33. (a) The pressure at 2 is $p_2 = 3p_1$, as given in the problem statement. The volume is $V_2 = V_1 = nRT_1/p_1$. The temperature is

$$T_2 = \frac{p_2V_2}{nR} = \frac{3p_1V_1}{nR} = 3T_1 \ .$$

The process $4 \to 1$ is adiabatic, so $p_4V_4^\gamma = p_1V_1^\gamma$ and

$$p_4 = \left(\frac{V_1}{V_4}\right)^\gamma p_1 = \frac{p_1}{4^\gamma} \ ,$$

since $V_4 = 4V_1$. The temperature at 4 is

$$T_4 = \frac{p_4V_4}{nR} = \left(\frac{p_1}{4^\gamma}\right)\left(\frac{4nRT_1}{p_1}\right)\left(\frac{1}{nR}\right) = \frac{T_1}{4^{\gamma-1}} \ .$$

The process $2 \to 3$ is adiabatic, so $p_2V_2^\gamma = p_3V_3^\gamma$ and $p_3 = (V_2/V_3)^\gamma p_2$. Substitute $V_3 = 4V_1$, $V_2 = V_1$, and $p_2 = 3p_1$ to obtain

$$p_3 = \frac{3p_1}{4^\gamma} \ .$$

The temperature is

$$T_3 = \frac{p_3V_3}{nR} = \left(\frac{1}{nR}\right)\left(\frac{3p_1}{4^\gamma}\right)\left(\frac{4nRT_1}{p_1}\right) = \frac{3T_1}{4^{\gamma-1}} \ ,$$

where $V_3 = V_4 = 4V_1 = 4nRT/p_1$ is used.

(b) The efficiency of the cycle is $\varepsilon = W/Q_{12}$, where $W$ is the total work done by the gas during the cycle and $Q_{12}$ is the energy added as heat during the $1 \to 2$ portion of the cycle, the only portion in which energy is added as heat. The work done during the portion of the cycle from 2 to 3 is $W_{23} = \int p\,dV$. Substitute $p = p_2V_2^\gamma/V^\gamma$ to obtain

$$W_{23} = p_2V_2^\gamma \int_{V_2}^{V_3} V^{-\gamma}\,dV = \left(\frac{p_2V_2^\gamma}{\gamma-1}\right)\left(V_2^{1-\gamma} - V_3^{1-\gamma}\right) \ .$$

Substitute $V_2 = V_1$, $V_3 = 4V_1$, and $p_3 = 3p_1$ to obtain

$$W_{23} = \left(\frac{3p_1V_1}{1-\gamma}\right)\left(1 - \frac{1}{4^{\gamma-1}}\right) = \left(\frac{3nRT_1}{\gamma-1}\right)\left(1 - \frac{1}{4^{\gamma-1}}\right) \ .$$

Similarly, the work done during the portion of the cycle from 4 to 1 is

$$W_{41} = \left(\frac{p_1V_1^\gamma}{\gamma-1}\right)\left(V_4^{1-\gamma} - V_1^{1-\gamma}\right) = -\left(\frac{p_1V_1}{\gamma-1}\right)\left(1 - \frac{1}{4^{\gamma-1}}\right) = -\left(\frac{nRT_1}{\gamma-1}\right)\left(1 - \frac{1}{4^{\gamma-1}}\right) \ .$$

No work is done during the $1 \to 2$ and $3 \to 4$ portions, so the total work done by the gas during the cycle is

$$W = W_{23} + W_{41} = \left(\frac{2nRT_1}{\gamma-1}\right)\left(1 - \frac{1}{4^{\gamma-1}}\right) \ .$$

The energy added as heat is $Q_{12} = nC_V(T_2 - T_1) = nC_V(3T_1 - T_1) = 2nC_VT_1$, where $C_V$ is the molar specific heat at constant volume. Now $\gamma = C_p/C_V = (C_V + R)/C_V = 1 + (R/C_V)$, so $C_V = R/(\gamma-1)$. Here $C_p$ is the molar specific heat at constant pressure, which for an ideal gas is $C_p = C_V + R$. Thus, $Q_{12} = 2nRT_1/(\gamma-1)$. The efficiency is

$$\varepsilon = \frac{2nRT_1}{\gamma-1}\left(1 - \frac{1}{4^{\gamma-1}}\right)\frac{\gamma-1}{2nRT_1} = 1 - \frac{1}{4^{\gamma-1}} \ .$$