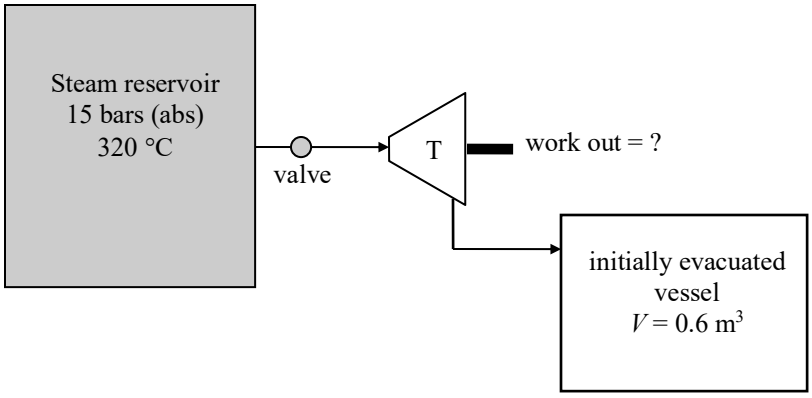
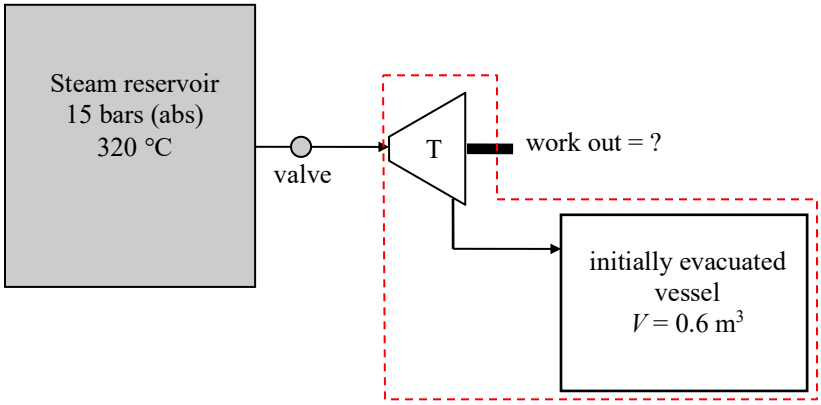
Steam at 15 bars (abs) and 320 °C is contained in a large tank. Connected to the tank through a valve is a turbine followed by a small initially evacuated vessel with a volume of 0.6 m^3. The valve is opened and the vessel fills with steam until the pressure is 15 bars (abs) and the temperature is 400 °C. The valve is then closed. The filling process takes place adiabatically and kinetic and potential energy effects are negligible. Determine the amount of work developed by the turbine, in kJ.



SOLUTION:

Apply the First Law to the control volume shown below assuming an unsteady, but uniform control volume with steady and uniform inlet and outlet properties. Heat transfer to the surroundings and the changes in the kinetic and potential energies within the control volume can be neglected.



$$\Delta E_{CV} - m_{in} h_{in} = \underset{CV}{Q_{into}} + \underset{CV}{W_{on}} \tag{1}$$

where

$$\Delta E_{CV} = \Delta U_{CV} = m_{CV,f} u_{CV,f} - m_{CV,i} u_{CV,i} \tag{2}$$

$m_{CV,i} = 0$ (the tank vessel is initially empty) (3)

$h_{in} = 3081.9$ kJ/kg (from steam tables with $p_{in} = 15$ bars (abs), $T_{in} = 320$ °C) (4)

$Q_{into\ CV} = 0$ (the process occurs adiabatically)

$m_{in} = m_{CV,f}$ (from conservation of mass) (5)

The final mass in the tank is found from the tank volume and the final specific volume,

$$m_{\mathrm{CV,f}} = \rho_{\mathrm{f}} V = \frac{V}{v_f} = 2.96 \text{ kg} \tag{6}$$

where $V = 0.6$ m^3 and $v_f = 0.2030$ m^3/kg (from steam tables at $p_f = 15$ bars (abs) and $T_f = 400$ °C). In addition, $u_f = 2951.3$ kJ/kg for the same conditions.

Substituting and simplifying gives:

$$W_{\underset{\mathrm{CV}}{\mathrm{on}}} = m_{\mathrm{CV,f}} \left(u_{\mathrm{CV,f}} - h_{\mathrm{in}} \right) = \left(2.96 \text{ kg} \right) \left(2951.3 \ \text{kJ}/\text{kg} - 3081.9 \ \text{kJ}/\text{kg} \right) \tag{7}$$

$$\boxed{\therefore W_{\underset{\mathrm{CV}}{\mathrm{on}}} = -386.6 \text{ kJ}} \tag{8}$$

Thus, 386.6 kJ of work is extracted from the process.

The final temperature in the tank is larger than the supply temperature because *pdV* work (in the enthalpy term) is converted into internal energy. Although some of the *pdV* work is extracted by the turbine, not all of it is; the remainder goes into increasing the internal energy of the steam in the tank.