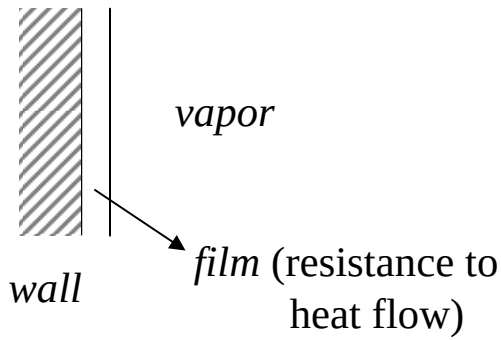
Chapter 13. Heat Transfer to Fluids with Phase Change

Phase change ~ addition or subtraction of heat at constant or nearly constant *T*

→ condensation of vapors & boiling of liquids

(Ex. condensation, evaporation, distillation, drying, crystallization …)

Heat Transfer from Condensing Vapors



Film-type condensation (막상응축):

more common

continuous layer of liquid

Dropwise condensation (적상응축):

begins to form at microscopic nucleation sites

(tiny pits, scratches, dust specks, …)

tube surface – extremely thin film of negligible thermal resistance

→ *h* for dropwise condensation ~ 5 to 10 times *h* for film-type condensation.

* Condensation of steam

Film-type: Both the steam and the metal tube are clean.

Dropwise: unwetted cooling surface & contaminated vapor

↓ drop promoters ~ mercaptans on copper alloy

oleic acid "

unstable & difficult to maintain

(*cf.* steel & aluminum ~ difficult to give drop)

→ For normal design, film-type condensation is assumed.

Ex.) Vertical tubes

$$h_x = \frac{k_f}{\delta}$$ ← condensate film을 통해 conduction으로만 열전달이 일어나는 경우로 가정

↓ local film thickness (usually, 1/100 ~ 1/1,000 of tube diameter)

$$\delta = \left(\frac{3\Gamma \mu_f}{\rho_f{}^2 g \cos\beta} \right)^{1/3}$$ --- Eq. (4.59)

↓ angle from the vertical ($\therefore = 0$)

Γ : condensate loading $(= \dfrac{\dot{m}}{b})$

~ mass rate per unit length of periphery

(b: breadth of the film)

$\therefore$ h_x (of vertical surface)

$$= k_f \left(\frac{{\rho_f}^2 g}{3 \Gamma \mu_f} \right)^{1/3}$$

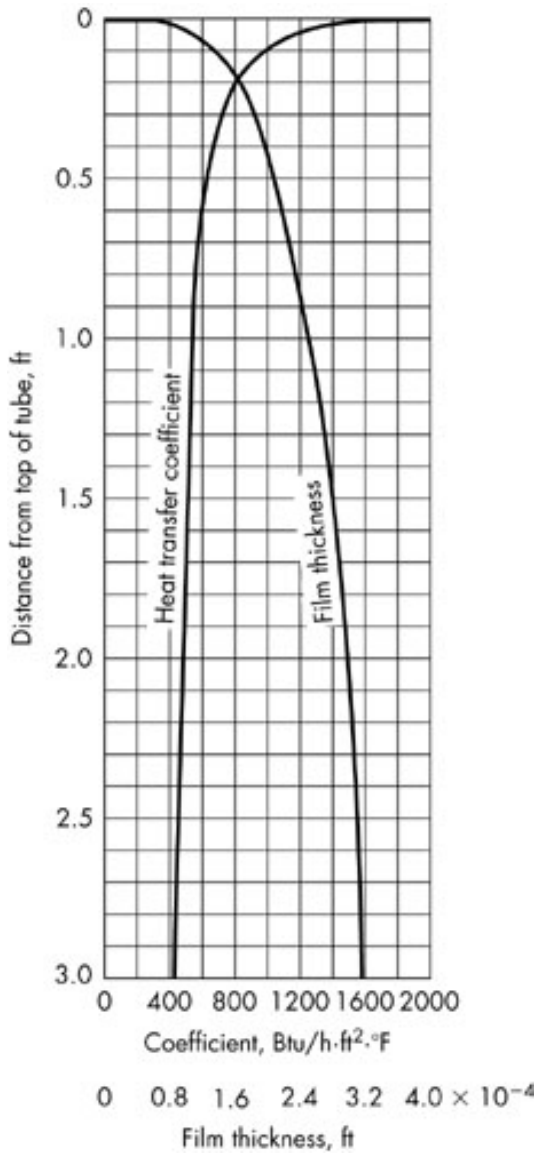
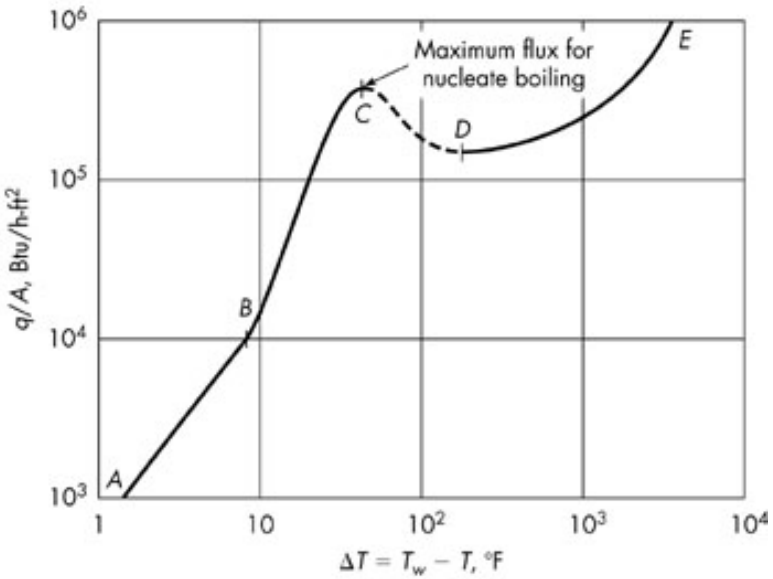


Fig. 13.1. Film thickness & local coefficients for methanol, descending film of condensate.

Heat Transfer to Boiling Liquids

* Pool boiling of saturated liquid

. Horizontal wire immersed in a vessel containing a boiling liquid



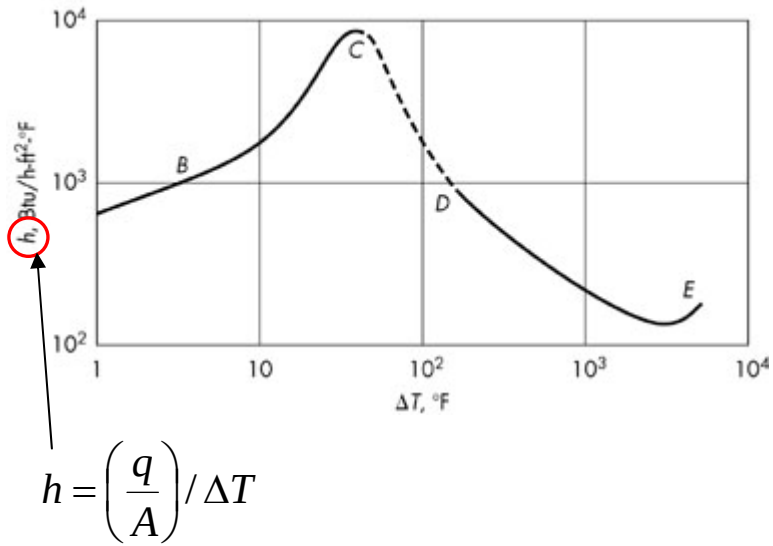


Fig. 13.4. Heat flux vs. temperature drop, boiling water at 212 °F on an electrically heated wire: *AB*, natural convection; *BC*, nucleate boiling; *CD*, transition boiling; *DE*, film boiling (T_w: wire T; T: boiling liquid T).

Fig. 13.5. h vs. ΔT, boiling of water at 1 atm on a horizontal wire. (Fig. 13.4를 변환시킨 그래프)

Four segments (from Figs. 13.4 & 5)

Natural convection (자연대류: **line *AB***): slope of 1.25

$$\therefore \frac{q}{A} = a\Delta T^{1.25}$$ --- Eq. (13.19) ← Eq. (12.72)와 일치

Nucleate boiling (핵비등: **line *BC***): slope of 3 ~ 4

Point *C*: critical temperature drop (임계온도강하)

peak flux를 나타내는 온도

Transition boiling (전이비등: **line *CD***):

Heat flux and *h* both fall as *T* drop is raised.

Point *D*: Leidenfrost point (heat flux가 최소인 점)

Film boiling (막비등: **line *DE***):

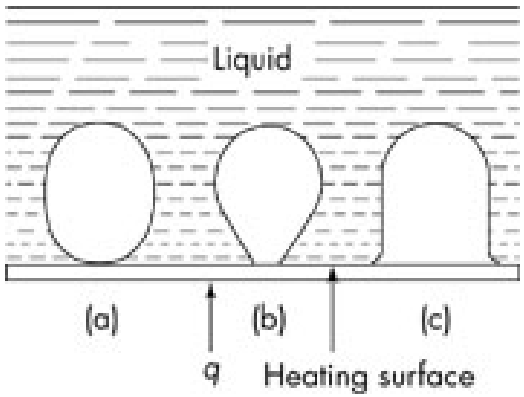
As *T* drop increases, the heat flux rises but *h* falls.

Film boiling is not usually desired because *h* is low for high *T* drop.

Radiation (복사: **beyond point *E***):

Radiation heat transfer becomes important at very high *T* drop.

Effect of bubble formation of interfacial tension



Interfacial tension between liquid & heating surface

(a) Small --- Bubble will pinch off easily.

(b) Intermediate

(c) Large --- Bubble tends to spread along the surface & blanket the heat transfer area.