



Heat transfer coefficients for water or steam in plain circular tubes: fully-developed turbulent flow

Endorsed by
The Institution of Chemical Engineers
The Institution of Mechanical Engineers

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Item was monitored and guided by the Heat Transfer Steering Group which first met in 1966 and now has the following membership:

Chairman	
Dr G.F. Hewitt	— HTFS, Atomic Energy Authority, Harwell
Vice-Chairman	
Prof. V. Walker	— Bradford University
Members	
Dr T.R. Bott	— Birmingham University
Mr T.D. Hazell	— Foster Wheeler Energy Ltd
Mr J.A. Hitchcock	— Central Electricity Research Laboratories
Prof. R.H. Sabersky*	— California Institute of Technology, USA
Mr E.A.D. Saunders	— Whessoe Ltd
Mr R.A. Smith	— Independent
Mr M.A. Taylor	— B.N.O.C. (Developments) Ltd
Mr G.H. Walter	— Imperial Chemical Industries Ltd
Mr N.G. Worley	— Babcock Power Ltd.

* Corresponding Member

The Steering Group has benefited from the participation of members from several engineering disciplines. Dr G.F. Hewitt has been appointed to represent the interests of chemical engineering as the nominee of the Institution of Chemical Engineers.

The work on this Item was carried out in the Heat Transfer Group of ESDU under the supervision of Mr N. Thompson, Group Head. The member of staff who undertook the construction and development of the Item was Mrs A.M. (D'Souza) Wye, Senior Engineer. For this particular Item the charts and tables presented were computer-generated by Babcock Power Ltd; this work was undertaken by Miss B.M. Markwick (Management Services Department) and was sponsored by ESDU.

(Continued on inside back cover)

HEAT TRANSFER COEFFICIENTS FOR WATER OR STEAM IN PLAIN CIRCULAR TUBES: fully-developed turbulent flow

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. PURPOSE AND APPLICABILITY OF THIS DATA ITEM	2
2.1 Applicability	2
3. BASIS OF THE DATA	3
4. CALCULATION PROCEDURE FOR THE ESTIMATION OF HEAT TRANSFER COEFFICIENT	4
4.1 Data for Steam	4
4.2 Data for Water	4
5. DERIVATION	5
6. TABLES OF ϕ	6
FIGURES 1-3	9 to 12

ESDU Copyright material. For current status contact ESDU.

HEAT TRANSFER COEFFICIENTS FOR WATER OR STEAM IN PLAIN CIRCULAR TUBES: fully-developed turbulent flow

1. NOTATION AND UNITS

		<i>SI Unit</i>
A	cross-sectional area for flow	m^2
c_p	specific heat capacity at constant pressure	$\text{J}/(\text{kg K})$
D	inside diameter of tube	m
f_D	correction factor for effect of tube diameter for water flow	
f_T	correction factor for variable fluid properties (see Section 2.1)	
H	enthalpy	kJ/kg
L	tube length	m
$\dot{M}$	mass flow	kg/s
$\dot{m}$	mass flux, $= \rho \bar{u} = \dot{M}/A$	$\text{kg}/(\text{m}^2 \text{ s})$
$\overline{Nu}$	mean Nusselt number, $\bar{\alpha}D/\lambda_b$	
p	pressure*	bar
Pr_b	Prandtl number $(c_p \mu / \lambda)_b$	
$\dot{q}$	heat flux	W/m^2
Re_b	Reynolds number, $\dot{m}D/\mu_b$	
T_b	fluid bulk temperature	K
T_w	tube wall temperature	K
$\bar{u}$	mean fluid velocity	m/s
$\bar{\alpha}$	mean heat transfer coefficient	$\text{W}/(\text{m}^2 \text{ K})$
λ	thermal conductivity	$\text{W}/(\text{m}^2 \text{ K})$
μ	dynamic viscosity	$\text{N s}/\text{m}^2$ (i.e. (kg/s m))
ρ	density	kg/m^3

Issued November 1981

ϕ physical property group, see Equation (3.3) $\text{K s}^{2.205} / (\text{kg}^{0.205} \text{ m}^{1.795})$

Subscripts

b evaluated at fluid bulk temperature, T_b

* $1 \text{ bar} = 1 \times 10^5 \text{ Pa} \equiv 1 \times 10^5 \text{ N/m}^2$.

2. PURPOSE AND APPLICABILITY OF THIS DATA ITEM

In many design processes involving single-phase heat transfer, the working fluid is water or steam. The purpose of this Data Item is to provide, directly, heat transfer coefficient data specifically for the fully-developed turbulent flow of water or steam in plain circular tubes. It is based on data presented in Item No. 67016¹ in the form of Equation (3.1) together with the appropriate physical property data for water substance.

The data in this Item are presented in an easy-to-use form of charts and tables in which the variation of the physical properties of water substance with temperature and pressure have already been taken into account. The heat transfer coefficient for the fully-developed turbulent flow of water and steam can be expressed as (see Section 3)

$$\frac{1}{\alpha} = \dot{m}^{-0.795} D^{0.205} \phi / f_T \quad (2.1)$$

where ϕ is a group of physical property terms defined by Equation (3.3) and f_T is a correction factor to account for the radial variation of fluid properties (see Section 2.1). The quantity ϕ is given by Figure 1 as a function of temperature and pressure, and in Figure 2 as a function of enthalpy and pressure. The use of Figure 2 is preferred when heat balances have to be calculated. The basis for Figures 1 and 2 is described in Section 3.

A particular application of the data is to cooling-water, for example in process heat exchangers. For this situation the heat transfer coefficient is presented directly in Figure 3 as a function of temperature, water velocity and tube diameter.

A summary of the general calculation procedures for steam and water flow is given in Section 4.

2.1 Applicability

The data presented in this Item are applicable for fully-developed turbulent flow in plain circular tubes of

- (i) water and steam on the saturation line for temperatures between 0°C and about 320°C and pressures between 0.01 and 100 bar.
- (ii) water or steam for non-saturation conditions for temperatures between 0°C and 800°C and pressures between 0.01 and 100 bar.

For bulk to wall temperature differences of less than 30°C, the factor f_T in Equation (2.1), accounting for the effect of radial variations in fluid properties, is approximately unity. For larger temperature differences the relevant value of f_T (taken from Item No. 68007²) must be used. Figure 3c provides values of f_T applying to water at pressures between 0.01 to 10 bar. For heating of steam, $T_w/T_b > 1$, where T_w and T_b are in Kelvin,

$$f_T = (T_w/T_b)^{0.18}, \quad (2.2)$$

and for cooling of steam, $T_w/T_b < 1$,

$$f_T = 1. \quad (2.3)$$

3. BASIS OF THE DATA

From Item No. 67016¹ the mean Nusselt number (assuming constant fluid properties) for the fully-developed turbulent flow of a single-phase fluid in a plain tube is given by

$$\overline{Nu} = \exp[-3.796 + 0.795 \log_e Re + 0.495 \log_e Pr - 0.0225 (\log_e Pr)^2] \quad (3.1)$$

where $\overline{Nu}$, Re and Pr are based on fluid properties evaluated at the bulk fluid temperature, T_b . Background information concerning the derivation and uncertainty of this equation is given in Item No. 67016¹.

Equation (3.1) can be expressed in the alternative form

$$\frac{1}{\alpha} = \dot{m}^{-0.795} D^{0.205} \phi \quad (3.2)$$

where the physical property group factor ϕ is given by

$$\phi = 44.52 \frac{\mu^{0.3}}{\lambda^{0.505} c_p^{0.495}} Pr^{0.0225 \ln Pr}. \quad (3.3)$$

For the specific case of water or steam flow the appropriate physical property values taken from Derivations 3, 5, 6 and 7 can be used to estimate ϕ for a wide range of temperatures and pressures. The physical property data taken from the same Derivation conform to the values given by the 1968-IFC Formulation and form the basis for the data presented in Figures 1 and 2 and the tables in Section 6. The tables and Figures 1 and 2 have been generated using computer programs developed by Babcock Power Limited (Derivation 9).

Other Equations^{4, 8} describing heat transfer to steam are generally based on the use of dimensionless groups using fluid properties evaluated at the mean film temperature, $(T_w + T_b)/2$. From the values of $\overline{Nu}$ obtained using such equations, for a given heat flux, the bulk fluid and wall temperatures are calculated by iteration. Equation (3.2) is based on the use of dimensionless groups with fluid properties evaluated at the bulk fluid temperature, T_b . This is generally a sufficiently accurate representation of the heat transfer process and avoids the need for iterative calculations.