TECHNICAL NOTE

The effects of inlet sharpness on the pipe contraction pressure loss coefficient

P. R. Bullen
Division of Mechanical and Aeronautical Engineering,
The Hatfield Polytechnic, Hatfield, Hertshire, AL10 9AB, UK

D. J. Cheeseman and L. A. Hussain
School of Mechanical, Aeronautical and Production Engineering,
Kingston Polytechnic, Kingston-upon-Thames, Surrey, KT2 6LA, UK

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Pipe contractions occur in heat exchangers at the entrance to tube bundles and in conjunction with enlargements, as ferrules which are often used for the close control of the flow distribution within the tube bundles. These contractions are normally sharp at the commencement of service but suffer erosion or corrosion over the lifetime of the plant. This significantly affects their pressure loss characteristics and upsets the flow distribution. Thus it is important to be able to predict the variation of contraction pressure loss coefficient with variations in the small-bore pipe inlet geometry, referred to as inlet sharpness. There are no known experimental data for the effects of inlet sharpness on the pipe contraction pressure loss coefficient, but there are data for intakes set flush in a plane wall which are used as approximations. Experimental data showing the variation of pressure loss coefficient with the inlet sharpness are presented and compared with the approximate data. The comparison shows significant differences.

Keywords: incompressible pipe flow; pipe contractions; inlet sharpness; loss coefficients

Introduction

The requirements for accuracy in the calculation of pipe contraction pressure loss are greatest when it is a significant component of the overall system pressure drop. This condition is met most commonly when ferrules, comprising a pipe contraction followed by a pipe enlargement, are used to control the flow distribution in a heat exchanger. There is evidence to indicate that the entrance to these ferrules suffers erosion and/or corrosion in service, resulting in changes in their pressure loss characteristics. These changes are often detrimental to plant operation, and it is, therefore, necessary to be able to allow for them in the design of the heat exchanger.

The sharpness of the contraction defined as the percentage rounding of the inlet to the small-bore pipe compared with the diameter of this small-bore pipe, r/d, is of great importance, since any deviation from an absolutely sharp inlet results in a lower loss coefficient. It is important, therefore, to be able to predict the variation of loss coefficient with the inlet sharpness. Previous workers omit to mention its effects, yet design procedures do refer to it.

There have been no known experimental investigations into the effects of inlet sharpness on the pipe contraction pressure loss coefficient. However, the literature contains three reviews and recommendations for design methods to estimate variation of pressure loss coefficient with inlet sharpness. These are Idel'Chick,[1] Miller,[2] and ESDU,[3] who quote data for radiused intakes set flush in a plane wall (i.e. $\sigma=0$); its application to pipe contractions is therefore questionable and would lead to an underestimate of the pressure loss coefficient (a pipe contraction has an additional corner loss associated with it). The comparison in Figure 1 (points transferred from the authors' curves) shows some significant differences. ESDU quotes Miller's data, but there appears to be an inconsistency at lower sharpness values (higher r/d values), which may be due to curve fitting by ESDU.

The need for accurate prediction of pressure loss coefficients for both sharp and rounded contractions and the lack of reliable experimental data has resulted in a program of work at Kingston Polytechnic in collaboration with Babcock Power Limited to determine pipe contraction pressure loss coefficients for a range of flow and geometry conditions. The results reported herein are a supplement to results already published,[4] which concentrated on sharp contractions.

Experimental work

Pipe contraction pressure loss coefficient data for two area ratios of $\sigma=0.209$ and $\sigma=0.521$, for inlet sharpnesses up to

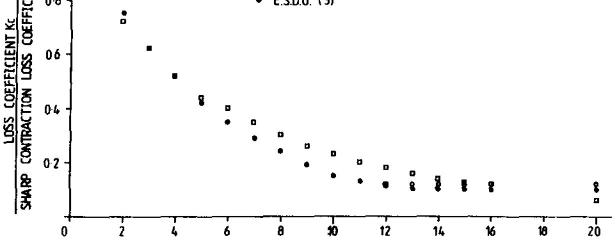

Figure 1 Various published data for radius inlets (area ratio $\sigma=0$)

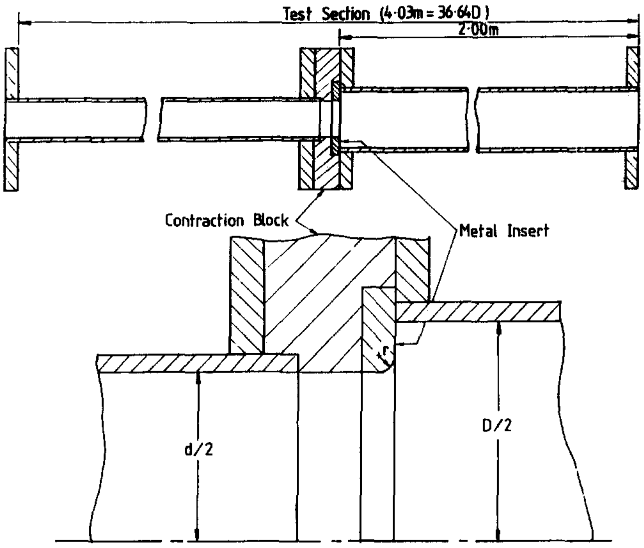

Figure 2 Test section and geometry

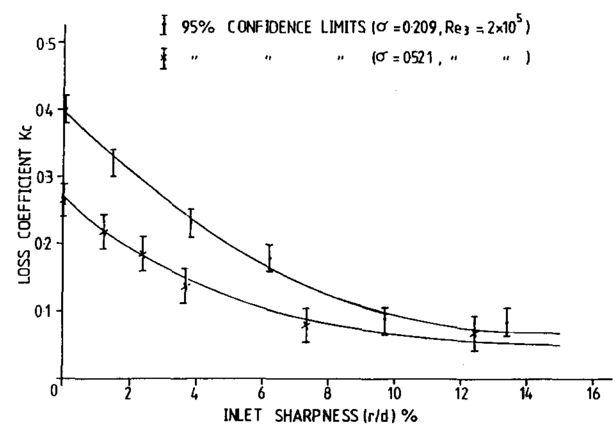

Figure 3 Variation of experimental loss coefficient with inlet sharpness

13.4% and for a range of Reynolds number (based on upstream pipe diameter) of 4×10^4 to 2×10^5 for incompressible flow have been obtained. The experimental detail and the test rig have been fully described in Ref. 4. The test section and geometry are shown in Figure 2. Different area ratios were obtained by changing the contraction block and downstream pipe, maintaining the upstream pipe diameter constant.

Discussion of results

The effects of inlet sharpness on the pipe contraction pressure loss coefficient have been investigated on two area ratios. The results obtained confirm that the loss coefficient is heavily dependent on the inlet sharpness (Figure 3). Initially there is a rapid decrease in the loss coefficient with decreasing sharpness

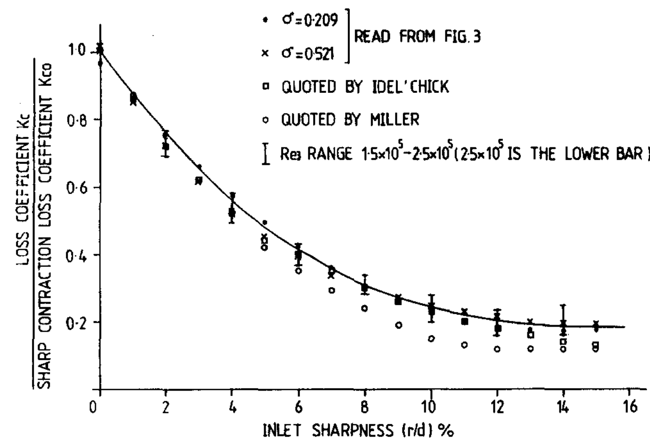

Figure 4 Variation of K_c/K_{co} with inlet sharpness

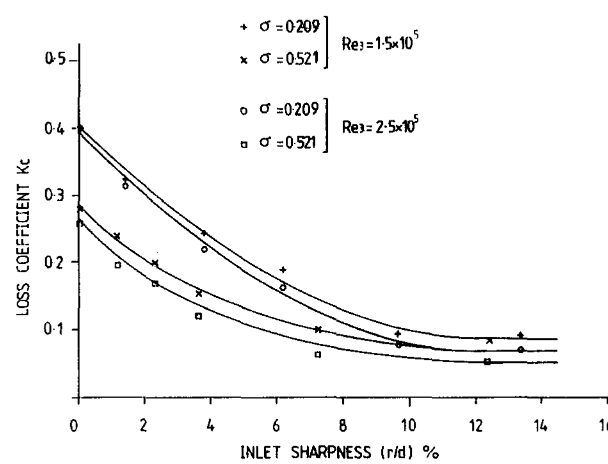

Figure 5 Variation of loss coefficient with area ratio for a sharp contraction ($Re_3 = 2 \times 10^5$)

(increasing r/d). As the sharpness decreases further, the loss coefficient appears to become less dependent on the inlet sharpness and appears to become completely independent for sharpness values less than about 13% ($r/d > 13\%$).

In order to generalize the results of Figure 3, the ratio K_c/K_{co} has been plotted against the inlet sharpness (Figure 4, points taken from Figure 3). The loss coefficient K_{co} for the sharp inlet has been obtained from Ref. 4, Figure 10, reproduced here for completeness as Figure 6. As is apparent from Figure 4, there is good agreement between the two sets of data, confirming that K_c/K_{co} is a reliable parameter. The values quoted by Miller, $\sigma = 0$, are also shown. As expected, these are lower than the experimental values because a pipe contraction has an additional corner loss associated with it, although the trend is similar. The experimental loss coefficient attains a constant value at slightly lower sharpness values compared to Ref. 2. It is also apparent from Figure 4 that our experimental results are in better agreement with Idel'Chicks values than Miller's,

Notation

d	Small-bore pipe diameter
K_c	Contraction pressure loss coefficient
K_{co}	Sharp contraction pressure loss coefficient
r	Contraction inlet radius
Re_3	Reynolds number based on small-bore pipe diameter
σ	Small-bore/large-bore pipe area ratio

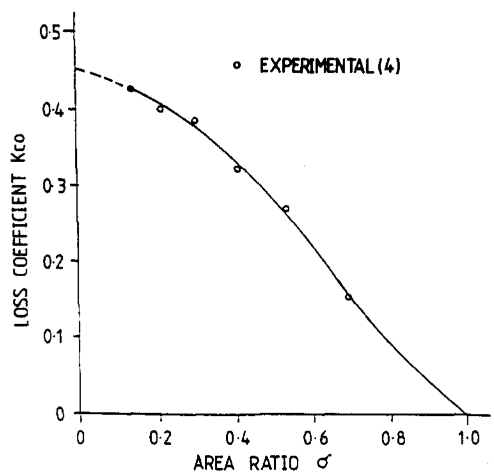

Figure 6 The effect of Reynolds number on the loss coefficient

although both are for area ratios $\sigma=0$. As mentioned in the introduction, these are the only data available for comparison.

The values of loss coefficient, together with an estimate of the experimental uncertainty, are shown in Figure 3 for a Reynolds number of 2×10^5 (based on small-bore pipe diameter). The effect of a variation of Reynolds number (Re_3) between 1.5×10^5 and 2.5×10^5 is shown in Figure 6. As can be seen, a higher Reynolds number decreases the loss coefficient, and a lower Reynolds number increases it for a given area ratio and inlet sharpness. This Reynolds number effect is reduced by using the ratio K_c/K_{co} shown in Figure 4. This figure is, therefore, recommended for design purposes.

Conclusions

1. The inlet sharpness has a significant effect on the pressure loss coefficient. For inlet sharpness up to 3% the ratio K_c/K_{co} decreases at a rate of approximately 0.12 per percentage drop in inlet sharpness.
2. Miller's data appear to be adequate for inlet sharpness up to about 3% but show significant deviations from the experimental data for lower sharpness values, the difference being as high as 56% at an inlet sharpness of 10%. The data compare better at higher Reynolds numbers.
3. Idel'Chick's data show better comparison with the experimental results presented, over the whole range tested.

Acknowledgments

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