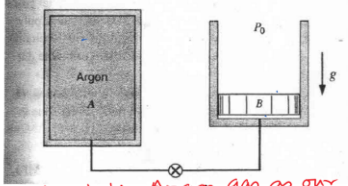
5 A 400-L tank, *A* (see Fig. P4.33), contains argon gas at 250 kPa and 30°C. Cylinder *B*, having a frictionless piston of such mass that a pressure of 150 kPa will float it, is initially empty. The valve is opened and argon flows into *B* and eventually reaches a uniform state of 150 kPa and 30°C throughout. What is the work done by the argon?



A key element here is the valve.

Across the valve an unresisted expansion takes place. This renders the process of expansion of the Ar gas from Chamber A (p decreases from 250 kPa to 150 kPa) to B (p shoots up to 150 kPa and then stays constant as the piston lifts up) irreversible.

We treat the Argon gas as our system

State 1	State 2
$p_1 = 250$ kPa	$p_2 = 150$ kPa
$V_1 = 0.4\ m^3$	$V_2 = ?$
$T_1 = 303$ K	$T_2 = 303$ K

Since the system is a closed one

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \Rightarrow V_2 = \frac{.4 \times 250}{150}\ m^3$$

$$\Rightarrow V_2 = 0.667\ m^3$$

Hence, although the temperature of the Argon gas initially and finally were at 300 K, the process is NOT isothermal.

Expansion across the valve is irreversible. So the $W = \int p dV$ cannot be applied.

So instead, we compute the "Boundary Work" (the work done as the boundary of the system extends) we calculate

$$W = \int F \cdot ds \Big|_{\text{on the piston}} = \int_1^2 p\, dV = 150 \times (V_2 - V_1)$$

$$= 150 \left(\frac{0.4 \times 250}{150} - 0.4 \right)$$

$$= 0.4 \times \frac{(250-150)}{150} \times 150 = 40 \text{ kJ}$$

* P.S. ‡ Had the expansion of the Ar from Chamber A to B taken place isothermally (Not possible by a valve, but by some hypothetical device), the work done could have been directly computed from the equation of the process, i.e.,

$$pV = \text{const.}$$

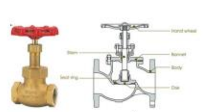
For an iso-thermal process (a polytropic process with $n = 1$)

$$W = \int_1^2 p dV = p_1 V_1 \ln \frac{V_2}{V_1} = p_2 V_2 \ln \frac{V_2}{V_1}$$

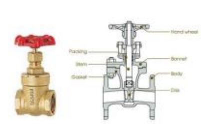
For our case $W = 0.4 \times 250 \ln \frac{0.667}{0.4} = 51.08$ kJ

Therefore, we are losing $51.08 - 40 = 11.08$ kJ of work potential by using the valve instead of a complicated gizmo that could have given us a reversible isothermal expansion.

Note: How does a valve work? What are different types of valves commonly used in plumbing?



① Globe Valve
Used for controlling the flow from no-flow (fully closed), to full-flow (fully open) & several intermediate flows are possible. Acts like the regulator of flow



② Gate Valve
Has either fully-open or fully-closed position. Acts like an on-off switch.