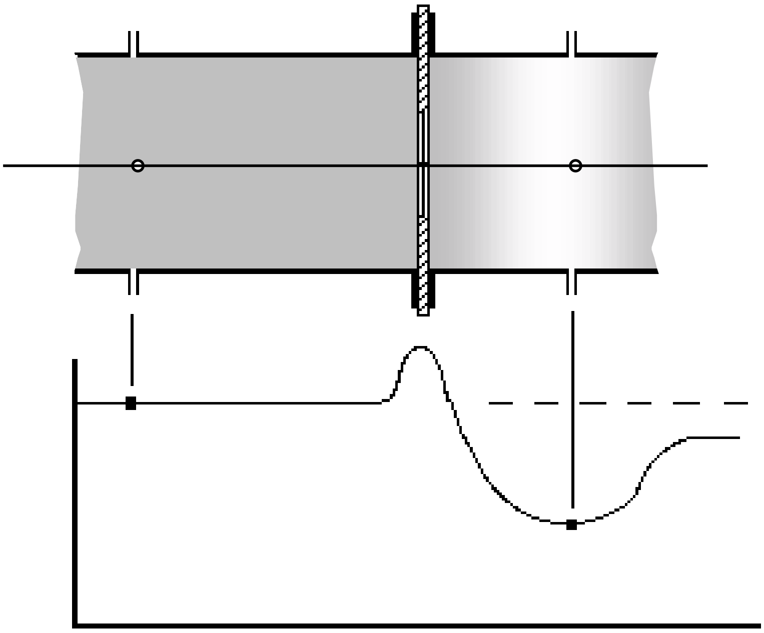
Locally Made
Equipment for Teaching & Research
in Agricultural Engineering

MEASUREMENT OF AIR FLOW

WITH ORIFICE PLATES

Manual No. 6



R. H. MACMILLAN

Senior Fellow
International Development Technologies Centre
University of Melbourne

r.macmillan@devtech.unimelb.edu.au

LOCALLY MADE EQUIPMENT FOR TEACHING AND RESEARCH IN AGRICULTURAL ENGINEERING

LIST OF TITLES IN THE SERIES

SERIES PREFACE

This manual is one of a series written to make available designs of basic equipment intended to be made by institutions for their own use in teaching and research in agricultural engineering and associated technologies. They are directed at the study of the functional performance of various machines and items of equipment and particularly at the important elements which determine that performance.

As well as providing drawings showing the main dimensions of the equipment, the manuals also include basic theory, design considerations, and techniques for their calibration and use. The designs are based, as far as possible, on the use of industrial components. In addition to specifying part numbers and sources of supply for purchased components, the latter have also been specified, where possible, in terms of size / capacity / performance so that suitable alternatives may be used.

A range of types of transducer from simple manually read devices to more complex electronic units may be used with the designs. In this way the latter can serve a range of users and can remain in use as the level of instrumentation grows.

The designs have been provided by individuals who have had experience in their development and use. We would value comment, criticism, and suggestions for improvements.

The assistance of the Australian International Development Assistance Bureau in providing financial support for the original preparation of the material for publication is gratefully acknowledged. They were originally printed and distributed to interested people by the Editor in 1991.

They are but are now being made available to a wider readership by being republished in a slightly amended form on the ePrints Repository of the University of Melbourne and can be down loaded free of charge at: http://eprints.unimelb.edu.au/

R.H. Macmillan
Editor

Senior Fellow
International Development Technologies Centre
Department of Civil and Environmental Engineering
University of Melbourne
Parkville Victoria 3010 Australia

r.macmillan@devtech.unimelb.edu.au

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MEASUREMENT OF AIR FLOW WITH ORIFICE PLATES

SUMMARY

This manual, which is one of a series on locally made equipment for teaching and research in agricultural engineering, presents data for the selection of an orifice plate diameter to measure air flow with a given pressure drop and the method of calculation of air flow rate for a given orifice plate with a measured pressure drop.

Key words*: Equipment, teaching, research, agricultural engineering, air flow, measurement, pipes, orifice plate, pressure drop.*

And when you can measure what you are speaking about and express it in numbers you know something about it but when you cannot express it in numbers your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely in your thoughts advanced to the stage of science.'

Popular Lectures and Addresses: William Thompson (Lord Kelvin)

1.0 INTRODUCTION

1.1 Background

Many agricultural operations involve air flow in pipes and through beds of agricultural products.

The design such systems requires a knowledge of the air flow rate and of the pressure loss in the pipe and/or bed. There are various methods of measuring the air flow but, for relatively small pipes, it is common practice to use a pressure difference device such as a orifice plate, venturi tube or nozzle.

Of these types the orifice plate is the simplest although it also causes the greatest net pressure loss in the system. In spite of this disadvantage the orifice plate is the most common and the version with D and D/2 tappings is the simplest to manufacture and its analysis and use (but not manufacture) is the subject of this manual.

The theory of the orifice plate is treated in most books on fluid mechanics and so will not be repeated here. However the selection of an orifice plate with known characteristics to measure a given flow and the calculation necessary for this purpose is given in the British Standard Specifications listed in the References.

Two types of problem exist:

* the selection of an orifice plate (diameter) for insertion in a given pipe to measure a given flow rate with a desired pressure drop.
* the calculation of the flow rate in a given pipe with a particular orifice plate (diameter) on the basis of the measured pressure drop.

The following is material, which has been extracted from those Standards (with permission) for orifice plates in particular, is applicable to both these air flow measurement problems.

The Standard applies to 'fluids' in general, so the principles and methods described in the following also apply to liquids and to water in particular. For such fluids the compressibility effects are negligible, the fluid density is constant and hence calculations although still iterative in principle are somewhat simplified.

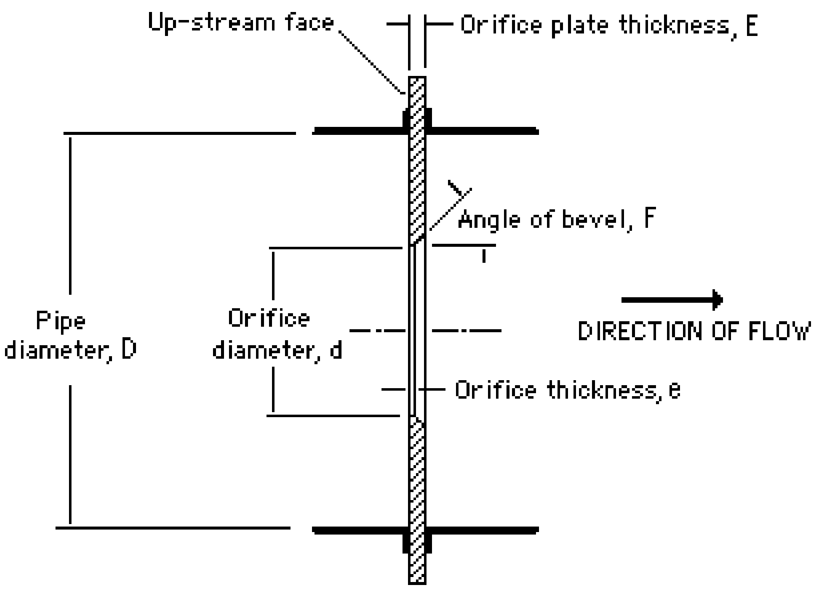

Figure 1: Orifice plate

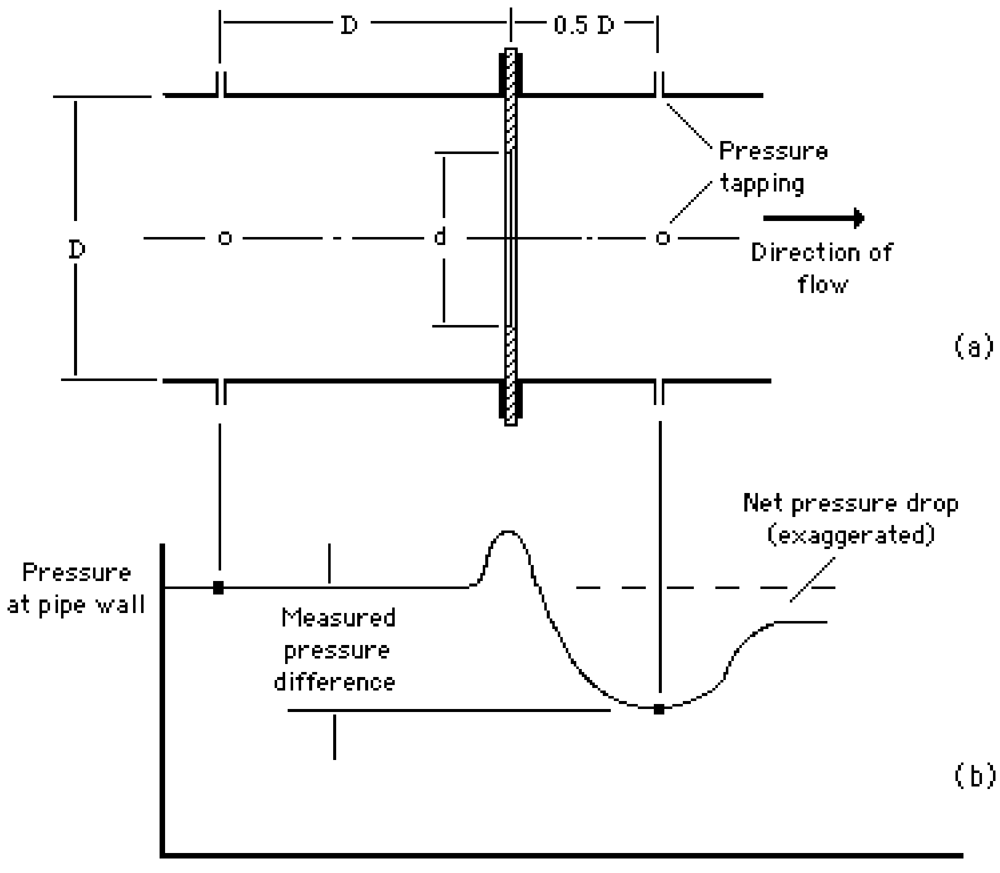

Figure 2:(a) Location of pressure tappings (b) Pressure distribution along wall

1.2 Measurement with an orifice plate

The orifice plate, which consists of a thin flat plate with a hole (an orifice), forms an annular obstruction in the pipe carrying the air stream (see Figure 1).

The rate of flow through the plate is calculated from a measurement of the difference between the pressures on the pipe wall at a distance D (pipe diameter) upstream of the plate and D/2 downstream of the plate; Figure 2. The pressure difference is usually measured by a manometer connected to pressure tappings (small pipes) inserted through the wall of the pipe.

The orifice plate causes a pressure drop to be developed which (for a given pipe and plate) is dependant on:

* the square of the flow rate through the pipe
* the properties of the fluid

The numerical relationship between the rate of flow and the pressure drop, which is the basis of the measurement, has been established, partly from theoretical considerations and partly on the basis of calibration tests for orifice plates installed in pipelines having a long straight length of approach pipe.

If the orifice plate and associated pipe are carefully made according to the dimensions and specifications given in the Standard, then the flow can be calculated in terms of the dimensions of the pipe and the orifice plate, the properties of the fluid and the measured pressure drop; calibration of the orifice plate is not necessary.

1.3 Principle of measurement

When fluid flows through a pressure difference device, the flow follows (approximately) the streamlines. In the case of a orifice plate the flowing stream issues from the orifice as a convergent jet which continues to contract for a short distance downstream of the orifice plate before it diverges to fill the pipe; the minimum cross-section, or neck, of the jet is known as the 'vena - contracta'. The area and position of the vena-contracta depends on the rate of flow, on the size of the orifice relative to the pipe and if the fluid is compressible, on the pressure difference. It is also sensitive to the shape of the upstream edge of the plate; it is smaller for square-edged than for other orifice plates.

The velocity of the flowing stream increases as it passes into the constriction and reaches a maximum in the plane of the minimum cross-section of the flowing stream (at the vena - contracta for an orifice plate). The kinetic energy of the stream, which is related to the squares of the local velocity, increases correspondingly. The consequent decrease in potential energy is manifested as a decrease in the static pressure of the fluid on the wall of the pipe (that is, at right angles to the direction of the flow lines).

This illustrated in the Figure 2(b) in which is shown the variation of the pressure on the pipe wall as the fluid passes through an orifice plate. As the fluid flows through the upstream pipe towards the device, the pressure on the pipe wall decreases very slowly owing to dissipation of energy as heat in frictional losses; this is not shown in the Figure. In the absence of the orifice, the pressure would continue to fall. Immediately in front of the orifice constriction there is a small increase in pressure on the pipe wall; it occurs with orifice plates because a part of the impact pressure on the plate is conveyed to the pipe wall. When the fluid enters the orifice, its velocity increases very rapidly and the pressure on the pipe wall falls abruptly as shown in the Figure. The pressure decreases to a minimum at the vena-contracta where the velocity is a maximum.

Downstream of the vena-contracta, the pressure on the pipe wall increases as the area of the flowing stream increases and as the velocity of the fluid falls to its initial value. The pressure does not, however, reach quite the value that it would have had in the absence of the device. The difference is known as the net pressure loss (shown exaggerated Figure2 (b)) and is due to dissipation of energy as heat in the damping of turbulent eddies by internal friction.

1.4 Measurement of pressure drop

The measurement of flow involves a measurement of the pressure of the air on the wall and in particular the pressure difference across the plate. This may be done by any suitable differential device but because the pressure difference is small, a relatively accurate measurement must be made.

An inclined tube manometer using water as the liquid is the simplest such device and can be purchased or made with some simple components such as transparent tubing. More complex commercially produced liquid and electronic manometers are also available.

2.0 ANALYSIS

2.1 Summary of relevant parameters

The important parameters in the use of the orifice plate are presented below;

	Defining equation	Unit	
Orifice			
* Pipe diameter	D	metre	
* Orifice diameter	d	metre	
* Diameter ratio	$\beta = \frac{d}{D}$	-	
Air			
* Temperature	t	^oC	
* Pressure at upstream conditions	p_u	kPa	
* Density at upstream conditions	$\rho_u = \frac{p_u}{RZ(t+273)}$	kg/m^3	(i)
* Compressibility factor	Z = 0.996	-	
* Gas constant	R = 287	J/kg.K	
* Isentropic exponent	$\gamma = 1.4$		
* Dynamic viscosity,	$\mu = 18.0 \times 10^{-6}$	Pa.s	
Flow			
* Pressure drop,	p	Pa	
* Reynolds Number (pipe)	$R_n = \frac{\rho_u v D}{\mu}$	-	(ii)
* Expansibility factor	$\varepsilon = 1 - (0.41 + .35\beta^4)\frac{\Delta p}{\gamma p_u}$	-	(iii)
* Flow coefficient	$\alpha = [1-\beta^4][0.59 + 0.05\beta^2 - 0.08\beta^6 + \{0.0037\beta^{1.25} + 0.011\beta^8\}\sqrt{\frac{10^6}{R_n}}]$		(iv)
* Flow rate - mass	$Q_m = \alpha\ \varepsilon \frac{\pi}{4} d^2 \sqrt{2\ \Delta p\ \rho_u}$	kg/s	(v)
- volume	$Q_v = \alpha\ \varepsilon \frac{\pi}{4} d^2 \sqrt{\frac{2\ \Delta p}{\rho_u}}$	m^3/s	(vi)

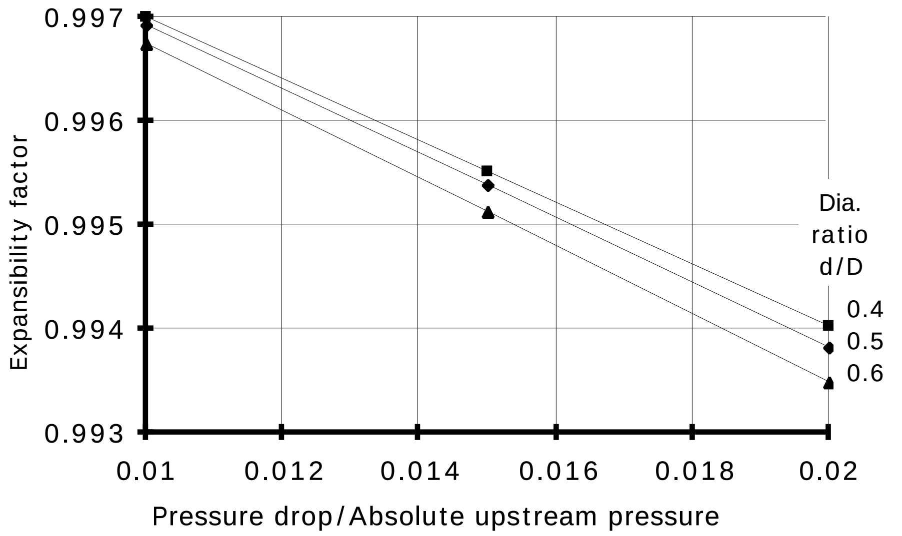

Figure 3: Variation in expansibility factor (ε) with pressure ratio ($\Delta p/p_u$) for various values of diameter ratio (β)

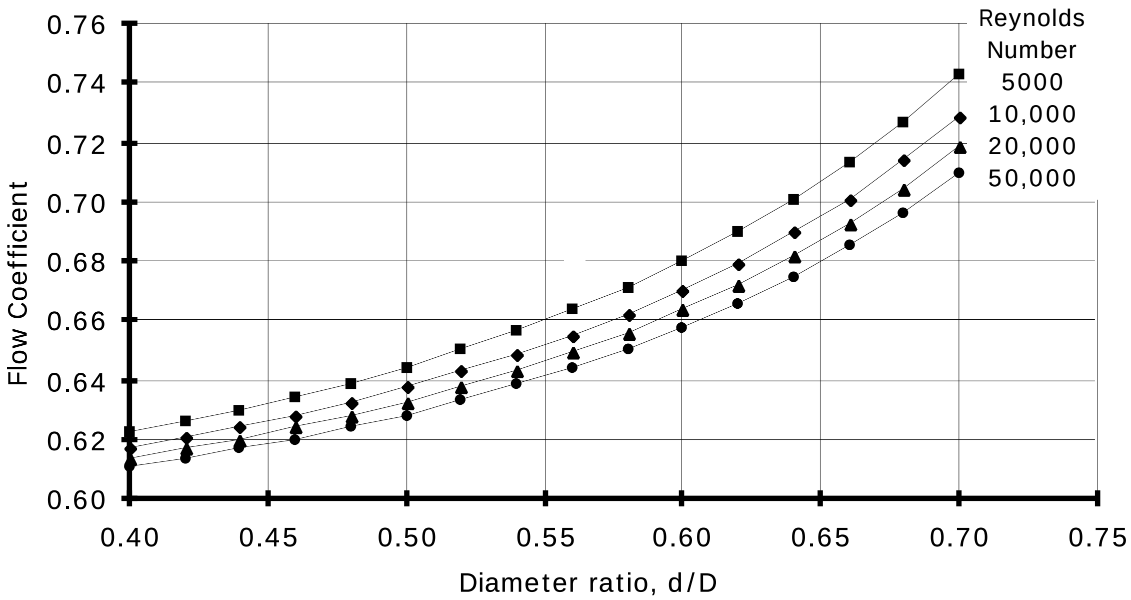

Figure 4: Variation of flow coefficient, (α) with diameter ratio, (β) for various values of Reynolds Number, R_N

2.2 Explanation of parameters

(a) Pipe diameter, D

(b) Orifice diameter, d

(c) Diameter ratio, β

The 'severity' of the orifice plate is represented by this dimensionless ratio.

(d) Temperature, t

The temperature as read (C) is used to calculate the absolute temperature in the universal gas equation.

(e) Upstream pressure, p_u

The pressure upstream of the orifice plate is required to calculate the density of the air and the flow rate at upstream conditions. It may be measured by connecting the upstream pressure tapping to a manometer alone.

(f) Density, ρ_u

This is required (for the conditions upstream of the orifice plate) in the calculation of mass flow. It is obtained from the general gas equation given above.

(g) Compressibility factor, Z.

This accounts for the compressibility of the gas in the universal gas equation.

(h) Gas constant, R

This is a constant in the universal gas equation which relates pressure, density and temperature.

(i) Isentropic exponent, γ

The expansibility factor, which allows for the compressibility of the gas, involves this exponent.

(j) Dynamic viscosity, μ

The viscosity defines the frictional characteristics of the air and is required to calculate the Reynolds Number. However, as noted above, only approximate values of the latter are required and so a constant value of 18 x10^{-6} Pa.s may be assumed for air between ambient and temperatures up to 40^{o}C (Ref. BS 848 Part 1 1980; Clause 22.11).

(k) Pressure drop, Δp

There is a pressure drop through the orifice plate as described in Section 1.3. This is as measured by the manometer and is related to the flow rate by the orifice equation.

(l) Velocity, v

The Reynolds number is based on the air velocity in the pipe. However the volume flow rate calculation is based on the air velocity through the orifice but it applies to the conditions upstream of the orifice plate.

(m) Reynolds Number, R

The Reynolds Number is a non dimensional number that characterises the flow and is a factor in the determination of the flow coefficient.

For calculation of flow through an orifice plate it is be based on the diameter D of and the velocity v of air flow through the pipe. The density upstream of the orifice plate and the viscosity of the air are also required.

(n) Expansibility Factor, ε

As a first approximation ε may be assumed to be 1 (or, for example, 0.996) as suggested in BS 848 Clause 22.10 for Δp values less than 1kPa (100 mm of water).

However if a more strict approach is desired, values of ε may be obtained from:

(i) Figure 3 which shows it plotted (using Equation (iii) above) for various value of the diameter ratio, β and the pressure drop / upstream pressure ratio.

(ii) the defining equation (iii) given above.

(o) Flow Coefficient, α

The flow coefficient is a function of the diameter ratio and, to a small degree, on the Reynolds Number of the flow.

It is therefore usually sufficient to assume a value of Reynolds Number to start with and then to use this to calculate a first estimate of the flow. If this flow is then used to calculate a revised value of Reynolds Number and a revised value of the flow coefficient an accurate value of the flow will be obtained.

If a reasonable value of Reynolds Number is chosen initially it will be found that, in many circumstances, only the first calculation is necessary; the second will not achieve a greater accuracy.

As a first approximation α may be obtained from Figure 4 which shows it plotted for various values of Reynolds Number and for various values of the diameter ratio β.

However if a more strict approach is desired, values of α may be obtained using Equation (iv) given above.

2.3 Estimation of orifice diameter for a given flow/pressure drop

2.3.1 Orifice diameter

The choice of orifice diameter is dependant on;

(1) the requirements of the Standard; the minimum is 12.5 mm (Ref; BS 1042: Section 1.1, Clause 7.1.7.1)

(ii) the air flow to be measured.

(iii) the capacity of the manometer available to measure the pressure drop across the orifice plate.

2.3.2 Flow rate - pressure drop - orifice plate diameter relationship

The coefficients α and ε are complex functions of the flow conditions but, for the purposes of determining the size of orifice for a given flow and a given pressure, it is reasonable to assume that they are constant . The air density may also be assumed constant for this purpose.

When this done the relationship between flow rate and pressure rate can be determined for different orifice sizes and for different pipe sizes using the equation:

$$Q_V = \alpha \ \varepsilon \ \frac{\pi}{4} d^2 \sqrt{\frac{2 \Delta p}{\rho_u}} \quad m^3/s \qquad \text{(vi)}$$

where

- α is taken from Figure 4 for a typical value of R and appropriate value of β
- ε = 0.997 (assumed constant)
- ρ_u = 1.128 kg/m (assumed constant)
- d = orifice diameter as plotted
- p = pressure drop (as plotted)

These are shown plotted in Figures 5 (a) to (d).

Note that this Figure is intended to assist in the selection of an orifice plate diameter for use with a given manometer or the selection of both orifice plate diameter and manometer range. It is not intended for the accurate calculation of flow from a given pressure drop.

An example of its use is given in Section 3.0

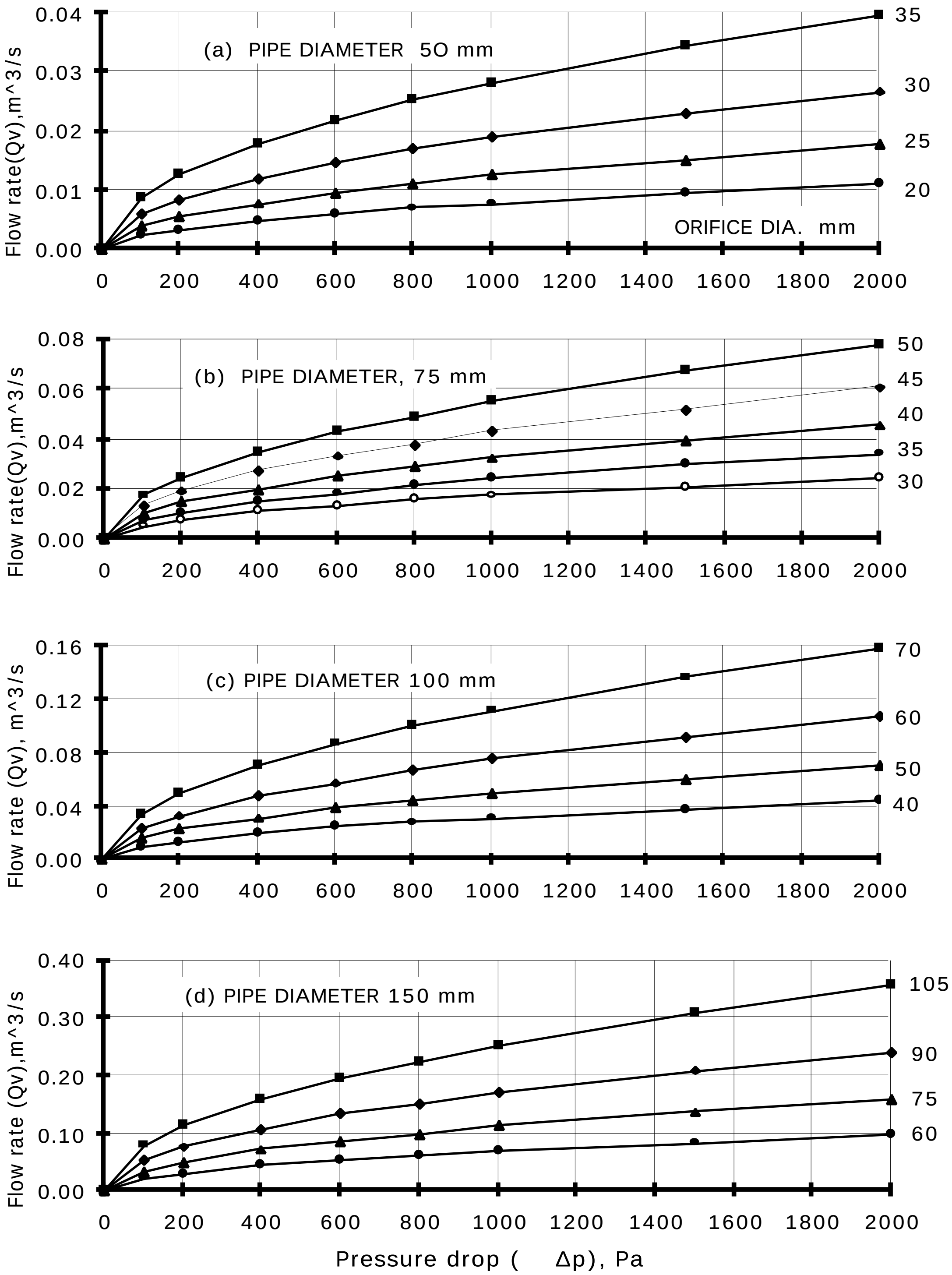

Figure 5: Variation of air flow rate (Qv) with pressure drop (Δp) for various orifice diameters (d) and pipe diameters (D)

2.4 Calculation of flow rate from measured pressure drop

2.4.1 General

The process of calculation is, strictly speaking, impossible because it requires the Reynolds Number for the flow before the flow coefficient and hence the flow can be calculated; ie it requires the answer before the answer can be calculated!

The engineering solution to this dilemma is to use an 'iterative' process of calculation as explained below.

2.4.2 Method

(a) Calculate the diameter ratio, β

(b) Assume initial value of Reynolds Number, Rn

(c) Read / calculate an initial value of flow coefficient, α

(d) Calculate the absolute pressure upstream of orifice plate, p_u

(e) Calculate the pressure ratio, $\frac{\Delta p}{p_u}$

(f) Read / calculate the expansibility factor, ε

(g) Calculate density upstream of orifice plate, ρ_u

(h) Calculate an initial value of volume flow rate, Q_v

(i) Calculate air velocity in the pipe, v

(j) Calculate a revised value of Reynolds Number, R_n

(k) Read/ calculate revised value of flow coefficient, α

(l) Calculate a revised value of volume flow rate, Q_v

(m) Check that the initial and revised values of volume rate are approximately equal.

(n) Calculate the mass flow rate, Q_m.

2.5 Approximate calculation

If an approximate calculation is required, we can neglect the expansibility effect and the variation in density.

Assume: $\varepsilon = 1.0$
$\rho_u = 1.23$ kg/m^3

Thus using Equation (vi)

$$Q_v = \alpha \ \varepsilon \ \frac{\pi}{4} d^2 \sqrt{\frac{2\,\Delta p}{\rho_u}} \quad \text{m}^3/\text{s} \qquad \text{(vi)}$$

$$= \alpha \ \varepsilon \ \frac{\pi}{4} d^2 \sqrt{\frac{2\,\Delta p}{1.23}} \quad \text{m}^3/\text{s}$$

$$= 1.0\,\alpha \ d^2 \sqrt{\Delta p} \qquad \text{(coincidently)}$$

If α is assumed constant for a typical value of, say 0.65,

$$Q_v = 0.65\, d^2 \sqrt{\Delta p}$$

3.0 EXAMPLE

3.1 Problem

In a grain drying experiment it is required to measure the air flow rate in a 50 mm pipe corresponding to an air velocity range of 0.1 to 0.3 m^3 /m^2. s through a grain bed 200 mm diameter. A manometer with a range of 0 to 100 mm water is available.

(a) Estimate the orifice size suitable for this work

In an actual experimental run the following data were taken:

* air temperature	= 30 C
* measured pressure at upstream tapping	= 170 mm water = 1700 Pa(approx)
* pressure drop through the orifice	= 91 mm water = 892 Pa
* atmospheric pressure	= 101.3 kPa

(b) Determine the mass flow rate in m /s and volume flow rate in kg/s.

3.2 Estimation of orifice size

Maximum air flow rate $= \frac{\pi}{4} (0.2)^2 \times 0.3$

$= 0.00942 \ m^3/s$

Inspection of Figure 5 (a) for 50 mm pipe and 100 mm water (1000 Pa approximately) shows that a 25 mm orifice would be suitable.

Minimum air flow rate $= \frac{\pi}{4} (0.2)^2 \times 0.1$

$= 0.00314 \ m^3/s$

Inspection of the same Figure shows that with a 25 mm orifice and this air flow the pressure drop would approximately 100 Pa or 10 mm of water.

If this pressure drop is too small it would be necessary to use a smaller orifice plate for the lower rates of air flow.

3.3 Calculation of flow rate

Diameter ratio, $\beta = \frac{d}{D} = \frac{25}{50} = 0.5$

Assume an initial value of Reynolds Number of 10,000

Inspection of Figure 4 for $\beta = 0.5$ and $R_N = 10{,}000$ shows an initial value of flow coefficient α of 0.637.

Absolute pressure at the upstream tapping

p = atmospheric pressure + measured pressure

= (101,300 + 1700) Pa

= 103,000 Pa

For the pressure drop through the orifice of 91 mm = 910 Pa,

Hence $\frac{\Delta p}{p_u} = \frac{892}{103{,}000}$

$= 0.01$ approximately

For this value of $\frac{\Delta p}{p_u}$ inspection of Figure 4 gives:

Expansibility factor, ε = 0.997

From above:

Compressibility factor, Z = 0.996

Universal gas constant, R = 287 J / kg.K

Hence the density at the upstream tapping,

$$\rho_u = \frac{p_u}{Z\ R\ (t + 273)}$$

$$= \frac{103000}{0.996 \times 287\ (30 + 273)}$$

$$= 1.189\ \text{kg/m}^3$$

Air (mass) flow rate, $Q_m = \alpha\ \varepsilon\ \frac{\pi}{4} d^2 \sqrt{2\ \Delta p\ \rho_u}$ kg/s (v)

$$= 0.637 \times 0.997\ \frac{\pi}{4}\ (.025)^2\ \sqrt{2 \times 892 \times 1.189}$$

$$= 0.0143\ \text{kg/s}$$

Air (volume) flow rate, $Q_v = \alpha\ \varepsilon\ \frac{\pi}{4} d^2 \sqrt{\frac{2\ \Delta p}{\rho_u}}$

$$= 0.637 \times 0.997\ \frac{\pi}{4}\ (0.025)^2 \sqrt{\frac{2 \times 892}{1.189}}$$

$$= 0.0121\ \text{m /s}$$

Air velocity in 50 mm pipe $= \frac{Q_v}{\frac{\pi}{4} D^2}$

$$= \frac{0.0121}{\frac{\pi}{4}(0.05)^2}$$

$$= 6.15\ \text{m/s}$$

Reynolds Number (pipe), $R_N = \dfrac{\rho_u \, v \, D}{\mu}$

$$= \frac{1.189 \text{ x } 6.15 \text{ x } 0.05 \text{ x } 10^{6}}{18}$$

$$= 20{,}300$$

On the basis of this number a new value of α can now be read from Figure 5 or calculated from the defining equation .

Thus $\alpha = 0.633$

Air (mass) flow rate, $Q_m = 0.633 \text{ x } 0.997 \dfrac{\pi}{4} (.025)^2 \sqrt{2 \text{ x } 892 \text{ x } 1.189}$

$$= 0.0143 \text{ kg/s}$$

Air (volume) flow rate, $Q_v = \dfrac{Q_m}{r_u}$

$$= \frac{0.0144}{1.189}$$

$$= 0.12 \text{ m}^3\text{/s}$$

The initial values are close to the former ones and so the former are sufficiently accurate, even though they are based on a Reynolds Number that is only half the actual value.

If a second air flow rate was being calculated a better choice of initial Reynolds Number could be made and the initial calculation of the flow rate would be sufficient; a calculation based on a revised value of α would not be necessary.

Using the approximation in Section 2.5 above gives:

$$Q_v = 0.65 d^2 \sqrt{\Delta p}$$

$$= 0.65 \text{ x } (0.025)^2 \sqrt{892}$$

$$= 0.0121 \text{ m}^3\text{/s}$$

4.0 REFERENCES

1. British Standard: Measurement in closed conduits

Part 1 Pressure differential devices

Section 1.1 Orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full BS 1042, 1981

Section 1.4 Guide to the use of devices specified in Sections 1.1 and 1.2 of BS 1042, 1981

2. **British Standard: Fans for General purposes** BS 848 Part 1 1980

5.0 ACKNOWLEDGEMENTS

Permission to copy extracts from BS1042 is gratefully acknowledged.

APPENDIX

ORIFICE PLATE

Figures 1 and 2 shows the details of the orifice plate and its mounting in the air duct. These details and the following clauses are extracted (with permission) from reference 1 above.

The material in *italics* is directly quoted. It has however been modified slightly to refer where appropriate to the orifice plate with D and D/2 tappings. The authors comments are in plain print.

6. INSTALLATION REQUIREMENTS

6.1 General

6.1.1 The method of measurement applies only to fluids flowing through a pipe-line of circular cross section.

6.1.2 The pipe shall run full at the measuring section.

6.1.3 The . . . orifice plate shall be installed in the pipe line at a position such that the flow conditions immediately upstream approach those of a fully developed profile and are free from swirl. Such conditions may be expected to exist if the installation complies with the requirements given in this clause.

6.1.4 The orifice plate shall be fitted between two sections of straight cylindrical pipe of constant cross sectional area in which there is no obstruction or branch connection (whether there is flow into or out of such connection during measurement) other than those specified in this British Standard. The pipe is considered straight when it appears so by visual inspection.

6.1. 5 The values of the pipe diameter to be used in the computation of the diameter ratio shall be the mean of the internal diameter over a length of 0.5D upstream of the upstream pressure tapping

6.1.6 The pipe bore shall be circular over the entire minimum length of straight pipe required. The cross section is taken to be circular if it appears so by mere visual inspection.

6.2 Minimum upstream and downstream straight lengths .

The minimum upstream and downstream lengths of straight pipe are dependant on the nature of the fitting and on the diameter ratio of the orifice plate. These are quoted in the Standard in Tables 3 and 4.

However for orifice plates with diameter ratios (orifice / pipe diameter) in the range 0.5 to 0.65 the minimum length for upstream pipe is in the range of 5 to 20 pipe diameters for 'symmetrical' fittings. A minimum upstream length of 20D would appear to be conservative.

Similarly for orifice plates with diameter ratios (orifice / pipe diameter) in the range 0.5 to 0.65 the minimum length for downstream pipe is in the range of 6 to 7 pipe diameters for all fittings. A minimum downstream length of 10D would appear to be conservative.

7. ORIFICE PLATES

7.1 Description

The axial plane cross-section of the plate is shown in Figure 1.

7.1.1 General shape

7.1.1.1 The part of the plate inside the pipe shall be circular and concentric with the pipe centre line. The faces shall always be flat and parallel.

7.1.2 Upstream face

7.1.2.1 The upstream face shall be flat . . . (See Clause 7.1.3.3)

7.1.2.3 It is useful to provide a distinctive mark which is visible even when the orifice plates is installed to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

It is also useful to show the orifice diameter and the pipe diameter on a part of the plate which is visible even when the orifice plate is installed.

7.1.3 Downstream face

7.1.3.1 The downstream face shall be flat and parallel with the upstream face.

7.1.3.3 The flatness and surface condition of the downstream face can be judged by mere visual inspection.

7.1.4 Thickness E and e

7.1.4.1 The thickness e of the orifice shall be between 0.005D and 0.02D.

7.1.4.3 The thickness E of the orifice plate shall be between e and 0.05D.

7.1.5 Angle of bevel F

7.1.5.1 If the thickness E of the plate exceeds the thickness e of the orifice, the plate shall be beveled on the downstream side. The beveled surface shall be well finished.

7.1.5.2 The angle of bevel F shall be between 30º and 45º.

7.1.6 Edges G,H and I

7.1.6.1 The upstream . . . and downstream edge . . . shall have neither wire edges, nor burrs nor, in general, any peculiarities visible to the naked eye.

7.1.6.2 The upstream edge shall be sharp. . . This requirement can generally be considered as satisfied when the upstream face of the orifice plate is finished by a very fine radial cut from the centre outwards.

7.1.7 Diameter of the orifice

7.1.7.1 The diameter d shall be equal to or greater than 12.5 mm. The ratio β=d/D is always equal to or greater than 0.2 and less than or equal t0 0.75. Within these limits the value of β is chosen by the user to define an orifice plate.

7.1.7.3 The orifice shall be cylindrical and perpendicular to the upstream face.

7.1.9 Material and manufacture

7.1.9.1 The plate can be manufactured of any material and in any way , provided it is and remains in accordance with the foregoing description during flow measurements. In particular the plate should be clean when the measurements are made.

To avoid rusting the use of non-ferrous material such as brass or aluminum for the manufacture of the orifice plate is recommended.

7.2 Pressure tappings

At least one upstream pressure tapping and one downstream pressure tapping shall be provided for each orifice plate.

7.2.1 Shape and diameter of pressure tappings

7.2.1.1 The centre line of the tapping shall meet the pipe centre line (ie, shall be radial) and shall be at right angles to it .

7.2.1.2 At the point of break-through the hole shall be circular. The edges shall be flush with the internal surface of the pipe wall and as sharp as possible. To ensure the elimination of all burrs or wire edges at the inner edge, rounding shall be permitted but shall be kept as small as possible.

7.2.2.3 Conformity of the pressure tappings to the two foregoing sub-clauses can be judged by mere visual inspection.

7.2.1.4 The diameter of the pressure tappings shall be less than 0.08D and preferably less than 12 mm.

7.2.3 Spacing of pressure tappings

7.2.3.4 Orifice plate with D and D/2 tappings (See Figure 2)

The spacing of the upstream pressure tapping is nominally equal to D but may be between 0.9D and 1.1D without modification of the flow coefficient.

The spacing of the downstream pressure tapping is nominally equal to 0.5D but may be between 0.49D and 0.51D without modification of the flow coefficient.

Both are measured from the <u>upstream</u> face of the orifice plate.

To avoid any asymmetrical pressure effects it is convenient to provide 3 or 4 tappings equally spaced around the circumference at both the upstream and downstream locations. These are then joined together with a manifold made from pipe T's and plastic hoze. This arrangement which is in accordance with British Standard 848 Part 1 Clause 22.4.1, provides a mean reading of the pressure across the pipe at each location.
