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$$\boxed{\bar{h} = 0.942\left[\frac{\rho_f(\rho_f-\rho_g)g\cos\theta\, k_f^3\, h'_{fg}}{L\,\mu_f\,\Delta T}\right]}$$

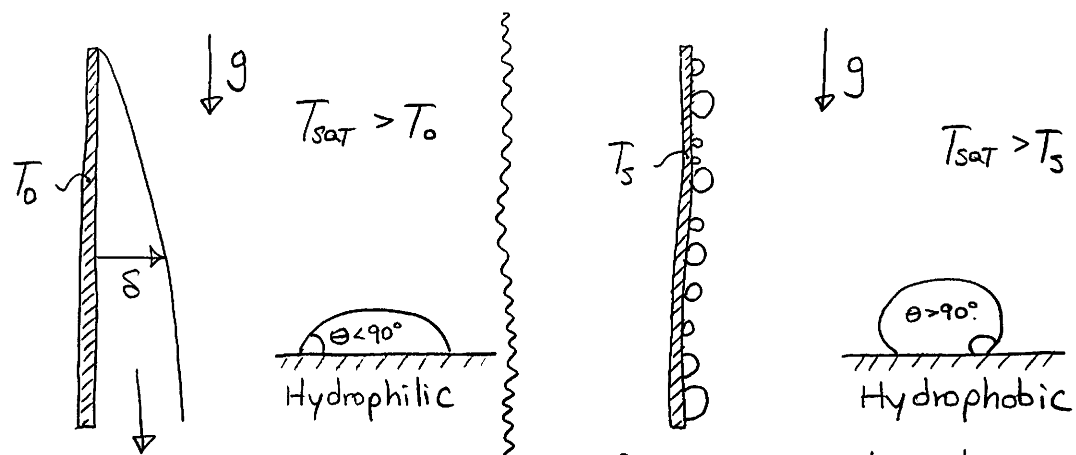
$\Rightarrow$ Average condensation heat transfer coefficient for an inclined plate.

Note, this result is exactly the same as the vertical plate result but with g replaced with $g\cos\theta$.

We can see from this general analysis that we can now solve for more complex shapes such as spheres, cones, etc...

Dropwise Condensation

So far, we have only dealt with filmwise condensation which occurs on surfaces where the developed condensate film wetts the surface. If however the surface is non-wetting discrete droplets will form and grow.



Filmwise Condensation | Dropwise Condensation.

Condensate drainage in dropwise condensation is governed by gravity and droplet coalescence and sliding down the surface. This sliding motion cleans the surface for re-nucleation making this mode of condensation highly advantageous.

	Filmwise	Dropwise
1)	Occurs on wetting substrates; metal oxides, glass, clean substrates	1) Occurs on non-wetting substances; fatty acids, polymers, oils, contaminated surfaces.

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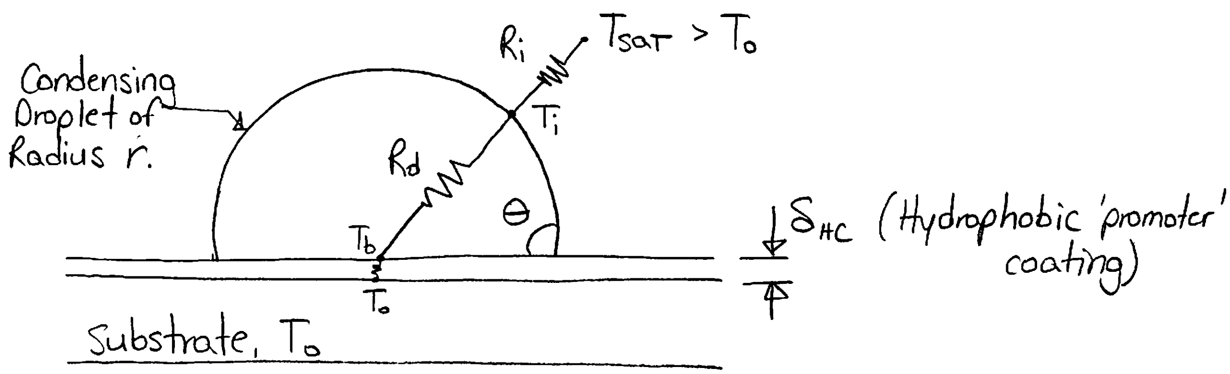
2) Most heat exchangers undergo filmwise condensation	2) Surfaces must be treated with ultra thin coatings of 'promoter' coating to undergo dropwise.
3) Relatively high $\bar{h}$ ($\sim 1000\,W/m^2K$)	3) Ultra high $\bar{h}$ ($\sim 100\,000\,W/m^2K$)
4) Durable	4) Not-robust, coatings degrade overtime
5) Not as sensitive to non-condensable gases.	5) Very sensitive to non-condensables due to rapid accumulation at surface

The Heat Transfer Mechanism (a model)

To model dropwise condensation, we must first understand the individual droplet heat transfer:



We can model the individual droplet heat transfer in terms of a simplified resistance network:

(for h_i, see pg. 721 of Mills)

$$R_i = \frac{1}{h_i A_i} = \frac{1}{h_i \underbrace{2\pi r^2(1-\cos\theta)}_{A_i}}$$

(Convective interfacial resistance, where h_i is the interfacial heat transfer coefficient, A_i is the interface area between liquid & vapor)

$$R_d = \frac{\theta}{4\pi k_f r \sin\theta} \cong \frac{L}{k_f A_d}$$

(Droplet conduction resistance, where A_d = effective droplet conduction area. $R_d \approx$ effective conduction factor).

$$R_{hc} = \frac{\delta_{HC}}{k_{HC} A_{HC}} = \frac{\delta_{HC}}{k_{HC}\,\pi r^2 \sin^2\theta}$$

(Coating conduction thermal resistance, where A_{HC} = area of the droplet base, and k_{HC} = hydrophobic coating thermal conductivity)

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We can now put our thermal resistances together and solve for the individual droplet heat transfer rate, q.

$$q(r,\theta) = \frac{\Delta T}{R_i + R_d + R_{HC}}$$

$$= \frac{\Delta T}{\frac{1}{h_i 2\pi r^2(1-\cos\theta)} + \frac{\theta}{4\pi k_f r \sin\theta} + \frac{\delta_{HC}}{k_{HC}\pi r^2 \sin^2\theta}}$$

$$\boxed{q(r,\theta) = \frac{\pi r^2 \Delta T}{\frac{1}{2h_i(1-\cos\theta)} + \frac{r\theta}{4k_f \sin\theta} + \frac{\delta_{HC}}{k_{HC}\sin^2\theta}}} \quad (1)$$

$\Rightarrow$ Individual Droplet Heat Transfer [W]

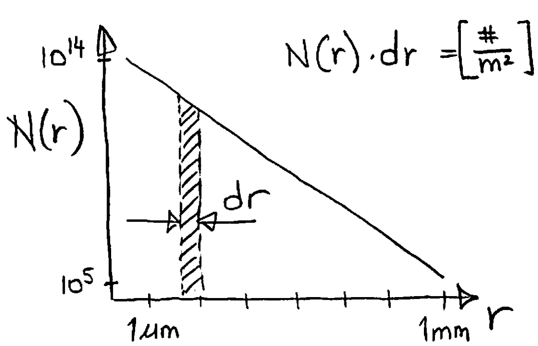
Now we need to know the distribution of droplet sizes on the condensing surface. Assuming θ = constant for all growing droplets, (safe assumption), Rose and LeFevre developed an experimental distribution:

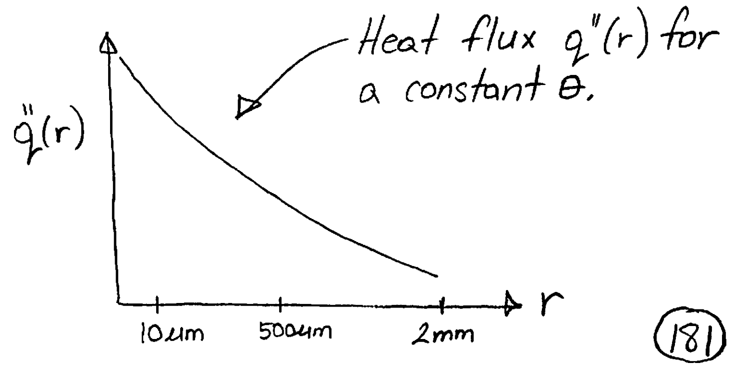
$$\boxed{N(r) = \frac{1}{3\pi r^2 \hat{r}}\left(\frac{r}{\hat{r}}\right)^{-2/3}} \quad (2)$$

; $\hat{r}$ = maximum size of droplet on the surface just before gravity removes it (≈ 1mm). $\hat{r} = f(\theta)$

Note, the units of $N(r)$ are # droplets/m^3. Physically, this distribution represents the number of droplets of radius r in a size range from r to $r+dr$.

Plotting our two results separatelly;





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Putting our equations ① and ② together, we can calculate an overall surface heat flux q''.

$$\boxed{q'' = \int_0^{\hat{r}} q(r,\theta) \cdot N(r)\, dr} \quad ③$$

⇒ Overall surface heat flux for dropwise condensation.

Equation ③ forms the basis for all dropwise condensation models and can predict experimental results very accuratelly (±15%). Many more models exist that have extended the previous model however all have used the same approach.

Equation ③ must be solved numerically, hence it's not as usefull as an analytical result. In general, experiments of steam condensat. show:

$$\boxed{q'' = (T_{sat} - 273.15)^{0.8}\left[5\Delta T + 0.3(\Delta T)^2\right]}$$

⇒ Rose correlation (experimental, see paper online)

↳ T_{sat} is the saturation temperature in Kelvin

$\Delta T = T_{sat} - T_o$

q'' = condensation heat flux in $[kW/m^2]$.

Example | Using the Rose correlation, compare the previous example having filmwise condensation to the $\bar{h}$ with dropwise.

Last example on page 172, we had:

$\Delta T = 10\,°K$

$P_{sat} = 1\,ATM$, $T_{sat} = 100°C = 373.15\,°K$

$\bar{h}_L = 8.68\ kW/m^2 \cdot K$

Now with dropwise condensation:

$$q'' = (373.15 - 273.15)^{0.8}\left[5(10) + 0.3(10)^2\right] = 3.184\ MW/m^2$$

$$\bar{h}_{L,DWC} = \frac{q''}{\Delta T} = 318.5\ kW/m^2 \cdot K$$

⇒ 36.7x enhancement over filmwise!

END OF LECTURE 22