CH EN 3453 – Heat Transfer

External Flow – Tube Banks!

Sections 7.4-7.5

Reminders…

- No school next week. Have fun!
- Homework #6 due today by 5:00 pm
- Homework #7 due Friday Oct. 24
  - Help session Wednesday, Oct. 22 4:30 pm
- Heat exchanger lab day Friday Oct. 24
  - Meet in room MEB 3520 (projects laboratory)
- Bethany teaches Mon and Wed after fall break

Tube Banks

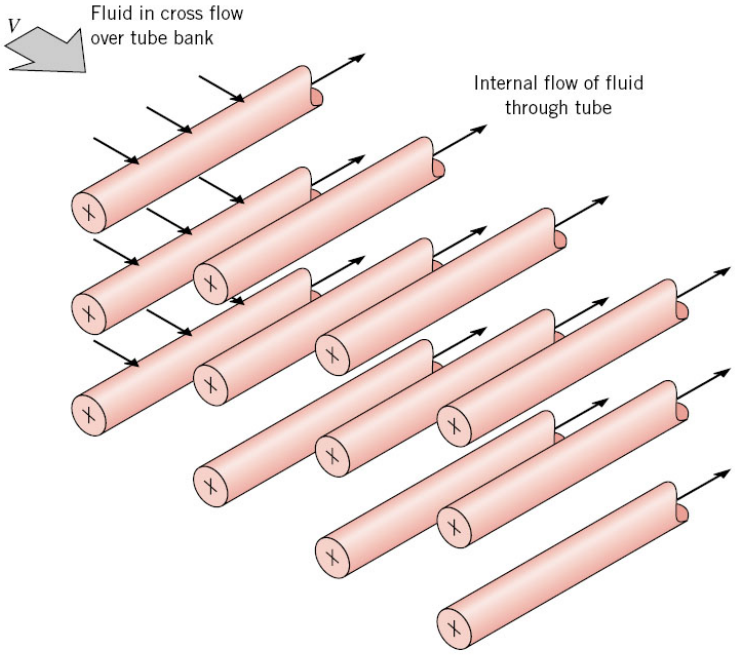


Figure 7.10 Schematic of a tube bank in cross flow.

Tube Bank Geometry

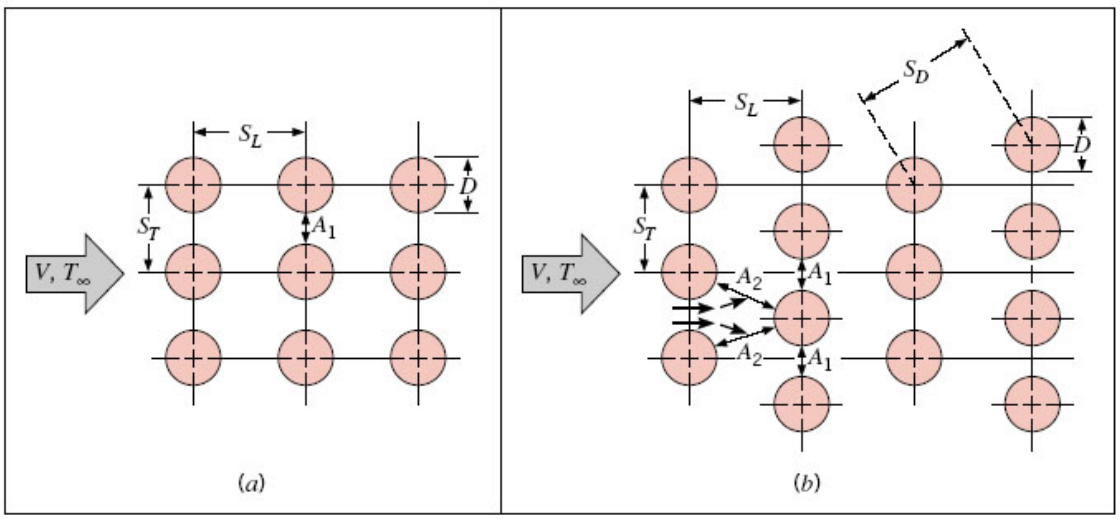


Figure 7.11 Tube arrangements in a bank. (a) Aligned. (b) Staggered.

Tube Bank Calculations

$$\mathrm{Re}_{D,\max} = \frac{\rho V_{\max} D}{\mu} = \frac{V_{\max} D}{\nu}$$

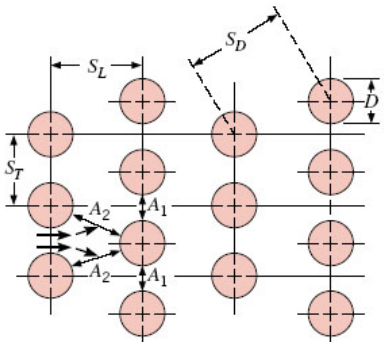
→ V_{max} depends on tube bank geometry…

→ If tubes are aligned or if they're staggered with $2A_2 > A_1$ then

$$V_{\max} = \frac{S_T}{S_T - D} V$$

→ Otherwise, if staggered and $2A_2 < A_1$

$$V_{\max} = \frac{S_T}{2(S_D - D)} V$$



Heat Transfer Correlations for Tube Banks

Zukauskas

$$\overline{\mathrm{Nu}}_D = C\,\mathrm{Re}_{D,\max}^{m}\,\mathrm{Pr}^{0.36}\left(\frac{\mathrm{Pr}}{\mathrm{Pr}_s}\right)^{1/4}$$

(Eq. 7.58)
(7.64 in 6th Ed.)

→ Properties evaluated at arithmetic mean of inlet & outlet temp

→ *C* and *m* from Table 7.5 (Table 7.7 in 6th Ed.)

→ If number of tubes (longitudinal NL) is < 20 use Table 7.6 (7.8 in 6th Ed.)

Table 7.5 Constants of Equation 7.56 for the tube bank in cross flow [15]

Configuration	$Re_{D,max}$	C	m
Aligned	$10–10^2$	0.80	0.40
Staggered	$10–10^2$	0.90	0.40
Aligned	$10^2–10^3$	Approximate as a single (isolated) cylinder	
Staggered	$10^2–10^3$		
Aligned $(S_T/S_L > 0.7)^a$	$10^3–2 \times 10^5$	0.27	0.63
Staggered $(S_T/S_L < 2)$	$10^3–2 \times 10^5$	$0.35(S_T/S_L)^{1/5}$	0.60
Staggered $(S_T/S_L > 2)$	$10^3–2 \times 10^5$	0.40	0.60
Aligned	$2 \times 10^5–2 \times 10^6$	0.021	0.84
Staggered	$2 \times 10^5–2 \times 10^6$	0.022	0.84

[a]For $S_T/S_L < 0.7$, heat transfer is inefficient and aligned tubes should not be used.

Table 7.6 Correction factor C_2 of Equation 7.57 for $N_L < 20$ ($Re_{D,max} \gtrsim 10^3$) [15]

N_L	1	2	3	4	5	7	10	13	16
Aligned	0.70	0.80	0.86	0.90	0.92	0.95	0.97	0.98	0.99
Staggered	0.64	0.76	0.84	0.89	0.92	0.95	0.97	0.98	0.99

Other Correlations for Tube Banks

Grimison (Equation and Table exist only in 6th edition)

$$\overline{\mathrm{Nu}}_D = 1.13 C_1 \mathrm{Re}_{D,\max}^{m} \mathrm{Pr}^{1/3} \qquad \textit{(Eq. 7.60)}$$

→ Properties evaluated at T_{film}

→ C_1 and m determined from Table 7.5 in 6th Edition

→ If number of tubes (longitudinal N_L) is < 10 use Table 7.6 (6th Ed)

TABLE 7.5 Constants of Equations 7.50 and 7.52 for airflow over a tube bank of 10 or more rows [19]

	S_T/D							
	1.25		1.5		2.0		3.0	
S_L/D	C_1	m	C_1	m	C_1	m	C_1	m
Aligned								
1.25	0.348	0.592	0.275	0.608	0.100	0.704	0.0633	0.752
1.50	0.367	0.586	0.250	0.620	0.101	0.702	0.0678	0.744
2.00	0.418	0.570	0.299	0.602	0.229	0.632	0.198	0.648
3.00	0.290	0.601	0.357	0.584	0.374	0.581	0.286	0.608
Staggered								
0.600	—	—	—	—	—	—	0.213	0.636
0.900	—	—	—	—	0.446	0.571	0.401	0.581
1.000	—	—	0.497	0.558	—	—	—	—
1.125	—	—	—	—	0.478	0.565	0.518	0.560
1.250	0.518	0.556	0.505	0.554	0.519	0.556	0.522	0.562
1.500	0.451	0.568	0.460	0.562	0.452	0.568	0.488	0.568
2.000	0.404	0.572	0.416	0.568	0.482	0.556	0.449	0.570
3.000	0.310	0.592	0.356	0.580	0.440	0.562	0.428	0.574

TABLE 7.6 Correction factor C_2 of Equation 7.53 for $N_L < 10$ [20]

N_L	1	2	3	4	5	6	7	8	9
Aligned	0.64	0.80	0.87	0.90	0.92	0.94	0.96	0.98	0.99
Staggered	0.68	0.75	0.83	0.89	0.92	0.95	0.97	0.98	0.99

Example Problem

A tube bank uses an aligned arrangement of 10-mm-diameter tubes with $S_T = S_L = 20$ mm. There are 10 rows of tubes with 50 tubes in each row. Consider an application for which cold water flows through the tubes, maintaining the outer surface temperature at 27°C, while flue gases at 427°C and a velocity of 5 m/s are in cross flow over the tubes. The properties of the flue gas may be approximated as those of atmospheric air at 427°C. What is the total rate of heat transfer per unit length of the tubes in the bank?