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Low-fin staggered tube banks: heat transfer and pressure loss for turbulent single-phase crossflow

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LOW-FIN STAGGERED TUBE BANKS: heat transfer and pressure loss for turbulent single-phase crossflow

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LOW-FIN STAGGERED TUBE BANKS: heat transfer and pressure loss for turbulent single-phase crossflow

1. NOTATION AND UNITS

The notation used is consistent with the ISO standard.

Two sets of self-consistent units are given, the SI and the British.

		<i>Units</i>	
		<i>SI</i>	<i>British</i>
A	total outside tube surface area ($= A_{ft} + A_{rt}$)	m^2	ft^2
A_{ft}	secondary surface area in unit length (see Section 4.6)	m^2/m	ft^2/ft
A_{rt}	primary surface area of tube in unit length at fin root (see Section 4.6)	m^2/m	ft^2/ft
B	parameter defined by Equation (3.2)	m	ft
c_p	specific heat capacity at constant pressure	$J/kg\ K$	$Btu/lb\ ^\circ F$
D_f	diameter of fin tip	m	ft
D_r	diameter of tube at fin root	m	ft
E_f	surface effectiveness (sometimes referred to as "weighted fin efficiency") (see Section 4.6)	—	—
e_f	fin efficiency (see Section 4.6)	—	—
g_c	constant in 2nd law of motion*	— (1.0)	$1bft/h^2\ 1bf$ (4.17×10^8)
h	fin height $= (D_f - D_r)/2$	m	ft
K	pressure loss coefficient per row (= number of velocity heads lost per row)	—	—
L	effective length of tube for heat transfer	m	ft
l	fin density (number of fins in unit length)	$1/m$	$1/ft$
$\dot{M}$	total mass rate of flow	kg/s	$1b/h$
$\dot{m}$	inter-tube mass flux at the minimum flow area $= \dot{M}/\dot{S}_{min}$	$kg/s\ m^2$	$1b/h\ ft^2$

For footnotes, refer to end of Notation section

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N_{rl}	number of tube rows in flow direction	—	—
N_{rt}	number of tube rows transverse to flow	—	—
N_t	total number of tubes	—	—
Nu	Nusselt number, $\alpha_c D_r / \lambda$	—	—
Nu_{ref}	reference Nusselt number as defined in Section 4.1	—	—
Pr	Prandtl number, $c_p \eta / \lambda$	—	—
ΔP	total static pressure loss over tube bank	N/m ² (Pa)	1bf/ft ²
Δp	static pressure loss per tube row	N/m ² (Pa)	1bf/ft ²
$\dot{Q}$	heat transfer rate	W	Btu/h
$\dot{q}$	heat flux from wall to fluid	W/m ²	Btu/h ft ²
Re	Reynolds number = $\dot{m} D_r / \eta$	—	—
S_{min}	minimum cross-sectional area for flow (see Sketches 3.3 and 4.1)	m ²	ft ²
s	mean gap between fins (see Sketch 3.1)	m	ft
s_l	longitudinal pitch of the tubes in flow direction	m	ft
s_t	tube pitch transverse to flow	m	ft
T	temperature	K	°R
T_{LA}	tube layout angle (see Sketch 3.2)	degrees	degrees
ΔT	temperature difference between wall and fluid (= $T_w - T_b$)	K	°F
U	overall heat transfer coefficient based on total outside area	W/m ² K	Btu/h ft ² °F
w	mean thickness of fin (see Sketch 3.1)	m	ft
α_c	coefficient of heat transfer between outer surface of tube and fluid as defined by Equation (4.1)	W/m ² K	Btu/h ft ² °F
α'_c	heat transfer coefficient corrected for surface effectiveness	W/m ² K	Btu/h ft ² °F
λ	thermal conductivity	W/m K	Btu/h °F ft
η	dynamic viscosity	kg/s m	1b/h ft

For footnotes refer to end of Notation

ρ	density of fluid	kg/m ³	1b/ft ³
Φ_1	function as defined in Equation (4.4)	—	—
Φ_2	function as defined in Equation (5.2)	—	—

Subscripts

b	bulk fluid value
c	constant fluid properties
eff	effective value
in	value at inlet
m	mean value
max	value based on minimum flow cross-sectional area between tubes normal to flow direction
out	value at outlet
r	value at root of fin
w	conditions at wall (<i>i.e.</i> fin root)

A bar (—) indicates a mean quantity

* Force = mass $\times$ acceleration/ g_c . In the SI system, the unit of force (N) is such that g_c is unity. In the British system using 1b force and 1b mass, g_c is numerically equal to the acceleration of a free-falling body.

2. PURPOSE, SCOPE AND APPLICABILITY OF THIS DATA ITEM

2.1 Purpose and Scope

One of the ways of increasing the heat transfer per unit length of a circular tube is to increase its outside surface area by roll-forming transverse fins from the tube wall material. This Data Item provides a method and data for evaluating the heat transfer and pressure loss for single phase, turbulent and uniform crossflow of a Newtonian fluid over a bank of low-finned tubes. Methods of calculating heat transfer and pressure loss are given in Sections 4 and 5 respectively. The accuracy of the results obtained using these methods is discussed in Section 8. A worked example illustrating the use of this Item is given in Section 9.

In this Item, the term “low-fin” is used to define fins of limited height which are formed on the tube outside wall, typically by cold rolling. Typical fin heights are from 0.76 mm to 3 mm on tubes of nominal size 12.7 mm to 38 mm, with from 11 to 32 fins per inch (433 to 1260 fins per metre). The ratio D_f/D_r has a range of 1.1 to 1.67 for the data used in the derivation of this Data Item.

Low-fin tubes are available in a variety of metallic materials to suit individual process conditions. Rolling processes give minor rippling on the inside tube surface. Where a conventional shell-and-tube exchanger is being re-tubed with finned tubes, the low-fin tube is often made with the outside diameter of the fins not exceeding the outside diameter of standard plain tubes. In this application, when compared with a plain

tube of the same outside diameter, the inside diameter of the finned tube is reduced. This reduces the inside heat transfer area, considerably increases the tubeside pressure drop and also increases the heat transfer for the same tubeside mass flow rate. Finning may be periodically interrupted or “skipped” along the length of the tube to leave a bare tube surface which is used to give support to the tube at a baffle plate.

The larger surface area to volume ratio of low-finned tubes compared with plain bare tubes can be used advantageously in heat exchangers where the shellside heat transfer coefficient is low relative to the inside heat transfer coefficient (the respective heat transfer coefficients taking fouling resistances into consideration), *i.e.* with gases and viscous liquids such as petroleum oils. Low-fin tubes also have an application where the tubeside velocity has to be held within close limits and the sum of the tube and shellside pressure drop must be minimised, *e.g.* in glycol injection heat exchangers. They may also be of benefit where space and weight are at a premium, *e.g.* offshore oil rigs and nuclear plant.

2.2 Applicability

The data in this Item were derived from experimental data based on:

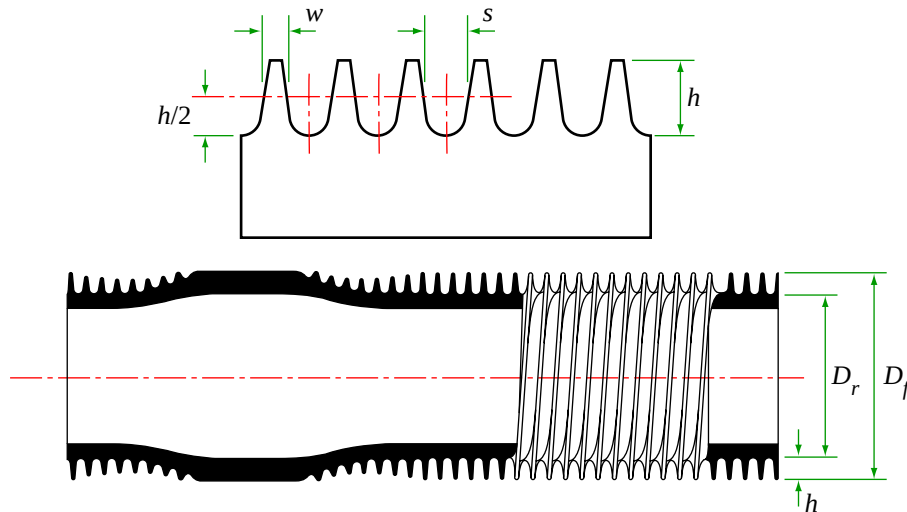
- (i) tube banks with pure crossflow,
- (ii) tube banks with integrally and uniformly finned tubes,
- (iii) tubes of nominal diameter $\frac{1}{2}$ in to $1\frac{1}{4}$ in (12.7 mm to 32 mm),
- (iv) Newtonian single-phase fluids outside the tubes (air and helium),
- (v) heat transfer conditions with negligible thermal radiation and free convection effects,
- (vi) zero heat generation within the heat transfer fluids,
- (vii) $10^3 \leq Re \leq 8 \times 10^5$,
- (viii) tube layout angle (*TLA*) of 30° as shown in Sketch 3.2.

The correlations presented in this Data Item are valid for $1.1 \leq D_f/D_r \leq 1.67$ and $0.8 \text{ mm} \leq (s + w) \leq 2.54 \text{ mm}$ (*i.e.* for the number of fins per inch between 10 and 32) within the accuracy indicated in Section 8. The heat transfer correlation has not been validated for a tube layout angle (*TLA*) of other than 30° nor for in-line tube arrangements due to an absence of data. However, to engineering accuracy, it is believed that the correlation is applicable for a *TLA* of 45° and of 60° and that the procedure of Reference 1 may be used to calculate the Nusselt number for an in-line tube arrangement of low fin tubes (see Section 4.5).

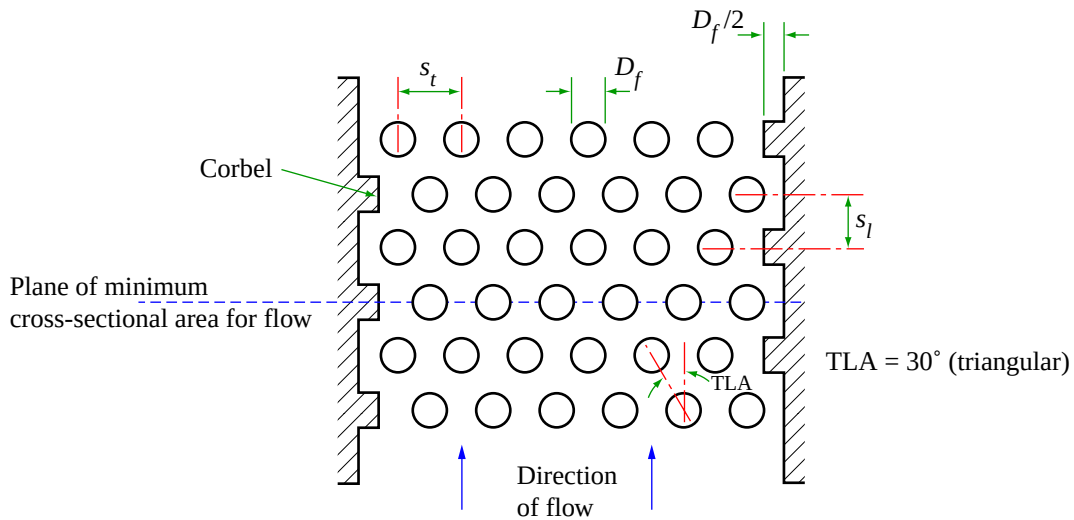
Although the method of this Data Item was derived from data for transverse flow across tube bundles it can also be applied to shell and tube exchangers provided that the external flow is predominantly transverse.

3. INPUT DATA REQUIRED

As a preliminary to evaluating the heat transfer and pressure loss, it is necessary to define or calculate the characteristic flow dimensions. The details of the fin profile can depend on the manufacturer and the tube material. Sketches 3.1 to 3.3 show the characteristic notation applicable to low-fin tubes. Values for the dimensions and production tolerances will usually be given by the tube manufacturer.



Sketch 3.1 Low-fin tube characteristic finning notation



Sketch 3.2 Staggered tube bank characteristic notation