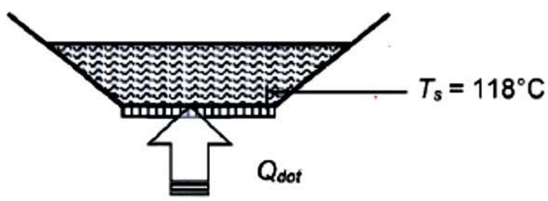
Example

A starving Rose-Hulman student is preparing Ramen Noodles in a copper-bottomed pan bought from Goodwill. The diameter of the bottom of the pan is 0.3-m, and is maintained at 118°C by an electric heating element.

(a) Estimate the power required to boil the water in the pan.
(b) What is the evaporation rate?
(c) Estimate the critical heat flux.
(d) Estimate the number of shrimp used to create one flavor packet for shrimp-flavored Ramen Noodles.



(a) $\Delta T_{EXCESS} = 118°C - 100°C = 18°C$

→ nucleate boiling.

$$\dot{q}_{nuc} = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \left[\frac{c_{p,l}(T_s - T_{sat})}{C_{sf} h_{fg} Pr_l^{n}}\right]^3$$

From surface/liquid combination.

$\mu_l = 0.282 \times 10^{-3}$ kg/m·s

$h_{fg} = 2257 \times 10^3$ J/kg

$g = 9.81$ m/s²

$\rho_l = 957.9$ kg/m³ $\rho_v = 0.5978$ kg/m³ $\sigma = 0.0589$ N/m

$c_{p,l} = 4217$ J/kg°C $Pr_l = 1.75$

$C_{s,f} = 0.0130$ $n = 1$

UNITS ARE $\frac{1}{m}$

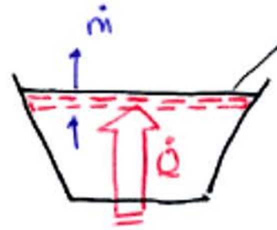
$$\dot{q}_{nuc} = \left(0.282\times10^{-3}\ \frac{kg}{m\cdot s}\right)\left(2257\times10^{3}\ \frac{J}{\cancel{kg}}\right)\left[\frac{9.81\ \frac{\cancel{m}}{\cancel{s^2}}\left(957.9\ \frac{\cancel{kg}}{m^{\cancel{3}2}} - 0.5978\ \frac{kg}{m^3}\right)}{0.0589\ \frac{\cancel{N}}{\cancel{m}}\left\langle\frac{\cancel{kg\cdot m}}{\cancel{N}\ \cancel{s^2}}\right\rangle}\right]^{1/2}$$

$$* \left[\frac{4217\ \frac{\cancel{J}}{\cancel{kg°C}}(18°)\cancel{°C}}{(0.0130)(2257\times10^{3})\ \frac{\cancel{J}}{\cancel{kg}}\cdot 1.75}\right]^3$$

$$= 821{,}000\ \frac{J}{m^2\cdot s} = 821\ kW/m^2$$

$$\dot{Q} = \dot{q}_{nuc}\cdot A = \dot{q}_{nuc}\cdot\frac{\pi D^2}{4} = \ldots = \boxed{58.8\ kW}$$

(b)



MOVING BOUNDARY (DROPS W/ WATER LEVEL)

CONS. of MASS

$$\frac{d}{dt}\underbrace{(m_{cv})}_{0} = \dot{m}_{in} - \dot{m}_{out}$$

NO SIZE

$$\dot{m}_{in} = \dot{m}_{out} = \dot{m}_{evap}$$

CONS. of ENERGY

$$\frac{d}{dt}\underbrace{(E)}_{0} = \dot{Q} + \underbrace{\dot{W}}_{0} + \dot{m}(h_{in} + ..) - \dot{m}(h_{out} + ..)$$

NO SIZE

$$0 = \dot{Q} + \dot{m}_{evap}(h_f) - \dot{m}_{out}(h_g) \qquad \dot{m}_{evap} = \dot{Q}/h_{fg}$$

$$= \frac{58.8\ \cancel{kW}}{2257\ \cancel{kJ}/kg}\left\langle\frac{kJ}{\cancel{kW}\cdot s}\right\rangle$$

$$= \boxed{0.027\ kg/s}$$

(c) CRITICAL HEAT FLUX

$$\dot{q}_{CHF} = C_{cr}\, h_{fg}\left[\sigma g \rho_v^2(\rho_L - \rho_v)\right]^{1/4}$$

BOTTOM of PAN IS A LARGE HORIZONTAL FLAT HEATER. ∴

$$C_{cr} = 0.149$$

$$= 0.149 \cdot 2257\times10^3\ \frac{J}{kg}$$

$$\times\left[0.0589\ \frac{\cancel{N}}{\cancel{m}}\cdot 9.81\ \frac{m}{s^2}\cdot 0.5978^2\ \frac{kg^2}{m^6}\right.$$

$$\left.\cdot(957.9 - 0.5978)\ \frac{kg}{m^3}\cdot\left\langle\frac{kg\cdot m}{\cancel{N}\cdot s^2}\right\rangle\right]^{1/4}$$

$$= 1{,}260{,}970\ \frac{J}{\cancel{kg}}\cdot\left[\frac{kg^4}{m^8 s^4}\right]^{1/4}\left\langle\frac{W\cdot s}{J}\right\rangle = \boxed{1{,}260{,}970\ \frac{W}{m^2}}$$