Water at $P = 100\text{kPa}$, $T = 200^\circ\text{C}$ is contained in a piston cylinder with a set of stops as shown. The piston is initially resting on the lower stops. The piston area is 0.1 m$^2$, the weight of the piston is 10 kN and the atmospheric pressure is 100 kPa. The water is heated and the piston eventually reaches the upper stops.

Unfortunately someone forgot to polish the inner cylinder wall and there is a layer of “gunk” from a height 0.5 to 0.7 m. This causes a non-negligible friction force acting on the piston as it moves from through this region. This frictional force increases with cylinder volume: $F_{\text{frict}} = 4000 V^2 - 10$ until the piston reaches a height of 0.7 m, after which the frictional force remains constant. (Note: The frictional force is in kN when the volume is given in m$^3$).

(a) Draw the process on a PV diagram.
(b) Calculate the amount of work done by the water in the cylinder during this process.
(c) Calculate the amount of heat transferred during this process. Note: you need properties to do this.
   Since I’m sure you haven’t memorized the tables you just need explain how you would identify the states if you had tables and then explain how you would find the heat transfer.
(d) Explain any assumptions used in your analysis

\[ \text{State} (1) \quad P_1 = 100 \text{kPa} \quad T_1 = 200^\circ\text{C} \quad V_1 = 0.05 \text{ m}^3 \]

\[ P = P_{\text{atm}} + \frac{F}{A} + \frac{mg}{A} \]

\[ P = \left(\frac{4000u^2 - 10}{0.1} + 100 + 100\right) \]

\[ P = 200 + 40000u^2 - 100 \]

\[ \text{at } u = 0.05 \quad P = 200 \text{kPa} = P_{\text{dif}}. \]

\[ \text{at } u = 0.07 \quad P = 296 \text{kPa} \]

\[ \text{State} (3) \quad P_3 = 296 \text{kPa} \quad V_3 = 0.07 \text{ m}^3 \]

\[ \text{State} (4) \quad P_4 = 296 \text{kPa} \quad V_4 = 0.1 \text{ m}^3 \]
Assumptions
1) Fixed mass (no leaks)
2) Quasi-equil process
3) ΔPE = ΔKE = 0

\( W = \int P \, dv = \int_{0.05}^{0.07} 100 + 40000v^2 \, dv + \int_{0.05}^{0.07} 29.6 \, dv \)

\[ = 100v + \frac{40000v^3}{3} \bigg|_{0.05}^{0.07} + 29.6(0.07 - 0.05) \]

\[ W = 13.8 \text{ kJ} \]

(c) \( Q = \Delta H + W = U_f - U_i + W \)

State (1) \( P_1 = 100 \text{ kPa} \), \( T_1 = 200^\circ C \)
\( U_1 = 2.17226 \)
\( m_1 = \frac{U_1}{V_1} = \frac{0.05}{2.17226} = 0.023 \text{ kg} \)

State (4) \( P_4 = 29.6 \text{ kPa} \), \( V_4 = 0.1 \text{ m}^3 \)
\( m_4 = m_1 = 0.023 \text{ kg} \)

\[ T = \frac{P_4}{R} = \frac{29.6 \times 0.344}{0.287} = 4.615 \text{ K} \]

\( U_4 \approx \frac{58179}{7118} \) (treat as 1.6)
\( Q = 0.023(58179 - 26580.05) + 13.8 = \frac{1164}{7118} \text{ kJ} \)