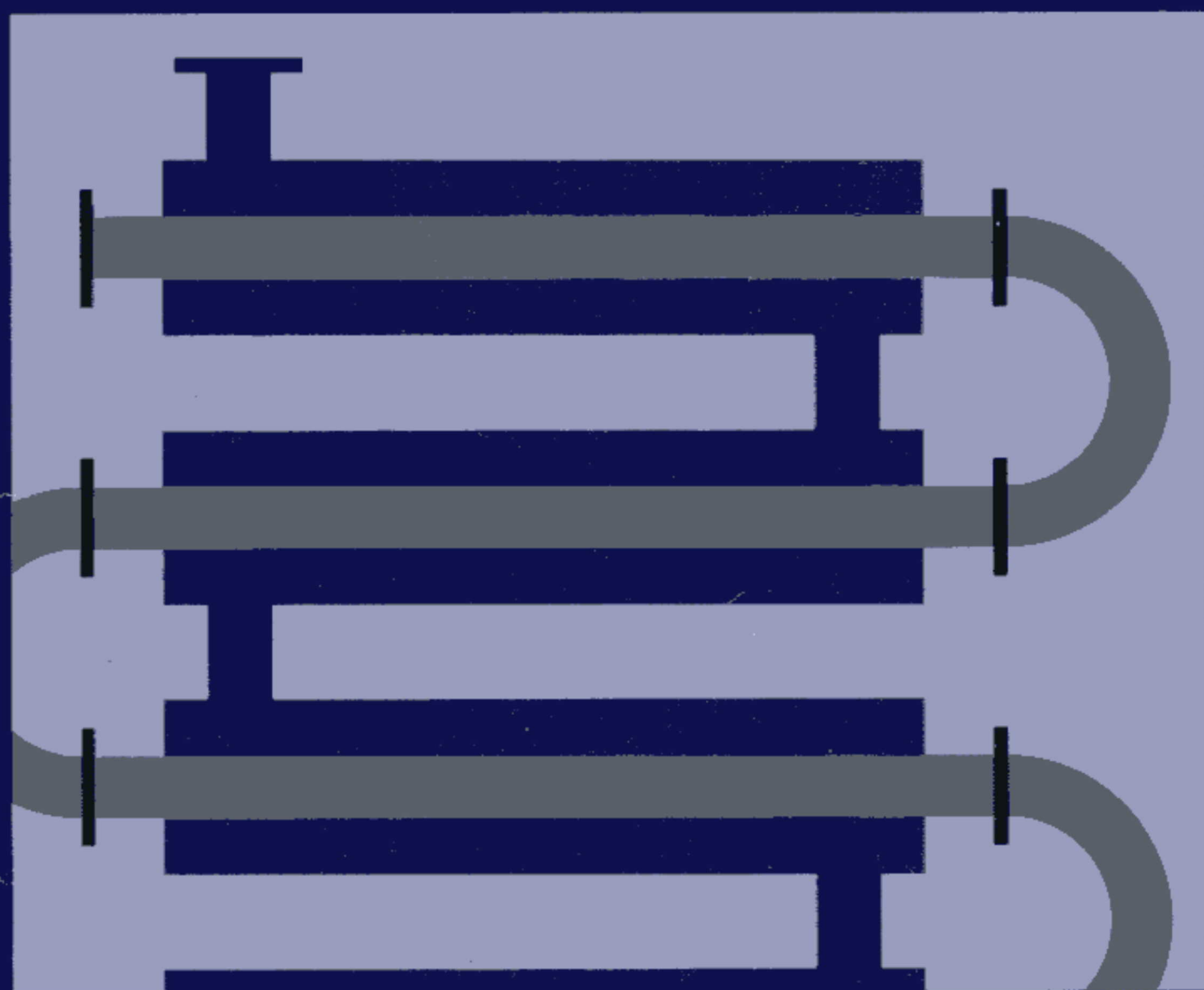
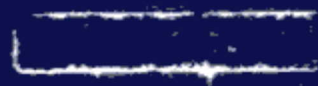


# INTRODUCTION TO HEAT TRANSFER

D Butterworth



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## Notation

Symbol	Designation	Units (SI)	Symbol	Designation	Units (SI)
$A$	Heat-transfer area for small portion of surface	$m^2$	$K_w$	Number of velocity heads lost for flow through window	—
$A_F$	Fin surface area	$m^2$	$L$	Tube length	$m$
$A_T$	Total heat-transfer area in heat exchanger (often referred to tube o.d.)	$m^2$	$N$	Number of tubes in a vertical row	—
$A_o$	Heat-transfer area referred to tube o.d.	$m^2$	$N_c$	Number of rows of tubes crossed	—
$A_{req}$	Heat-transfer area which would be required to achieve the heat load	$m^2$	$N_p$	Number of tube-side passes	—
$C$	Specific heat capacity of fluid	$J/kg\ K$	$N_t$	Number of tubes in a transverse row	—
$C_G$	Gas-phase specific heat capacity	$J/kg\ K$	$Nu$	Nusselt number (see Table 2)	—
$C_L$	Liquid-phase specific heat capacity	$J/kg\ K$	$P$	Channel perimeter; parameter defined by eqn (58)	—
$D_i$	Tube internal diameter (i.d.)	$m$	$Pr$	Prandtl number (see Table 2)	—
$D_1$	Outside diameter of lagging	$m$	$Pr_L$	Prandtl number for the liquid phase	—
$D_o$	Tube external diameter (o.d.)	$m$	$Q$	Heat load in small area $A$ of exchanger surface	$W$
$D_w$	Mean diameter of tube wall given by eqn (40b)	$m$	$Q_T$	Total heat load for exchanger	$W$
$E$	Parameter given by eqn (18)	—	$R$	Parameter defined by eqn (59)	—
$F$	Prandtl number correction factor for natural convection	—	$R_w$	Ratio of tubes in windows to tubes in cross-flow zones	—
$F_B$	Bypass correction factor for heat transfer	—	$Re$	Reynolds number (see Table 2)	—
$F_B'$	Bypass correction factor for pressure drop	—	$Re_L$	Reynolds number of the liquid flow alone; eqn (31)	—
$F_L$	Leakage correction factor for heat transfer	—	$Re_c$	Cross-flow Reynolds number defined by eqn (23)	—
$F_L'$	Leakage correction factor for pressure drop	—	$Re_g$	Cross-flow Reynolds number defined on basis of gaps between tubes; eqn (67)	—
$F_N$	Heat-transfer correction factor for number of rows crossed	—	$S$	Flow area	$m^2$
$F_T$	MTD-value correction factor for non-counter-current flow	—	$S_L$	Total flow area for leakage in one baffle	$m^2$
$F_w$	Heat-transfer correction factor for windows	—	$S_w$	Flow area through baffle window	$m^2$
$F_c$	Convective-boiling correction factor	—	$S_c$	Nucleation suppression factor in Chen (1966) correlation	—
$G$	Mass flow per unit area in uniform channel	$kg/s\ m^2$	$S_m$	Minimum cross-flow area given by eqn (25); for circular bundles it is taken near the equator	$m^2$
$Gr$	Grashof number (see Table 2)	—	$S_{sb}$	Leakage flow area for gap between shell and baffle	$m^2$
$Gz$	Graetz number (see Table 2)	—	$S_{tb}$	Leakage flow area for gaps between tubes and baffle	$m^2$
$H$	Enthalpy, shell-side specific enthalpy	$J/kg$	$T$	Bulk temperature, shell-side bulk temperature	$K$
$H_F$	Fin height	$m$	$T_R$	Reference temperature for enthalpy	$K$
$H_c$	Baffle overlap height or height of cross-flow zone	$m$	$T_{cold}$	Cold-side temperature	$K$
$H_{cut}$	Baffle cutdown height	$m$	$T_{hot}$	Hot-side temperature	$K$
$H_{in}$	Shell-side inlet enthalpy	$J/kg$	$T_{in}$	Shell-side inlet temperature	$K$
$H_{out}$	Shell-side outlet enthalpy	$J/kg$	$T_{out}$	Shell-side outlet temperature	$K$
$H_1, H_2$	Enthalpy shown on Fig. 34	$J/kg$	$T_s$	Saturation temperature	$K$
$J$	Parameter given by eqn (37)	—	$T_w$	Temperature of fluid adjacent to the wall	$K$
$K$	Number of velocity heads lost in headers and/or tube entry	—	$U$	Local overall heat-transfer coefficient	$W/m^2K$
			$\bar{U}$	Average overall heat-transfer coefficient	$W/m^2K$

Symbol	Designation	Units (SI)	Symbol	Designation	Units (SI)
$V_G$	Gas-phase superficial velocity	m/s	$\alpha_F$	Heat-transfer coefficient referred to fin surface area	$W/m^2 K$
$V_L$	Liquid-phase superficial velocity	m/s	$\alpha_{1Z}$	Heat-transfer coefficient given by Forster-Zuber (1955) pool boiling correlation	$W/m^2 K$
$W$	Stream mass flowrate, shell-side mass flowrate	kg/s	$\alpha_1$	Heat-transfer coefficient for cross flow to an ideal tube bank	$W/m^2 K$
$W_G$	Gas mass flowrate	kg/s	$\alpha_N$	Condensing coefficient for $N$ tubes in a vertical row	$W/m^2 K$
$W_L$	Liquid mass flowrate	kg/s	$\alpha_{Nu}$	Condensing coefficient on a horizontal tube as given by the Nusselt (1916) equation	$W/m^2 K$
$X_{tt}$	Two-phase flow parameter defined by eqn (33)	—	$\alpha_w$	Wall heat-transfer coefficient	$W/m^2 K$
$Y$	Tube pitch	m	$\alpha_{con}$	Convective component of boiling heat-transfer coefficient	$W/m^2 K$
$Y_F$	Fin pitch ( $y_F + \delta_F$ )	m	$\alpha_i$	Heat-transfer coefficient inside tube	$W/m^2 K$
$Y_b$	Baffle pitch	m	$\alpha_1$	Heat-transfer coefficient on the outside of lagging	$W/m^2 K$
$Y_l$	Longitudinal pitch (see Figs 4 and 5)	m	$\alpha_{nuc}$	Nucleate component of convective boiling heat-transfer coefficient	$W/m^2 K$
$Y_t$	Transverse pitch (see Figs 4 and 5)	m	$\alpha_o$	Heat-transfer coefficient outside tube	$W/m^2 K$
$Z$	Parameter given by $(\mu_L^2 / \rho_L (\rho_L - \rho_G) g)^{1/3}$	m	$\alpha_1$	Coefficient on one side of a plate	$W/m^2 K$
$a$	Constant in eqn (22) and Table 3	—	$\alpha_2$	Coefficient on the other side of a plate	$W/m^2 K$
$f$	Friction factor for flow in tubes	—	$\beta$	Coefficient of cubical expansion	1/K
$f_c$	Friction factor for flow across tube banks	—	$\Gamma$	Condensation rate per unit perimeter of tube	kg/s m
$g$	Gravitational acceleration	$m/s^2 (9.81)$	$\Gamma'$	Condensation rate per unit length of tube	kg/s m
$h$	Enthalpy of tube-side fluid	J/kg	$\Delta A$	Heat-transfer area calculated for a zone	$m^2$
$h_{in}$	Tube-side inlet enthalpy	J/kg	$\Delta H$	Change in enthalpy of shell-side fluid over a zone	J/kg
$h_{out}$	Tube-side outlet enthalpy	J/kg	$\Delta p$	Pressure drop	Pa
$k$	Thermal conductivity	W/m K	$\Delta p_c$	Pressure drop in cross-flow region of baffle space	Pa
$k_L$	Liquid thermal conductivity	W/m K	$\Delta p_t$	Pressure drop for cross-flow in an ideal bundle	Pa
$k_l$	Lagging thermal conductivity	W/m K	$\delta$	Thickness of equivalent laminar film	m
$k_w$	Wall thermal conductivity	W/m K	$\delta_F$	Fin thickness	m
$l$	Characteristic length in dimensionless groups (see Table 1)	m	$\eta$	Fin effectiveness	—
$m$	Index in eqn (22) given in Table 3	—	$\theta$	Mean temperature difference (MTD)	K
$p$	Pressure	Pa	$\theta_{in}$	Logarithmic mean temperature difference (LMTD)	K
$p_s$	Saturation pressure	Pa	$\theta_{cc}$	Mean temperature difference for counter-current flow	K
$p_w$	Saturation pressure corresponding to wall temperature	Pa	$\lambda$	Latent heat of vaporization	J/kg
$q$	Heat flux	$W/m^2$	$\mu$	Viscosity	$N s/m^2$
$q_{crit}$	Critical heat flux	$W/m^2$	$\mu_G$	Gas-phase viscosity	$N s/m^2$
$r$	Fouling resistance	$K m^2/W$	$\mu_L$	Liquid-phase viscosity	$N s/m^2$
$r_F$	Fouling resistance on fin surface	$K m^2/W$	$\rho$	Density	$kg/m^3$
$r_i$	Fouling resistance inside tubes	$K m^2/W$	$\rho_G$	Gas-phase density	$kg/m^3$
$r_o$	Fouling resistance outside tubes	$K m^2/W$	$\rho_L$	Liquid-phase density	$kg/m^3$
$r_w$	Resistance of tube wall	$K m^2/W$	$\sigma$	Surface tension	N/m
$r_1$	Fouling resistance on one side of a plate	$K m^2/W$	$\omega$	Flow width per transverse pitch (see Fig. 5)	m
$r_2$	Fouling resistance on the other side of a plate	$K m^2/W$			
$t$	Tube-side bulk temperature	K			
$t_{in}$	Tube-side inlet temperature	K			
$t_{out}$	Tube-side outlet temperature	K			
$u$	Fluid mean velocity	m/s			
$u_m$	Cross-flow velocity calculated at the minimum area (for circular tube bundles, calculated at the equator of the bundles)	m/s			
$u_w$	Velocity of fluid through the baffle window	m/s			
$w$	Tube-side stream mass flowrate	kg/s			
$y_F$	Distance between fins	m			
$y_w$	Wall thickness	m			
$\alpha$	Heat-transfer coefficient	$W/m^2 K$			
$\alpha_{DB}$	Heat-transfer coefficient calculated from Dittus-Boelter method	$W/m^2 K$			

