Step 1: **Establish the Intermediate State Absolute Temperatures**

Temperature at State 2 (T_2):

Using the isentropic pressure-temperature relation, the temperature at the end of the compression stroke is calculated as follows:

$$T_2 = T_1\left[\frac{P_2}{P_1}\right]^{\frac{k-1}{k}} = (300\ K)\left[\frac{1200\ kPa}{150\ kPa}\right]^{\frac{1.4-1}{1.4}} = 543.4342\ K$$

Temperature at State 3 (T_3):

Process 2-3 describes an isobaric expansion, meaning $P_3 = P_2 = 1200$ kPa. Because the cycle resets from State 3 back to State 1 through a constant volume (isometric) process, the volume at State 3 is equal to the volume at State 1 ($V_3 = V_1$). Applying Charles' Law for a constant-volume state change between points 3 and 1 gives:

$$T_3 = T_1\left[\frac{P_3}{P_1}\right] = (300\ K)\left[\frac{1200\ kPa}{150\ kPa}\right] = 2400\ K$$

Step 2: **Compute Cycle Heat Flows**

- **Process 1-2 (Isentropic):** No heat transfer occurs along a perfectly insulated adiabatic path:

$$\frac{Q_{1-2}}{m} = 0$$

- **Process 2-3 (Isobaric Heat Addition):** Heat added at constant pressure is calculated using the change in enthalpy:

$$\frac{Q_{2-3}}{m} = C_p\left(T_3 - T_2\right) = \left(1.0062\ \frac{kJ}{kg-K}\right)(2400\ -\ 543.4342)K\ =\ 1868.0765\ \frac{kJ}{kg}$$

- **Process 3-1 (Isometric Heat Rejection):** Heat rejected at constant volume is evaluated through the internal energy change:

$$\frac{Q_{3-1}}{m} = C_v\left(T_1 - T_3\right) = \left(0.7186\ \frac{kJ}{kg-K}\right)(300\ -\ 2400)K\ =-\ 1509.0600\ \frac{kJ}{kg}$$

Step 3: **Compute Cycle Work**

- **Process 1-2: Isentropic Compression (W_{1-2})**

  Because this process is **isentropic** (reversible adiabatic), no heat is transferred (Q = 0). According to the Non-Flow Energy Equation (NFEE), the work done is equal to the negative change in internal energy:

$$\frac{W_{1-2}}{m} = -\ \Delta U =-\ C_v\left(T_2 - T_1\right) = \left(0.7186\ \frac{kJ}{kg-K}\right)(543.4342\ -\ 300)K\ =-\ 174.9318\ \frac{kJ}{kg}$$

The negative sign tells us that work was **inputted into** or required by the system to compress the air.

- **Process 2-3: Isobaric Heat Addition (**$W_{2\text{-}3}$**)**

$$\frac{W_{2-3}}{m} = R\left(T_3 - T_2\right) = \left(0.287\ \frac{kJ}{kg-K}\right)(2400\ -\ 543.4342)K\ =\ 532.8344\ \frac{kJ}{kg}$$

*The positive sign tells us that the gas did work **on the surroundings** as it expanded due to the heat addition.*

- **Process 3-1: Isometric Heat Rejection (**$W_{3\text{-}1}$**)**

  This process occurs at a **constant volume** (V = C), meaning the air is trapped in a rigid space while cooling down.

$$\frac{W_{3-1}}{m} = 0\ \frac{kJ}{kg}$$

By summing the total work transfers along the process paths $\left(\Sigma W_{NET} = \frac{W_{1-2}}{m} + \frac{W_{2-3}}{m} + \frac{W_{3-1}}{m}\right)$, the net specific work output equals:

$$\Sigma W_{NET} =-\ 174.9318\ \frac{kJ}{kg} +\ 532.8344\ \frac{kJ}{kg}\frac{W_{3-1}}{m} +\ 0\ \frac{kJ}{kg}\ =\ 357.9026\frac{kJ}{kg}$$

Thermal Efficiency (e_{cycle}**)**

Using these values, the cycle thermal efficiency is determined by:

$$e_{cycle} = \frac{\Sigma W_{NET}}{\Sigma Q_A} = \frac{357.9026\,\frac{kJ}{kg}}{1868.0765\,\frac{kJ}{kg}} =\ 19.16\%$$

This sample problem provides important insights into real-world engine design. The power cycle analyzed here achieves a relatively low thermal efficiency of only 19.16%, despite reaching a peak combustion temperature of 2400K and a peak internal pressure of 1200kPa.

In industrial practice, sustaining an operational thermal load of 2400 K requires specialized, high-cost alloys to ensure the structural integrity of the cylinder walls. Generating less than 20% efficiency from such a high thermal load is economically impractical compared to a standard four-stroke cycle, which uses an additional isentropic expansion step to extract more mechanical work from the gas before rejecting heat.