31. (a) If $T_{\rm H}$ is the temperature of the high-temperature reservoir and $T_{\rm L}$ is the temperature of the low-temperature reservoir, then the maximum efficiency of the engine is

$$\varepsilon = \frac{T_{\rm H} - T_{\rm L}}{T_{\rm H}} = \frac{(800 + 40)\,{\rm K}}{(800 + 273)\ {\rm K}} = 0.78\ .$$

(b) The efficiency is defined by $\varepsilon = |W|/|Q_{\rm H}|$, where W is the work done by the engine and $Q_{\rm H}$ is the heat input. W is positive. Over a complete cycle, $Q_{\rm H} = W + |Q_{\rm L}|$, where $Q_{\rm L}$ is the heat output, so $\varepsilon = W/(W + |Q_{\rm L}|)$ and $|Q_{\rm L}| = W[(1/\varepsilon) - 1]$. Now $\varepsilon = (T_{\rm H} - T_{\rm L})/T_{\rm H}$, where $T_{\rm H}$ is the temperature of the high-temperature heat reservoir and $T_{\rm L}$ is the temperature of the low-temperature reservoir. Thus,

$$\frac{1}{\varepsilon} - 1 = \frac{T_{\rm L}}{T_{\rm H} - T_{\rm L}} \qquad \text{and} \qquad |Q_{\rm L}| = \frac{WT_{\rm L}}{T_{\rm H} - T_{\rm L}}\ .$$

The heat output is used to melt ice at temperature $T_i = -40°{\rm C}$. The ice must be brought to $0°{\rm C}$, then melted, so $|Q_{\rm L}| = mc(T_f - T_i) + mL_F$, where m is the mass of ice melted, T_f is the melting temperature ($0°$ C), c is the specific heat of ice, and L_F is the heat of fusion of ice. Thus, $WT_{\rm L}/(T_{\rm H} - T_{\rm L}) = mc(T_f - T_i) + mL_F$. We differentiate with respect to time and replace dW/dt with P, the power output of the engine, and obtain $PT_{\rm L}/(T_{\rm H} - T_{\rm L}) = (dm/dt)[c(T_f - T_i) + L_F\,]$. Thus,

$$\frac{dm}{dt} = \left(\frac{PT_{\rm L}}{T_{\rm H} - T_{\rm L}}\right)\left(\frac{1}{c(T_f - T_i) + L_F}\right)\ .$$

Now, $P = 100 \times 10^6\,{\rm W}$, $T_{\rm L} = 0 + 273 = 273\,{\rm K}$, $T_{\rm H} = 800 + 273 = 1073\,{\rm K}$, $T_i = -40 + 273 = 233\,{\rm K}$, $T_f = 0 + 273 = 273\,{\rm K}$, $c = 2220\,{\rm J/kg{\cdot}K}$, and $L_F = 333 \times 10^3\,{\rm J/kg}$, so

$$\begin{aligned}\frac{dm}{dt} &= \left[\frac{(100 \times 10^6\,{\rm J/s})(273\,{\rm K})}{1073\,{\rm K} - 273\,{\rm K}}\right]\left[\frac{1}{(2220\,{\rm J/kg\cdot K})(273\,{\rm K} - 233\,{\rm K}) + 333 \times 10^3\,{\rm J/kg}}\right] \\ &= 82\ {\rm kg/s}\ .\end{aligned}$$

We note that the engine is now operated between $0°{\rm C}$ and $800°{\rm C}$.