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Pressure losses in curved ducts: coils

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THE PREPARATION OF THIS DATA ITEM

The work of the permanent professional staff of the Engineering Sciences Data Unit on this particular Item was monitored and guided by the Fluid Mechanics Steering Group which had the following constitution:

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The work on this Item was carried out in the Fluid Mechanics and Physical Properties Group of the Engineering Sciences Data Unit under the supervision of Mr N. Thompson. The member of staff who undertook the technical work involved in the initial assessment of the available information and the construction and subsequent development of the Item was

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The Fluid Mechanics Steering Group, which first met in April 1970, has the co-operation of many engineers and scientists, in industry, research establishments and universities from whom much assistance and information is being received.

PRESSURE LOSSES IN CURVED DUCTS: COILS

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PRESSURE LOSSES IN CURVED DUCTS: COILS

1. NOTATION AND DEFINITIONS

1.1 Notation

		<i>SI Units</i>
A	internal cross-sectional area* of pipe	m^2
b	transverse pitch of coil (see Sketches 1.2 and 1.3)	m
D	diameter of coil, $2R$	m
D_c	mean diameter of curvature for helical coil (see Section 1.3)	m
D_s	mean spiral diameter (defined by Equation (6.1) in Section 6)	m
D_T	turn diameter of helical coil (see Section 1.3)	m
d	internal diameter* of circular cross-sectional pipe	m
d_o	external diameter of circular cross-sectional pipe (see Sketches 1.1, 1.2 and 1.3)	m
f	friction factor for flow in helical coil of circular cross section (defined by Equation (4.1) in Section 4.1)	-
f'	friction factor for flow in helical coil of circular cross section at reference conditions (defined in Section 4.1)	-
f_s	Fanning friction factor for fully-developed flow in a straight pipe, $\Delta p_s / [4(\frac{1}{2}\rho V^2)(L/d)]$; the value may be obtained from ESDU ¹	-
G	mass flow rate per unit cross-sectional area, m/A	kg/s m^2
g	acceleration due to gravity	m/s^2
H	change in vertical height between coil inlet and outlet (see Sketches 1.1 and 1.3)	m
h	axial pitch of coil (see Sketches 1.1 and 1.3)	m
K_s	static-pressure loss coefficient, $4fL/d$	
L	length of pipe measured along pipe centre-line (for coils see Section 1.3)	m
l	co-ordinate measured along centre-line of pipe	m
m	mass flow rate	kg/s
N	number of turns of coil, $\beta/360$	-
p	static pressure	Pa, N/m^2
Δp_s	static-pressure drop	Pa, N/m^2

For footnotes see end of Notation Section.

R	radius of coil (see Sketches 1.1, 1.2 and 1.3)	m
R_c	mean radius of curvature of helical coil, $D_c/2$	m
Re	Reynolds number, Gd/μ_b	-
Re_A	upper limit of Reynolds number, given by Equation (5.1), for which Equation (5.4) is applicable	-
Re_B	upper limit of Reynolds number, given by Equation (5.2), for which Equation (5.5) is applicable	-
Re_C	lower limit of Reynolds number, given by Equation (5.3), for which Equation (5.6) is applicable	-
r, θ, z	cylindrical co-ordinates	m, radian, m
T	static temperature	K
V	mean flow velocity, $m/(\rho A)$ or G/ρ	m/s
β	total angle of turn of coil	degree
γ	pitch angle of helical coil (see Section 1.3)	degree
ε	effective roughness height of pipe surface (typical values are given in Table 11.2)	m
μ	dynamic viscosity of fluid	N s/m ²
ρ	density of fluid	kg/m ³
ϕ_1	correction factor for effects of cross-sectional fluid property variations on friction factor	-
ϕ_2	correction factor for effect of surface roughness effects on friction factor	-

Subscripts

b	refers to bulk value of quantity x at section where $x_b = \frac{1}{m} \int_o^A x dm$
i	refers to conditions, or value of quantity, at inlet to coil
min	refers to minimum value of quantity
max	refers to maximum value of quantity
n	refers to successive calculations of quantity where $n = 1, 2, 3$ etc.
o	refers to conditions, or value of quantity, at outlet of coil
w	refers to pipe wall conditions

* The internal cross-sectional dimensions to be used in this Item must be actual values and not the nominal values quoted by manufacturers which may be considerably different.

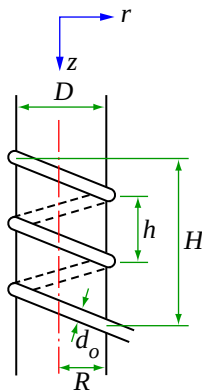
1.2 Definitions

A *coil* is any curved tube or pipe bent into the shape of an arc subtending an angle greater than or equal to 360 degrees, i.e. $\beta \geq 360^\circ$.

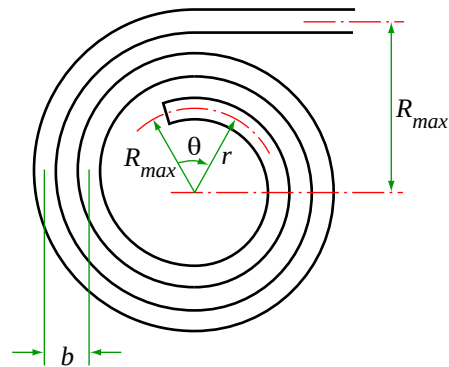
A *helical coil* (see Sketch 1.1) is a coil whose curvature, as measured by D or D_c and pitch, h , is constant at all sections along its length. The cylindrical co-ordinates of a helical coil are given by:

$$r = R, \theta = \theta, z = \frac{h\theta}{2\pi}. \quad (1.1)$$

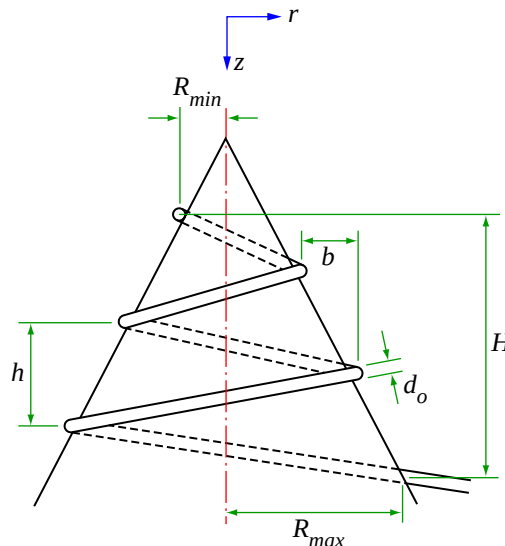
A *spiral coil* is a coil whose curvature varies continuously along its length in some prescribed manner.



Sketch 1.1 Helical coil



Sketch 1.2 Archimedian coil



Sketch 1.3 Combined helical Archimedian coil

An *Archimedian** coil (see Sketch 1.2) is a two-dimensional spiral coil whose pitch, b , is constant. The polar coordinates of such a coil are given by:

$$r - R_{min} = \frac{b\theta}{2\pi}, \theta = \theta. \quad (1.2)$$

A *combined helical Archimedian coil* (see Sketch 1.3) is a three-dimensional spiral coil whose pitches, h and b , are constant. The cylindrical co-ordinates of this coil are given by:

$$r - R_{min} = \frac{b\theta}{2\pi}, \theta = \theta, z = \frac{h\theta}{2\pi}. \quad (1.3)$$

1.3 Coil Geometry

(a) Helical coil

Diameter of curvature, D_c

$$D_c = D + \frac{h^2}{\pi^2 D}. \quad (1.4)$$

Length of coil, L

$$L = \pi DN \left[1 + \frac{h^2}{\pi^2 D^2} \right]^{1/2}. \quad (1.5)$$

When $h/d \leq 0.5$ Equation (1.5) is approximated within two per cent by

$$L = \pi DN. \quad (1.6)$$

An alternative way of expressing Equation (1.5) is

$$L = \pi D_T N, \quad (1.7)$$

where the turn diameter, D_T , is given by

$$D_T = D \left[1 + \frac{h^2}{\pi^2 D^2} \right]^{1/2}. \quad (1.8)$$

Pitch angle, γ

$$\gamma = \tan^{-1} \left(\frac{h}{\pi D} \right). \quad (1.9)$$

$$(1.10)$$

(b) Archimedian coil

* Otherwise known as a pancake coil.

Length of coil, L

$$L = \frac{1}{2} \left(\frac{b}{2\pi} \right) [\theta(1 + \theta^2)^{1/2} + \sinh^{-1}(\theta)]_{\theta_i}^{\theta_o} . \quad (1.11)$$

(c) Combined helical Archimedian coil

Length of coil, L

$$L = \frac{1}{2} \left[\theta \sqrt{a^2(1 + \theta^2) + e^2} + \frac{(a^2 + e^2)}{a} \sinh^{-1} \left\{ \frac{a\theta}{(a^2 + e^2)^{1/2}} \right\} \right]_{\theta_i}^{\theta_o} , \quad (1.12)$$

where $a = \frac{b}{2\pi}$ and $e = \frac{h}{2\pi}$.

2. INTRODUCTION

This Item presents static-pressure drop data for flow through helical coils and gives some guidance for non-helical coils. The types of coil considered in this Item are defined in Section 1.2.

The data for helical coils are given in the form of non-dimensional friction factors, f , and the effects of the following parameters are considered:

- (i) Reynolds number, Re ,
- (ii) non-dimensional surface roughness of the coil tube, ε / d ,
- (iii) diameter ratio of the coil, D/d or D_c/d ,
- (iv) pitch ratio of the coil, h/D .

In addition known temperature variations through the coil can be taken into account. A complementary Data Item (Reference 3) gives the corresponding heat transfer data.

The principal restrictions on the application of the data are shown on the Figures to which they apply. Further information on the applicability of the data is given in Section 3 whilst Section 8 gives details on the uncertainty of the data.

3. APPLICABILITY OF DATA FOR HELICAL COILS

The data are only applicable to:

- (i) helical coils of constant pitch, h , having constant diameter tubing of circular cross section (for non-circular cross sections see Section 7.2),
- (ii) single-phase fluids,
- (iii) fluids that can be regarded as incompressible (for the application of the data in this Item to gases the Mach number of the flow should be ≤ 0.4) and Newtonian,
- (iv) pipe systems running full.

The recommended ranges of applicability of the major parameters influencing static-pressure drop are given in the following Table.

Parameter	Range
Re	$\leq 10^6$
ϵ/d	≤ 0.02
D/d	≥ 5
h/d	≤ 5
μ_w/μ_b (for liquids)	0.3 to 5
T_w/T_b (for gases)	0.3 to 3

Detailed information on the ranges (and Derivations) of the experimental data is given in Table 11.1.

4. CALCULATION OF HELICAL COIL PRESSURE DROP*

4.1 Static-pressure Drop Equation

The overall static-pressure drop due to flow in a helical coil of circular cross section is given by Equation (4.1) which consists of the sum of three terms.

$$\Delta p_s = 4f \left(\frac{G^2}{2\rho_b} \right) \frac{L}{d} + G^2 \left(\frac{1}{\rho_{b,o}} - \frac{1}{\rho_{b,i}} \right) + g\rho_b H. \quad (4.1)$$

The first term, which is always positive, deals with the irrecoverable component of static-pressure drop and depends on a value of f which may be obtained from the data in this Item.

The second term deals with the momentum component of static-pressure drop and can be either positive or negative.

The third term deals with the gravitational component of static-pressure drop and this also can be either positive or negative.

If the coil is divided into a series of coil lengths (to allow for large variations in the fluid physical properties through the coil), the overall pressure drop through the coil is given by the sum of the values calculated from Equation (4.1) for each separate length.

The helical coil friction factor, f , is presented in the form of a reference value, f' , which is appropriate to the following conditions:

- (a) there are no temperature differences between the bulk fluid and the walls of the coil tubing,
- (b) the coil tubing is smooth.

Correction factors, ϕ_1 and ϕ_2 , are applied to f' such that

$$f = f' \phi_1 \phi_2, \quad (4.2)$$

where

ϕ_1 accounts for variations in cross-sectional fluid properties ($\phi_1 = 1$ for $T_b = T_w$),

ϕ_2 accounts for surface roughness effects ($\phi_2 = 1$ for $\epsilon/d \leq 1 \times 10^{-5}$ or $Re \leq Re_B$).

Methods of evaluating f' , ϕ_1 and ϕ_2 are given in Section 5.

* Section 6 suggests how the methods and data for the calculation of pressure drop in helical coils may be applied to other types of coils.