# Paper 12

# Ageing Effects on Orifice Metering

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# AGEING EFFECTS ON ORIFICE METERING

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## 1 INTRODUCTION

Orifice plate flowmeters are affected by upstream installation. This paper describes the effect of some changes to the installation which occur with time after the orifice plate is installed. Orifice plates require a significant upstream straight length of pipework, and one way of reducing the required upstream straight length is to use a flow conditioner. Although the former ISO 5167-1:1991 [1] did not encourage the use of flow conditioners to a great extent, the new version does: see ISO 5167-1: 2003 [2] and ISO 5167-2: 2003 [3]. However, the sharp edges of a perforated plate flow conditioner may become rounded or a perforated plate flow conditioner may with time become partially blocked. Whereas orifice plates are regularly checked in service, flow conditioners are much less frequently checked. Therefore the first set of tests assessed the effects of rounding the upstream edge of a Zanker Flow Conditioner Plate and of blocking a row of holes in the plate. The Zanker Flow Conditioner Plate was chosen as it is not patented and of the unpatented conditioners included in ISO 5167-2: 2003 it gives the shortest upstream lengths.

A second problem is that the inside of the pipe upstream of the orifice plate may roughen in service. Whereas the effect of rough pipe on an orifice plate is well known if the roughness is uniform round the pipe, often in practice the pipe only roughens over the bottom quarter of the pipe. The second set of tests assessed the effects of rough sandpaper (actually silicon carbide paper, commonly called wet and dry paper) attached to the bottom quarter of the pipe, of the same rough sandpaper attached to half of the pipe, and of the same rough sandpaper attached to the whole pipe.

In addition to work on the effects of ageing, additional work is presented here to examine whether shorter lengths upstream of orifice plates can be obtained by using a chamfered Zanker Flow Conditioner Plate or a Spearman Flow Conditioner rather than a Zanker Flow Conditioner Plate.

## 2 THE EFFECT OF DAMAGED FLOW CONDITIONERS ON AN ORIFICE PLATE

### 2.1 The orifice meter and the upstream pipework

A 100 mm (4-inch) meter with two pairs of corner and two pairs of flange tappings was used to collect the required data. The two pairs of corner tappings lay in a single plane, which was perpendicular to the single plane in which the two pairs of flange tappings lay (as shown in Figure 3d). The orifice meter and its upstream pipework were Schedule 40, with all the upstream pipes machined (and in most cases honed) so that they were very close in diameter to the orifice meter itself. The orifice meter had a measured internal diameter of 102.28 mm and a length from the orifice plate to the first flange upstream or downstream of 5*D*. The upstream pipes were dowelled to ensure that they were concentric with each other and with the meter itself.

## 2.2 The data collected

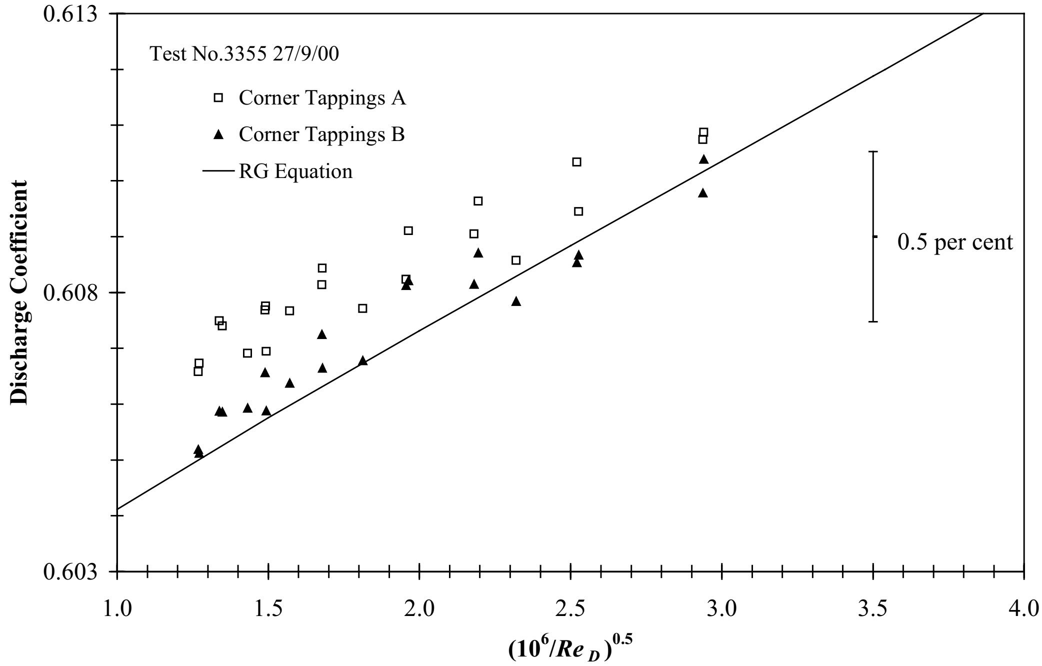


**Figure 1. Baseline data for $\beta = 0.67$ using corner tappings**

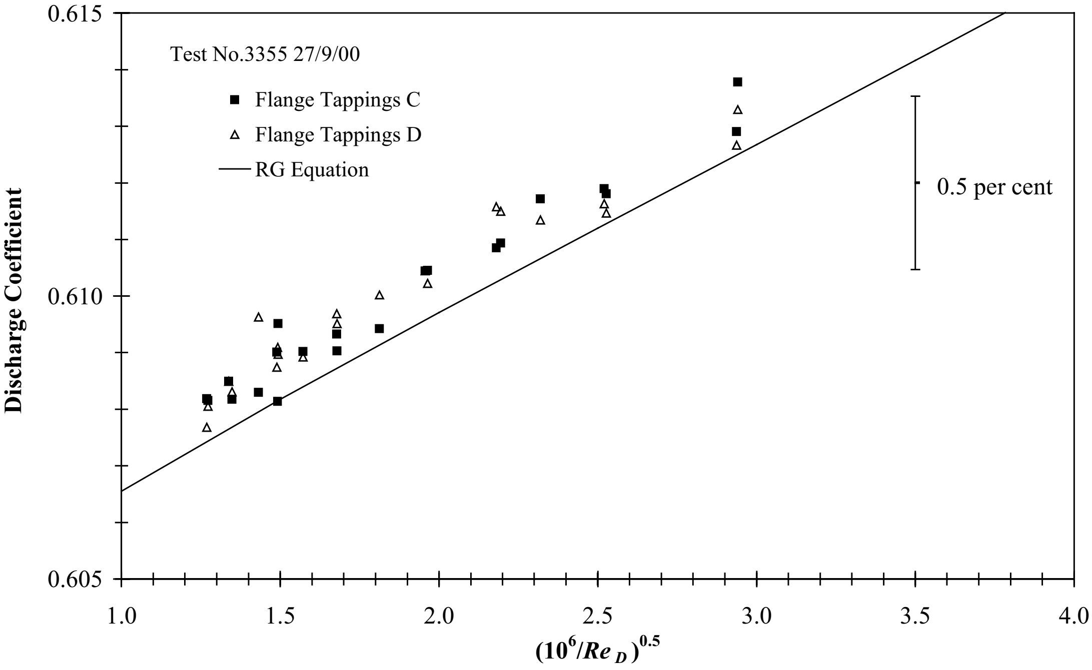
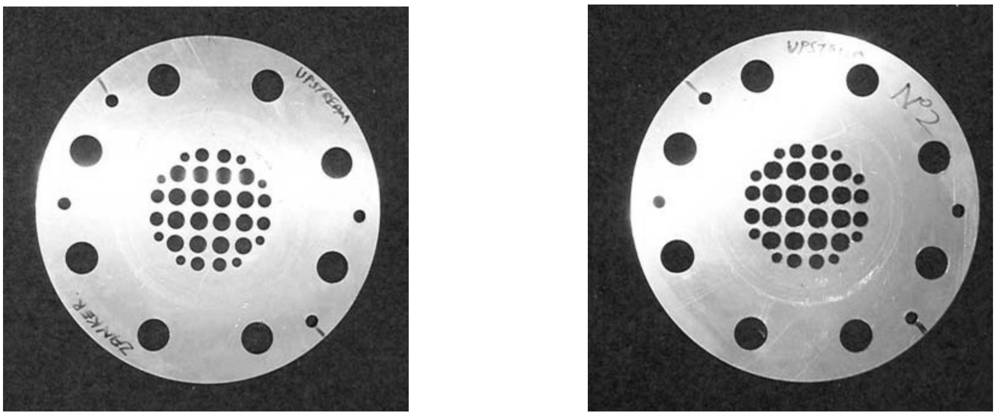


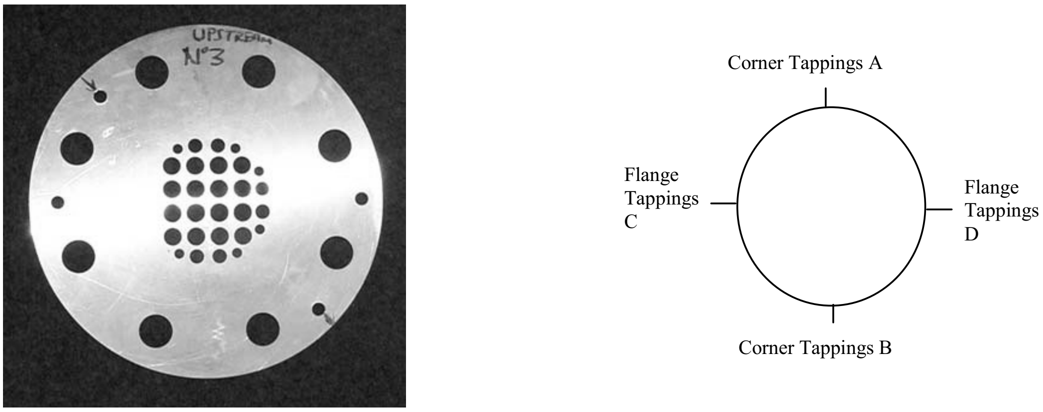
**Figure 2. Baseline data for $\beta = 0.67$ using flange tappings**

The data were collected in water in NEL's national standard large water flow facility over a pipe Reynolds number range of approximately $10^5$ to $6 \times 10^5$. The data were collected with an orifice plate of $\beta = 0.67$. The reason for doing this was that the effect of upstream pipework installations on orifice plates is proportional to $\beta^{3.5}$ provided that the flow is non-swirling; this can be seen for example from Reference 4 and from the Computational Fluid Dynamics referred to in Reference 5 and indeed from the discharge coefficient equation itself [3]: the pipe Reynolds number term is proportional to $\beta^{3.5}$ because it is essentially a velocity profile term. A value of 0.67 for $\beta$ is required for the compliance test on flow conditioners in ISO 5167-1: 2003. Data were collected using water/air and water/mercury manometers.

The baselines shown in Figures 1 and 2 were collected with 46*D* of honed pipe upstream of the orifice plate preceded by 39*D* of pipe of Schedule 10 preceded by a tube bundle flow conditioner. The baseline data in Figures 1 and 2 are shown together with the discharge coefficient equation as given in ISO 5167-2: 2003. Later, a second baseline was run. This time the same 46*D* of honed pipe was placed upstream of the orifice plate, but this time it was preceded by another 29*D* of pipe of Schedule 40 preceded by a short length of Schedule 10 preceded by the same tube bundle flow conditioner. The differences from the original baseline were small and will be quantified later. So the mean of the original and the final baselines (by averaging the coefficients of the fitted lines) was used as the overall baseline.



a) Zanker Flow Conditioner Plate b) Chamfered Zanker Flow Conditioner Plate



c) Partially blocked Zanker Flow Conditioner Plate d) Pressure tapping locations

**Figure 3 The flow conditioners and pressure tapping locations (viewed from upstream)**

After the initial baselines were run the orifice plate was calibrated downstream of a Zanker Flow Conditioner Plate which is in accordance with ISO 5167-2: 2003 and, subsequently, downstream of two modified Zanker Flow Conditioner Plates in turn. The Zanker Flow Conditioner Plates were preceded by 41*D* of honed pipe (as described in 2.1) preceded by additional 4-inch pipe of Schedule 10 preceded by a tube bundle flow conditioner. The flow conditioners were installed 8*D* upstream of the orifice plate since, following ISO 5167-2: 2003, this is approximately the closest permissible location to the orifice plate and so modifications to the conditioner are likely to have particularly large effects. The first modification tested was a 1 mm 45° chamfer on the upstream side of each hole, to simulate erosion. The average hole size was a little less than 12 mm. The second modification tested was to use a plate in which an outside row of 4 holes in the standard drawing of the Plate (e.g. in Fig. 10 of ISO 5167-2: 2003) was not drilled, to simulate a row of holes blocked by debris. The undrilled row was adjacent to Flange Tappings C. The flow conditioners are shown in Figure 3, which also shows the orientation of the flow conditioners relative to the pressure tappings.

To illustrate the method of analysis the data collected with a standard Zanker Flow Conditioner Plate 8*D* upstream of the orifice plate are shown in Figures 4 and 5. The mean value of $(10^6/Re_D)^{0.5}$ for this installation is 1.939 and is marked on each figure; this value gives the minimum uncertainty for that line fit. The difference between the fitted line for the installation at this value of $(10^6/Re_D)^{0.5}$ and the baseline is evaluated, first for each pair of tappings and then for the mean of the pairs of tappings, and considered to be the shift for this installation. The difference for each pair of tappings is marked on Figures 4 and 5 (in this case $\Delta C$ is negative). Using the same method the difference between the subsequent and the original baselines was evaluated: the mean of the differences for each of the four pairs of tappings is -0.005 per cent.

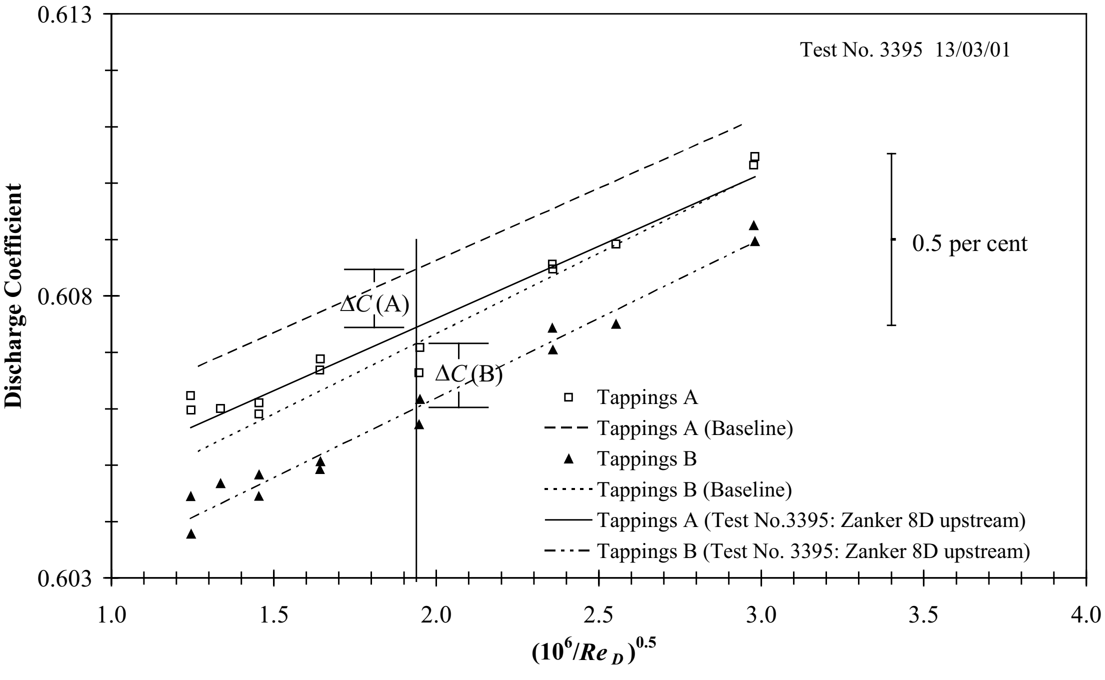


**Figure 4. Data with Zanker flow conditioner plate 8*D* upstream of the orifice plate ($\beta$ = 0.67) using corner tappings**

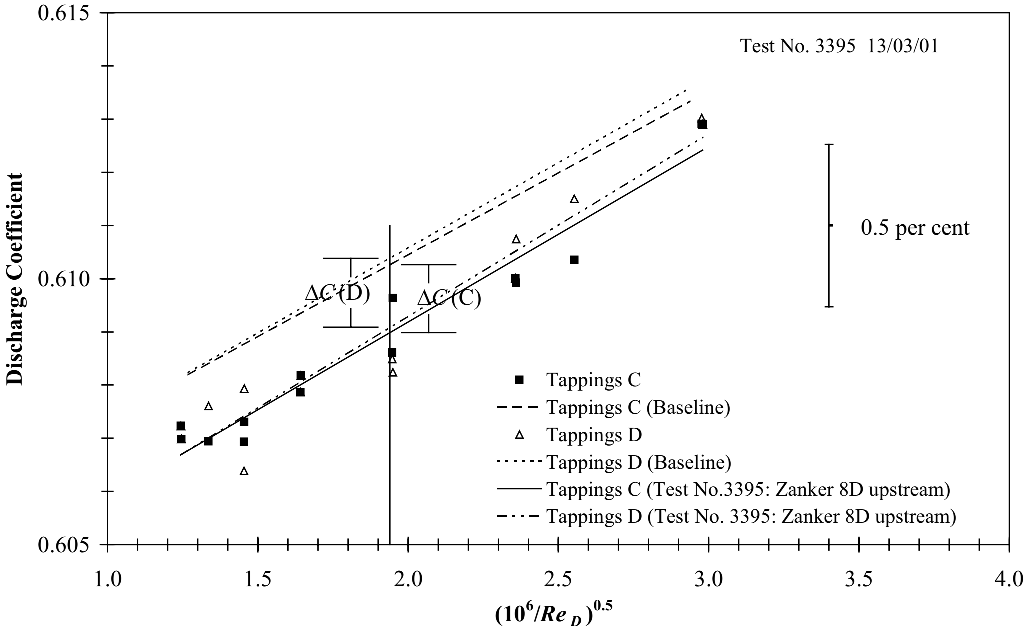


**Figure 5. Data with Zanker flow conditioner plate 8$D$ upstream of the orifice plate ($\beta$ = 0.67) using flange tappings**

The shifts in discharge coefficient with the Zanker Flow Conditioner Plate and the two modified versions of the plate were evaluated as described above and are given in Figure 6. It is clear that partially blocking a plate has a much larger effect than chamfering it, even though the chamfer was quite large. In fact, because the chamfer had a beneficial effect, further work was done (and is described later in this paper) on the use of chamfered Zanker Flow Conditioner Plates.

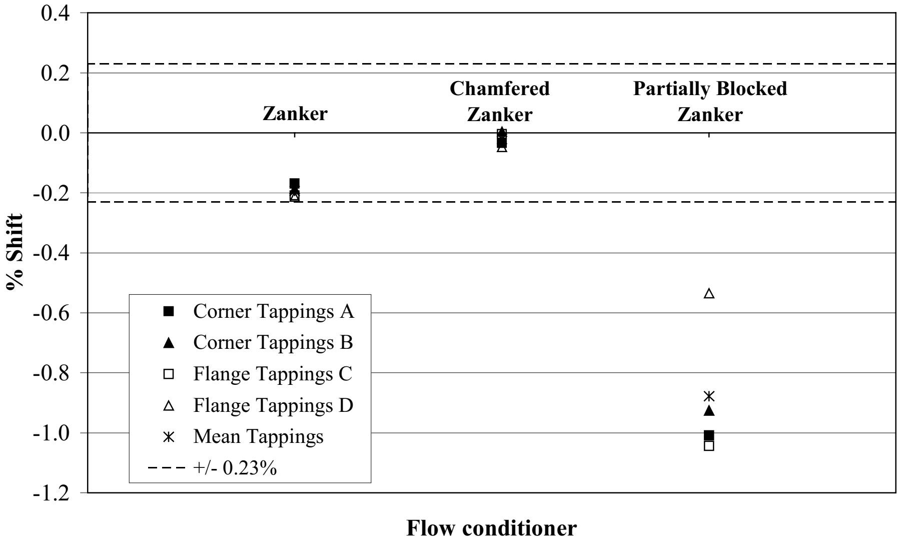


**Figure 6. Effect of damage to a Zanker flow conditioner plate 8$D$ upstream of an orifice plate ($\beta$ = 0.67)**

The uncertainty of the shifts in discharge coefficient for a single pair of tappings is 0.082 per cent. Where there is no significant difference between the different pairs of tappings and the mean values are the best estimate of the shift for all tappings, the uncertainty of the shifts in discharge coefficient using the mean of four pairs of tappings is 0.055 per cent.

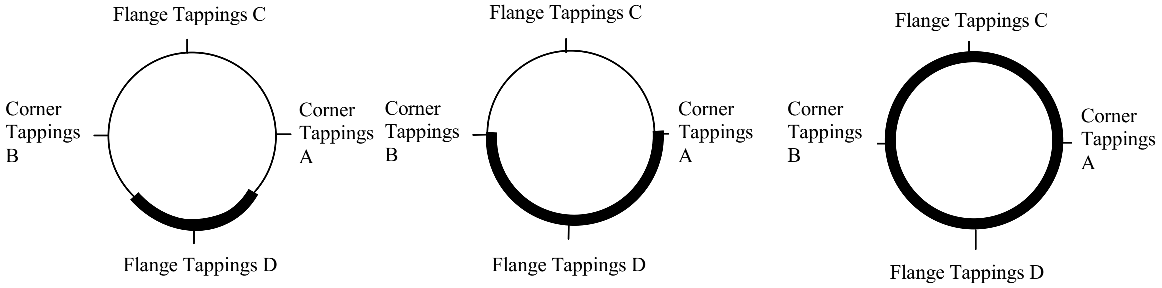
## 3 THE EFFECT OF ROUGH PIPEWORK UPSTREAM OF AN ORIFICE PLATE

One common problem in flow measurement is roughening of the pipework. There have been several papers which have considered this problem, e.g. References 6, 4, 7 and 8. Reference 7 shows that

$$\Delta C = 3.5\beta^{3.5}\Delta\lambda, \tag{1}$$

where $\Delta C$ is the shift in discharge coefficient and $\Delta\lambda$ is the change in friction factor (see Schlichting [9]). The data have a large scatter about this equation, partly because generally $\Delta\lambda$ is not measured directly. It is often calculated from measured values of roughness. All this work only applies for roughness which is uniform round the pipe. In practice roughness is often non-uniform, because in gas pipelines liquid is particularly present on the bottom of the pipe.

Video recordings of the inside of 10-inch pipes (230 mm ID) were kindly lent by BP Amoco, and from these it was concluded that it would not be unreasonable to assume that values of roughness height $k$ of the order of 0.5 mm would be possible. To achieve the same relative roughness in a 100 mm pipe gives $k$ of the order of 0.2 mm. This corresponds to a P80 Sandpaper (actually silicon carbide paper, commonly called wet and dry paper) with a grain size of 197 μm. It was decided to work also with a smoother sandpaper (P240) with a grain size of 60 μm. Sandpaper of each roughness was obtained and glued to the inside of the pipe from ½$D$ upstream of the orifice plate to 10$D$ upstream of it. Generally the discharge coefficient is largely affected by the pipe roughness over the 10$D$ upstream of the orifice plate, and it was necessary to leave 25 mm clean upstream of the flange tappings as the sandpaper was simply glued to the surface. Flange Tappings D were at the bottom of the pipe (see Figure 7) and except where the whole pipe was rough the sandpaper was at the bottom of the pipe and symmetrical about the bottom of the pipe. It was not simple to ensure that the sandpaper remained stuck to the surface, but with the rougher sandpaper data were obtained in which the sandpaper remained satisfactorily stuck to the walls. The smoother sandpaper was generally weaker, and so in addition to the tendency to become unstuck it also became wavy in use, and no satisfactory data could be obtained.



**a) Quarter pipe roughened b) Half pipe roughened c) Whole pipe roughened**

**Figure 7 Roughened portions of pipes relative to the pressure tappings**

The data obtained with the rougher sandpaper are presented in Figure 8. It is interesting that similar data are obtained with each pair of tappings and that the shift is approximately proportional to the fraction of the pipe which is rough. According to Equation (1) for uniformly rough pipe the predicted shift in discharge coefficient at $Re_D = 2.74 \times 10^5$ was 1.26 per cent, using the Colebrook-White Equation [9] to determine the friction factor and assuming that the smooth pipe had $R_a = 0.8$ μm and that $k = \pi R_a$. Additionally it would be expected that for entirely rough pipe the thickness of the roughness elements and the paper might increase the shift in discharge coefficient by 0.4 per cent. So the measured shift in discharge coefficient of 1.98 per cent compares quite well with the predicted value of 1.66 per cent.

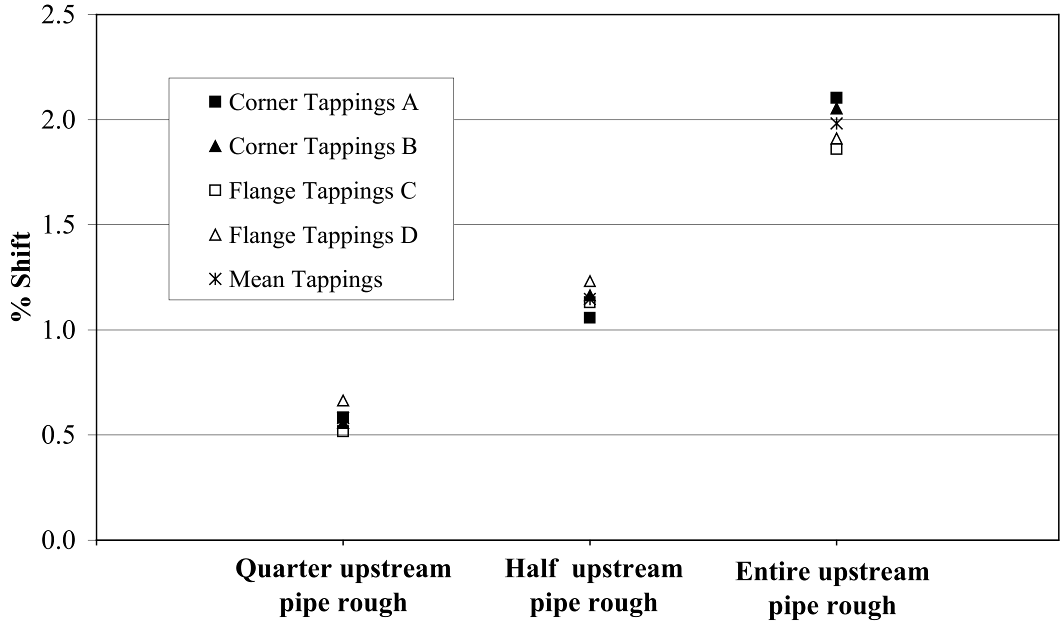


**Figure 8. Effect of rough pipe upstream of an orifice plate ($\beta = 0.67$).**

## 4 REDUCED UPSTREAM STRAIGHT LENGTHS

### 4.1 The compliance test

Instead of requiring the use of particular flow conditioners ISO 5167-1: 2003 contains a compliance test so that if a flow conditioner provides sufficiently small shifts in discharge coefficient downstream of certain major flow disturbers then it can be used with the same type of primary device downstream of any upstream fitting. Once the compliance test has been met the flow conditioner can be used with a primary device with any value of $\beta$ up to 0.67 without increasing the uncertainty of the discharge coefficient to take account of the installation. Additional test work is required if $\beta$ is to exceed 0.67. The ranges of distances, expressed in terms of numbers of pipe diameters, between the flow conditioner and the primary device and between the upstream fitting and the flow conditioner which are used in the tests determine the acceptable ranges of distances when the flowmeter is used. Most of the test work is undertaken for $\beta = 0.67$ on the basis that if a flow conditioner performs successfully for $\beta = 0.67$ it will perform successfully for smaller $\beta$. This is certainly true in non-swirling flow. However this is not necessarily true for high swirl; so the test in high swirl is also performed for $\beta = 0.4$, as, for an orifice plate at any rate, the effect of high swirl is greater for $\beta = 0.4$ than for $\beta = 0.67$. A complete description of the compliance test will be found in ISO 5167-1: 2003.

### 4.2 Chamfered Zanker Flow Conditioner Plate and Orifice Plate

Because the chamfered Zanker Flow Conditioner Plate (with a 1 mm chamfer on each hole on a 102 mm plate) gave a very small shift in discharge coefficient from that obtained in a long straight pipe when the Zanker Plate was installed in good flow conditions 8*D* upstream of the orifice plate, it was decided to install the same chamfered Zanker Plate in good flow conditions 5*D* and 12*D* upstream of the orifice plate. The data are excellent, and the calculated shifts in discharge coefficient for the chamfered Zanker Flow Conditioner Plate in good flow conditions over a range of distances from the orifice plate are given in Figure 9. There was the possibility that the chamfered Zanker Flow Conditioner Plate might give better performance than the Zanker Flow Conditioner Plate in its unmodified form.

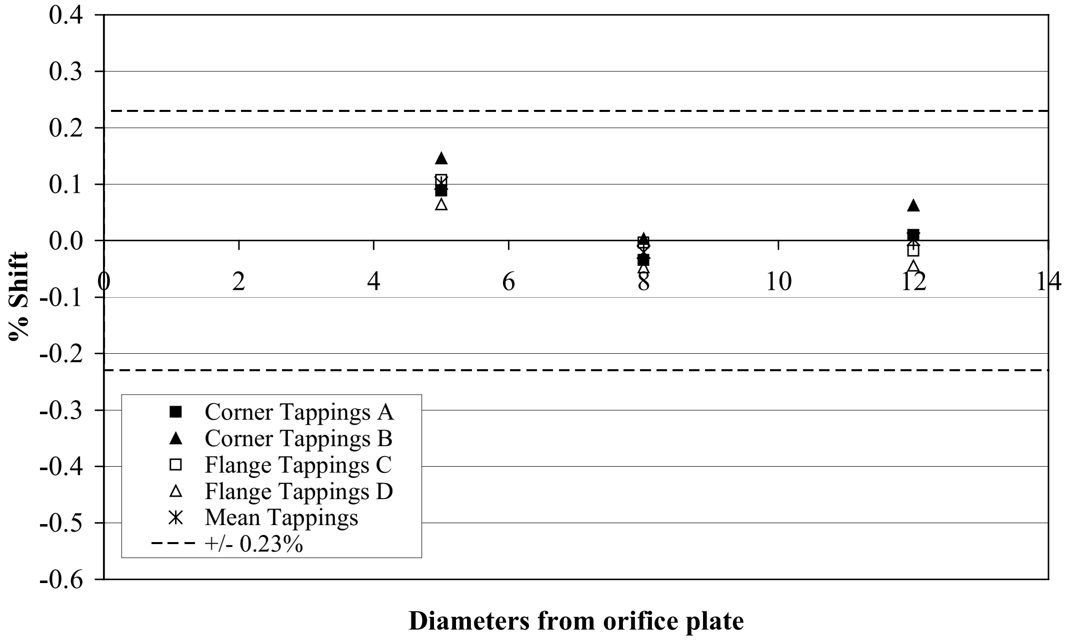


**Figure 9. Effect of chamfered Zanker Flow Conditioner Plate upstream of an orifice plate ($\beta = 0.67$) in good flow conditions**

On the basis of such good data it was necessary to collect additional data with a chamfered Zanker Flow Conditioner Plate in disturbed flow conditions. To meet the compliance test the first upstream flow disturber to be used was a D-shaped plate. The D-shaped plate was of thickness 3 mm with a 1.5 mm chamfer on its downstream face. Flange Tappings D were in the same angular position in the pipe as the middle of the circumference of the open portion of the D on the wall. The calculated shifts in discharge coefficient for the chamfered Zanker Flow Conditioner Plate downstream of the D-shaped plate over a range of distances from the orifice plate are given in Figure 10. The phrase 'Conditioner at *xD*' means that the conditioner is located *xD* from the orifice plate. Since an overall distance of only 17*D* from upstream fitting to orifice plate is required with a Zanker Flow Conditioner Plate [3, 10] there was no point in pursuing work with the chamfered Zanker Flow Conditioner Plate and orifice plate further.

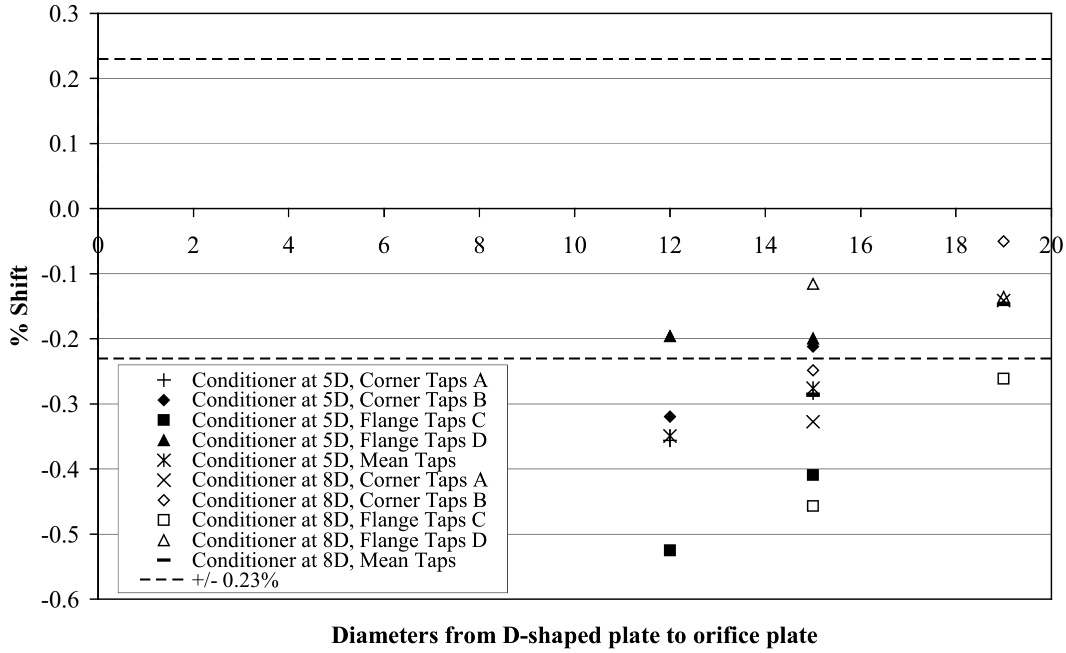


**Figure 10. Effect of Chamfered Zanker Flow Conditioner Plate in asymmetric flow conditions on an orifice plate ($\beta = 0.67$).**

### 4.3 Spearman Flow Conditioner and Orifice Plate

Another device which might reduce the required straight length upstream of orifice plates is the Spearman Flow Conditioner. The orifice plate was calibrated downstream of a Spearman Flow Conditioner which is in accordance with ISO 5167-2: 2003. The orifice plate was preceded by 46*D* of honed pipe preceded by additional 4-inch pipe of Schedule 10 preceded by a tube bundle flow conditioner. The Spearman Flow Conditioner was installed within the honed section at distances 5*D*, 9*D*, and 14*D* upstream of the orifice plate.

The calculated shifts in discharge coefficient for the Spearman Flow Conditioner in good flow conditions over a range of distances from the orifice plate are given in Figure 11. Although the Spearman Flow Conditioner performs quite well 5*D* upstream of the orifice plate, its failures (albeit small) 9*D* and 14*D* upstream of the orifice plate imply that it does not provide velocity and turbulence profiles sufficiently close to fully developed and tending asymptotically to them until a distance greater than 14*D* has passed. Since an overall distance of only 17*D* from upstream fitting to orifice plate is required with a Zanker Flow Conditioner Plate there was no point in pursuing work with the Spearman Flow Conditioner and orifice plate further.

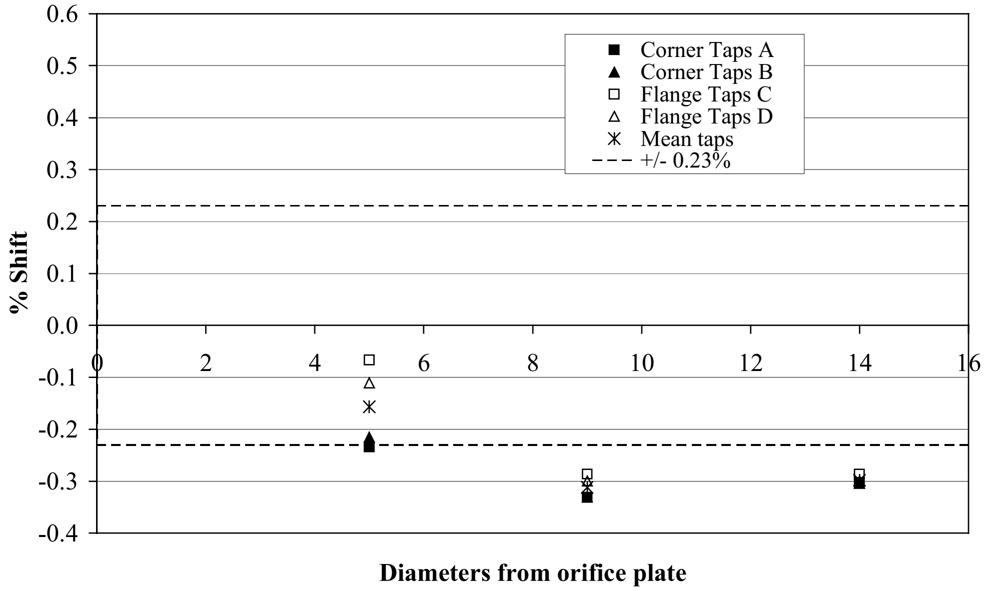


**Figure 11. Effect of a Spearman flow conditioner upstream of an orifice plate ($\beta = 0.67$) in good flow conditions**

## 5 CONCLUSIONS

The effect of damage to a perforated plate on an orifice plate discharge coefficient has been measured by installing two damaged Zanker Flow Conditioner Plates in turn upstream of an orifice plate. Chamfering a Zanker Flow Conditioner Plate has much less effect on the discharge coefficient than blocking a row of holes.

The effect of roughening a quarter, a half or the whole of the pipe upstream of an orifice plate has been measured. The shift in discharge coefficient is approximately proportional to the fraction of the pipe which is rough.

Test work has been undertaken to establish the required upstream lengths when a flow conditioner is installed upstream of an orifice plate. In the context of the work on ageing of flow conditioners a chamfered Zanker Flow Conditioner Plate appeared to have potential to be a good flow conditioner. Data were collected, and its performance with an orifice plate was inferior to that of a Zanker Flow Conditioner Plate. A Spearman Perforated Plate was tested upstream of an orifice plate. Its performance with an orifice plate was also inferior to that of a Zanker Flow Conditioner Plate.

## ACKNOWLEDGEMENTS

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The loan of video recordings of the inside of 10-inch pipes by BP Amoco is gratefully acknowledged.

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## NOTATION

| | | |
|---|---|---|
| $C$ | Discharge coefficient | - |
| $\Delta C$ | Shift in discharge coefficient | - |
| $D$ | Diameter of upstream pipe | m |
| $k$ | Pipe roughness (height of sand grain) | m |
| $R_a$ | Arithmetical mean deviation of the roughness profile | m |
| $Re_D$ | Pipe Reynolds number $\left(=\frac{4Q}{\pi D \nu}\right)$ | - |
| $\beta$ | Diameter ratio (= $d/D$) | - |
| $\lambda$ | Friction factor | - |

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