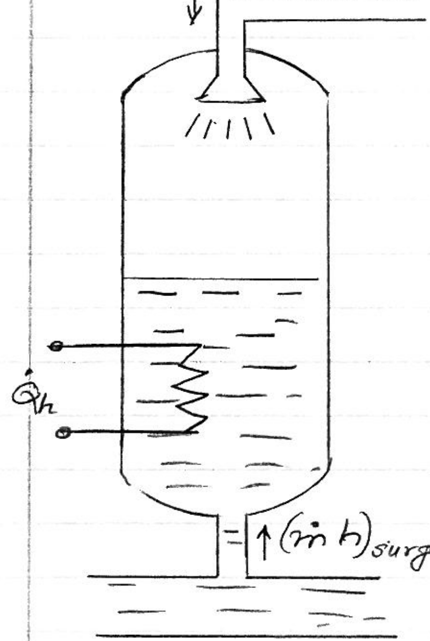
PRESSURIZER



Equalibrium Single-Region.

Mass balance:

$$\frac{d}{dt} m = \dot{m}_{surge} + \dot{m}_{spray} \quad -①$$

Energy balance:

$$\frac{d}{dt}(mu) = \dot{m}_{surge} h_{surge} + \dot{m}_{spray} h_{spray} + \dot{Q}_h - p\frac{d}{dt}(mv) \quad -②$$

$$m = m_v + m_l$$
$$mu = m_v u_v + m_l u_l$$
$$mv = m_v v_v + m_l v_l$$

$$\frac{d}{dt}(mv) = \frac{d}{dt}(m_v v_v + m_l v_l) = 0 \quad -③$$

(Constant volume)

Prescribed inputs: $\dot{m}_{spray}$, h_{spray}, $\dot{m}_{surge}$, h_{surge} & $\dot{Q}$

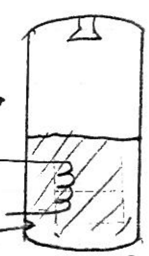
Unknown: p, m_v, m_l, u_v, v_v, u_l, and v_l.

Equation of state:

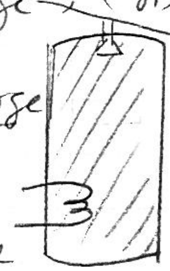
$$\left.\begin{aligned} u_v &\equiv u_g = f(p) \\ u_l &\equiv u_f = f(p) \\ v_v &\equiv v_g = f(p) \\ v_l &\equiv v_f = f(p) \end{aligned}\right\} \text{saturation condition.}$$

Final Pressure:

Initial state: $(V_{f1})_{outsurge}$ $(V_{g1})_{insurge}$



Final state: A: $(V_{f2})_{insurge}$



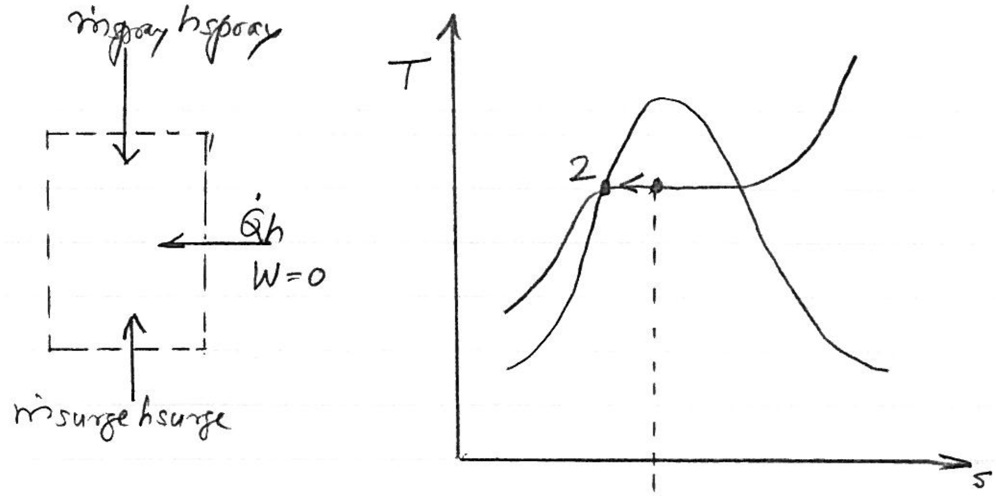
B: $(V_{f2})_{outsurge}$ $(V_{g2})_{outsurge}$

$$V_T = (V_{g1})_{insurge} + (V_{f1})_{outsurge}$$

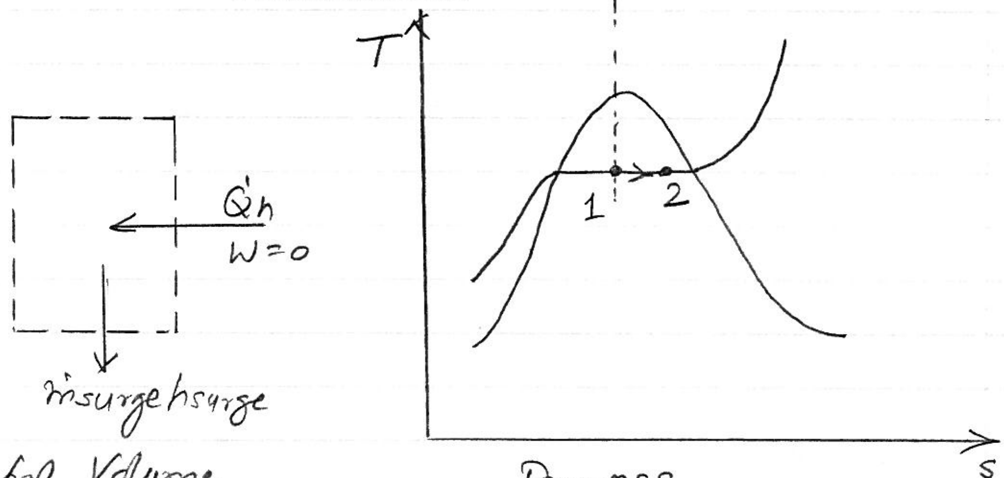
Unknown: m_l, m_v, $\dot{Q}$

Inputs: $\dot{m}_{spray}$, h_{spray}, $\dot{m}_{surge}$, h_{surge} & p.

INSURGE



OUTSURGE



Control Volume   Process.

Integrate equations ①–③ between initial (1) and final states (2)

$$m_2 - m_1 = m_{surge} + m_{spray}$$

$$m_2 u_2 - m_1 u_1 = m_{surge} h_{surge} + m_{spray} h_{spray} + Q_h.$$

$$m_2 v_2 = m_1 v_1$$

For insurge: final state is saturated water at initial pressure

$$m_{f2} = m_{surge} + m_{spray} + \overbrace{m_{f1} + m_{g1}}^{m_1}$$

$$m_{f2} = m_{surge}(1+f) + m_{f1} + m_{g1} \quad -④$$

$$f\, m_{surge} = m_{spray}.$$

$$m_{f2} u_{f2} = m_{surge}(h_{surge} + f h_{spray}) + m_{g1} u_{g1} + m_{f1} u_{f1} + Q_h. \quad -⑤$$

$$m_{f2} v_{f2} = m_{g1} v_{g1} + m_{f1} v_{f1}. \quad -⑥$$

State (1) & (2) are saturated at same pressure.

from ⑤ and ⑥

$$m_{g1} = \frac{v_f [m_{surge}(h_{surge} + f h_{spray}) + Q_h]}{v_g u_f - v_f u_g} \quad -⑦$$

and from ④ and ⑤

$$m_{g1} = \frac{m_{surge}(1+f) v_f}{v_g - v_f} \quad -⑧$$

From ⑦ & ⑧

$$(Q_h)_{insurge} = \frac{m_{surge}(1+f)[v_g u_f - v_f u_g]}{v_g - v_f}$$

$$- m_{surge}(h_{surge} + f h_{spray})$$

Steam volume $(V_{g1})_{insurge} = m_{g1} v_g$

For outsurge case,

mass balance: $m_{f2} + m_{g2} - m_{f1} - m_{g1} = - m_{surge}$

energy balance:

$$m_{f2} u_{f2} + m_{g2} u_{g2} - m_{f1} u_{f1} - m_{g1} u_{g1} = - m_{surge} h_{surge} + Q_h.$$

volume constraint: $m_{f2} v_{f2} + m_{g2} v_{g2} = m_{f1} v_{f1} + m_{g1} v_{g1}$

$$m_{f1} = m_{f2} + m_{surge} \frac{v_g}{v_g - v_f}$$

and

$$m_{f1} = m_{f2} + \frac{Q_h - m_{surge} h_{surge}}{\frac{v_f}{v_g} u_g - u_f}$$

$$(Q_h)_{outsurge} = m_{surge} h_{surge} - \left(u_f - \frac{v_f}{v_g} u_g\right)\left(m_{surge} \frac{v_g}{v_g - v_f}\right)$$

$$(V_{f_1})_{outsurge} = m_{f_1} v_f$$

total volume: $V_T = (V_{g_1})_{insurge} + (V_{f_1})_{outsurge}$

Example: Pressurizer Sizing

Determine size of the pressurizer that can accomodate a maximum outsurge of 14,000 kg and hotleg insurge of 9500 kg for the conditions of Table

Table 7-3 Conditions for pressurizer design problem

Saturation pressure	15.5 MPa	(2250 psia)
Saturation temperature	618.3°K	(652.9°F)
Saturation properties		
u_f	1.60×10^6 J/kg	(689.9 B/lb)
u_g	2.44×10^6 J/kg	(1050.6 B/lb)
v_f	1.68×10^{-3} m³/kg	(0.02698 ft³/lb)
v_g	9.81×10^{-3} m³/kg	(0.15692 ft³/lb)
Mass of maximum outsurge	14,000 kg	
Mass of maximum insurge	9,500 kg	
Hot leg insurge enthalpy	1.43×10^6 J/kg	(612.8 B/lb)
Cold leg spray enthalpy	1.27×10^6 J/kg	(546.8 B/lb)
Cold leg spray expressed as a fraction of hot leg insurge (f)	0.03	
Outsurge enthalpy	1.63×10^6 J/kg	(701.1 B/lb)
Mass of liquid water necessary to cover the heaters (requires an assumption about the pressurizer configuration)	1827 kg	

Solution:

$$(Q_h)_{insurge} = \frac{m_{surge}(1+f)[v_g u_f - v_f u_g]}{v_g - v_f} = 1.06 \times 10^7 \text{ J}$$

$$m_{g_1} = \frac{m_{surge}(1+f) v_f}{v_g - v_f} = 2022 \text{ kg}$$

$$(V_{g1})_{in\,surge} = m_{g1} v_g = 19.84\ m^3.$$

$$(Q_h)_{out\,surge} = m_{surge} h_{surge} - \left(u_f - \frac{v_f}{v_g} u_g\right)\left(m_{surge} \frac{v_g}{v_g - v_f}\right)$$

$$= 2.851 \times 10^9\ J$$

$$m_{f1} = m_{f2} + m_{surge} \frac{v_g}{v_g - v_f} = 1.872 \times 10^4\ kg$$

$$(V_{f1})_{out\,surge} = m_{f1} v_f = 31.45\ m^3$$

Total volume $= V_T = (V_{g1})_{in\,surge} + (V_{f1})_{out\,surge} = 51.29\ m^3$

$\longrightarrow\times$ —