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Pressure losses in valves

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PRESSURE LOSSES IN VALVES

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PRESSURE LOSSES IN VALVES

1. NOTATION AND UNITS

Three coherent systems of units are given below. These systems allow the equations given in the Item to be used without the inclusion of conversion factors

		<i>SI</i>	<i>British</i>	
C_K	corrected pressure loss coefficient ^(a)	—	—	—
C'_K	uncorrected pressure loss coefficient ^(a)	—	—	—
C_v	flow coefficient	(b)	(b)	(b)
D	actual internal diameter of pipe ^(c)	m	ft	ft
D_n	nominal pipe diameter ^(c)	m	ft	ft
f	Fanning friction factor	—	—	—
g	local acceleration due to gravity	m/s ²	ft/s ²	ft/s ²
Δh	loss of head in terms of fluid flowing, corresponding to pressure loss Δp	m	ft	ft
L_d, L_u	length of straight pipe downstream and upstream of valve respectively	m	ft	ft
Δp	pressure loss attributable to valve ^(a)	N/m ²	*pdl/ft ²	lbf/ft ²
Q	volume rate of flow	m ³ /s	ft ³ /s	ft ³ /s
Re_{Dn}	Reynolds number based on D_n , $\frac{V_n D_n}{\nu}$	—	—	—
V	mean flow velocity, $Q/\frac{\pi}{4}D^2$	m/s	ft/s	ft/s
V_n	nominal mean flow velocity, $Q/\frac{\pi}{4}D_n^2$	m/s	ft/s	ft/s
α_1	correction factor for partial opening of valve	—	—	—
α_2	correction factor for low Reynolds number	—	—	—
δ	degree of opening of valve ^(d)	—	—	—
ν	kinematic viscosity [†] of fluid	m ² /s	ft ² /s	ft ² /s
ρ	density of fluid	kg/m ³	lb/ft ³	‡slug/ft ³

* 1 pdl = 31.08×10⁻³ lbf; 1 pdl/ft² = 215.8×10⁻⁶ lbf/in².

† Kinematic viscosity = dynamic viscosity/density.

‡ 1 slug = 32.17 lb.

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NOTES

- (a) Definitions of Δp and C_K are given in ESDU 69016⁴ where the difference between gross and net values is explained. In the present Item gross values are used (see also Section 3).
- (b) The flow coefficient, C_v , is commonly used as a measure of "valve capacity". It is basically defined in British Units as the rate of flow in UKgal/min, of water at 60°F, when the pressure drop across the valve is 1 lbf/in². If the rate of flow is known for some other value of pressure drop, C_v may be derived from the relation

$$C_v \text{ (UKgal/min)} = Q \text{ (UKgal/min)} \sqrt{\frac{\Delta p \text{ (lbf/in}^2\text{)} / 1 \text{ lbf/in}^2}{\text{specific gravity of fluid}}}$$

$$\begin{aligned} 1 \text{ UKgal/min at } 1 \text{ lbf/in}^2 \text{ pressure drop} &= 6.291 \times 10^{-3} \text{ m}^3/\text{s at } 1 \text{ N/m}^2 \\ &= 182.1 \times 10^{-3} \text{ ft}^3/\text{s at } 1 \text{ pdl/ft}^2 \\ &= 32.11 \times 10^{-3} \text{ ft}^3/\text{s at } 1 \text{ lbf/ft}^2. \end{aligned}$$

- (c) Valve sizes are usually given as the nominal pipe diameter, D_n , for which the end connections are designed. This is the basic dimension used in this Item. However, when ESDU 66027² is used to calculate the losses in the associated straight pipes, the actual internal pipe diameter, D , must be used in those calculations.
- (d) The degree of valve opening is defined in this Item as the ratio (travel of valve control from closed position)/(travel of valve control from closed to fully open), *e.g.* number of turns open/number of turns to fully open. Thus, $\delta = 0$ for fully closed valves and $\delta = 1$ for fully open valves.

2. INTRODUCTION

In this Item information is given on the pressure loss for single-phase flow through a number of types of shut-off and simple flow control valves.

The information is presented in the form of non-dimensional pressure loss coefficients and applies for the flow of liquids and also for the flow of gases at low Mach numbers*.

The types of valves included are illustrated and described in Section 6 where the appropriate Figures giving data are indicated. Also included in Section 6 are typical size ranges, temperature and pressure limits and examples of the applications of the various types. This latter information is intended as initial guidance on the suitability of a valve for a particular duty. The final choice should be considered in conjunction with manufacturers and their literature. References 1 and 3 will be of assistance in locating appropriate manufacturers.

An Appendix lists some alternative names found during the preparation of this Item and classifies them in terms of the main types given in Section 6.

The information given is based on data from Derivations 6 to 25 and on data supplied by a number of valve manufacturers. It is only approximate for various reasons. In general, valves of different sizes and from different manufacturers, although broadly similar, are not exactly geometrically similar. In small sizes, one valve body may be offered with a variety of end connection sizes and in some cases a valve of one nominal size may be available with several seat sizes. If the pressure loss is derived from pressures measured too close to the valve, and therefore not in regions of fully-developed flow, inconsistencies arise and this accounts for some scatter of the data. In some cases there are approximations such as the neglect of Reynolds number effects.

A large number of standard specifications for valves are issued by the national standards organisations, by industrial companies and other organisations. Such standards usually refer to materials and construction of valves and do not give pressure loss data.

* The Mach number of a gas flow is the local flow velocity divided by the local speed of sound. As the Mach number at the valve inlet increases above about 0.2 the effects of compressibility start to become noticeable. However, for the purposes of this Item, and especially in the case of straight through valves, the effects are unlikely to be significant for Mach numbers up to about 0.5.

3. CALCULATION OF PRESSURE LOSS

The pressure loss attributable to a valve in a pipeline is given by

$$\Delta p = C_K \times \frac{1}{2} \rho V_n^2 \quad (3.1)$$

and the corresponding head loss, in terms of fluid flowing, by

$$\Delta h = C_K \times V_n^2 / 2g,$$

where the velocity V_n is based on the nominal valve size, D_n . In this Item, C_K is given in terms of a basic coefficient, C_K' (Figures 1 to 11), applicable for fully open valves and for $Re_{Dn} \geq 10^4$ to which correction factors, α_1 (Figures 12 to 15) and α_2 (Figures 16 and 17), must be applied to account for partial opening and for $Re_{Dn} < 10^4$ respectively. Thus

$$C_K = C_K' \times \alpha_1 \times \alpha_2.$$

To obtain the overall pressure loss, Δp_{AB} , between two points A and B, in regions of fully-developed flow, which span a valve, the friction losses in the straight pipes upstream and downstream of the valve must be added to the loss given by Equation (3.1). Thus

$$\Delta p_{AB} = \Delta p + \frac{1}{2} \rho V^2 \times 4f \frac{L_u + L_d}{D},$$

and

$$\Delta h_{AB} = \Delta h + (V^2 / 2g) \times 4f \frac{L_u + L_d}{D},$$

where V is based on the actual pipe bore, D . For non-circular section ductwork, D_n and D should be replaced by the equivalent hydraulic diameter ($4 \times$ cross-sectional area/wetted perimeter). Values of f for various surfaces are given in ESDU 66027².

If points A and B are taken close to the valve, or the next component upstream or downstream is close to the valve, A and B may not be in fully-developed flow. (See Reference 4 for a discussion of interference effects.) However, for most practical purposes, when using the information given in this Item, the error introduced will not be significant provided that $L_u/D > 2$ and $L_d/D > 5$ and that the total length of straight pipe immediately upstream is at least $10D$.

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5. EXAMPLE

This example is worked in both British and SI units. The data for the latter case are rounded off from the exact equivalent values.

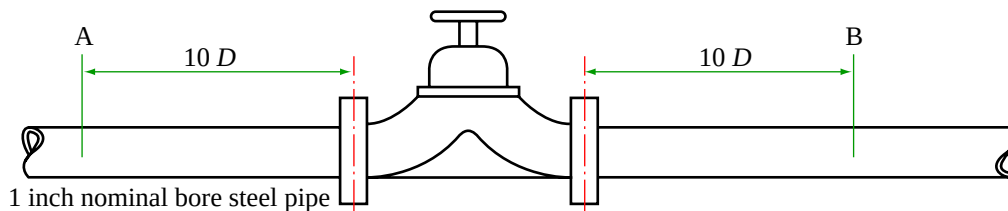
Part of a test rig includes a diaphragm valve as shown in the sketch below. What will be the approximate pressure loss between points A and B for water and for oil flowing at 15 UKgal/min ($1.14 \times 10^{-3} \text{ m}^3/\text{s}$) with the valve fully open? For water,

$$\text{density} = 62.4 \text{ lb/ft}^3 (10^3 \text{ kg/m}^3); \text{ kinematic viscosity} = 1 \text{ cSt} = 10.76 \times 10^{-6} \text{ ft}^2/\text{s} (10^{-6} \text{ m}^2/\text{s}),$$

and for the oil,

$$\text{density} = 50 \text{ lb/ft}^3 (800 \text{ kg/m}^3); \text{ kinematic viscosity} = 140 \text{ cSt} = 1.506 \times 10^{-3} \text{ ft}^2/\text{s} (140 \times 10^{-6} \text{ m}^2/\text{s}).$$

The actual bore of the steel pipe is 1.05 inches (26.7 mm).



	British Units	SI Units
Nominal velocity $V_n = Q/\frac{\pi}{4}D_n^2$	$15 \times 2.676 \times 10^{-3} / \frac{\pi}{4} \left(\frac{1}{12}\right)^2$	$1.14 \times 10^{-3} / \frac{\pi}{4} (25.4 \times 10^{-3})^2$
	$= 7.36 \text{ ft/s.}$	$= 2.25 \text{ m/s.}$
For the straight pipe, $V = Q/\frac{\pi}{4}D^2$	6.68 ft/s.	2.04 m/s.

(a) Water

Reynolds number $Re_{Dn} = \frac{V_n D_n}{\nu}$	$7.36 \times \frac{1}{12} \times \frac{1}{10.76 \times 10^{-6}}$	$\frac{2.25 \times (25.4 \times 10^{-3})}{10^{-6}}$
	$= 57 \times 10^3.$	$= 57 \times 10^3.$

Section 6.5 indicates that Figure 11 gives data for diaphragm valves. It is evident from the shape of the valve that it is of Pattern 1 as shown on the Figure and for a 1 inch (25.4 mm) valve, $C'_K = 2.3$. Since the valve is fully open and $Re_{Dn} > 10^4$, $\alpha_1 = 1$ and $\alpha_2 = 1$. Thus $C_K = C'_K$.

	British Units	SI Units
For the straight pipe, $Re_D = VD/\nu$	54×10^3	54×10^3
Using ESDU 66027, for steel pipe, f	6.6×10^{-3}	6.6×10^{-3}

The pressure loss between A and B is given by

$$\Delta p_{AB} = \frac{1}{2} \rho V_n^2 C_K + \frac{1}{2} \rho V^2 4f \frac{L_u + L_d}{D}.$$

Thus Δp_{AB} is

$\frac{1}{2} \times 62.4 (7.36^2 \times 2.3 + 6.68^2 \times 4 \times 6.6 \times 10^{-3} \times 20)$ $= 31.2 (124.6 + 23.6)$ $= 4620 \text{ pdl/ft}^2$ $\approx 1 \text{ lbf/in}^2.$	$\frac{1}{2} \times 10^3 (2.25^2 \times 2.3 + 2.04^2 \times 4 \times 6.6 \times 10^{-3} \times 20)$ $= 500 (11.64 + 2.20)$ $= 6.92 \times 10^3 \text{ N/m}^2.$
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(b) Oil

Reynolds number $Re_{Dn} = \frac{V_n D_n}{\nu}$	$7.36 \times \frac{1}{12} \times \frac{1}{1.506 \times 10^{-3}}$ $= 410$	$\frac{2.25 \times 25.4 \times 10^{-3}}{140 \times 10^{-6}}$ $= 410$
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From Figure 11, C'_K is again 2.3 but since $Re_{Dn} < 10^4$, $\alpha_2 \neq 1$. From Figure 17, $\alpha_2 = 1.4$. Since the valve is fully open, $\alpha_1 = 1$.