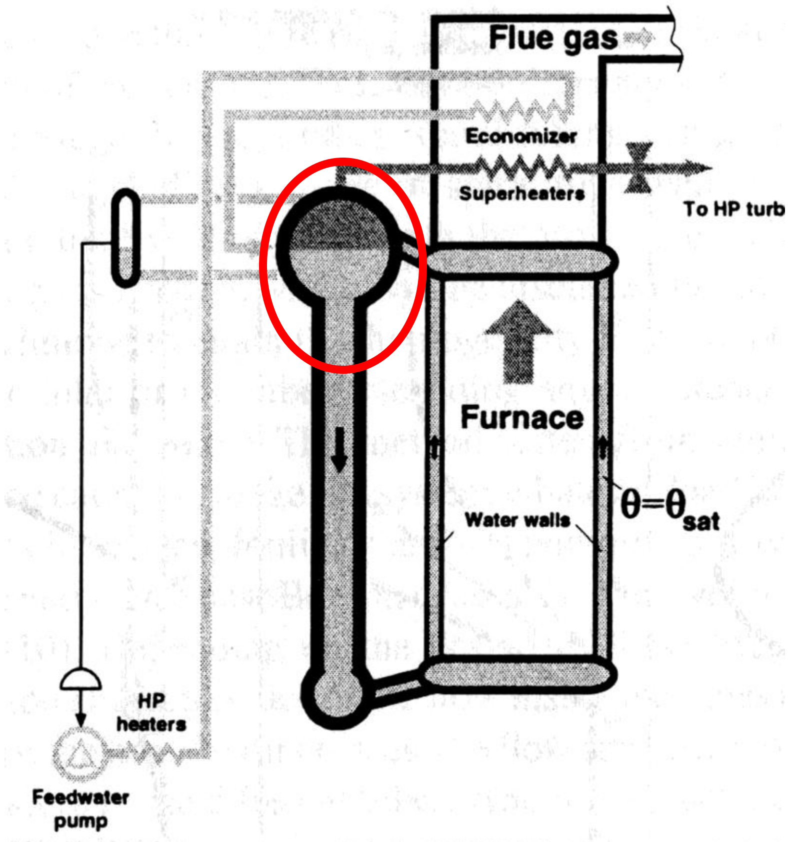
NATURAL CIRCULATION

UNIT 20

TYPES OF CIRCULATION

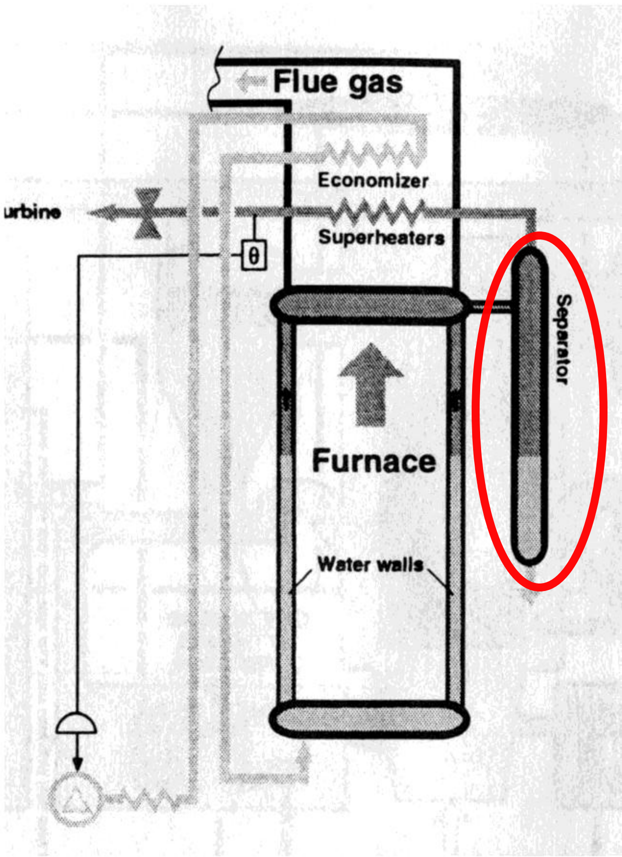
- NATURAL (Water-steam moves due to density difference)
- FORCED ONCE THROUGH (water-steam is moved by pump)
- ASSISTED CIRCULATION (pump helps water steam circulate)

NATURAL CIRCULATION



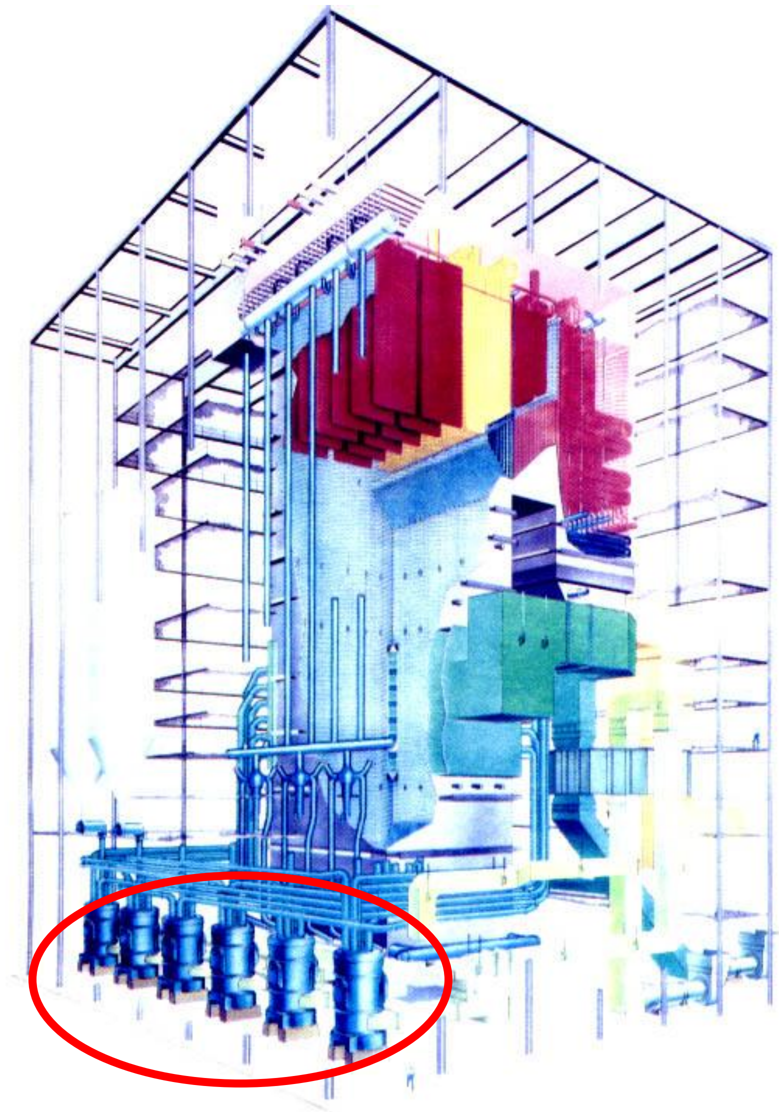
- Water flows down the downcomer under gravity
- Water & steam rises through furnace evaporator tubes
- Steam leaves drum & passes through superheater
- Feed pump feeds water to the drum

ONCE THROUGH FORCED



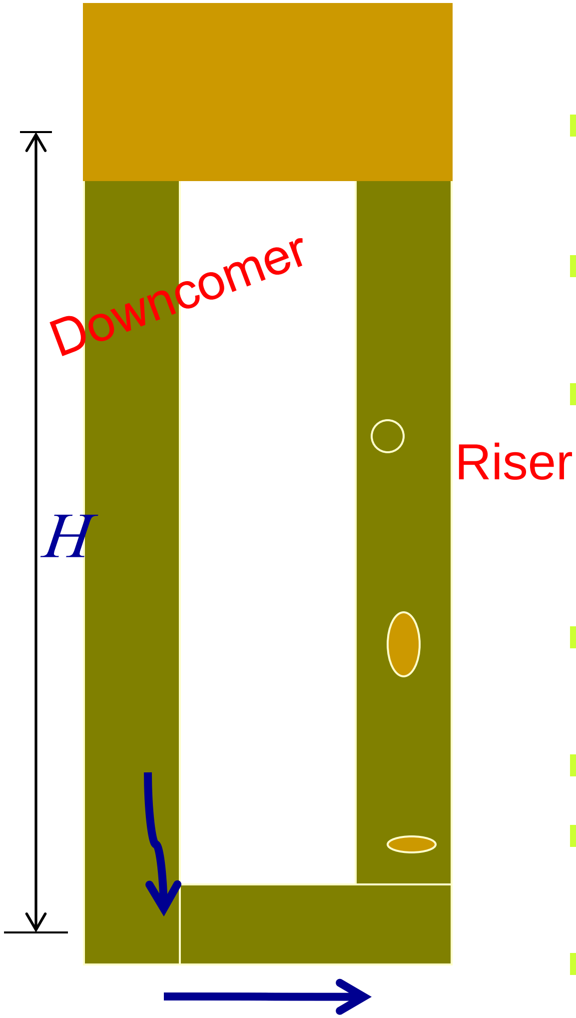
- Pump forces water through economizer, evaporator, separator & superheater.
- Water separated from steam in a vertical separator
- No recirculation

ASSISTED CIRCULATION



Controlled Circulation®

Why water-steam mixture circulates



- Pressure on left (downcomer- water),
  $P_{dc} = H\,\gamma_w$ N/m^2 ($\gamma = \rho\, g$)
- Pressure on side (riser- water+steam)
  $P_r = H\,\gamma_{sw}$ N/m^2.
- As $\gamma_w > \gamma_{sw}$ $P_{dc} > P_r$.
  So, water will flow from left column to right under a Motive head,
  $P_m = H(\gamma_w - \gamma_{sw})$
- Flow results in fluid resistance ΔP_r reducing available head in riser
- Available head, $P_{av} = P_m - \Delta P_r$
- When steady flow sets in available just balances fluid resistance in downcomer ΔP_w
- $\Delta P_w = P_{av}$
- $\gamma_{sw} = (\rho_{bottom} + \rho_{top})g/2$

Circulation Ratio

- Circulation ratio is the ratio of water passing into a riser and the steam generated in it (CR $= m/m_g$).
- Dryness fraction, x (m_g/m) in the mixture leaving a riser is inverse of circulation ratio (x= G”/G = 1/CR)

- $5 < CR < 25$
  m = water flow in DC= $m_g + m_l$ =Mixture flow in riser

Slip ratio

- Void fraction = α

  $$\alpha = \frac{\text{Vol of steam}}{(\text{Vol of liquid + Vol of steam})}$$

- In a riser steam rises faster than saturated water
- SLIP RATIO, *S* is ratio

  $$S = \frac{\text{Steam velocity}}{\text{Water velocity}}$$

- Area ratio
  $\alpha = A_g/(A_g + A_l)$ at a section
- Specific volume of a mixture, *v*
  $v = (1-x)v_l + x\, v_g$
- Density of mixture, = $\alpha\rho_g + (1-\alpha)\,\rho_l$

Sp. Wt of mixture (sec. 12-1-5)

- Define superficial (reduced) velocity,
  W = (Volume flow rate/Tube cross-section area)
- Weight flow rate of steam, $G'' = W''A(\gamma''/g)$
- Water flow rate (G) becomes mixtures of steam (G'') & saturated water (G') in evaporator.
- $G = G' + G''$
  Substitution gives $W = W' + W''(\gamma''/\gamma')$
- Volume fraction of steam

$$\beta = \frac{W''.A}{W''.A + W'.A} = \frac{1}{\frac{W}{W''} + 1 - \frac{\gamma''}{\gamma'}}$$

Pressure drop

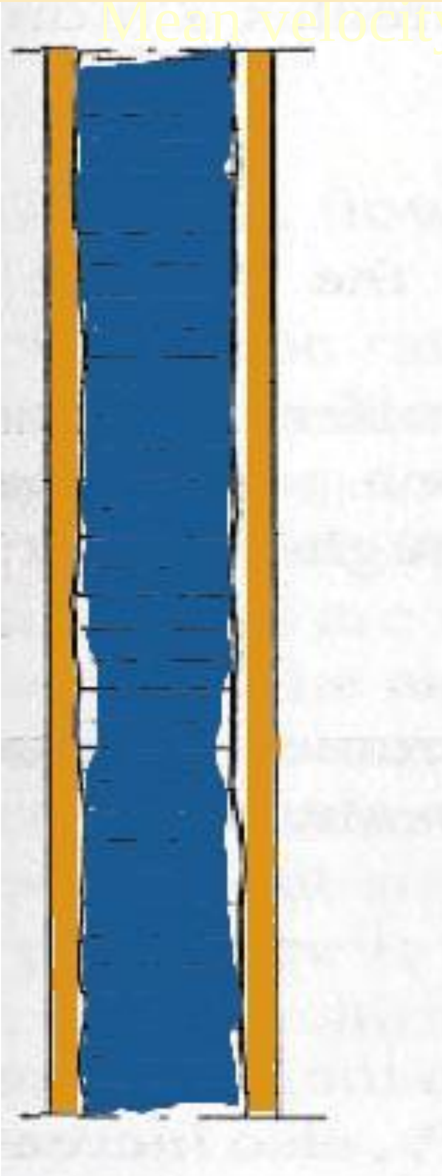
- Velocity in downcomer lies between 0.4 to 1.4 m/s

$$\Delta P = \frac{fL}{D} \rho \frac{V^2}{2}$$

$$m = n \frac{\pi}{4} D^2 \rho_l V$$

Area fraction for steam in riser tubes

Mean velocity of steam-water mixture



- Fraction of tube cross-section area occupied by steam = ϕ
- Actual steam velocity = W''/ϕ
  Actual water velocity = $W'/(1-\phi)$ m/s
- Φ depends on pressure, angle of tube W''/W, and W^2/d
- These are found from graphs (12-3)
  $\phi = \phi_0 K_\alpha K_p$
- Considering buoyancy of steam (weight of displaced water) in a section the motive force P drives steam in riser is written as
  $P = H_s \phi (\gamma' - \gamma'')$

Steam-water flow mixture flow

- For a small section weight of mixture is equal to the sum of steam & water. It gives
  $\gamma_m = \phi.'\gamma' + (1-\phi)\gamma'$
- Mean Sp. Wt of mixture is written as $\lambda_m = \dfrac{\gamma'}{1+\dfrac{W''}{W'}\left(1-\dfrac{\gamma''}{\gamma'}\right)}$
- Av. velocity of mixture

$$W_m = \frac{W''.\gamma'}{\gamma_m} = W + W''\left(1-\frac{\gamma''}{\gamma'}\right)$$

- (Hydrostatic pressure-Flow resistance +drum pressure) in Downcomer =
  (Hydrostatic pr + Flow resistance + Pressure at top) in Riser

Pressure drop in steam water mixture

$$\Delta P_m = K\frac{W_m^2}{2g}\gamma_m ; W_m\gamma_m = W\gamma'$$

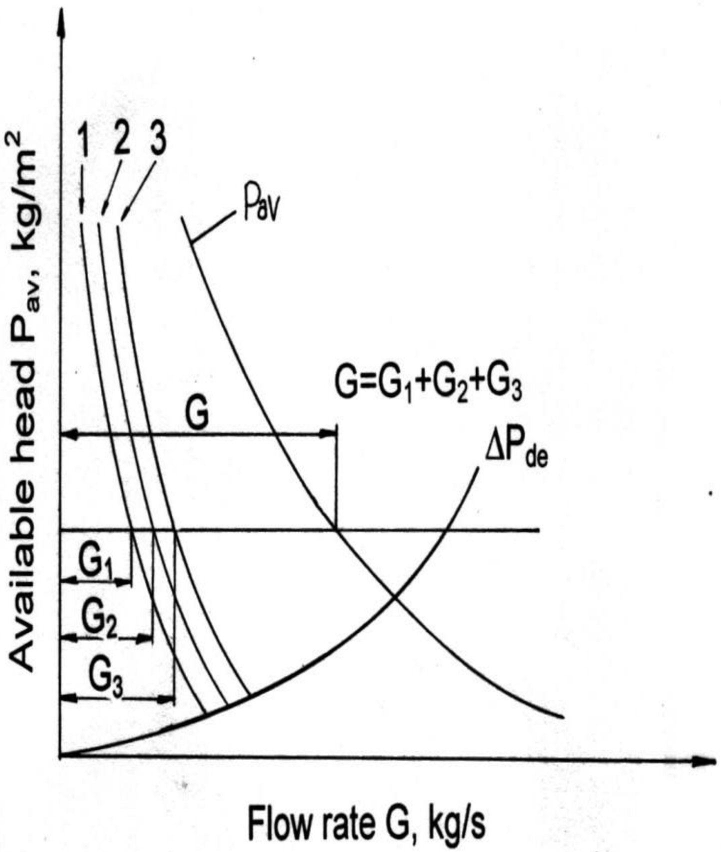
$$\Delta P_m = K\frac{W_m}{2g}W\gamma' = K\frac{W^2}{2g}\gamma'\left(1+\frac{W''}{W}\left(1-\frac{\gamma''}{\gamma'}\right)\right)$$

$$K = \frac{fL}{d} + \Sigma k$$

Circulation calculations- I

1. Available heads across any riser tube, P_{av1} must be equal to the resistance in the downcomer, ΔP_{dc}
2. First calculate ΔP_{dc} for various values of G and plot them against G
3. Then assume a flow rate G_1 through riser 1. Calculate steam generated in it for a given heat flux.
4. Calculate motive head P_m & flow resistances ΔP_r,
5. Find its available head in the riser, $P_{av1}(= P_m - \Delta P_r)$.
6. Repeat it with other values of flow G_2, G_3 etc through riser 1.
7. Plot this on the same graph against G
8. Intersection of these two graphs gives the circulation

Circulation calculations -II



- Plot P_{av1} against G_1 etc.
- Repeat it for other risers, G_2, G_3 etc.
- Resistance of downcomer ΔP_{dc},is calculated & plotted against total flow rate, $G = G_1+G_2+G_3+ \ldots_{..}$
- Intersection of two curves ($\Delta P_{dc} = P_{av}$) gives the circulation

Height of economizer section (12-4)

- Economizer section of riser tubes picks up sensible heat. Pressure at this point, P_{ec} is higher than that in the drum due to hydrostatic head
- $P_{ec} - P_d = H\,\gamma'_d - H_{ec}\gamma'_{ec} - \Delta P_{dc}$

  $\Delta P_{dc} = [f(H+H_{ec})/d + K_{en}]W^2/2g$

- Saturation enthalpy increases with pressure. Its value at the point of boiling

  $h' = H_{sat} + dh/dP.\Delta P$

- Drum receives G' water from riser with enthalpy h' and cold make up water G'' with enthalpy h_1.. Water mixture G enters downcomer with enthalpy h_m, So,
- $$h_1 G' + h'(G-G'') = h_m G$$

  $h_m = [(K-1).h' + h_1]/K$

- Heat added to this water for boiling, $\Delta h_{ud} = h' - h_m$

  $= (h' - h_1)/K = Q/G$

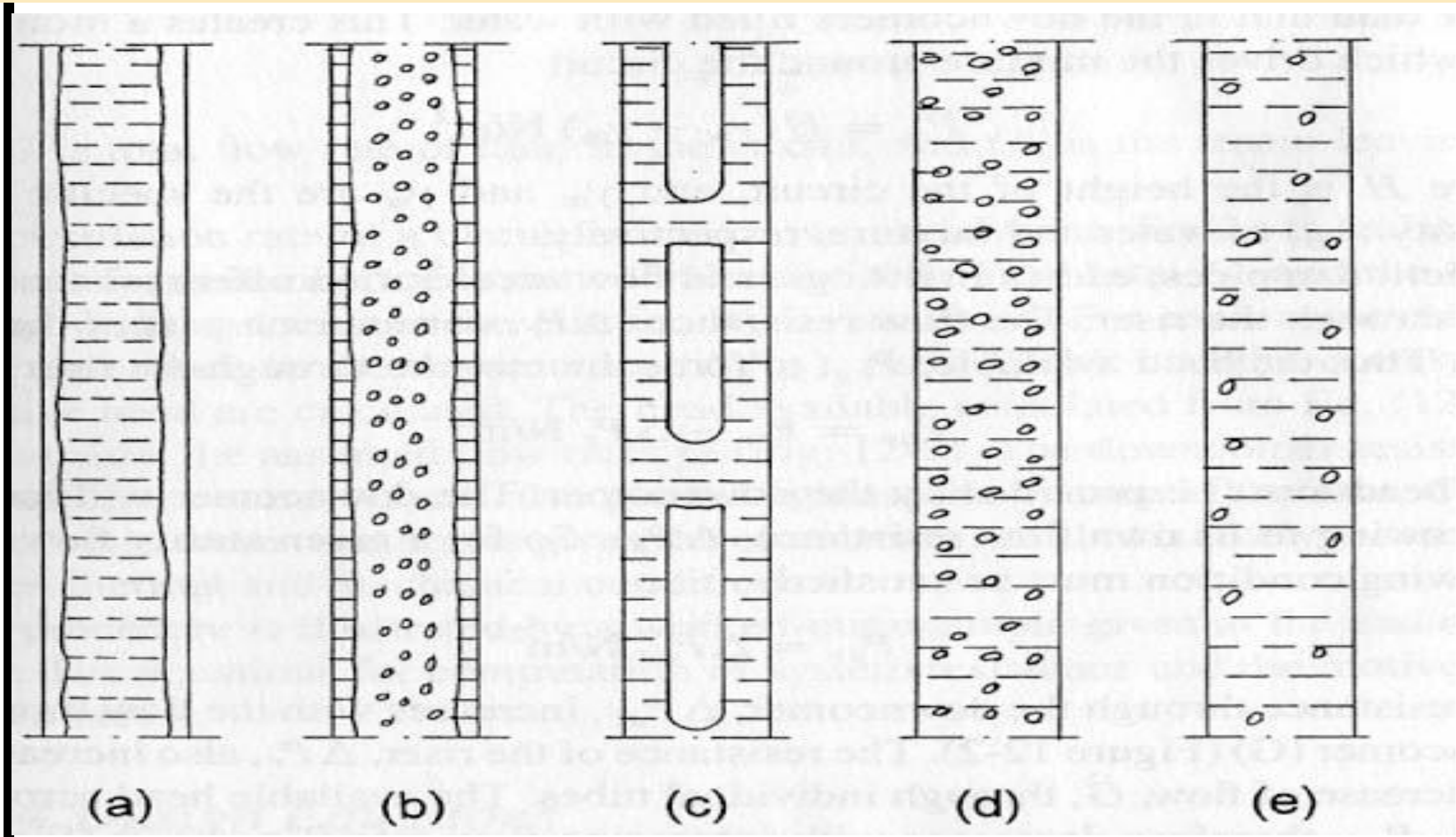
- Where Q is the heat received by the economizer section

  $Q = H_{ec} q$ where q is the heat absorbed per unit height of the section.

PROBLEM

- A furnace wall of a natural circulation boiler (18m long, 76.2 mm OD and 6.1 mm thick) receives saturated water at 80 bar and 1.5 m/s velocity. Assuming a circulation ratio of 12.5 and a slip ratio (velocity of steam/velocity of saturated water) of 1.2 determine:
- a) the pressure head developed across 18m
- b) the heat transfer rate per unit projected area of the riser tube
- c) the void fraction (volume fraction of steam) at riser exit

TYPES OF BOILING IN A TUBE



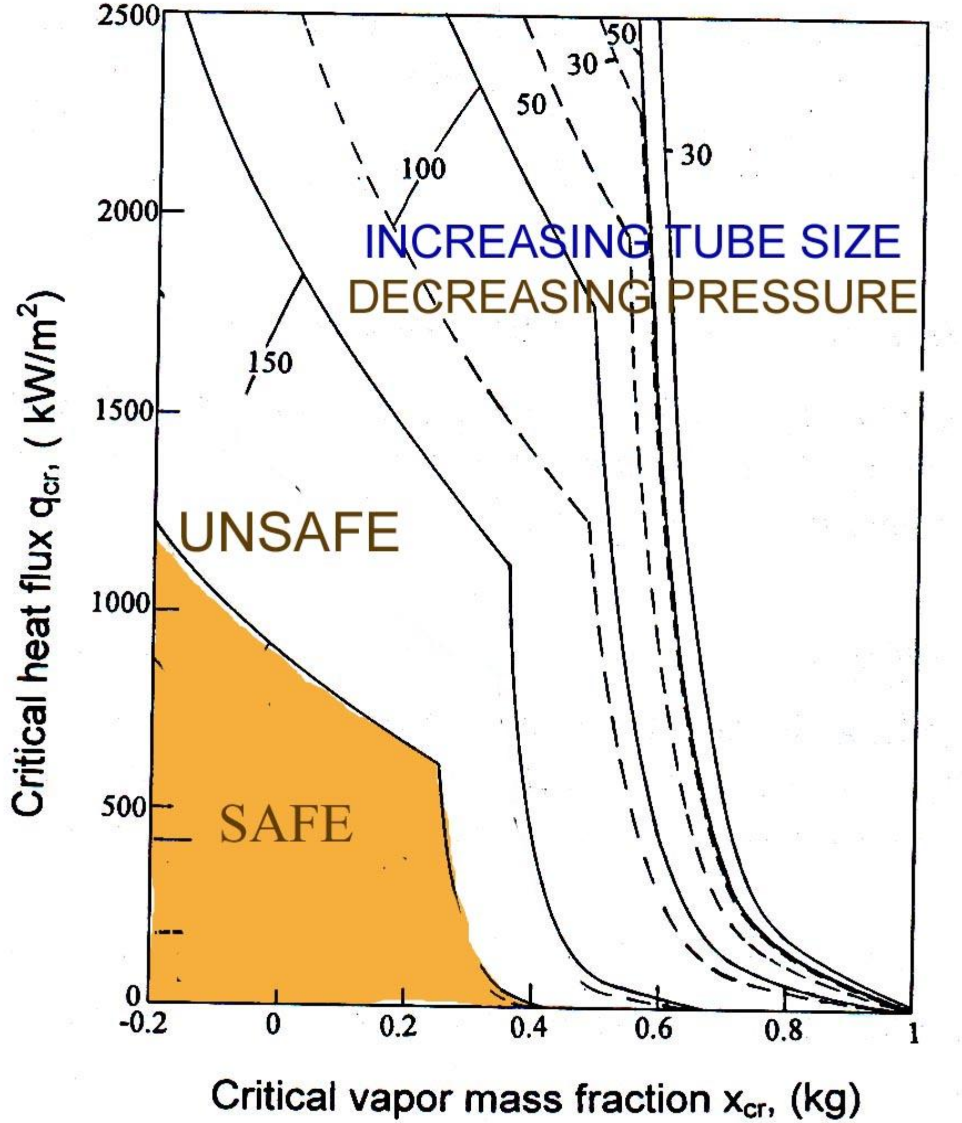
Film SLUG NUCLEATE SUB-COOL

CRITICAL HEAT FLUX (CHF)

- If heat flux on a tube exceeds CHF, film boiling begins sharply raising its metal temperature due to reduced heat transfer
- Tube may burst due to:
  1. Metal temperature rises to where creep life is exceeded
  2. Dissolve solids (NaOH) concentrate on tube inner wall causing caustic attack (Table 14-4)

- CHF depends on
  - Steam fraction is water
  - tube orientation
  - flow condition
  - tube material & inner surface finish

Critical heat flux



Critical heat flux & steam fraction depends on many factors. For example for 4.9 <P < 29.4 bar

Q_{cr}=1.84.10^{9}exp(0.137P)/[x^{8}m$^{2.66}$(1000d)$^{.56}$

X_{cr}=10.79exp(0.017P)/[q$^{.125}$m$^{.333}$(1000d)$^{.07}$]

INCLINED TUBE

- In an inclined tube lighter steam collects near the upper surface and heavier water on the lower wall. Thus upper surface reaches critical condition before the lower surface.
  $X_{upper} = X_{cr} - \Delta X_{cr}$
  $X_{lower} = X_{cr} + \Delta X_{cr}$

$$\Delta x_{cr} = \frac{16}{(2 + Fr')^2},$$

$$Fr' = \frac{x_{cr}.m}{\sqrt{g.d.\rho_s(\rho_l - \rho_s)\cos\theta}}$$