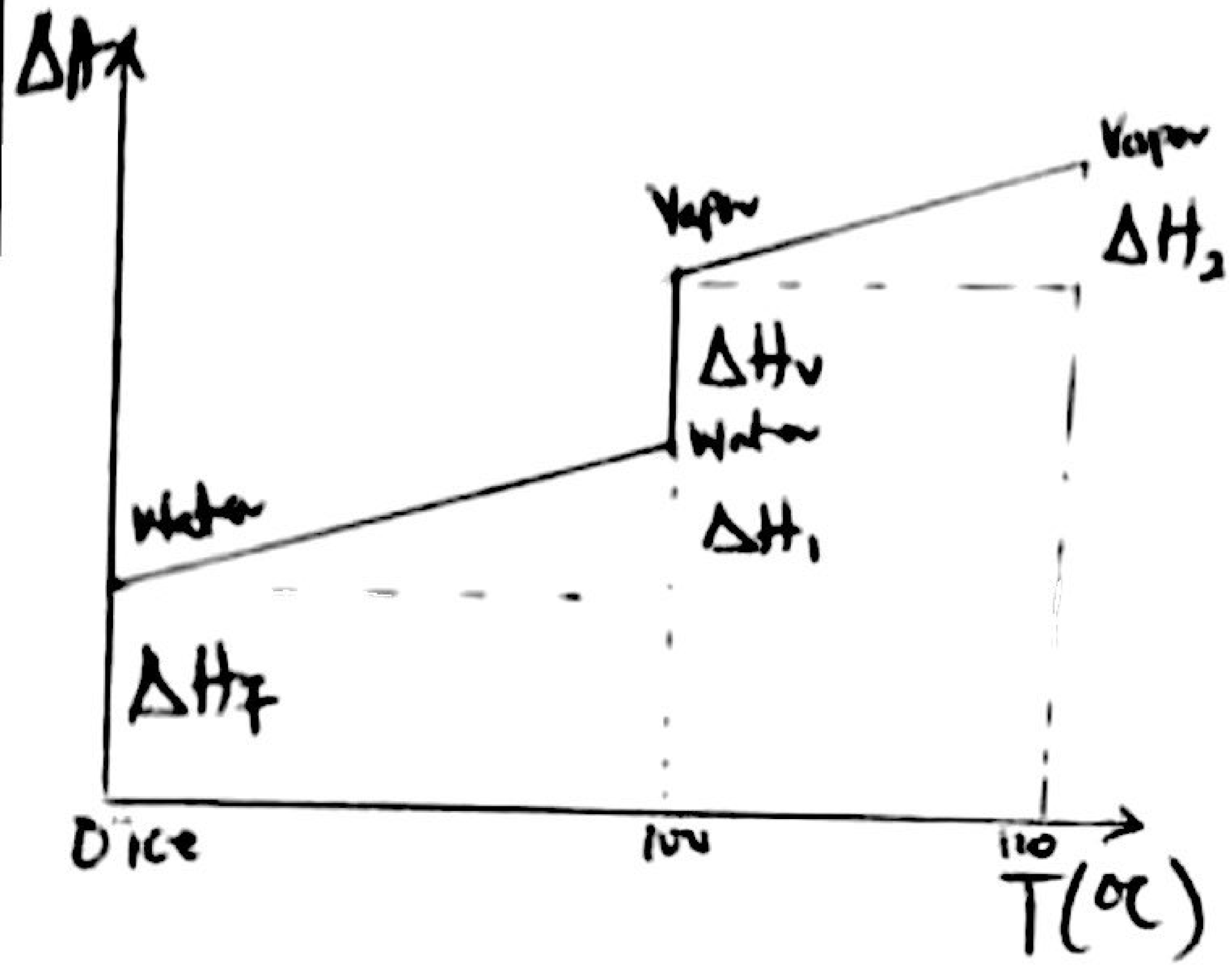
$$\Delta \hat{H}_v = 2256\ J/g \text{ at } 100°C,\ 101.3\ kPa$$

$$C_p(Lq, H_2O) = 18.296 + 47.212\times10^{-2}T - 133.88\times10^{-5}T^2 + 1314\times10^{-9}T^3$$

$$C_p(Vap, H_2O) = 33.46 + 0.688\times10^{-2}T + 0.7604\times10^{-5}T^2 - 3.593\times10^{-9}T^3$$

$$C_p = \left[\frac{J}{gmol \cdot k}\right]$$

Sol.



$$\Delta \dot{H}_1 = \int_{273.15}^{373.15} (18.296 + 47.212\times10^{-2}T - 133.88\times10^{-5}T^2 + 1314\times10^{-9}T^3)\,dT$$

$$\therefore \Delta H_1 = 7534.33\ \frac{J}{gmol}$$

$$\Delta H_2 = \int_{373.15}^{383.15} (33.46 + 0.688\times10^{-2}T + 0.7604\times10^{-5}T^2 - 3.593\times10^{-9}T^3)\,dT$$

$$\therefore \Delta H_2 = 740.21\ \frac{J}{gmol}$$

$$\Delta H_{total} = \Delta H_f + n\Delta \dot{H}_1 + \Delta H_v + n\,\Delta \dot{H}_2$$

$$\therefore \Delta \dot{H}_f = 335\ \frac{J}{g} = 335\ \frac{kJ}{kg}$$

$$\Delta H_v = 2256\ \frac{J}{g} = 2256\ \frac{kJ}{kg}$$

$$\therefore \Delta H = \int_{T_1}^{T_2} C_p\, dT$$

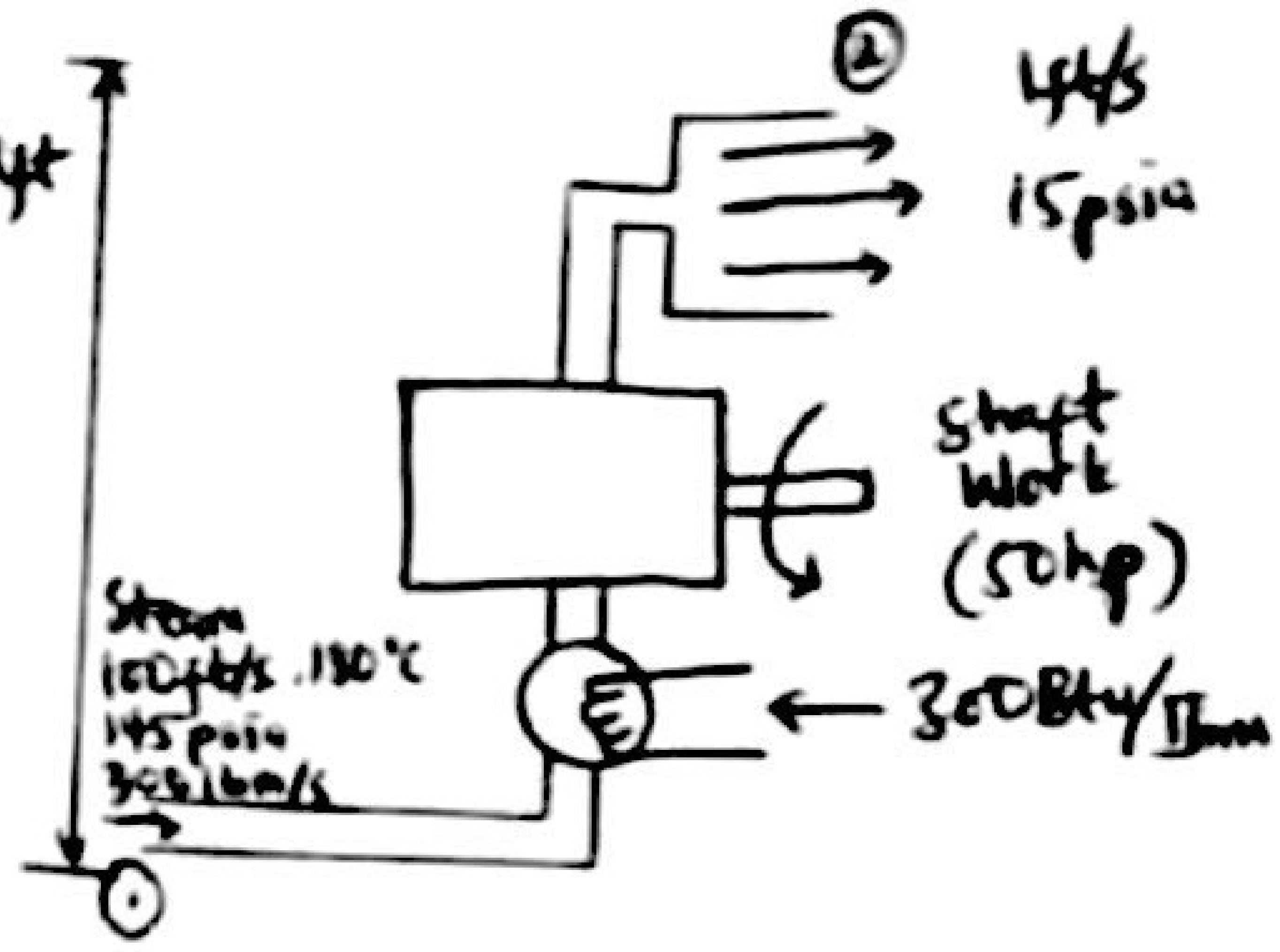
$$\therefore \Delta H_{total} = 335\ \frac{kJ}{kg} + \left(7534.33\ \frac{J}{gmol} \times \frac{55.6\ gmol}{1\ kg}\right) + 2256\ \frac{kJ}{kg} + \left(740.21\ \frac{J}{gmol} \times \frac{55.6\ gmol}{1\ kg}\right)$$

$$\therefore \Delta H_{total} = 335\ \frac{kJ}{kg} + 418.91\ \frac{kJ}{kg} + 2256\ \frac{kJ}{kg} + 41.16\ \frac{kJ}{kg}$$

$$\therefore \Delta H_{total} = 3051.07\ \frac{kJ}{kg}$$

Question 3

Superheated steam is expanded through a turbine of 50 horse power and finally exits through a diffuser at 50psia and a velocity 1fts^{-1}. The elevation change is 200ft. Calculate the outlet temperature assuming negligible pressure drop due to friction and inlet steam flow of 300 lb/hr.



Soln

General Energy Balance:

$$\Delta U + \Delta E_k + \Delta E_p = Q - W$$

$$\Delta U + \Delta E_k + \Delta E_p = Q - (P\Delta V + W_s)$$

$$\Delta U + P\Delta U + \Delta E_k + \Delta E_p = Q - W_s$$

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$\therefore Q = 300\frac{Btu}{lbm}\left|\frac{1055.06J}{1Btu}\right|\frac{lbm}{0.454kg}$$

$$Q = 697.176\frac{kJ}{kg}\left|\frac{0.454kg}{lbm}\right|\frac{300lbm}{s} = 92503.8kW$$

$$\therefore W_s = 50hp\left|\frac{735.50W}{1hp}\right. = 36.78\frac{kJ}{s}$$

$$V_1 = 100\frac{ft}{s} = 30.48\frac{m}{s}$$

$$V_2 = 1\frac{ft}{s} = 0.3048\frac{m}{s}$$

$$\Delta E_k = \frac{1}{2}m(V_2^2 - V_1^2)$$

$$m = 300\frac{lbm}{s} = 136.2\frac{kg}{s}$$

$$\Delta E_k = \frac{1}{2}\times 136.2\times(0.3048^2 - 30.48^2)$$

$$= -63.26\,kW$$

$$H = 200ft = 60.96m$$

$$\Delta E_p = mgH$$

$$\therefore m = 136.2\frac{kg}{s}, \; g = 9.81ms^{-2}$$

$$\Delta E_p = 136.2\frac{kg}{s}\times 9.81\frac{m}{s^2}\times 60.96m$$

$$\Delta E_p = 81.45\,kW$$

$$\therefore \Delta H = Q - W_s - \Delta E_k - \Delta E_p$$

$$\Delta H = 92503.8 - 36.78 - (-63.26) - 81.45$$

$$\therefore \Delta H = 92448.8\,kW$$

$$\therefore \Delta H = m(H_2 - H_1)$$

From steam tables:

H_1 (superheated steam @ 180°C, 145 psia) =

$$H_1 = 2776.2\frac{kJ}{kg}$$

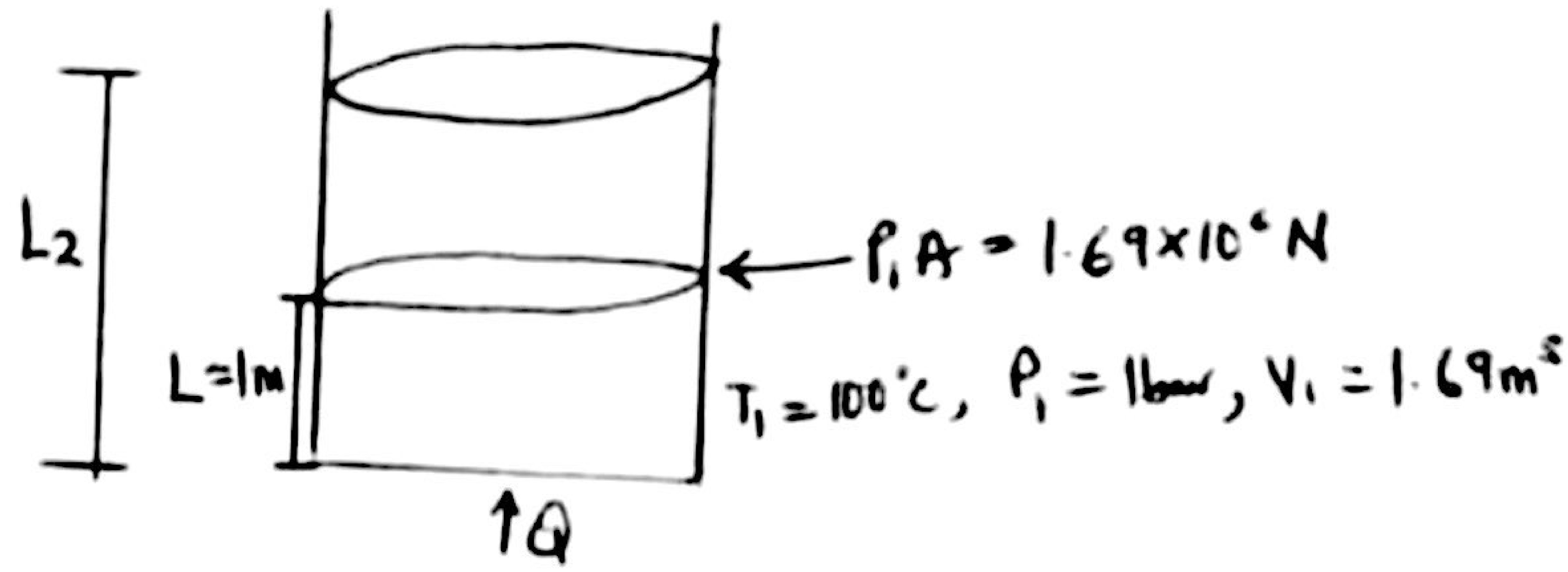
$$\therefore H_2 = \frac{\Delta H}{m} + H_1$$

$$H_2 = \frac{92448.8kW}{136.2kg/s} + 2776.2\frac{kJ}{kg}$$

$$H_2 = 3454.97\frac{kJ}{kg}$$

From steam tables, H_2 (enthalpy of outlet) corresponds to approximately 484°C for superheated steam @ 15psia.

1kg steam at a pressure 1 bar contained in a cylinder of cross-sectional area $1.69 m^2$. The cylinder is heated externally to raise the temperature to 300°C. Assume no heat loss to the environment. Calculate the amount of heat required for the process. Apply steam tables.



Soln

General Energy Balance:

$$\Delta\hat{U} + \Delta\hat{E}_k + \Delta\hat{E}_p = \hat{Q} - \hat{W}$$

kinetic energy is negligible $\Delta\hat{E}_k = 0$

$$\therefore \Delta\hat{U} + \Delta\hat{E}_p = \hat{Q} - \hat{W}$$

For compressive or expansive systems,

$$\hat{W} = P\Delta V + W_s$$

$$\therefore \Delta\hat{U} + \Delta E_p = Q - P\Delta V - W_s$$

$$\Delta U + P\Delta V + \Delta E_p = Q - W_s$$

$$\Delta\hat{H} + \Delta E_p = Q - W_s$$

No shaft work $\therefore W_s = 0$

$$\therefore \Delta\hat{H} + \Delta\hat{E}_p = Q$$

$$gh = \Delta\hat{E}_p$$

$$\frac{\Delta E_p}{m} = 9.81 ms^{-2} \times 1m = 9.81 m^2 s^{-2}$$

$$= 9.81 J$$

$$\therefore \Delta\hat{H} = H_2 - H_1$$

From steam tables:

H_2 (saturated steam @ 300°C, 1 bar)

$$= 3074 \frac{kJ}{kg}$$

H_1 (saturated steam @ 100°C, 1 bar)

$$= 2676 \frac{kJ}{kg}$$

$$\therefore \Delta\hat{H} + \Delta\hat{E}_p = Q$$

$$(3074 - 2676)\frac{kJ}{kg} + 9.81 \times 10^{-3}\frac{kJ}{kg} = Q$$

$$398 \frac{kJ}{kg} + 9.81 \times 10^{-3} \frac{kJ}{kg} = Q$$

$$\therefore Q = 398.01 \frac{kJ}{kg}$$