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DEVELOPMENT OF A FLOW CONDITIONER

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ABSTRACT

This paper gives a review of the major activities of the systematic process to develop a flow conditioner (FC) which can be used to reduce the required length of an orifice metering station.

A theoretical design procedure for the development of a FC is presented together with the main findings from experiments performed in test rigs using air at atmospheric pressure and natural gas at high pressure. Orifice meter discharge coefficient (Cd) measurements at 100 bar in natural gas show that Short Metering Systems (SMS) of 15D with the Mark 5 FC installed have very good performance.

NOMENCLATURE

A : Cross section area [m^2]
a : Hole diameter [mm]
Cd : Discharge coefficient [-]
D : Internal pipe diameter [m]
K : Pressure loss coefficient []
n : Number of holes []
m : Number of area rings []
P : Pressure [Pa]
R : Pipe radius or ring radius [mm]
Re : Reynolds number [-]
U : Axial velocity [m/s]
Y : radial position referred to the wall [m]
β : Diameter ratio of the orifice meter [-]
Φ : Ratio of the flow area in vena contracta to the pipe area [-]
λ : Porosity [-]
ρ : Density [kg/m^3]

subscripts:

i : Ring number
m : Mean value
o : Stagnation value
vc : Vena contracta

1. INTRODUCTION

1.1 BACKGROUND

For over sixty years, the concentric orifice meter has remained the predominant meter for natural gas metering applications. Even if more modern flowmeters appear on the market, orifice meters continue to be a preferred choice by many users because of the simple technology, the existence of well-known standards and the long experience with the meters. Unfortunately, the accuracy of an orifice meter is affected by flow perturbances, especially swirl, and even 100D may not be enough to fulfil the ISO-5167 requirement of less than +/- 2° swirl (ref. 1).

Orifice metering stations offshore are very heavy and expensive installations because of the long upstream pipelength that are required in ISO-5167 (ref. 2). Therefore a lot of effort is put into developing FCs that can reduce the upstream length required to eliminate swirl and develop a fully developed velocity profile. A review of the work done so far is presented by Gallagher and Beaty (ref. 3).

K-Lab has since 1987 co-operated with IFE and University of Salford on the development of a series of FCs. This paper deals only with the development of the Mark series of FC and testing at IFE and K-Lab.

The development was inspired by section 7.4 of ISO-5167. This section states that if the flow conditions immediately upstream of the primary device can be demonstrated to sufficiently approach those of a fully developed velocity profile (within +/- 5%) and be free from swirl (within +/- 2°), then the uncertainty range claimed by the standard remains applicable. It was decided to attempt to design a new FC to reach this condition within 15D downstream of a flow disturbance, independently of the velocity and swirl profiles existing upstream of the FC.

1.2 GOALS FOR THE FC DEVELOPMENT

In the early days of the project, the following goals were listed :

The new FC should :

- Eliminate swirl (within +/- 2°).
- Generate a fully developed velocity profile (within +/- 5%) maximum 15D downstream of the flow perturbance.
- Give low pressure drop across the FC.
- Be simple and cheap to manufacture.
- Give similar or better measurement accuracy compared to a standard ISO-5167 installation.

1.3 DEVELOPMENT PROGRAM

When the design objectives for the FC development were identified, a research plan with several activities was established. The main ones are listed below :

- Develop a theoretical model for the design of the FCs.
- Manufacture FCs according to the theoretical model.
- Test the FCs in air at atmospheric pressure.
- Develop a tool to measure velocity and swirl (swirl probe) which can be used in natural gas at North Sea conditions (up to 150 bar).
- Test the FC in natural gas at high pressure.
- Acquire orifice meter performance data (Cd) in natural gas at high pressure.
- Make a result database for FCs.
- Obtain general acceptance for the technology.

2. DESIGN OF THE FLOW CONDITIONERS

2.1 A THEORETICAL DESIGN MODEL

Initially a simple theoretical model for the flow through the holes in the FC was established. Based on formulas deducted from his theory and some practical modifications the new FC was designed.

A design procedure for the FCs is presented below. It is based on a simplified theoretical model which calculates the pressure loss through the holes in the FC.

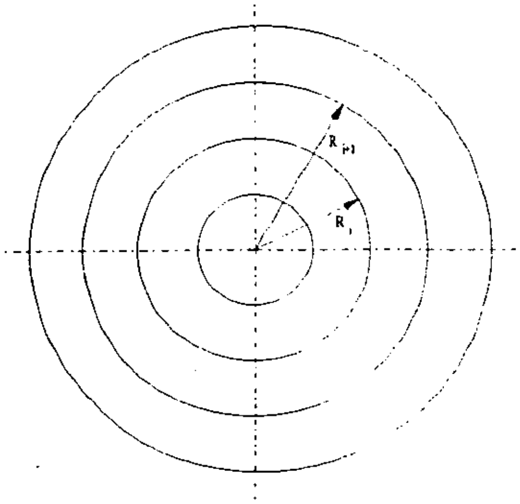

Figure 1.
Discretisation of the flow area

The cross sectional area in the flow conditioner is first discretised into rings as shown in figure 1. Each ring area is then described by an inner and outer radius, and includes one or more holes.

The velocity profile immediately upstream of the flow conditioner is assumed flat, while the velocity profile downstream is assumed fully developed. A "quasi one-dimensional" illustration of the flow profile through the flow conditioner is shown in figure 2.

The area of the flow conditioner is divided into rings, and each ring is regarded as a separate flow channel. The outlet velocity shall correspond to the discrete velocity in the fully developed profile. The flow through each ring is treated separately, and the holes are dimensioned to introduce a sufficient pressure loss to give near fully developed flow downstream. The pressure loss from a distance upstream of the flow conditioner to a distance downstream through all flow channels are equal.

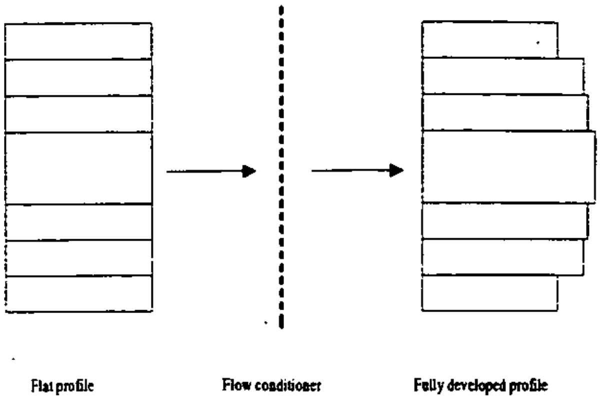

Figure 2.
Discretisation of the velocity profile

Consider the flow through one of these flowchannels. It can be divided into flow through a sudden contraction, figure 3, and flow through a sudden enlargement, figure 4. The two parts are first treated separately and then coupled through the total pressure loss. The flow is considered one-dimensional and incompressible.

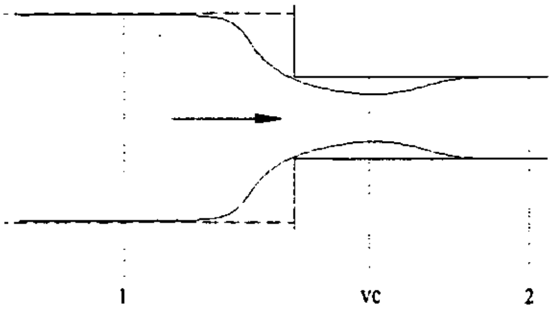

Figure 3.
Turbulent flow through a sudden contraction

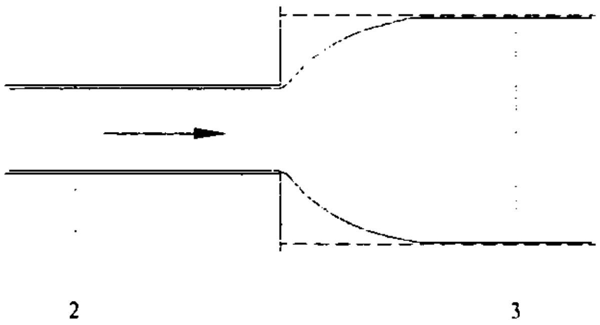

Figure 4.
Turbulent flow through a sudden enlargement

An equation which relates the total pressure coefficient of the flow conditioner, K_o, to the ring porosity, λ_i, and the ratio between the local velocity in the fully developed profile, U_i, corresponding to the location of the ring to the mean velocity, U_m, can now be derived. The equation reads

$$K_0 = \frac{0.7 \cdot (1-\lambda_i)}{\lambda_i^2} + [(1-\lambda_i)/\lambda_i]^2 \cdot (U_i/U_m)^2 \qquad (1)$$

The two terms on the right hand side of eq. (1) express the pressure loss due to the sudden area contraction and enlargement caused by the holes in the ring, respectively. The equation does not take into account the friction against the hole walls. For FC plates in which the length of the holes are typically 2-6 times the hole diameter, this is a reasonable simplification.

The total pressure loss coefficient is defined as

$$K_0 \equiv \frac{\Delta P_0}{0.5 \cdot \rho \cdot U_m^2} \qquad (2)$$

where ρ is the fluid density and P_o the total pressure difference over the FC in terms of the stagnation pressures.

The porosity of a ring flowchannel is defined as the ratio between the area of the holes to the total ring area. Thus, the porosity of ring no. *i* can be calculated as

$$\lambda_i = \frac{n \cdot (\pi/4) \cdot a^2}{\pi \cdot (R_{i+1}^2 - R_i^2)} \qquad (3)$$

where n is the number of holes in the ring, *a* is the diameter of each hole, and R_{i+1} and R_i the outer and inner radius of the ring.

Eq. (1) forms the basis of the design procedure. The porosity of each ring will be determined to get a predefined velocity profile and total pressure loss.

The shape of a fully developed velocity profile will change with the Reynolds number up to about $3 \cdot 10^7$ (for smooth pipes to even higher Re-numbers). According to Wilcox et al. (ref. 4) the ratio U/U_m can be represented as a function of the radial distance from the pipe axis by the equation

$$\frac{U}{U_m} = 1.173 \cdot \left(\frac{Y}{R}\right)^{1/9} \qquad (4)$$

Here *Y* is the distance from the pipe wall and R is the internal pipe radius. This formula can be employed for determination of the U_i-values in eq. (1).

The area of each ring is divided into *n* holes, each with a diameter *a*. Physical limitations restrict the diameter and the number of holes by the following constraints:

$$R_{i+1} - R_i > a + 2 \tag{5}$$

and

$$n(a+2) < 2\pi \cdot (R_{i+1} + R_i)/2 \tag{6}$$

where R_i is the inner radius and R_{i+1} the outer radius of ring i. These constraints ensure that the diameter of each hole is smaller than the width of the ring, and that the sum of the hole diameters is less than the circumference of the ring. An additional requirement is of course that the number of holes, n, must be an integer.

For a given porosity there is normally not a unique solution to the above equations. To solve the equations either the size of each hole or the number of holes have to be maximised.

The design of a flow conditioner geometry can then be determined by the following steps:

1. Define the porosity (or pressure loss) for the flow conditioner. Calculate the pressure loss (or porosity) by eq. (1) applied at the radial position where the upstream velocity equals the downstream velocity, i.e. $U_i/U_m=1.0$.

2. Define the number of rings. Select m axial velocities to represent the fully developed axial velocity profile and determine the radial location of each corresponding ring using eq. (4).

3. Calculate the porosity of each ring using eq. (1).

4. Calculate the area of each hole and the number of holes in each ring by either maximising the hole diameter or the number of holes. For this purpose eq. (3), (5) and (6) are employed.

2.2 THE DIFFERENT MODELS

The results from the examination of the performance of Mark 2 have been presented in ref. 4 and 5. This FC show excellent performance as swirl remover, but was not equally good in straightening out asymmetric velocity profiles. Therefore the design of Mark 2 was gradually improved resulting in the Mark 3, Mark 4, Mark 4 ch (chamfered) and culminating in the Mark 5 FC. At an early stage, the decision was taken to maintain a thickness of 50mm for the FC when it was installed in a test rig having an internal pipe diameter equal to 140mm. This eliminated one of the variables in the problem, leaving only the layout of the holes in the cross-section to be optimised.

The design of the FCs was based on the theory above. For Mark 3 the hole diameters were maximised (point 4 above). Plate thickness, porosity and the number of rings were copied from the Mark 2 conditioner.

Mark 4 was designed to introduce higher pressure loss in order to increase the ability to handle more asymmetric inlet profiles than the previous versions. The porosity was defined to be 0,40 in this model.

Mark 5 was designed from the same concept as Mark 3 and Mark 4, but was given larger porosity in order to reduce the pressure loss coefficient. For Mark 5 the hole diameters were maximised. A pressure loss coefficient equal to 2,0 was specified which yields an overall porosity equal to 0.53.

Some design data are listed in table 1 below :

FC	Porosity	Pressure loss coefficient
Mark 2	0,51	2,38
Mark 3	0,51	2,57
Mark 4	0,40	4,65
Mark 4, ch	0,40	3,28
Mark 5	0,53	2,13

Table 1.
The prescribed overall porosity of the FCs and the measured pressure loss coefficients obtained from experiments using air at atmospheric pressure.

All FCs have one centrehole and 4 concentric rings with holes. The thickness is common for all FCs and equal to 0.357D. Figure 5 shows the basic layout.

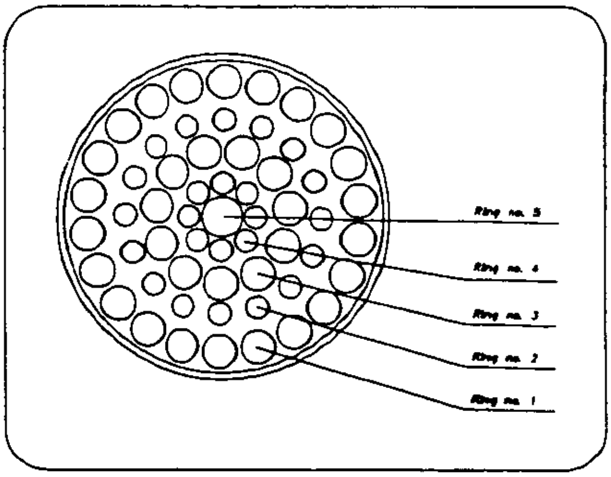

Figure 5.
K-Lab Mark 2 flow conditioner

3. EXPERIMENTAL SET UP FOR THE ATMOSPHERIC TESTS

3.1 THE TEST SECTION

The experiments using air at atmospheric pressure were done in a test rig of plexiglas having an internal pipe diameter equal to 140mm. Air is sucked through the loop by a positive displacement pump yielding constant volumetric flowrate. The pipe Reynolds number in the test section is 2.6 10^5. In this project three different geometrical disturbances at the inlet to the test section have been used.

3.2 THE SINGLE BEND RIG

In the single 90°-bend geometry a 9D straight pipe with a perforated plate at the inlet followed by a 90° bend is connected to the test section. The radius of curvature of the bend is 1.5D. The set up is shown in figure 6. Axial velocity profiles and swirl angle profiles can be measured at 1D, 3D, 5D, 10D and 15D, while the FC can be installed 3D, 4D, 5D, 6D, 7D and 8D downstream of the bend.

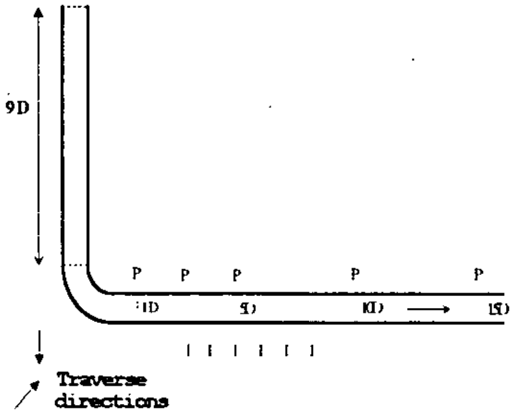

Figure 6.
The single 90° bend geometry. The points P represent the traverse positions, the points I the positions for flow conditioner installation. The curvature of the bend is 1.5D.

3.3 THE TWISTED S-BEND RIG

A twisted S-bend with a perforated plate at the inlet is connected to the test section, and traverses to measure the axial velocity profile and the swirl angles can be done at 1D, 3D, 5D, 10D and 15D downstream from the second bend. The flow conditioner can be positioned at 3D, 4D, 5D, 6D, 7D and 8D, see figure 7. The length of straight pipe between the two bends is 1.25D, and the radius of curvature of the bends is 1.5D.

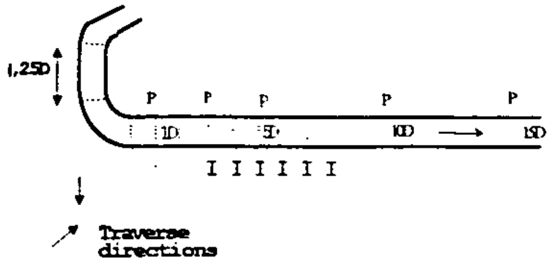

Figure 7.
The twisted S-bend geometry. The points P represent the traverse positions and the points I the positions for flow conditioner location. The curvature r/D of the bends is 1.5D.

3.4 THE FLAT PROFILE TEST RIG

In order to study the flow disturbances caused by the flow conditioner itself, a special set up referred to as the flat profile test rig, was built. The rig consists of a 10D long straight pipe upstream of the flow conditioner with a perforated plate positioned at the pipe inlet. Downstream of the flow conditioner the velocity profiles can be measured at 5D, 6D, 7D, 8D, 9D 10D and 12D. A drawing of the set up is shown in figure 8.

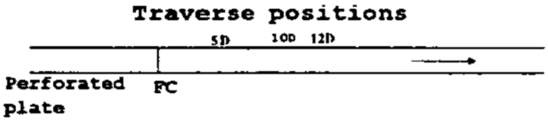

Figure 8.
The flat profile test rig

3.5 PRIMARY MEASUREMENT DEVICES

A pitot static tube was used for the axial velocity profile measurements. The swirl angles were measured by a 10mm thick 2 hole cylinder pitot tube. Both these instruments were connected to a differential pressure manometer type 5 Airflow manufactured by Airflow Development.

4. ATMOSPHERIC TEST RESULTS

4.1 INTRODUCTORY REMARKS

Mark 2, Mark 3, Mark 4 and Mark 5 which all have the same basic layout with one centerhole and 4 concentric rings with holes were tested in the air loop. Only the main conclusions from these experiments will be presented here.

The results obtained with Mark 2 are presented in ref. 4. With Mark 2 the ISO-5167 section 7.4 requirements were fulfilled 15D downstream from the single bend and the twisted S-bend.

Mark 3 gave better results than Mark 2. With Mark 3 the ISO-5167 requirements were fulfilled 12D downstream from the bend. Mark 4 was even better and the required length between the bend and the orifice plate was reduced to 11D.

Mark 5 exhibited the lowest pressure loss coefficient which is considered as a very important property for a FC. If a Short Metering System with Mark 5 fulfils the ISO-5167 requirements at 15D downstream of the tested disturbances and has good orifice meter performance, this FC-model can therefore be considered as an optimum design based upon our requirements mentioned in Section 1.2. In the following attention will only be given to the results obtained using Mark 5.

4.2 REFERENCE VELOCITY PROFILE

The fully developed velocity profile measured downstream from 101D lengths of straight pipe is shown in figure 9. The pipe Reynolds number was 2.6 10^5. The profile will be used as "reference profile" in the subsequent graphs.

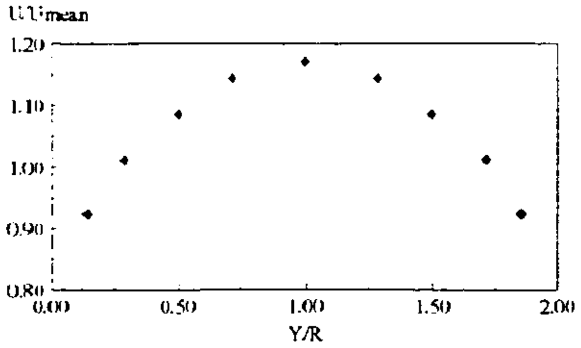

Figure 9.
Fully developed velocity profile measured downstream of 101D straight pipe. $Re = 2.6 \cdot 10^5$.

4.3 TEST OF THE DISTURBANCE INTRODUCED BY THE FLOW CONDITIONER ITSELF

Axial velocity profiles measured downstream of the Mark 5 FC in the Flat Profile Rig are shown in Figure 10. The profile at 5D has almost recovered to fully developed but is still too peaked. At 12D the measured profile is identical to the fully developed velocity profile in Figure 9.

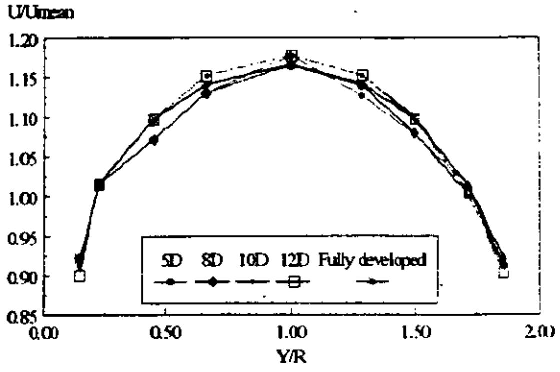

Figure 10.
Axial velocity profiles. Mark 5 positioned downstream of flat velocity profile.

4.4 SINGLE BEND TESTS

Figure 11 and 12 show the velocity profiles in two perpendicular planes when no flow conditioner was installed. The corresponding swirl angles are presented in Figure 13. The traverse directions are defined in Figure 5. In Figure 14 the results obtained with the flow conditioner located at 8D are presented as percentage deviations in U/Umean from the corresponding ratios in the fully developed profile. The dotted lines visualise the ISO-5167 requirement to the deviation of the axial velocity profile from the fully developed profile.

The swirl angles were measured at the same positions as the velocities. Maximum deviation between the swirl angles measured within the same traverse was 0.5 degrees, which is comfortably within the ISO-5167 requirement. However, the relative swirl along each traverse is measured to within +/- 0.5 degree uncertainty. Thus, a maximum variation in the swirl angle measurements of 1 degree means that no swirl actually has been detected in the flow.

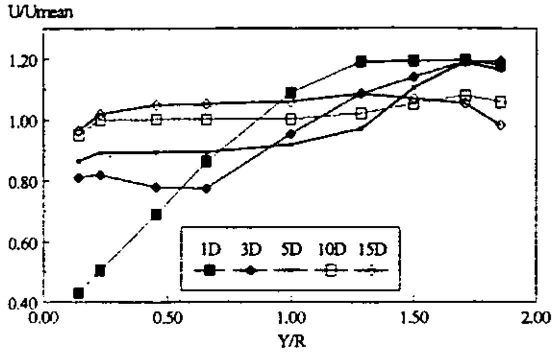

Figure 11.
Measured axial velocity profiles downstream of the single 90⁰ bend. Vertical traverses. No FC was installed downstream of the flow disturbance.

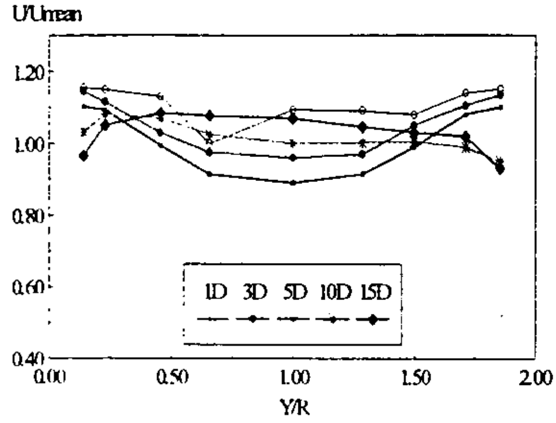

Figure 12.
Measured axial velocity profiles downstream of the single 90⁰ bend. Horizontal traverses. No FC was installed downstream of the flow disturbance.

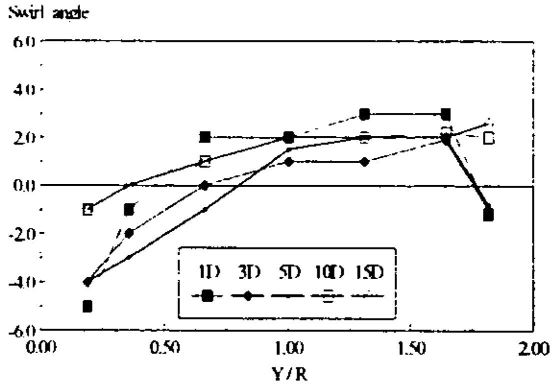

Figure 13.
Measured swirl angle profiles downstream of the single 90⁰ bend. Horizontal traverses. No FC was installed downstream of the flow disturbance.

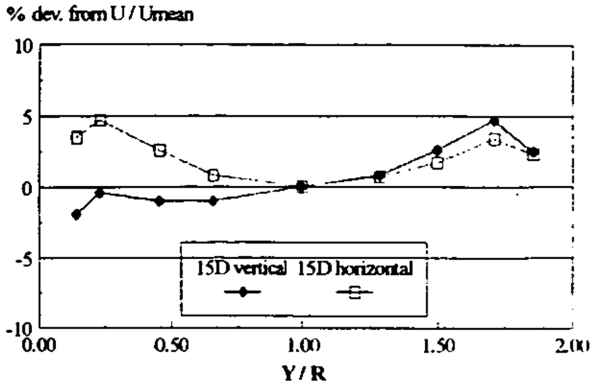

Figure 14.
Deviation of the measured axial velocity profile from the fully developed profile downstream of the 90⁰ bend. Mark 5 was installed 8D downstream of the flow disturbance.

4.5 TWISTED S-BEND

The axial velocity profiles measured downstream of the twisted S-bend with no FC installed in the rig are shown in figure 15 and 16. The corresponding swirl angle profiles are plotted in figure 17. The traverse directions are defined in Figure 7. Figure 18 presents the deviation in U/Umean from the corresponding ratios in the fully developed velocity profiles when the FC was installed 8D downstream from the last bend. The measurements were done at 15D.

Also for this configuration traverses of the swirl angles were measured, and again the maximum swirl angle found was 0.5 degrees, which mean that no swirl has been detected in the flow.

4.6 CONCLUSION OF AIR TESTS

The ISO-5167 requirements are satisfied both with respect to the axial velocity profile and the swirl angles 15D downstream of a single 90° bend and a twisted S-bend when Mark 5 is installed 8D downstream of the flow disturbance. Figure 14 and 18 show that the velocity profile is not completely developed. The aim was however, to satisfy the ISO-requirements, and therefore this performance is acceptable.

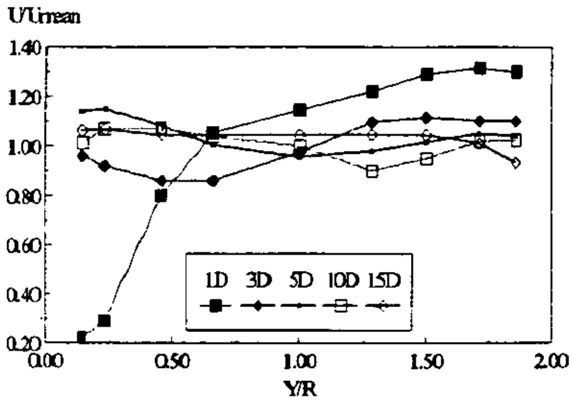

Figure 15.
Measured axial velocity profiles downstream of twisted S-bend. Vertical traverses. No FC was installed downstream of the flow disturbance.

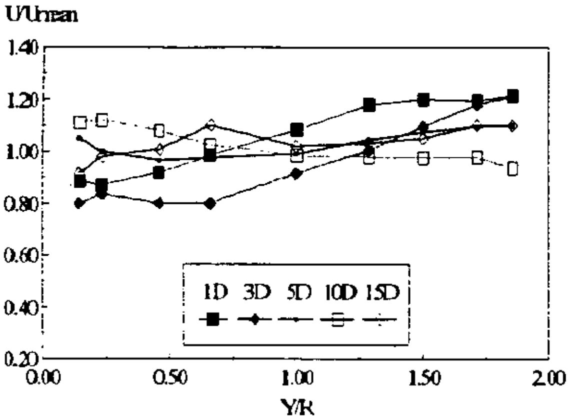

Figure 16.
Measured axial velocity profiles downstream of twisted S-bend. Horizontal traverses. No FC was installed downstream of the flow disturbance.

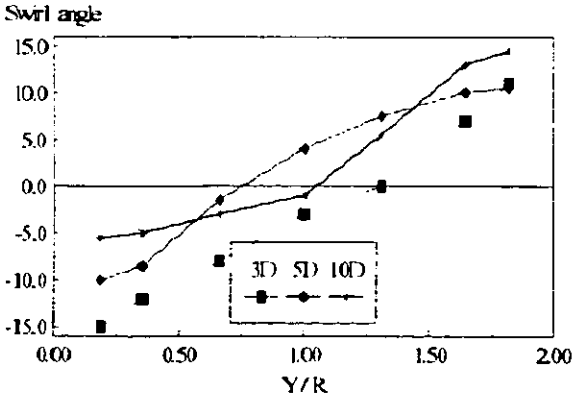

Figure 17.
Measured swirl angle profiles downstream of twisted S-bend. Horizontal traverses. No FC was installed downstream of the flow disturbance.

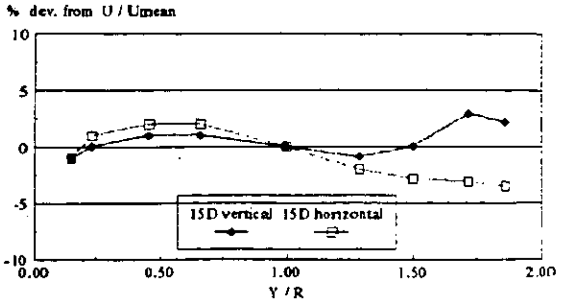

Figure 18.
Deviation of the measured axial velocity profile from the fully developed profile downstream of twisted S-bend. Mark 5 was installed 8 D downstream of the flow disturbance.

5 EXPERIMENTAL SET-UP FOR THE HIGH PRESSURE TESTS

5.1 HIGH PRESSURE TEST LOOP

The high pressure tests were performed at 100 bar and 37°C in dry natural gas (85% methane, 13% ethane and 2% other components).

All the tests were carried out in a 6 inch nominal bore test section with an internal pipe diameter of 140mm. The FCs were tested downstream of a single 90° bend and a twisted S-bend similar to those used in the atmospheric air rig.

The reference flowmeters are a bank of sonic nozzles, built according to ISO-9300, which have been primary calibrated in a gravimetric calibration rig over the range 20 to 100 bar. For the discharge coefficient (Cd) measurements a 6" Daniel Orifice meter (model M7591) was used. All applied instruments had calibration certificates traceable to international standards.

5.2 SWIRL PROBE

A swirl probe was designed and manufactured to measure velocity and swirl in natural gas up to 150 bar in the test-section. Before the final design was made, the performance of 3 cylindrical Pitot probe was investigated.

The following probes were tested :

- 10mm diameter 2-holes probe with 60° between the holes
- 17mm diameter 2-holes probe with 60° between the holes
- 17mm diameter 3-holes probe with 36.2° between the holes

The results are described and discussed in ref. 6. Based upon this study the swirl probe was designed with a 12mm cylinder and 3 holes with 35.4° between the holes.

6.0 HIGH PRESSURE TEST RESULTS

6.1 REFERENCE VELOCITY PROFILE

As mentioned earlier, the Mark 2 to Mark 5 FCs have been designed to produce a 9th power law velocity profile given by equation (4). From figure 19 it can be seen that the 9th power law velocity profile fits the measured velocity profile 341D downstream of a twisted S-bend at a Reynolds number $1.5 \cdot 10^7$ very well.

Thus the 9th power law profile has been used as reference profile for the high pressure tests.

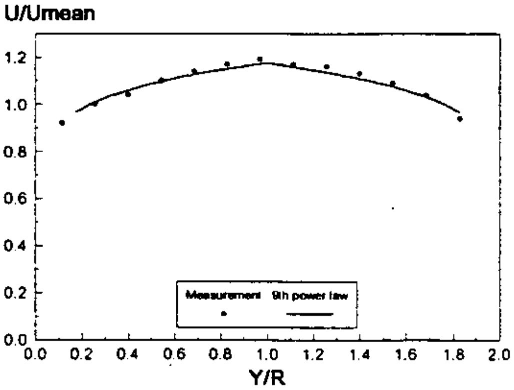

Figure 19.
Fully developed velocity profile. Re = $1.5 \cdot 10^7$

6.2 SINGLE BEND TESTS

Figure 20 shows the horizontal velocity profile 15D downstream of the single bend at 2 different Reynolds numbers when no FC was installed in the rig. It can be seen that some of the measurements are outside the ISO-5167 recommendation. Figure 21 shows the velocity profile when Mark 5 is used. The results are now within the 5% band of the fully developed velocity profile. Both with and without the FC the swirl measured at this position is well within the ISO-5167 requirements.

6.3 TWISTED S-BEND TESTS

The horizontal velocity profile 15D downstream of the twisted S-bend can be seen in Figure 22. The same profile when Mark 5 is used is shown in Figure 23.

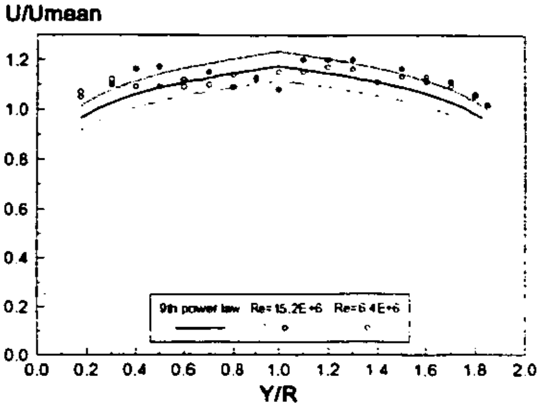

Figure 20.
Horizontal velocity profile 15D downstream of a single 90° bend.

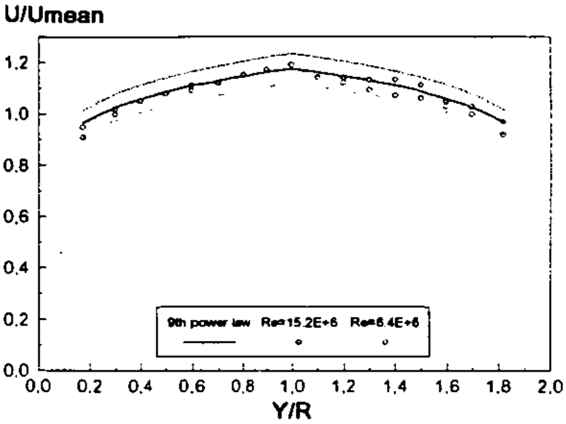

Figure 21.
Horizontal velocity profile 15D downstream of a single 90° bend when Mark 5 is used.

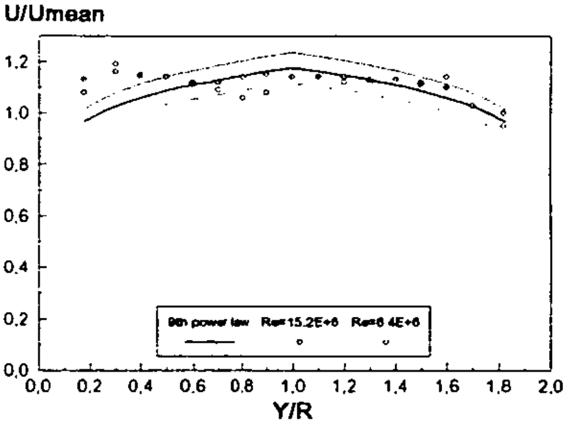

Figure 22.
Horizontal velocity profile 15D downstream of a twisted S-bend.

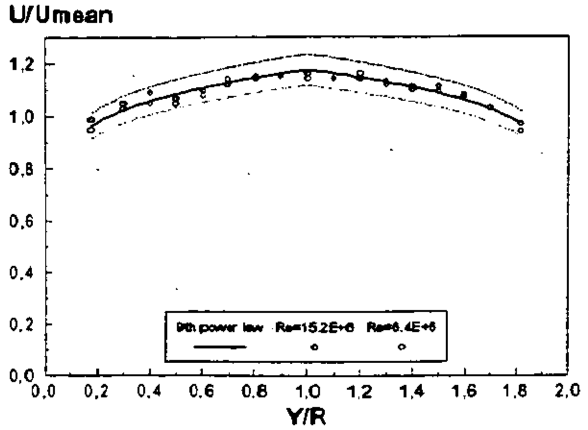

Figure 23.
Horizontal velocity profile 15D downstream of a twisted S-bend when Mark 5 was used.

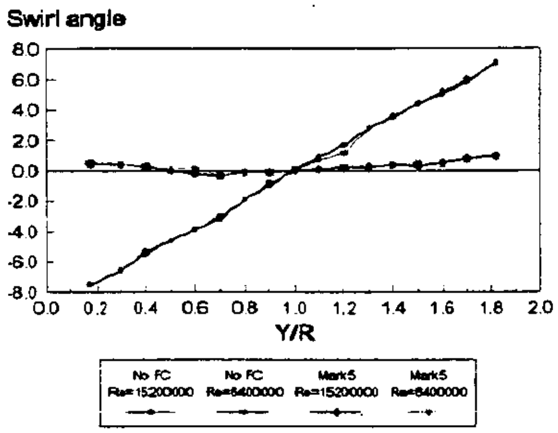

Figure 24.
Horizontal swirl angle profile 15D downstream of a twisted S-bend. Results with and without Mark 5.

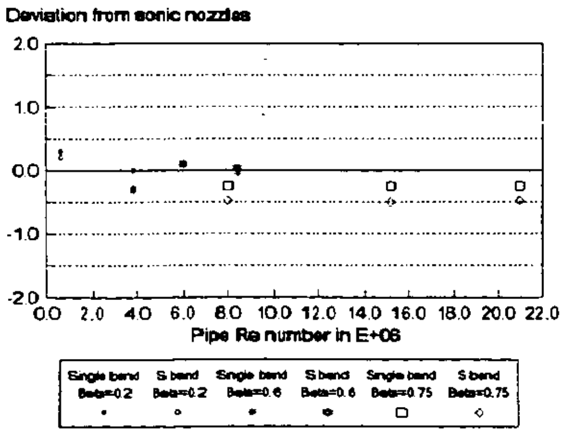

Figure 25.
Calibration of a 15D SMS with Mark 5. Results for different configurations and different beta-ratios.

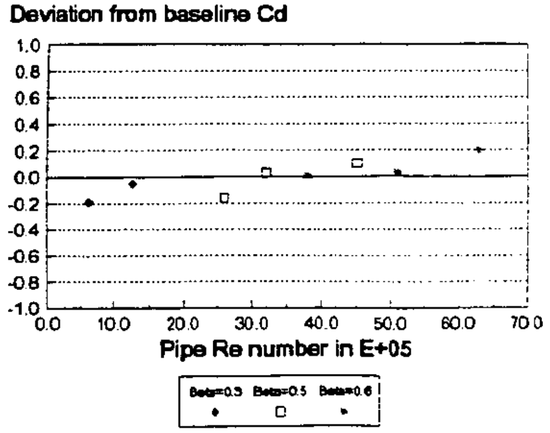

Figure 26.
ΔCd for a 15D SMS with Mark 5. Deviation from "baseline" Cd measurements.

The swirl angle for this configuration with and without the FC is shown in Figure 24. From the results presented above it is demonstrated both how Mark 5 transforms the velocity profile from distorted to nearly fully developed and how it removes the swirl.

6.4 MEASUREMENTS OF DISCHARGE COEFFICIENT

The aim of the ISO-5167 recommendation is to describe how to build an orifice gas metering station and obtaining a gas measurement-error within +/- 1.0%.

The ultimate question is then how well a Short Metering System (SMS) with Mark 5 FC and an overall length of 15D behaves when it is calibrated. In figure 25 tests between the flow element and the upstream disturbances are shown for β-ratios equal to 0.2, 0.6 and 0.75. The results show that the Cd deviations from the reference sonic nozzles are within +/- 0.5%. The tests were done at 100 bar with Reynolds number between $5 \cdot 10^4$ and $2 \cdot 10^7$.

Normally the performance of the FCs is compared against some "base-line" Cd calibrations. For some common β-ratios (0.3, 0.5 and 0.6) these calibrations were carried out at 48D lengths of straight pipe with Mark 5 installed at the inlet. Then the results obtained at 15D downstream of a twisted S-bend were checked against these "baseline" data. The results are found in figure 26. It can be seen that all the results are within +/- 0.2%.

These "baseline" Cds are also compared against data obtained with the upstream length required by ISO-5167 downstream of a twisted S-bend. The results are shown in figure 27. It can be seen that all these Cds are lower than the "baseline" data, and in the worst case the deviation is nearly 0.5%.

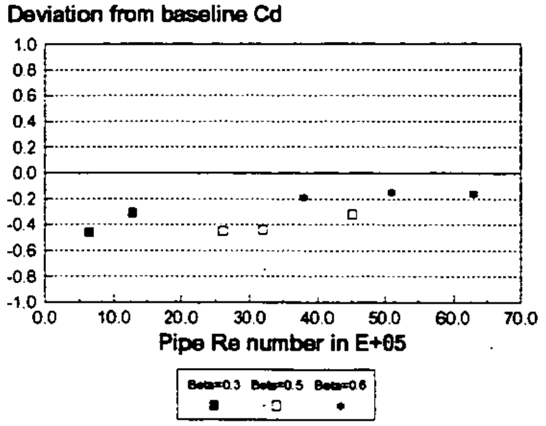

Figure 27.
Cd between normal ISO-5167 installation length downstream from a twisted S-bend and "baseline" Cd measurements.

6.5 DISCUSSION

It has been shown that also at high pressure (100 bar) Mark 5 effectively eliminates the swirl 15D downstream of a single bend and a twisted S-bend. The velocity profile at this position for the 2 configurations examined is not 100% developed but well within the ISO-5167 recommendation which was the objective to reach for the development project.

The measurements of the discharge coefficient show that the performance of a SMS with a total length of 15D compares with the sonic nozzles within +/- 0.5%. This is good results as a normal ISO-installation may have an uncertainty up to 1%.

The Cd-shift between the "base-line" calibration and the SMS-system is within +/- 0.2% at Reynolds number between $6.4 \cdot 10^5$ and $6.3 \cdot 10^6$. Also these results are considered very satisfactory as they have been obtained at high pressure (100 bar). However this Cd-shift is wanted as low as possible, and there is still some room for improvement here (+/- 0.1%).

Another finding during these tests is that today's ISO-5167 recommendation does not require long enough upstream lengths after twisted S-bends for the removal of swirl. It is well known that swirl cause undermeasuring of the flow (ref. 7) which is also shown in figure 27. These testresults (fig. 24) demonstrate that Mark 5 is an efficient swirl-remover and avoid this undermeasuring.

To summarise, this SMS shows small deviation (within +/- 0.2%) from the "base-line" Cd-data. It also gives better results than a standard ISO-5167 installation downstream of a twisted S-bend, confirming that the SMS-concept with Mark 5 installed fully compares with an ISO-5167 installation as was the project objective.

The interest for FCs in the metering community is increasing continuously because the large demand for cheaper and better metering systems. The challenge now is therefore to further collect performance data for a result-database and work for general acceptance of this technology. All the attention the FCs have received the last couple of years confirms the promising potential of this technology.

The metering technology evolves all the time, and it is still possible to slightly improve the performance of the FCs. The new tabs/vanes FC is an example of an encouraging improvement (ref. 8) where K-Lab and University of Salford co-operate.

7.0 CONCLUSION

In this paper the main research activities in developing a good FC is described. The aim was to build a Short Metering Systems (SMS) of maximum 15D which fulfilled the ISO-5167 requirements.

- First a theoretical design model was developed.
- From that model FCs with different porosity (between 0.4 and 0.51) and pressure loss coefficients (between 2.13 and 4.65) have been designed.
- The different FCs were then tested in air at atmospheric pressure. Mark 5, which has the lowest pressure loss coefficient of 2.1, fulfilled the ISO-5167 requirements 15D downstream of a single 90° bend and a twisted S-bend.
- A cylindrical Pitot probe with 3 holes for measuring velocity and swirl in a 6 inch pipe up to 150 bar was designed and manufactured.
- The performance of the SMS with Mark 5 was tested at 15D at high pressure. The ISO-5167 requirements for fully developed flow were fulfilled.
- The SMS with β-ratios equal to 0.2, 0.6 and 0.75 were tested against sonic nozzles at 100 bar for Reynolds numbers between $5 \cdot 10^4$ and $2 \cdot 10^7$. The results showed a deviation within +/- 0.5% .
- The SMS was also compared against "base-line" Cd data for common β-ratios, (0.3, 0.5 and 0.6). All

the results were within +/- 0.2%.

- The comparison between a 15D SMS with Mark 5 and an ordinary installation with normal ISO requirements for upstream lengths, shows that the SMS with Mark 5 performs similarly or better.
- Since Mark 5 fulfils the ISO-5167 requirements and gives good Cd performance at 15D, this FC can be applied in Short Metering Systems.

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