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High-fin staggered tube banks: heat transfer and pressure drop for turbulent single phase gas flow

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HIGH-FIN STAGGERED TUBE BANKS: heat transfer and pressure drop for turbulent single phase gas flow

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HIGH-FIN STAGGERED TUBE BANKS: heat transfer and pressure drop for turbulent single phase gas flow

1. NOTATION AND UNITS

The notation used is consistent with the ISO standard.

Two systems of self-consistent units are given: SI and British.

		SI	British
A	total external surface area of bundle (Equation (3.1))	m ²	ft ²
A_b	total external surface area of bare tubes at fin root diameter (Equation (3.2))	m ²	ft ²
A_{fo}	total secondary external surface area (Equation (3.6))	m ²	ft ²
A_{min}	minimum cross-sectional area for flow through bundle (Equations (3.8) and (3.10))	m ²	ft ²
A_{py}	total primary external surface area (Equation (3.5))	m ²	ft ²
a_{proj}	projected flow area per length between two adjacent tubes in a row (Equation (A1.1))	m ² /m	ft ² /ft
a_{tube}	projected area per length of a single tube (Equation (A1.2))	m ² /m	ft ² /ft
c_p	specific heat capacity at constant pressure	J/kg K	Btu/lb°F
D_f	fin tip diameter	m	ft
D_r	fin root diameter (Sketch 3.1)	m	ft
E_f	total surface effectiveness or weighted fin efficiency (Equation (5.6))	—	—
e_f	fin efficiency (Equation (5.7))	—	—
F_1	heat transfer correction factor for physical property variations	—	—
F_2	heat transfer correction factor for number of tube rows crossed	—	—
F_3	pressure drop correction factor for physical property variations	—	—
F_4	pressure drop correction factor for number of tube rows crossed	—	—
F_f	fin efficiency correction factor	—	—

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g_c	constant of proportionality in Newton's 2nd law of motion	– (1.0)	lb ft/lbf h ² (4.17 × 10 ⁸)
h_f	fin height (Sketch 3.1)	m	ft
K	pressure loss coefficient per row	–	–
K_{is}	isothermal pressure loss coefficient per row	–	–
L	effective length of tube for heat transfer	m	ft
L_f	length of external flow path (Equation (A1.3))	m	ft
m	parameter in expression for fin efficiency defined by Equation (5.8)	m ⁻¹	ft ⁻¹
$\dot{m}$	inter-tube mass flux at minimum flow area	kg/s m ²	lb/h ft ²
N	fin density (number of fins in unit length) = $1/p_f$	m ⁻¹	ft ⁻¹
Nu	effective mean or apparent Nusselt number (Equation (5.4))	–	–
$\overline{Nu}_c$	mean or true convective Nusselt number = $\alpha_c D_r / \lambda$	–	–
n	total number of tubes in a bundle	–	–
n_r	number of tube rows in flow direction	–	–
n_t	effective number of tubes per row to be used for calculating minimum cross-sectional area of flow through bundle in Equations (3.8) and (3.10)	–	–
ΔP	total static pressure loss of a bundle (Equation (6.3))	N/m ² (Pa)	lbf/ft ²
Pr_b	Prandtl number at bulk temperature = $c_p \eta / \lambda$	–	–
p_f	fin pitch (Sketch 3.1)	m	ft
p_l	longitudinal pitch of tubes in flow direction (Sketches 3.2 and 3.3)	m	ft
p_t	tube pitch transverse to flow (Sketches 3.2 and 3.3)	m	ft
Δp	static pressure loss per tube row	N/m ² (Pa)	lbf/ft ²
$\dot{Q}$	heat transfer rate	W	Btu/h
$\dot{q}$	local heat flux = $\frac{\dot{Q}}{A}$	W/m ²	Btu/ft ² h
Re	Reynolds number at bulk temperature = $\dot{m} D_r / \eta$	–	–
s	mean gap between fins (Sketch 3.1)	m	ft

T_b	mean bulk gas temperature	K	°R
T_w	tube wall temperature at fin root	K	°R
t_f	mean fin thickness (Sketch 3.1)	m	ft
V_{free}	free volume of a tube bundle (Equation (A1.6))	m ³	ft ³
V_{tb}	total volume of tubes in a bundle (Equation (A1.4))	m ³	ft ³
V_{tk}	volume of duct containing bundle (Equation (A1.5))	m ³	ft ³
α_c	coefficient of heat transfer between outer surface of tube and fluid as defined by Equation (5.1)	W/m ² K	Btu/ft ² h°F
α'_c	heat transfer coefficient corrected for total surface effectiveness	W/m ² K	Btu/ft ² h°F
γ	ratio of total external surface area to total volume of bundle (Equation (A1.7))	m ⁻¹	ft ⁻¹
ε	ratio of external surface area to external bare surface area at fin root diameter (Equation (3.3))	—	—
η	dynamic viscosity	kg/s m	lb/ft h
λ	thermal conductivity	W/m K	Btu/ft h°F
ξ	fin efficiency correction factor for fins of tapered cross-section (Equation (5.10))	—	—
Π	projected perimeter per length of a single tube (Equation (A1.8))	m/m	ft/ft
ρ	fluid density	kg/m ³	lb/ft ³
σ	ratio of minimum bundle free flow area to total frontal area (Equation (3.4))	—	—
Φ_1, Φ_2	functions	—	—
φ	corrected fin height (Equation (5.9))	m	ft

Subscripts

b	fluid value at mean bulk temperature
f	fin
i	value at inlet
m	mean value
o	value at outlet

2. INTRODUCTION

2.1 Purpose and Scope

When a gas flows across a tube bundle the heat transfer per unit length may be increased significantly by attaching fins to the outside of the tubes. This Data Item presents methods for calculating heat transfer and pressure drop for uniform turbulent crossflow of a gas over a bank of annular or helically wound high fin tubes. Calculation methods for heat transfer and pressure drop are given in Sections 5.2 and 6.2 whilst their accuracy is discussed in Section 10.

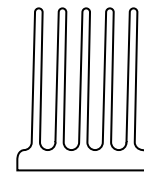
The advantages of high fin extended surfaces are greatest where the outside heat transfer coefficient is low compared with the inside combined film and fouling coefficient. This is typically the case with air-cooled heat exchangers and dry cooling towers and is frequently so in heat recovery situations.

High fin tubes typically have fin heights in the range 0.25 in (6 mm) to 0.625 in (16 mm) whilst the base tubes are between 0.375 in (10 mm) and 2 in (51 mm) nominal outside diameter, the ratio of fin tip to fin root diameters being in the range 1.2 to 2.4. For certain high temperature heat recovery applications fin heights up to 1.25 in (32 mm) on larger diameter tubes may be used. Fin densities are in the range 4-11 fins per inch (157-433 fins per metre), equivalent to fin pitches of 0.25 in to 0.091 in (6.4 mm to 2.3 mm).

Types of fin and methods of attachment to the base tube are many. In this Item plain, circular fins of rectangular or tapered cross-section on round tubes are considered. Methods of fin attachment include the following.

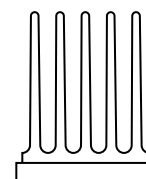
i) Integral Construction.

The fins are formed on the outside of the tube wall, typically by a rolling process for non-ferrous materials or by machining in the case of steels used in high temperature heat recovery applications.



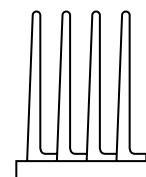
ii) Integral Bimetallic or Muff Fin.

This is a duplex construction. The fins are formed as for integral construction out of an appropriate material, frequently aluminium, in the form of an outer sleeve tube positioned over a base tube, typically carbon steel. The rolling process not only forms the fins but also ensures effective thermal contact between the sleeve and base tube.

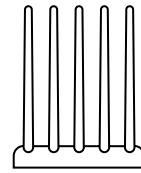
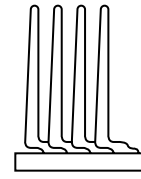


iii) Tension Wound L-Footed Fins.

The fin material, frequently aluminium, is preformed into an L-shape and wound under tension on to the base tube, the fin material being firmly secured at both ends of the tube. Correct tensioning of the fin material during manufacture ensures effective thermal contact between the fins and the base tube.



- iv) **Tension Wound Overlapped L-footed Fins.**
This construction is a development of the simple tension wound L-footed fins and is designed to provide greater protection to the base tube in externally corrosive environments. Additionally the outside surface of the bare tube may be knurled prior to winding the fin material. The underside of the L-foot is knurled as a result of the finning process and thermal contact at the fin root is enhanced.
- v) **Embedded, Grooved or G-Fins.**
The fin material is fed under tension into a preformed groove in the tube. The material ploughed out in forming the groove is peened back against the sides of the fin material to provide secure attachment.
- vi) **Welded Construction.**
Welded attachment is a common form of construction in high temperature heat recovery applications.



The methods of this Data Item are not applicable to serrated, crimped, wire, slotted, stud or plate fins and are confined to tubes of circular cross-section.

2.2 Range of Data

The data upon which this Item is based apply to the following conditions:

- (i) tube banks in pure crossflow,
- (ii) single phase gas flow outside the tubes,
- (iii) heat transfer with negligible thermal radiation and zero heat generation within the fluid,
- (iv) forced-convective flow with negligible free convection effects,
- (v) staggered tube layout,
- (vi) tube banks with constant fin density from row to row,
- (vii) $2000 < Re < 50\,000$,
- (viii) bare tube nominal diameter 3/8 in to 2 in (9.5 mm to 51 mm),
- (ix) fin density 4 to 11.1 fins per in (157 to 437 fins per m),
- (x) fin height 0.22 in to 0.65 in (5.6 mm to 16.5 mm),
- (xi) ratio of fin tip diameter to fin root diameter from 1.4 to 2.4.

3. INPUT DATA REQUIREMENTS

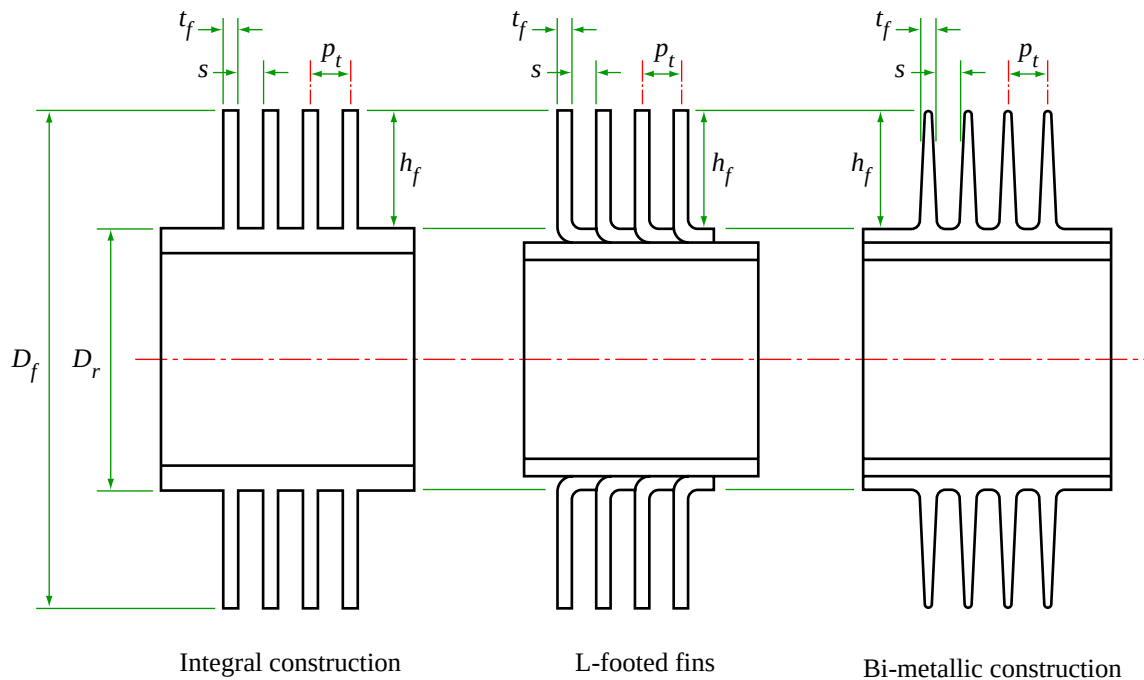
3.1 Characteristic Tube and Bundle Dimensions

The outside geometry of a fin tube bundle is defined by eight dimensions illustrated in Sketches 3.1, 3.2 and 3.3. These dimensions are as follows:

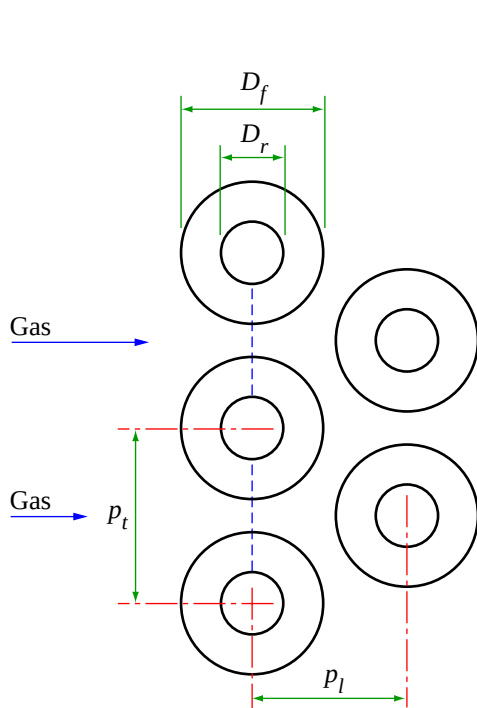
D_f	fin tip diameter
D_r	fin root diameter
N or p_f	fin density or fin pitch
n	total number of tubes in bundle
n_r	number of tube rows in flow direction
p_l	tube pitch in direction of flow, see Sketches 3.2 and 3.3
p_t	tube pitch transverse to direction of flow, see Sketches 3.2 and 3.3
t_f	mean fin thickness (for tapered profile fins the thicknesses at the fin tip and root, t_{f1} and t_{f2} respectively, may be required in order to establish t_f).

Related dimensions which can be defined in terms of these quantities are

h_f	fin height = $\frac{1}{2}(D_f - D_r)$
s	mean gap between fins $1/N - t_f = p_f = t_f$.

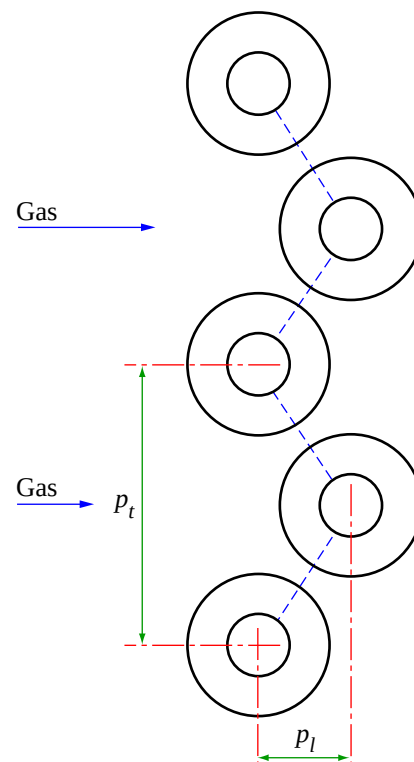


Sketch 3.1 High-fin tube dimensions



**Sketch 3.2 Tube bundle dimensions.
Minimum flow area in plane transverse to
flow direction**

$$\frac{p_l}{D_r} > \frac{1}{2} \sqrt{\frac{2p_t}{D_r} + 1}$$



**Sketch 3.3 Tube bundle dimensions.
Minimum flow area along diagonals between
adjacent tube rows**

$$\frac{p_l}{D_r} < \frac{1}{2} \sqrt{\frac{2p_t}{D_r} + 1}$$