



Condensation inside tubes: computer program for pressure drop in straight tubes (horizontal and vertical with downflow)

Associated software: ESDUpac A9314

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 The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants.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 Data Item was monitored and guided by the Heat Transfer Steering Group Committee. This Committee first met in 1966 and now has the following membership:

Chairman		
Eur. Ing. D. Butterworth	—	HTFS, Atomic Energy Authority, Harwell
Vice-Chairman		
Dr R. Cheesewright	—	Brunel University
Members		
Mr R.J. Allam	—	Air Products Ltd
Dr T.R. Bott	—	Birmingham University
Prof. P.J. Heggs	—	Bradford University
Eur. Ing. T.J. Loraine	—	Toshiba International (Europe) Ltd
Dr A. C. Pauls*	—	Monsanto Company, USA
Prof. R.H. Sabersky*	—	California Institute of Technology, USA
Mr E.A.D. Saunders	—	Independent
Dr J. Taborek*	—	Independent
Eur. Ing. M.A. Taylor	—	Independent
Mr G.H. Walter	—	Independent
Dr D. Wilkie	—	Independent
Eur. Ing. D.A. Winkworth	—	Foster Wheeler Energy Ltd.

* Corresponding Member

The preparation of the computer program and the construction and subsequent development of the Data Item was undertaken by

Mr S.J. Garvey — Engineer.

The person with overall responsibility for the work in this subject area is Mr S.J. Pugh, Head of Process Engineering Technology.

CONDENSATION INSIDE TUBES: computer program for pressure drop in straight tubes (horizontal and vertical with downflow)

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	3
3. RUNNING THE PROGRAM	3
4. METHODS OF PREDICTING THE RELATIONSHIP BETWEEN ρ_g , T_{sat} AND p	4
4.1 Methods of Predicting the Relationship between T_{sat} and p	4
4.1.1 The Antoine equation	4
4.1.2 The Wagner equation	4
4.1.3 Tabulated Data	4
4.2 Methods of Predicting the Relationship between ρ_g and T_{sat}	5
4.2.1 The Ideal Gas Law	5
4.2.2 ESDU recommended equation	5
4.2.3 Tabulated data	5
5. DESCRIPTION OF INPUT AND OUTPUT DATA	6
5.1 Input Description	6
5.2 Example Data Input Files	9
5.3 Program Output	11
5.4 Sample Output	11
6. DERIVATION	17

CONDENSATION INSIDE TUBES: computer program for pressure drop in straight tubes (horizontal and vertical with downflow)

1. NOTATION AND UNITS

		Units
		SI
a_{1-4}	constants in Wagner equation, Equation (4.2)	—
A	constant in Antoine equation, Equation (4.1)	—
b_{1-5}	constants in Equation (4.4)	—
B	constant in Antoine equation, Equation (4.1)	—
C	constant in Antoine equation, Equation (4.1)	—
D	internal diameter of tube	m
L	total cooled length of tube before condensing begins	m
L_1	cooled length of tube before condensing begins	m
L_d	downstream uncooled length of tube	m
L_u	upstream uncooled length of tube	m
$\dot{M}$	total mass flow rate inside tubes	kg/s
N_T	number of tubes in parallel	—
p	static pressure	N/m ² *
T	temperature	K
x_g	quality (dryness fraction)	—
z	distance along the tube from inlet	m
Δh_v	latent heat of vaporisation	J/kg
ε	surface roughness	m
η	dynamic viscosity of fluid	kg/s m
ρ	density of fluid	kg/m ³
σ	surface tension	N/m

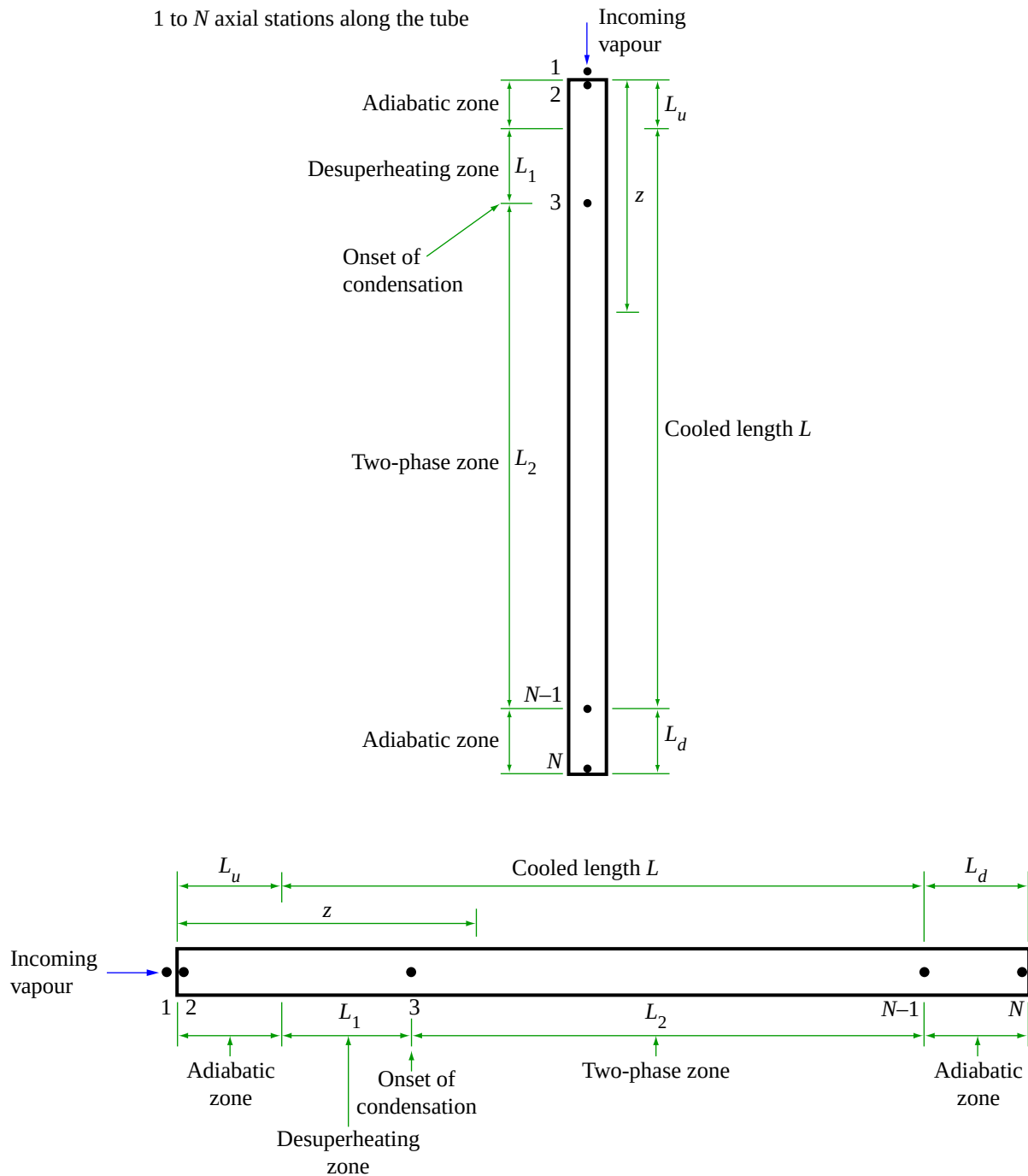
Subscripts

c	critical
g	vapour

l liquid

sat under saturated conditions

* It is recommended elsewhere that physical property data be obtained from the Physical Data, Chemical Engineering series. For consistency with this series the units kPa are also used. In all cases of pressure quantities it is clearly stated which units are to be used.



2. INTRODUCTION

This Data Item is one of a group on the condensation of single component vapours inside straight tubes of circular cross-section. It provides guidance of the use of a computer program, ESDUpac A9314, which calculates the pressure drop of condensing vapours inside horizontal tubes and inside vertical tubes with downflow. The methods on which the program is based are fully described in ESDU 91023¹ (for horizontal flow) and ESDU 90024² (for vertical downflow).

Part of the data required is the relationship between saturation temperature and vapour pressure and between the saturation temperature and vapour density. The program has several options for specifying these relationships and Section 4 describes these in detail.

Section 5 describes the required input data and the output. A number of examples which illustrate the use of the program are presented.

3. RUNNING THE PROGRAM

On selecting ESDUpac A9314 from the menu of available programs within ESDUview, the user is prompted for all the input data. Guidance is provided on all the variables and on all the features of ESDUview in the context-sensitive help facility. At various points throughout the operation checks are carried out on the entered data. Error messages alert the user to incorrect numerical values and guide in their correction; other potential problems are highlighted by warning messages.

The user may find in Section 5 additional useful guidance (complementary to that in the ESDUview help facility) on the program variables and model details.

4. METHODS OF PREDICTING THE RELATIONSHIP BETWEEN ρ_g , T_{sat} AND p

Numerical values of the vapour density of a single component fluid are usually provided as a function of saturation temperature. A knowledge of the relationship between pressure and saturation temperature is therefore required to calculate the vapour density at points along the tube. The program requires the user to select one of three methods to model the relationship between T_{sat} and p for a pure component. These methods are the Antoine* equation, the Wagner* equation or an interpolation method using tabulated data. The relationship between ρ_g and T_{sat} can be specified for a single component using either the Ideal Gas Law, an equation recommended by ESDU* or an interpolation method using tabulated data. These physical property variation equations are presented in Sections 4.1 and 4.2 and a description of the input data required for all the above options is described in Section 5.

4.1 Methods of Predicting the Relationship between T_{sat} and p

This Section describes the form of the Antoine equation, Wagner equation and the method based on tabulated data. It is essential to specify the input data to the program in the prescribed units as the program employs conversion factors.

4.1.1 The Antoine equation

The Antoine equation takes the form

$$\log_e p = A + \frac{B}{T + C}. \quad (4.1)$$

ESDU* issues data on the Antoine constants, A , B and C , for a range of compounds derived using **the units of kPa for pressure and K for temperature**. See Section 5 for the input order of these constants.

4.1.2 The Wagner equation

The Wagner equation takes the form

$$\log_e p = \log_e p_c + \frac{T_c}{T} (a_1 q + a_2 q^{1.5} + a_3 q^{2.5} + a_4 q^5). \quad (4.2)$$

$$q = \left(1 - \frac{T}{T_c}\right)^{1/3}.$$

ESDU* issues data on the Wagner constants, a_1 to a_4 , critical temperature, T_c , and critical pressure, p_c for a range of compounds derived using **the units of kPa for pressure and K for temperature**. See Section 5 for the order of input for these constants.

4.1.3 Tabulated Data

The program also has the facility to accept tabulated data encompassing the required range of T_{sat} and p . Up to 10 pairs of data points may be specified in **the units of kPa for pressure and k for temperature**. The program performs linear interpolation for intermediate values and gives an error warning if the required values are outside the entered range. See Section 5 for the order of input for these data.

* For information on this method and the values of the constants for a range of fluids see the Physical Properties, Chemical Engineering series.