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SHORTENING INSTALLATION LENGTHS USING A LOW LOSS VANED FLOW CONDITIONER

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SUMMARY

Recent developments in flow conditioning have shown that pre conditioning a disturbed flow prior to a perforated plate flow conditioner can produce a device capable of producing 'ideal' flow conditions within very short installation lengths. Whilst this approach involves combining two devices and thus complicates the installation the benefits gained in terms of shortened installation lengths and improved downstream flow quality far outweigh this disadvantage. The present paper is concerned with a further investigation into the vaned plate described by Laws & Ouazzane(1) and Laws et al(2) resulting in a low loss integrated design capable of operating within very short installation lengths. The improved performance of orifice plates with β ratios between 0.4 and 0.7 when installed 3 diameters downstream of this conditioner is demonstrated. Preliminary results obtained in natural gas at a pressure of 100 bar for a 60% porosity plate in conjunction with a $\beta = 0.5$ orifice plate confirm the beneficial effects of the vaned plate on orifice plate performance.

Key Words: Flow straightener, flow conditioner, installation errors.

NOTATION

Cd	Orifice plate discharge coefficient.
K	Pressure loss coefficient = $(\frac{\Delta p}{0.5\rho\bar{u}^2})$.
D	Pipe diameter.
r	Radial distance measured from pipe centre line.
R	Pipe radius.
Re	Reynolds number
u,u'	time mean local, fluctuating velocity.
$\bar{u}$	average time mean velocity.
y	Distance measured radially from pipe wall
z	axial distance measured from plane of conditioner (- upstream, + downstream).
β	Orifice plate diameter ratio.
ρ	Density.

1. INTRODUCTION

The technology of flow conditioning has developed rapidly in recent years. The devices included in the flow standards have now been complemented by a number of short perforated plate devices involving porosity grading capable of producing acceptable time mean flow conditions within an overall installation length of 12-15 pipe diameters.

Such perforated plate devices are usually effective with an upstream settling length of 3-4 pipe diameters and can produce acceptable time mean flow conditions within 8-9 pipe diameters dependant on the nature of the approach flow (the degree of asymmetry, swirl magnitude etc.). Immediately downstream of the plate in the first 2-3 diameters of the development there is a highly turbulent jet mixing zone in which both the swirl and asymmetry in the upstream flow are destroyed and the flow re-distributed by the porosity grading of the plate. This mixing zone contributes to an increase in the turbulence intensity of the downstream flow. Consequently a longer development length is usually required before an established turbulence structure can be developed.

The Mitsubishi perforated plate described by Akashi et al (3) was the first short, perforated plate to be developed. The plate consists of 35 holes each of diameter, d =0.13D, distributed hexagonally over the plate surface and is of depth, d. This plate has not however been widely used in industry and has been shown by a number of investigators to, in certain cases, both fail to produce acceptable time mean profile quality and to reduce swirl effectively, (see refs 4,5). Nevertheless this plate can be considered as the first stage in the evolution of an efficient, short perforated plate design indicating to the flow measurement community that the recommended lengths of the devices included in the flow standards ISO 5167 and AGA/API 3 (6,7) may be unnecessary.

The Laws plate (see fig 2) described in Laws(8,9) has a central hole and two surrounding rings of holes. The hole sizes in the centre, inner and outer rings and the number of holes in the inner and outer ring are such as to distribute the downstream flow to produce fully developed flow in a relatively short downstream length. Details on the plate geometry are given in Laws(9) and a comparison between the performance of the Mitsubishi and Laws plates is given in Laws (8,9).

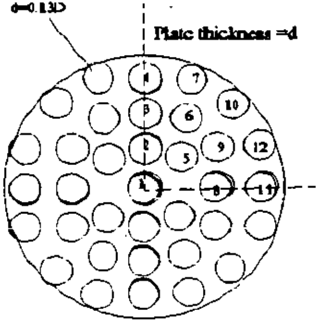

FIG 1. MITSUBISHI PERFORATED PLATE

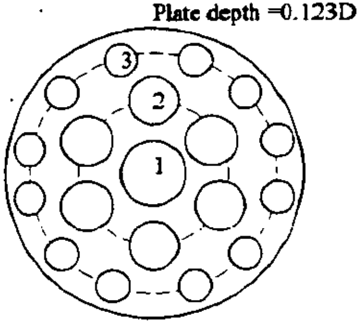

FIG 2 LAWS PERFORATED PLATE

The Zanker flow conditioner included in ISO 5167 (see fig 3) which consists of a thin perforated plate followed by a boxed honeycomb section 1 pipe diameter in length is a hybrid device combining the grading of porosity introduced by the perforated plate with the swirl removing capabilities of a honeycomb section. Though several investigations have concentrated on the effect of the Zanker conditioner on orifice plate discharge coefficient errors few have focused on the flow quality produced by the Zanker conditioner or attempted to distinguish between the contribution due to the plate and that of the honeycomb. Laws and Ouazzane (10) however looked in detail at the effect of the depth of the plate in the Zanker conditioner on the performance of the conditioner and have shown that as the perforated plate is thickened the downstream honeycomb becomes effectively redundant. Thus a Zanker plate of a depth similar to the Laws and Mitsubishi plates appeared to be capable of both removing swirl and improving flow quality.

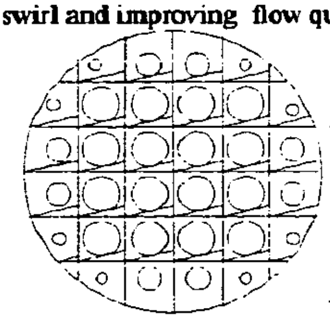

FIG 3. THE ZANKER FLOW CONDITIONER

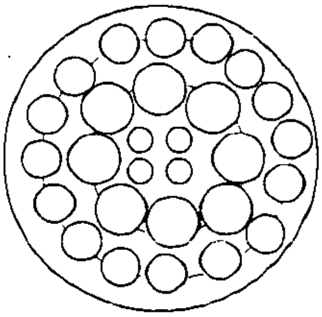

FIG 4. THE NEL PLATE

More recently a perforated plate conditioner has been designed by Spearman et al (11) working at NEL (see fig 4). This plate can be regarded as a combination of the Laws and Zanker plates having the graded porosity and hole sizes equivalent to a graded 1:8:16 Laws plate but replacing the central hole of the Laws design with the square grid hole arrangement of the Zanker design. The selection of the square central geometry limits the usefulness of this design since the need to maintain. for manufacturing purposes, some solid material between the central holes prevents the porosity of this plate being increased significantly above its present value. Thus the pressure loss of this plate is significantly higher than that for the Laws or Mitsubishi design though comparable with that of a thick Zanker design at a value of about 3.5.

The paper presented discusses the performance of the perforated plates currently available in terms of their effectiveness in meeting the ISO 5167 time mean flow criteria. This requires conditions within ± 5% of the profile of u/umax profile obtained after a development length of 100 pipe diameters to be attained together with a swirl angle within $\pm 2^{o}$.

Recently Laws & Ouazzane(1), and Laws et al(2) have shown that the addition of vanes upstream of, or actually on the plate itself, produces a significant improvement in the plate capability. The refined device is illustrated in figure 5.

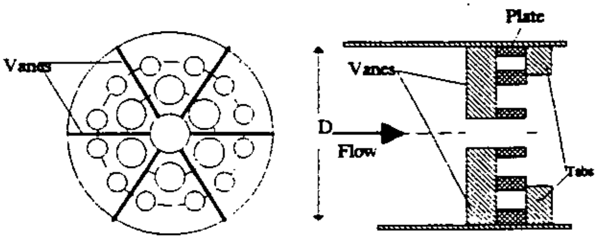

FIG 5 MODIFIED LAWS PLATE WITH VANES AND TABS ON PLATE

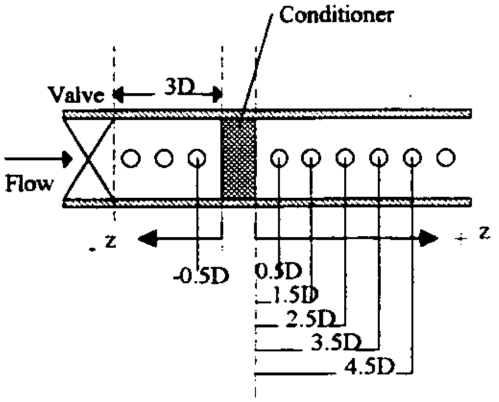

FIGURE 6 TEST ARRANGEMENT USED

They have shown that the vanes reduce significantly the asymmetry in a distorted upstream flow leaving the plate to operate in a less hostile flow environment. The additional feature of vanes on the plate improves the overall component performance significantly giving a device which can produce both acceptable time mean flow and axial turbulence intensity profiles within short upstream and downstream installation lengths with very low overall pressure loss. The flow quality produced by a vaned Laws' plate with a porosity of 70% (having a loss coefficient of approximately 0.7) will be presented and compared with the equivalent results for the perforated plates discussed previously.

2 TEST CONFIGURATION

The open circuit air rig used was of 0.103m diameter. The test section was preceded by a ball valve which was used to generate different upstream flow conditions Three different valve settings were used. valve open . 50% closed and 70% closed. The conditioner tested was placed 3 pipe diameters downstream of the valve outlet plane. Each test section consisted of pipe sections 3 pipe diameters in length. each pipe section contained 3 instrument ports at a 1 diameter pitch along the axial length. The pipe sections, which were made from cast aluminium were designed with carefully machined flange faces enabling a number of sections to be linked together to give a smooth leak-free assembly of selected length. Measurements of time mean velocity and axial turbulence intensity were made at a number of axial locations downstream of the devices tested over a test length extending to 7.5 diameters downstream of the device. The time mean profiles were obtained using pressure probes and the turbulence intensity measurements made using a constant temperature hot-wire anemometer using straight single hot-wire sensors. The measurements were made in air at a test Reynolds number based on the pipe diameter of 1.8×10^5. The experimental data is presented in the form of profiles of non-dimensional velocity $u/\bar{u}$ and also profiles of axial turbulence intensity $\sqrt{\overline{u'^2}}/u$. On the figures the plane of the conditioner has been taken as z=0 with the distance upstream of the conditioner denoted by $z < 0$ and downstream by $z > 0$. (see figure 6). Orifice discharge coefficient errors for a series of orifice plates placed 3 diameters downstream of the vaned 70% porosity Laws plate are presented for tests in atmospheric air. Preliminary results obtained at K-Lab are also presented for tests conducted at a pressure of 100bar in natural gas for a 60% porosity vaned Laws plate in conjunction with a $\beta=0.5$ orifice plate.

3. EXPERIMENTAL RESULTS FOR PERFORATED PLATES

Space prohibits the inclusion of detailed experimental data for the different plates tested. However for each plate tested the results obtained when the device was placed 3 pipe diameters from the ball valve set either fully open or 50% closed are presented. Figs 7a,b show the results for the Mitsubishi plate which can clearly cope well with the well behaved upstream flow when the valve was set fully open but less well when the upstream flow is distorted as for the case when the valve was set 50% closed. The pressure loss for the Mitsubishi plate is however low at a value of about 1.4 dynamic heads.

The equivalent results for a 60% porosity Laws plate with a pressure loss again of around 1.4 dynamic heads are shown in figs 8a and b. These show that the Laws plate appears capable of coping with both the clean and disturbed approach flow case. Both plates however require the first 2-3 pipe diameters of downstream development length before the turbulent mixing from the individual jets to be completed.

Figs 9a,b show the results for the thick Zanker plate (no honeycomb) which again can cope well with the valve fully open but yielded a slight asymmetry when the valve was set 50% closed. The pressure loss coefficient for this device is also high at around 4.

Figs 10a, b show the corresponding results for the NEL plate which gives rise to a slight central wake associated with the central blocking of the plate which mixes out quickly resulting in a well behaved though slightly overpeaked profile when the valve was set fully open and a similar central wake and slightly underpeaked profile when the valve was set 50% closed. The pressure loss coefficient for this plate is also relatively high at around 3.5.

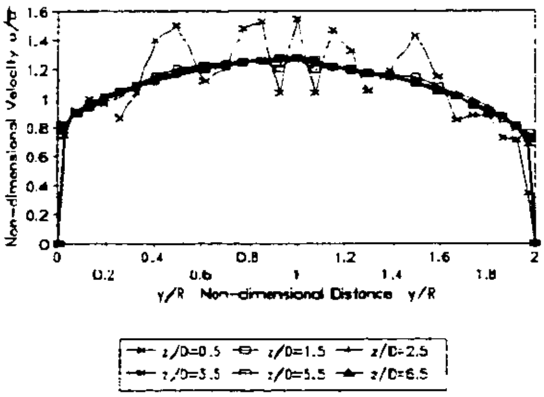

FIG 7a TIME MEAN PROFILES MEASURED DOWNSTREAM OF MITSUBISHI PLATE VALVE OPEN

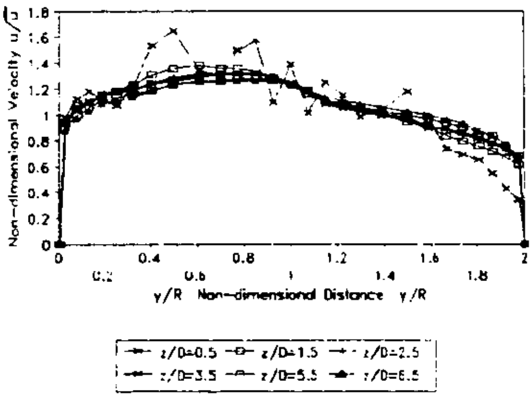

FIG 7b TIME MEAN PROFILES MEASURED DOWNSTREAM OF MITSUBISHI PLATE VALVE 50% CLOSED

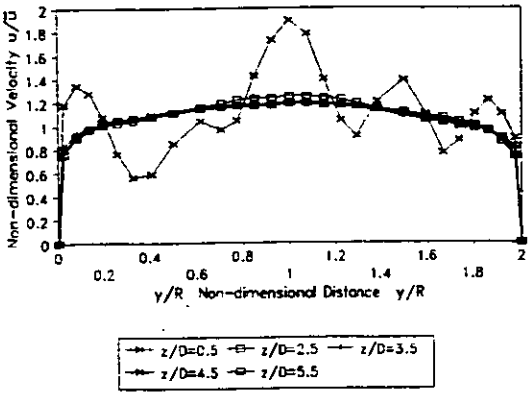

FIG 8a TIME MEAN VELOCITY PROFILES DOWNSTREAM OF 60% LAWS PLATE VALVE FULLY OPEN

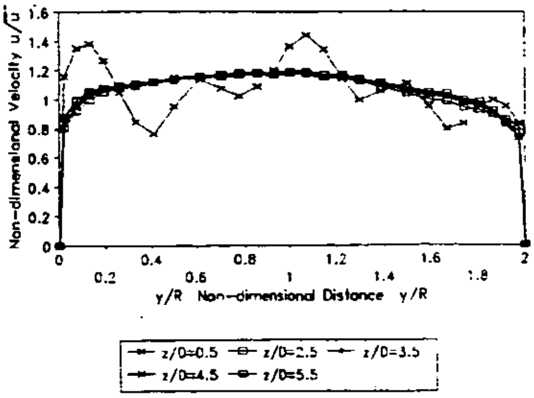

FIG 8b TIME MEAN VELOCITY PROFILE DOWNSTREAM OF 60% LAWS PLATE VALVE 50% CLOSED

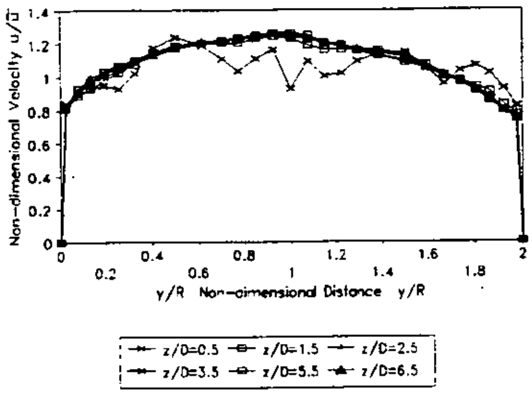

FIG 9a TIME MEAN VELOCITY PROFILES MEASURED DOWNSTREAM OF THICK ZANKER PLATE VALVE FULLY OPEN

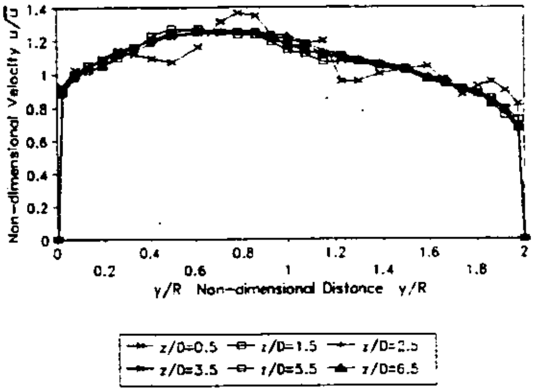

FIG 9b TIME MEAN VELOCITY PROFILES MEASURED DOWNSTREAM OF THICK ZANKER PLATE VALVE 50% CLOSED

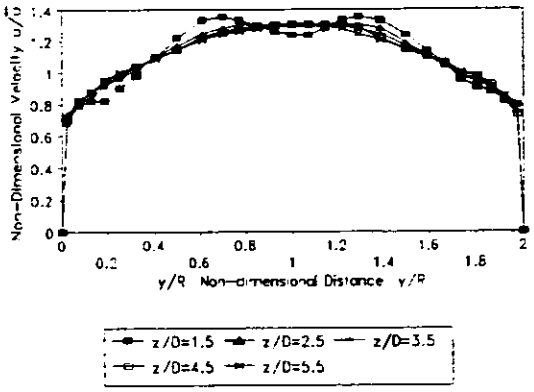

FIG 10a TIME MEAN VELOCITY PROFILES MEASURED DOWNSTREAM OF NEL PLATE VALVE FULLY OPEN

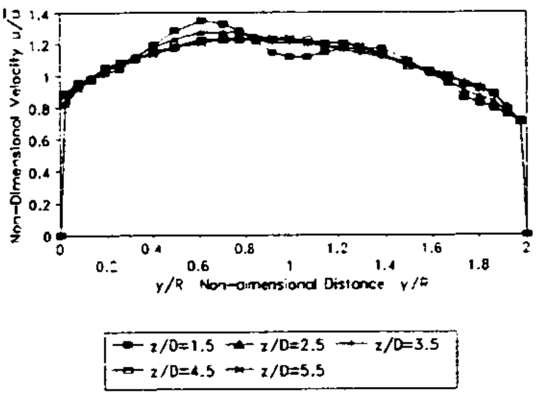

FIG 10b TIME MEAN VELOCITY PROFILES MEASURED DOWNSTREAM OF NEL PLATE VALVE 50% CLOSED

All the plates tested exhibited certain common features related to their method of operation suggesting that no matter how refined the hole design a perforated plate alone would not be capable of satisfying all the desirable features of an ideal flow conditioner. For all the plates a comparative study of the axial turbulence intensity profiles indicated that though a time mean profile meeting the ISO 5167 requirements could be produced within an overall length of some 12-15 diameters a much longer length would be required to develop an associated 'fully developed' turbulence distribution. Similarly none of the plates tested proved capable of operating efficiently when the upstream settling length was significantly reduced below 3 pipe diameters or the severity of the upstream distortion significantly increased. Thus to produce any significant improvement in conditioner performance an alternative to the perforated plate alone is required.

4. EXPERIMENTAL RESULTS FOR THE VANED LAWS' PLATE (70% POROSITY)

Laws and Ouazzane have demonstrated that by combining the graded porosity Laws plate with a series of radial vanes mounted on the surface of the plate, resulting in a device as shown in fig 5, it is possible to produce a flow conditioner which performs significantly better than the perforated plate alone in that a vaned plate appears capable of producing conditions very close in both time mean flow and axial turbulence intensity structure with those associated with fully developed flow. Figs 11a-c show the time mean profiles measured downstream of a 70% porosity vaned Laws' plate for three different upstream distortions. Settings 1, 2 and 3 correspond to the valve set fully open, 50% closed and 70% closed. clearly for all three cases the downstream profiles quickly become well established. The significant effect of the upstream vanes on the initial turbulent jet mixing can be clearly seen by comparing the profiles obtained at z/D=0.5 with those already presented in figs 8a,b for the Laws plate alone.

With this 'hybrid' arrangement it is possible to produce conditions within the ISO 5167 limits within a downstream settling length as short as 1.5 diameters as fig 11d illustrated, although better agreement is achieved if the downstream length is increased to 2.5 diameters. Similarly it is possible to shorten the upstream length considerably down to a length of 1 pipe diameter.

The porosity of the plate can be varied (results for 50% and 60% porosity plates have already been presented in Laws & Ouazzane(1,2)) though the 70% porosity plate appeared to be marginally better than the other versions tested.

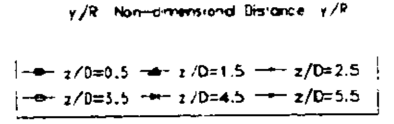

FIG 11A VELOCITY PROFILES DOWNSTREAM OF 70% LAWS PLATE WITH VANES AND FINS VALVE OPEN

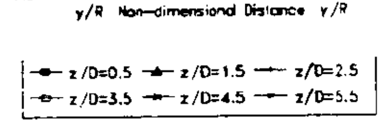

FIG 11B VELOCITY PROFILES DOWNSTREAM OF 70% LAWS PLATE WITH VANES AND FINS VALVE 50% CLOSED

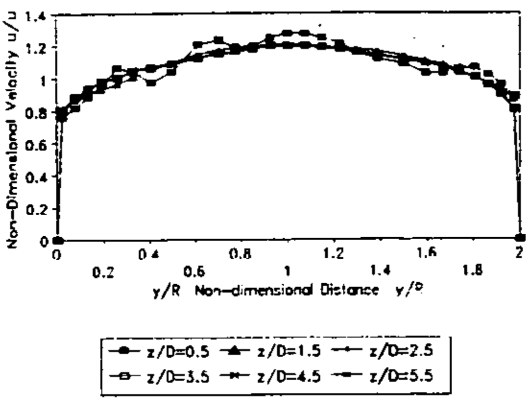

FIG 11C VELOCITY PROFILES DOWNSTREAM OF 70% LAWS PLATE WITH VANES AND FINS VALVE 70% CLOSED

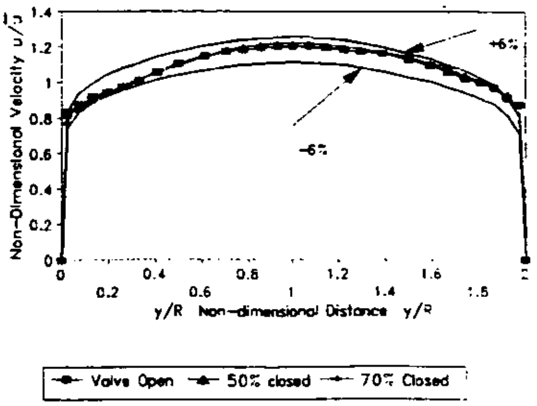

FIG 11D COMPARISON OF TIME MEAN VELOCITY MEASURED AT Z/D=1.5 DOWNSTREAM OF 70% LAWS PLATE WITH VANES AND FINS

5. EFFECT ON ORIFICE PLATE DISCHARGE COEFFICIENT ERROR

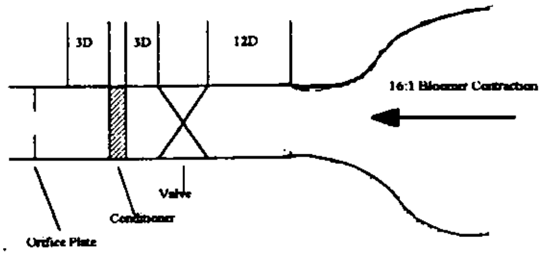

FIG 12 ORIFICE PLATE TEST LAYOUT

The test configuration used is shown in fig 12. The 70% porosity Laws plate with vanes and tabs as described previously was positioned 3 pipe diameters downstream of the exit plane of a sliding vane valve and the orifice plate positioned downstream of the conditioner so that there was 3 pipe diameters between the conditioner and the upstream tapping of the orifice plate. The valve was positioned 12 pipe diameters from the pipe inlet. The pipe inlet was preceded by a well designed 16:1 area ratio Bloomer contraction and the pressure drop across the contraction was used as the primary measuring device. Thus the mean velocity as determined from the pressure drop across the contraction was used to determine the orifice plate discharge coefficient as obtained from the pressure drop across the orifice plate. Recognising that with this measurement technique absolute accuracy could not be achieved it being estimated that the mean velocity could not be determined to within an accuracy of ±0.4% it was considered to be more appropriate to compare the discharge coefficient of the orifice plates as determined in the installation in fig 12 with the equivalent discharge coefficient values when the plate was installed at 100 pipe diameters from the pipe inlet. Thus the discharge coefficient errors referred to subsequently refer to differences between measured values and those determined from a calibration of the orifice plate at z/D=100.

The orifice discharge coefficient with and without the flow conditioner installed has been determined for three valve positions. Note that when the flow conditioner was removed the orifice plate was maintained in the same position i.e. then with approximately 6 pipe diameters between the valve exit plane and the upstream tapping of the orifice plate.

For all the orifice plates tested the maximum error in Cd was 0.15% with the conditioner in line compared to values upto 4% without the inclusion of the conditioner.

β=0.4 Orifice Plate

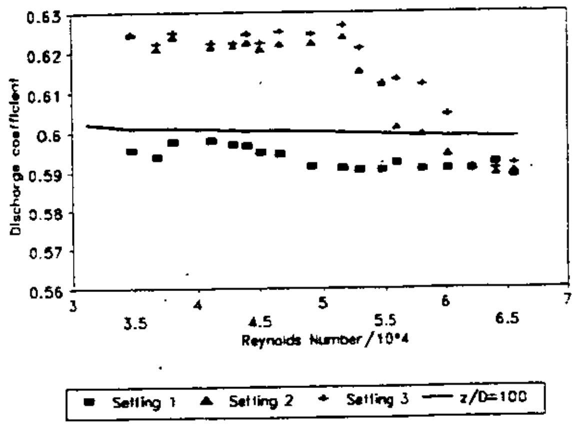

FIG 12A DISCHARGE COEFFICIENT VARIATION DIFFERENT CASES WITHOUT THE CONDITIONER

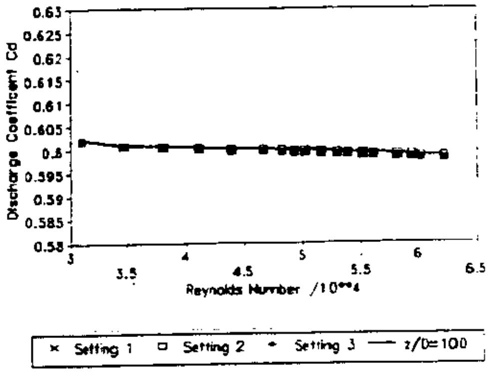

FIG 12B DISCHARGE COEFFICIENT VARIATION DIFFERENT CASES WITH THE CONDITIONER

β=0.5 Orifice Plate

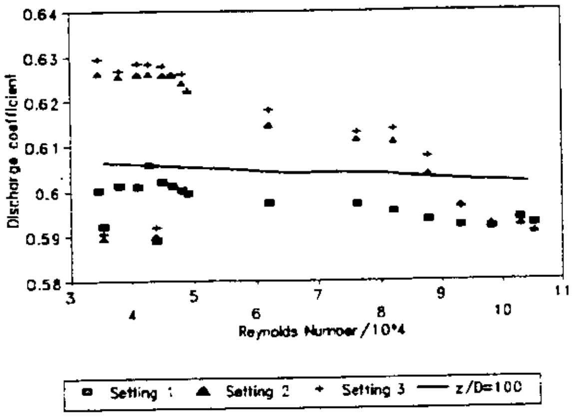

FIG 13A COMPARISON OF DISCHARGE COEFFICIENTS WITHOUT FLOW CONDITIONER

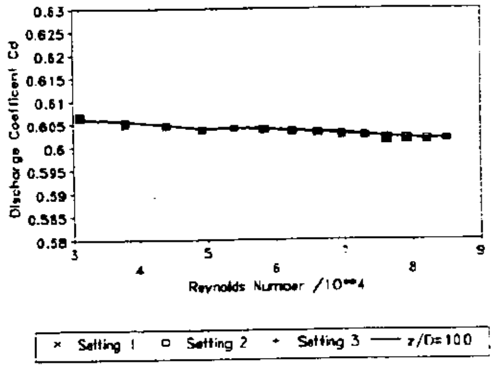

FIG 13B DISCHARGE COEFFICIENT VARIATION FOR THE DIFFERENT CASES WITH THE CONDITIONER

β=0.6 Orifice Plate

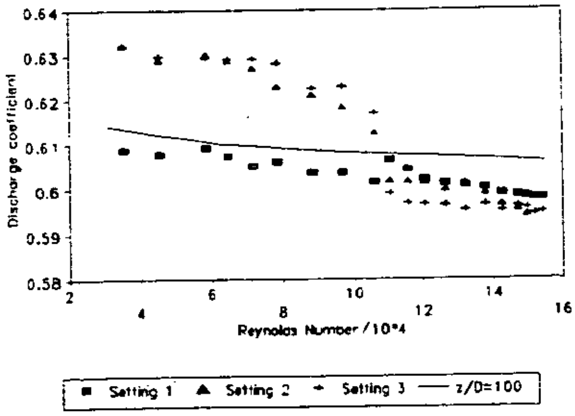

FIG 14A DISCHARGE COEFFICIENT VARIATION DIFFERENT CASES WITHOUT THE CONDITIONER

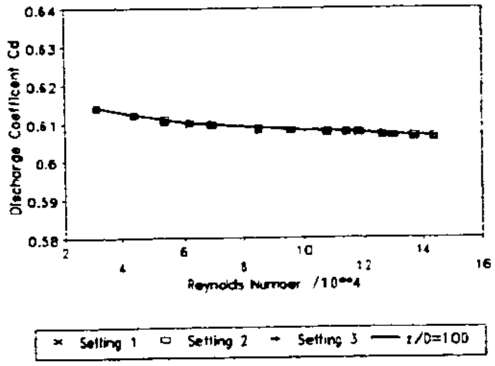

FIG 14B DISCHARGE COEFFICIENT VARIATION DIFFERENT CASES WITH THE CONDITIONER

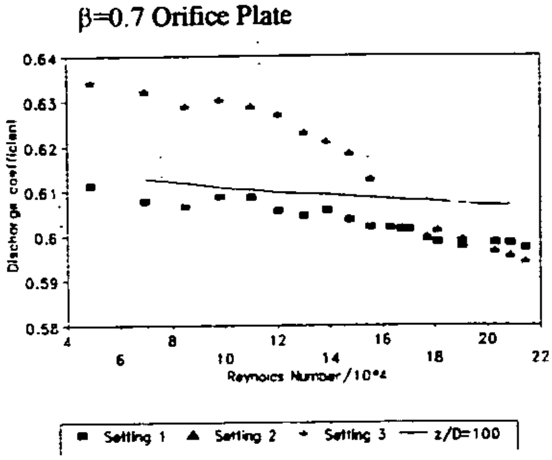

FIG 15A COMPARISON OF DISCHARGE COEFFICIENT FOR DIFFERENT VALVE SETTINGS WITHOUT CONDITIONER

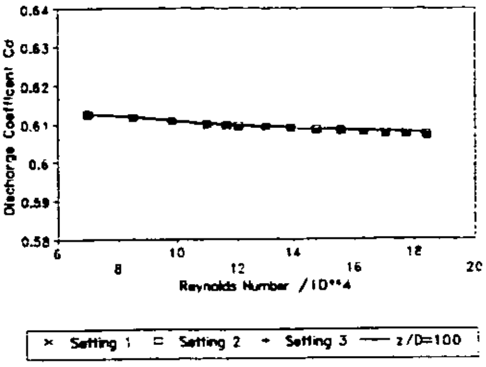

FIG 15B COMPARISON OF DISCHARGE COEFFICIENT FOR DIFFERENT VALVE SETTINGS WITH CONDITIONER

The results for the 70% porosity plate appear marginally better than those for the 60% porosity plate presented in Laws et al(2). In the line size used in the present tests i.e. 0.103m, 70% was the maximum porosity that could be achieved whilst maintaining the structural rigidity of the plate. In larger line sizes a higher plate porosity could be practical and it would be of interest to assess the performance of a higher porosity plate in these circumstances.

Complete confidence in the vaned plate behaviour requires more detailed testing at different pressures, Reynolds numbers and in different line sizes. Preliminary results at high pressure for a β = 0.5 orifice plate installed downstream of single and double 90^0 bends are shown in fig 16. These test were carried out at K-Lab in natural gas in a 0.1397m diameter pipe using a 60% porosity vaned plate installed 3.1D downstream of the bend outlet flange with the orifice plate located 5.3D downstream of the conditioner. Repeatability in the measurements is estimated as ±0.5%.

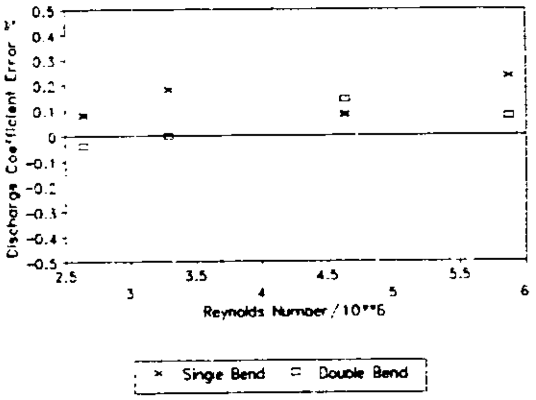

FIG 16 DISCHARGE COEFFICIENT ERROR FOR β = 0.5 ORIFICE PLATE OBTAINED IN NATURAL GAS AT 100BAR.

6. ENHANCEMENT IN PERFORMANCE OF PERFORATED PLATES

Whilst a more fundamental study into the mechanism by which the vanes and plate interact is required before the behaviour of the vaned plate can be fully understood a careful study of the turbulence intensity measured upstream and downstream of a perforated plate with and without vanes indicates that the vanes have a significant effect on the turbulence structure of the flowfield both upstream and downstream of the plate. In consequence vanes can be used upstream of other perforated plates to enhance the plate performance. Preliminary results are presented here for the axial turbulence intensity measured downstream of the thick Zanker plate with and without radial vanes installed 1 pipe diameter upstream of the plate for the case when the valve is set 50% closed.

Fig 17a shows the axial turbulence intensity profiles measured at different stations downstream of the thick version of the Zanker plate installed 3 diameters from the outlet plane of the valve. Fig 17b shows the same plate preceded by a set of eight radial vanes of depth D/8. The improvement in the form and magnitude of the turbulence profiles is clear. Figs 18a and 18b show the equivalent results when the valve is 70% closed. The improvement in the turbulence profile is again evident.

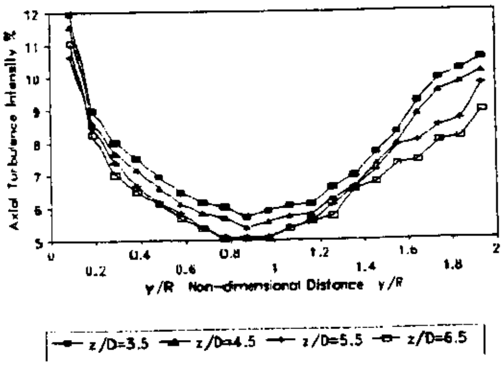

FIG 17A AXIAL TURBULENCE INTENSITY DOWNSTREAM OF THICK ZANKER PLATE VALVE 50% CLOSED

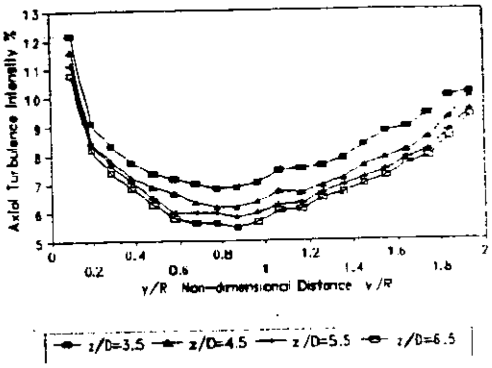

FIG 18A AXIAL TURBULENCE INTENSITY DOWNSTREAM OF THICK ZANKER PLATE VALVE 70% CLOSED

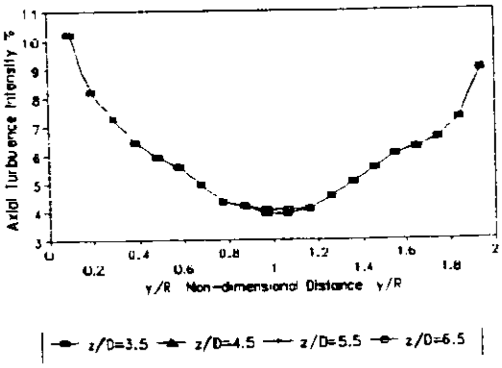

FIG 17B AXIAL TURBULENCE INTENSITY DOWNSTREAM OF THICK ZANKER PLATE PRECEDED BY RADIAL VANES VALVE 50% CLOSED

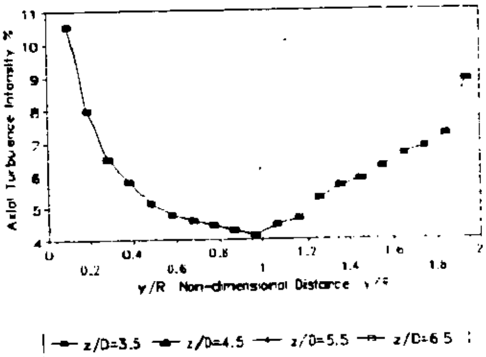

FIG 18B AXIAL TURBULENCE INTENSITY DOWNSTREAM OF THICK ZANKER PLATE PRECEDED BY RADIAL VANES VALVE 70% CLOSED

CONCLUSIONS

A modified vaned Laws plate, easy to manufacture and install, has been introduced which has been demonstrated to be capable of delivering flow conditions which meet the ISO 5167 requirements within an overall installation length of some 5-6 pipe diameters incurring a pressure loss of approximately 0.7 dynamic heads. The improvement in the performance of orifice plates of area ratios of 0.4-0.7 installed in close proximity to this vaned perforated plate flow conditioner has been demonstrated in atmospheric air. Preliminary tests conducted at high pressure using a 60% porosity plate with a pressure loss coefficient of approximately 1.4 give confidence in the behaviour of the vaned plate geometry.

The findings reported here are covered by British Patent Application No: 9319025.4.

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