19.2. **Model:** The heat engine follows a closed cycle, which consists of four individual processes.
Visualize: Please refer to Figure Ex19.2.
Solve: **(a)** The work done by the heat engine per cycle is the area enclosed by the *p*-versus-*V* graph. We get

$$W_{\text{out}} = (400\ \text{kPa} - 100\ \text{kPa})\left(100 \times 10^{-6}\ \text{m}^3\right) = 30\ \text{J}$$

The heat energy leaving the engine is $Q_{\text{C}} = 90\ \text{J} + 25\ \text{J} = 115\ \text{J}$. The heat input is calculated as follows:

$$W_{\text{out}} = Q_{\text{H}} - Q_{\text{C}} \Rightarrow Q_{\text{H}} = Q_{\text{C}} + W_{\text{out}} = 115\ \text{J} + 30\ \text{J} = 145\ \text{J}$$

(b) The thermal efficiency of the engine is

$$\eta = \frac{W_{\text{out}}}{Q_{\text{H}}} = \frac{30\ \text{J}}{145\ \text{J}} = 0.207$$

Assess: Practical engines have thermal efficiencies in the range $\eta \approx 0.1 - 0.4$.