Problem Description:

A frictionless piston is raised slowly by heating the gas contained in the cylinder.

Given:

- $P_1 = 0.2 \text{ MPa}$
- $P_{12}$ (constant pressure)
- $V_1 = 1.0 \text{ m}^3$
- $V_2 = 2.0 \text{ m}^3$
- $Q_{12} = 2000 \text{ kJ} = 2 \text{ MJ}$

Determine: Change in internal energy, $\Delta U_{12}$

Engineering Model:
- Quasi-Equilibrium process
- System is the gas only
- Neglects kinetic and potential energy effects

Governing Equation:

1st Law for closed system: $\Delta KE + \Delta PE + \Delta U = Q_{in} + W_{in} - Q_{out} - W_{out}$ (1)

Work: $W_{12} = \int P \, dV$ (2)

Steps:

1. Apply 1st Law to system:

   $Q_{in,12} = W_{12} + \Delta KE + \Delta PE + \Delta U_{12}$

2. Solving for $\Delta U_{12}$:

   $\Delta U_{12} = Q_{in,12} - W_{12}$

3. To determine $W_{12}$, use Eq. (2):

   $W_{12} = |W_{12}| = \int P \, dV$

4. Substituting (4) into (3):

   $\Rightarrow \Delta U_{12} = U_2 - U_1 = Q_{in,12} - |P(V_2 - V_1)|$

Numerical Substitution:

$W_{12} = 0.2 \text{ MPa} \cdot (2.0 - 1.0) \text{ m}^3 \cdot \frac{1152 \text{ J}}{1 \text{ Pa} \cdot \text{ m}^3} = 0.2 \text{ MJ}$

$\Delta U_{12} = 2 - 0.2 = 1.8 \text{ MJ}$