CODE OF PRACTICE FOR ISO 5167

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PREPARATION OF A CODE OF PRACTICE FOR ISO 5167

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NOTATION

a, b	Constants
C	Orifice-plate discharge coefficient
D	Pipe diameters
D'	Diameters at which orifice is supported
E	Elastic modules
h	Orifice plate thickness
N	Number of data points
p_1	Static pressure at upstream pressure tap
q_m	Mass flowrate
Re_D	Reynolds number based on pipe diameters
Y	Variable defined by equation (1)
Z	Compressibility factor
β	Orifice diameter ratio
Δp	Differential pressure across orifice
$(\Delta p)_y$	Differential pressure corresponding to yield stress of orifice
Δq_m	Error in flow measurement
ΔZ	Difference between computed and measured values of Z.
ε	Expansibility correction
κ	Isentropic exponent
ρ	Density
σ_y	Yield stress of orifice plate material

1 INTRODUCTION

The use of differential pressure meters has been common since the early 1900s and several national and international standards and recommendations have been published since then to provide guidance on how to manufacture and use them. The most recent International Standard on this subject, ISO 5167 (1), was published in 1980. Although it was accepted by all countries except the USA as the best compromise between the various data and opinions proffered from numerous sources, it was also recognised that a number of its recommendations were based on experiments which were not entirely conclusive.

The Standard deals with orifice plates, nozzles and venturis, but it is the first of these which is by far the most frequently used, and one of the areas in which it is particularly dominant is in the metering of natural gas. In the USA alone the value of the gas consumed annually is 50 billion dollars, and in the UK it is 6 billion pounds and it has been calculated by two independent methods that the value of gas unaccounted for in the USA because of metering errors is about $700,000 per day. Again for the USA it has been estimated that over one million orifice plates are in use in industry, and the cost of replacing them would be $10,000 each on average. The widespread interest in orifice metering research and the strenuous efforts made to produce Standards which are universally agreed are therefore fully justified commercially.

2 BACKGROUND TO ISO 5167

The limited information on which the recommendations of ISO 5167 are based is nowhere demonstrated more clearly than in the values used for the discharge coefficients of orifice plates. The formulae from which they are calculated was developed by Stolz (2) in the mid-70s and used data from only two sources: Beitler (3) and Witte (4). Beitler's tests were conducted in a manner well in advance of anything which had previously been done, and great care was taken to document every detail which was considered important. Nevertheless, of the 1000 or so test points, Stolz felt justified in using only 303 since others either lacked vital information or showed evidence of being invalid, eg in some cases the edge sharpness of the plate was recorded as questionable. It was possible to use approximately 300 test points from Witte's data, but confidence in them was diminished by the fact that all of the raw data, and even the derived coefficients themselves, had been lost by 1975. Their use was therefore based on graphs which appeared in publications and on a few points plotted by Ruppel (5).

Many requirements are given in ISO 5167 in connection with the use of orifice plates (the sharpness of the edge, concentricity of the orifice with the pipe, the flatness of the plate, the pipe roughness, the required straight lengths upstream and downstream, accuracy of location of the pressure taps etc) and there are varying degrees of confidence in them, but even where perfection can be clearly defined it is not always known how closely Beitler's or Witte's tests met this, eg Beitler merely stated that for his tests "as near as perfect concentricity was obtained".

Despite all of this there is great confidence in the validity of most of ISO 5167. This stems from a concerted world-wide effort to examine direct and indirect evidence and in many cases the resulting specifications have erred on the side of caution.

3 THE NEED FOR A CODE OF PRACTICE

From the foregoing it will be realised that in many cases it is not possible to identify a single unambiguous reason for the requirements laid down by ISO 5167. Indeed it has been said that many of the compromises arrived at "were built on judgement rather than evidence"(6). One reason for deciding to produce a Code of Practice was therefore to give some explanation of the specifications in the Standard and an indication of the circumstances under which they apply.

Even before ISO 5167 was published it was realised that it contained some ambiguities and guidance which was not as clear as it might be. Rather than delay further the publication of a badly needed document which had already been many years in preparation, it was printed and note taken of sections which required further clarification. More queries quickly emerged as industry began to use the document, and omissions were also notified to be ISO Sub-committee of Technical Committee 30 through member countries. The most striking of these was that no mention whatsoever was made of how to measure the differential pressure generated between the orifice plate tappings.

A third purpose of the Code of Practice was to provide guidance on how some of the constraints of the Standard could be met, eg a limit is given for the extent to which an orifice may deviate from being perfectly flat, but no guidance was provided for how this could be checked under flowing conditions which is vital since the force of the flow can distort the orifice.

For these reasons Working Group 8 of ISO TC30/SC2, the Sub-committee responsible for the preparation of ISO 5167, was created and began work shortly after the SC2 meeting at Braunschweig, Germany in December 1981. Six meetings have been held and a draft which was considered by TC30/SC2 at its last meeting (Gaithersburg, Nov 1983) is now being revised in the light of comments received then and subsequently from member countries. It is expected that this revision will be completed by the end of 1984 and circulated to member countries for comment and discussion at the next meeting of TC30/SC 2, in the latter half of 1985.

The Code is therefore not finalised and so it is an appropriate time to consider at this Workshop the more important features in it in order that comments can be made and taken into account.

4 MAIN FEATURES OF DRAFT CODE OF PRACTICE

The Code concentrates very much on orifice plates; despite requests for contributions on nozzles and venturis virtually nothing has been submitted, reflecting the fact that orifice plates are the main concern in most countries.

Initially it was planned that the Code of Practice would be a separate document, and it was decided that the clause numbering would be the same as in ISO 5167 to enable easy cross-referencing. The wisdom of this is now being debated since comments are not required on every clause of ISO 5167, giving the code numbering a disjointed appearance. In addition some duplication of information already in ISO 5167 is unavoidable if the Code is to be an easily understood, self-contained document. Consideration is therefore being given to the options of including the code as an Appendix to ISO 5167 or inserting the clauses from the Code after the corresponding clauses in the Standard. The need for some form of index in ISO 5167 is recognised and if included also in the code it would assist the user to locate quickly guidance on particular points.

The main technical features of the present draft are summarised here by grouping them into information omitted from ISO 5167, explanations of how to apply ISO 5167, and supplementary information needed to use the Standard.

4.1 Information Omitted From ISO 5167

The lack of any indication in the Standard of the uncertainty associated with flow measurements made in accordance with it was deliberate since there was no guidance on the choice or use of equipment for measuring differential pressure, but the code suggests that ±1 per cent is what could be achieved.

One requirement which had caused uneasiness among users of the Standard had been that any flow straightener used should be preceded and followed by 20D and 22D of straight pipe respectively; this appeared to nullify the whole point of using a straightener, which is to reduce the straight length of pipe required upstream of the flowmeter. The Code explains however that this general requirement is to cover the possibility of any disturbance preceding the flowmeter and goes on to provide fuller details than the Standard on the construction of straighteners. Their head losses are also given, but only for good flow conditions.

On the subject of uncertainty assessment, the relative importance of different sources of error is presented in tabular form, and there is guidance on how to estimate the uncertainty in total flowrate when a number of orifice plates are installed in parallel.

4.2 Explanations of How to Apply ISO 5167

An essential first step in using an orifice plate is to calculate the diameter ratio required since this is dependent on the acceptable pressure loss, the generation of a reasonable differential pressure, and must be such that it lies within the permissible range for the Reynolds numbers which are to be covered. It is necessary to use an iterative procedure to do this; several methods are possible, but some are unnecessarily complex. The Code presents a simple procedure as follows

put

$$Y = \frac{q_m}{\frac{\pi D^2}{4}\sqrt{(2\rho\Delta p)}} \qquad (1)$$

Then, substituting from equation (1) in

$$q_m = \frac{C\varepsilon\beta^2}{\sqrt{(1-\beta^4)}}\,\frac{\pi D^2}{4}\sqrt{(2\rho\Delta p)} \qquad (2)$$

and rearanging after squaring gives:

$$\beta^4 = \left\{1 + \left(\frac{C\varepsilon}{Y}\right)^2\right\}^{-1} \qquad (3)$$

The iterative procedure then becomes:

1 Calculate Y

2 Assume $\beta = 0.5$

3 Calculate $\varepsilon = 1 - (0.41 + 0.35\beta^4)\frac{\Delta p}{\kappa p_1}$

4 Assume C = 0.6

5 Calculate β from equation (3)

6 Calculate Re_D

7 Calculate C from the Stolz equation (using value of β found in step 5)

8 Recalculate ε (using value of β found in step 5)

9 Recalculate β from equation (3) (using C and ε from steps 7 and 8)

Steps 7, 8 and 9 can then be repeated as often as required until successive values of β differ by an acceptably small amount. Normally they will need to be repeated only once.

Similarly a procedure is presented for the calculation of flowrate when the Reynolds number is so low that the discharge coefficient is not independent of the flowrate.

The value used for the maximum permissible eccentricity of an orifice plate relative to the pipe axis, and the method of checking that this is not exceeded, have long been the subject of debate. A recent paper by Norman et al(/) has resolved the dispute about the requirements, and these are presented in the form of a graph which is reproduced here as Fig. 1. A number of diagrams in the Code describe alternative ways of ensuring the eccentricity is within permissible limits.

A further major problem has been the specification that the orifice plate shall be flat. According to the Standard the plate is flat if 'the slope of a straight line connecting any two points of its surface in relation to a plane perpindicular to the centre line is less than 1 per cent', but no guidance is given on how to check if this requirement is met under flowing conditions, and indeed it is only implied in the Standard that the limit applies in flowing conditions and not 'on the bench'. Norman(/) has shown that the relative error in flowrate measurement, $\Delta q_m/q_m$, is given by

$$\frac{\Delta q_m}{q_m} = -\frac{\Delta p}{E}\left(\frac{D'}{h}\right)^2\left(\frac{aD'}{h} - b\right) \qquad (4)$$

where h is the plate thickness,

E is the elastic modulus of the orifice plate material,

D' is the diameter at which the orifice plate is supported, and

a and b are constants given by the following table

β	0.2	0.3	0.4	0.5	0.6	0.7
a	0.021 77	0.027 52	0.029 46	0.028 00	0.024 60	0.018 70
b	1.102 3	0.974 5	0.849 9	0.729 9	0.615 8	0.508 2

He has also shown that if the 1 per cent slope limit applies to the orifice before installation, the resulting errors could range from 0.2 per cent for $\beta = 0.2$ to 0.12 per cent for $\beta = 0.7$. In order to keep errors due to this source under 0.1 per cent for all conditions, the maximum permissible slope on the orifice surface when measured on the bench would have to be about 0.5 per cent. To be safe the Code therefore recommends a limit of 0.1 per cent, and suggests that the plate material, thickness etc is chosen such that the maximum error predicted by equation (4) is 0.1 per cent.

These requirements refer to elastic deformation, but if there is a transient surge in flow it is important to be able to check if an orifice has undergone plastic deformation, since then all subsequent measurements would be in error, even for relatively low differential pressures. The Code provides the information that the differential pressure $(\Delta p)_y$ which will cause plastic deformation is given by

$$(\Delta p)_y = \frac{\sigma_y \left(\frac{h}{D'}\right)^2}{1.5(0.454 - 0.434\beta)} \qquad (5)$$

where σ_y is the yield stress of the orifice-plate material.

For further practical assistance, the materials most commonly used for manufacturing orifice plates are listed together with approximate values of their elastic modulus, yield stress and coefficient of thermal expansion.

4.3 Supplementary Information Required for Using ISO 5167

In addition to the information on orifice-plate materials referred to above, guidance is given on how to determine the physical properties of the fluid being metered. Because orifices are used in such a wide range of applications no attempt is made to provide these data, but instead a list of 21 references is given from which full details of most fluids can be obtained.

An Annex to the Code provides comprehensive advice on the relative merits of various methods of computing the compressibility factor of a gas. This is necessary for the calculation of the density of complex mixtures such as natural gas, and the information provided originates from a study carried out by the Groupe Européen de Recherches Gazières (GERG). The computational methods covered are:

- The method of corresponding states (CSP-BG)
- Methods using Redlich-Kwong equation of state (RKW-GDF, RKW-RG)
- Methods using Benedict-Webb-Rubin equation of state (BWR1, BWR2)
- Methods using AGA NX 19 (AGA NX 19 mod., Br. Korr. 3H).

No method was found to be satisfactory for all gas compositions, the 95 per cent confidence limits of the results obtained ranging from ±0.6 to ±72.8 per cent. Tables are therefore given to indicate which was found to be best for various types of gas. Fig. 2 illustrates the results obtained, which can be seen to be dependent on the calorific value and density of the gas. Acceptability of a method was defined in terms of the root mean square error (RMSE) obtained when the computational results were compared with experimental data, this being defined as

$$\mathrm{RMSE} = \sqrt{\left\{\frac{\Sigma(\Delta Z)^2}{N}\right\}}$$

where ΔZ is the difference between the computed and experimental value of Z, N being the number of data points. The methods were grouped into those which gave an RMSE of less than 0.3 per cent for all the tests on a particular gas and those which could provide this value of RMSE when 50 per cent of the tests were considered.

As noted earlier, a major omission from ISO 5167 was information on the choice and use of auxiliary instrumentation. The Code devotes some 20 pages and 13 tables and figures to this subject, the main topics covered being:

- Pressure measurement. Reference is made to ISO 2186(8), and problems demanding special care are identified as ensuring no false back-pressure is generated, choosing isolating valves, and the use of condensation and gas collecting chambers. Descriptions are given of different types of tranducer.

- Temperature measurement. Purposes of the measurements, dealing with temperature fluctuations, corrections to be applied and precautions to be taken when making measurements.

- Density measurement. Methods of measurement are described and advantages and disadvantages of in-line, bypass and computational methods are given.

In addition there is a section on the general precautions to be followed when installing and using auxiliary instrumentation, with particular reference to difficulties associated with electrical supply and electrical installations. The whole section on instrumentation is supplemented by tables giving the characteristics and ranges of application of various types of different devices, and there are figures to illustrate preferred installation arrangements.

5 CONCLUSION

The Code of Practice is certain to provide valuable support for ISO 5167. Although it is not yet finalised the draft already contains the majority of the information necessary to make the Standard more easily used by those who are not expert in flow measurement using differential pressure meters, and to make it less ambiguous for those who are, or who wish to use it as the basis of a contractual agreement. It has been possible to describe only the main features here, but from them it can be seen that the Working Group has made good progress in a relatively short period of time. Even when it is published it is unlikely that the document will cover everything which a potential user of ISO 5167 will wish to know, but as is always the case with new Standards the quickest way to make progress is to publish, receive comments and then produce a revision to take these into account.

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LIST OF FIGURES

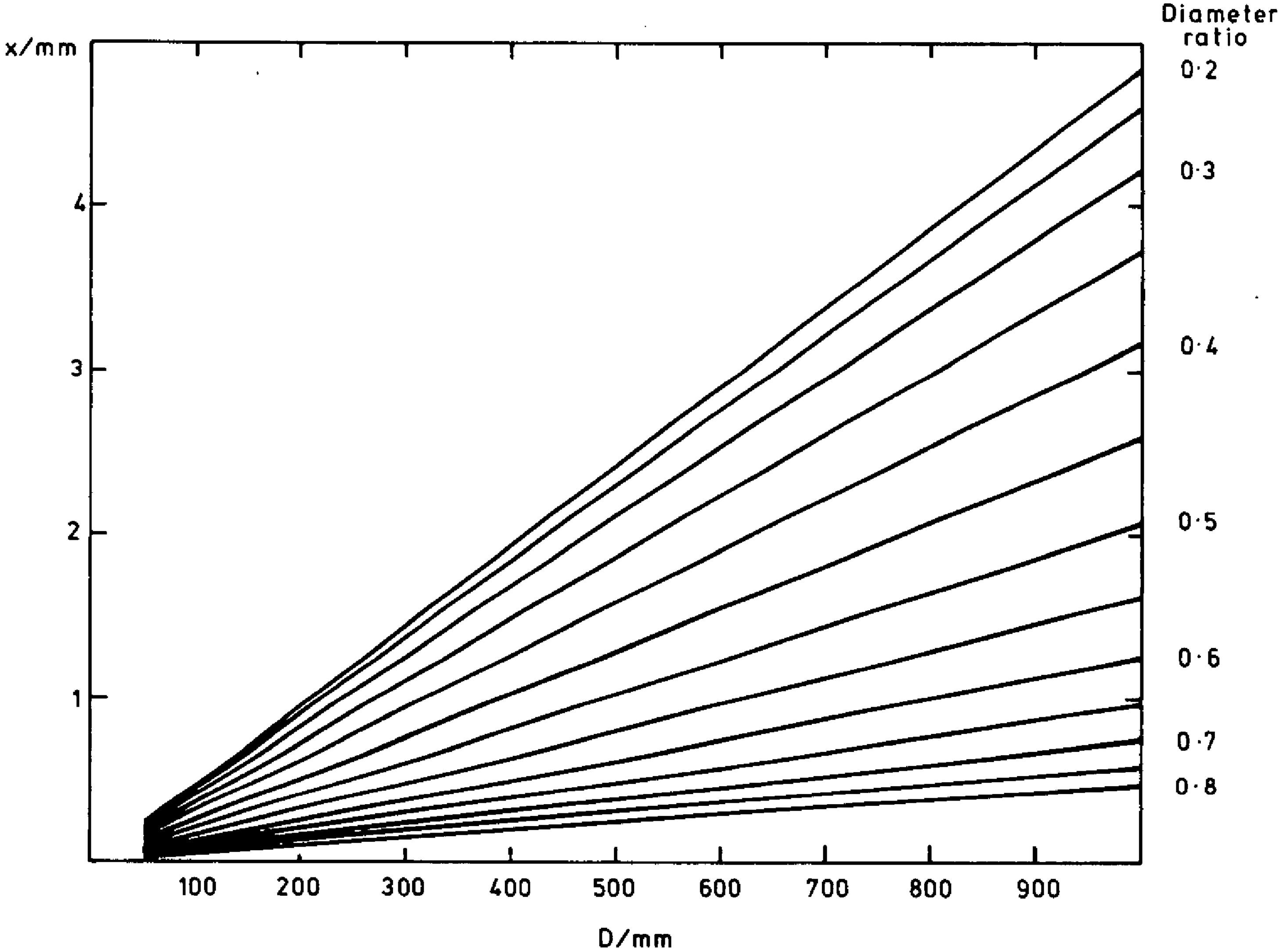
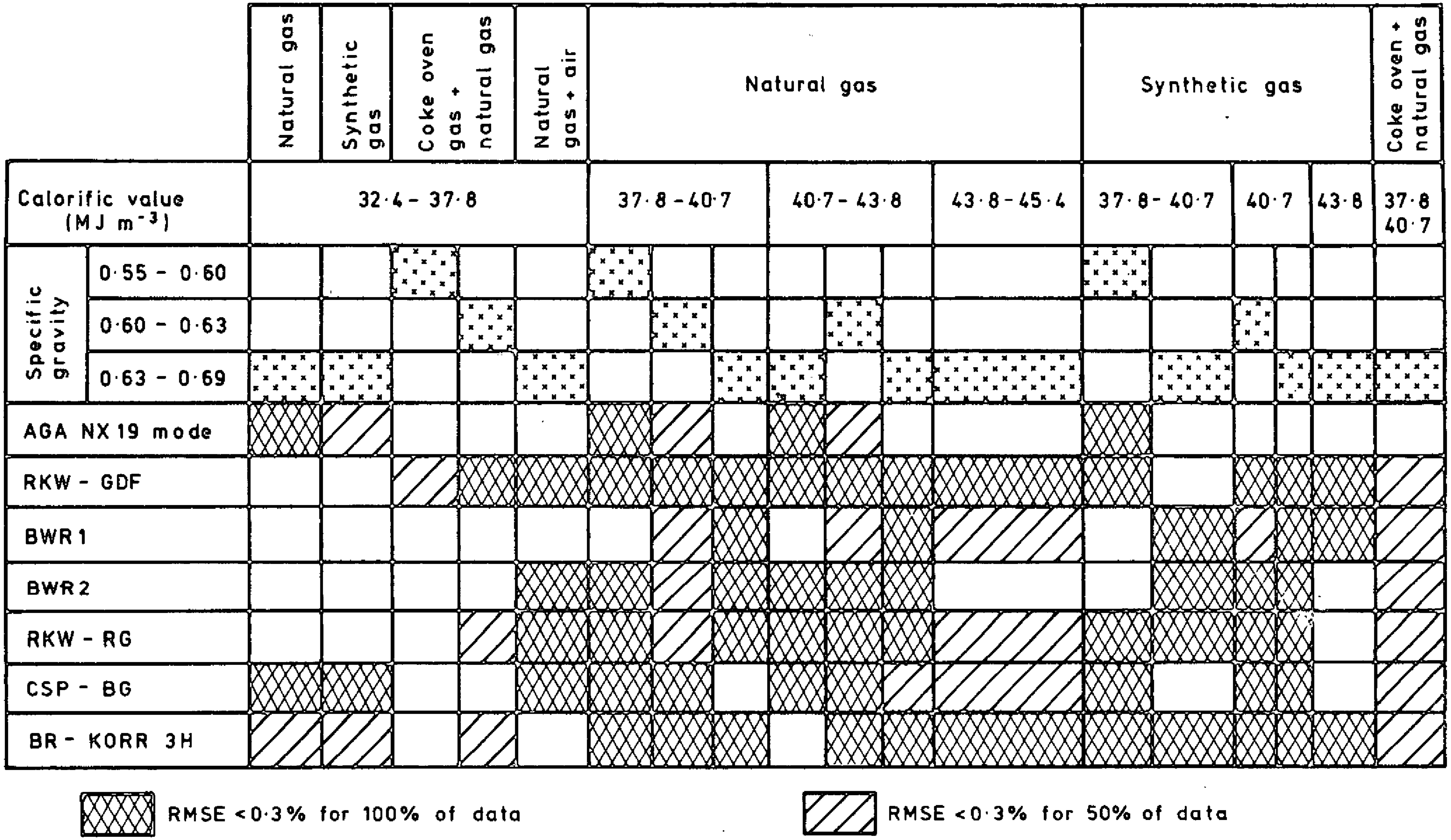


Fig 1 Permitted Distances Between Orifice and Pipe Centre Lines



		Natural gas	Synthetic gas	Coke oven gas + natural gas		Natural gas + air	Natural gas							Synthetic gas					Coke oven + natural gas
Calorific value (MJ m^{-3})		32·4 – 37·8					37·8 – 40·7			40·7 – 43·8			43·8 – 45·4	37·8 – 40·7		40·7		43·8	37·8 40·7
Specific gravity	0·55 – 0·60			⁙			⁙							⁙					
	0·60 – 0·63				⁙			⁙			⁙					⁙			
	0·63 – 0·69	⁙	⁙			⁙			⁙	⁙		⁙	⁙		⁙		⁙	⁙	⁙
AGA NX 19 mode		▩	▨				▩	▨		▩	▨			▩					
RKW - GDF				▨	▩	▩	▩	▩	▩	▩	▩	▩	▩	▩		▩	▩	▩	▨
BWR 1								▨	▩		▨	▩	▨		▩	▨	▩	▩	▨
BWR 2						▩	▩	▨	▩	▩	▩	▩			▩	▩	▩		▨
RKW - RG					▨	▩	▩	▨	▩	▩	▩	▩	▨	▩	▩	▩	▩		▨
CSP - BG		▩	▩			▩	▩	▩		▩	▩	▨	▨	▩		▩	▩		▨
BR - KORR 3H		▨	▨		▨		▩	▩	▩		▩	▩	▩	▩	▩	▩	▩	▩	▨

▩ RMSE <0·3% for 100% of data

▨ RMSE <0·3% for 50% of data

Fig 2 Applicability of Computational Methods for Compressibility