FOCUS DISCUSSION GROUP E

Effect of Increasing Plate Thickness on the Metering Accuracy of an 8 Inch Orifice Meter Run.

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EFFECT OF INCREASING PLATE THICKNESS ON THE METERING ACCURACY OF AN 8 INCH ORIFICE METER.

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ABSTRACT

The present study investigates the use of a thicker (0.25in.) orifice plate in a standard 8inch orifice meter run. In particular, the effect of retrofitting existing meter runs (*old fitting*) designed for 0.125in. thick plates as well as the performance of newly designed meter runs (*new fitting*) for 0.25in. plates is studied. For the 0.25in. thick plate, the effect of bevel angle and orifice edge thickness on metering accuracy is also evaluated.

Results obtained indicate that :

a) 0.25in. thick orifice plates perform identically when used in old fittings or in new fittings. The use of 0.25in. thick orifice plates would not only increase the capacity of the meter run but also result in repeatable metering independent of β-ratio. For $0.3 \leq \beta \leq 0.6$, (i.e. for mass flow > 3kg/s), the average error is around 0.31% with a 2σ of ±0.13%.

b) in old fittings, for β-ratios ≥ 0.4, there is no difference between the 0.25in. and the 0.125in. plates. For β-ratios < 0.4, the 0.25in. thick plates would over-register by around 0.3%.

c) bevel angle ($30^\circ \leq \alpha \leq 45^\circ$) and orifice bore edge thickness (0.06in. ≤ e ≤ 0.16in.), do not have a measurable effect on the metering accuracy in old or new fittings.

d) plate thickness (0.125in. v/s 0.25in.) does not affect the performance of non-beveled plates in the old fitting.

e) data indicates that for the 0.125in. thick plate, the difference between the beveled and non-beveled plates depends on the β-ratio and does not indicate a specific trend. In the case of the 0.25in. thick plates, the non-beveled plates tend to under-register in comparison to the beveled plates at β-ratios < 0.4.

1.0 INTRODUCTION

It has been recognized in the past that the capacity of a orifice meter run could be increased by increasing the differential pressure to values beyond the allowed 50kPa (200in.). The issues to be recognized in adopting such a procedure are that

1. the plate should not deform permanently and
2. the plate should not undergo elastic deformation since this could lead to metering error.

The first issue can be easily addressed using available stress analysis expressions [1]. The orifice fitting is treated as a simply supported circular plate with a central hole. Results of this analysis are shown in Figure 1. The allowable differential pressure before permanent deformation is governed by the β-ratio and the ratio of the support diameter to the plate thickness (aspect ratio). If differential pressures of at least 200kPa are to be used for β-ratios ≥ 0.2, then the aspect ratio of the plate should be around 40.

The second issue is also a function of the above two parameters [2], [3], [4], [5], [6]. Apart from this work, originating from the British Gas Engineering Research Station, other work on this subject matter has also been published [7], [8], [9]. The effect of plate deformation on metering error [2] is presented in Figures 2a,b,c & d. It is evident that if the metering errors due to plate deformation are to be minimized (<0.05%), then the aspect ratio should be less than 40. Experimental work performed on natural gas [10] at the NOVA gas dynamic Test Facility, confirmed the theoretical estimates shown in Figure 2 for aspect ratios of 32 (4in. meter run) and 80 (10in. meter run). Details of the theoretical estimates are also presented by [10].

On examining metering standards and existing 8in. meter runs in the NOVA system, it would not be possible to increase the capacity of these meter runs under the current specifications i.e. recommended plate thickness of 0.125in (an aspect ratio of 67.5). One approach to increase the capacity would be to use a thicker plate e.g. 0.25in. (an aspect ratio of 33.75). This results in the following issues that need to be addressed.

1. In the case of retrofitting existing meter runs with 0.25in. plates, one would be altering the location of the pressure taps. Standards stipulate that the flange taps should be located 1inch from the upstream and downstream surface of the plate respectively. On using the thicker plate, the location of the taps from the respective surfaces would now be 0.9375in. The question to be answered is whether, this small shift in tap locations causes a significant

error in metering ? Further, can the R-G equation be modified to accommodate the new tap locations as part of the tap term ?

2. A corollary of the above issue is that if the upstream edge is the governing parameter for the flow structure, then the upstream edge will now be located 1.1875in. from the downstream tap instead of the 1.125in. as in the case of the 0.125in. thick plate. This change in the flow structure could alter the measured pressure drop and hence the measured flow rate.
3. If we buy into point #2, then consider the new fitting i.e. one manufactured for the 0.25in. thick plate with the appropriate location for the flange taps. In this case all specifications of the A.G.A. standard are met i.e. the plate thickness does not exceed the maximum value and the flange taps are appropriately placed. If the issue raised in point # 2 is now applied, the distance from the upstream edge to the downstream tap is now 1.25in. Would this further affect metering error adversely ?
4. The issues are further complicated by the fact that the orifice database on which the equation was generated apparantly does not include any data from an 8in. meter run.

From NOVA's perspective, the need to increase meter capacity exists. This can be done quite easily for the 4in. and 6in. meter runs without any adverse effects on the measured flow. There exists a need to increase the capacity of 8in. meter runs. If NOVA is to request vendors to supply meter runs appropriately designed for the 0.25in. thick plate, it is important that we ensure that the performance of a retrofitted meter compares well with that of the new meter design.

Hence, the objectives of the project are follows :

a) To evaluate the performance of old 8in. meter runs designed for 0.125in. thick plates.

b) To examine the effect of retrofitting old 8in. meter runs with 0.25in. thick plates.

c) To study the performance of the new 8in. meter run designed for 0.25in. thick plates.

d) To study the effect of bevel angle and bore edge thickness on metering accuracy.

2.0 EXPERIMENTAL FACILITY

Experiments were performed in natural gas at NOVA's Gas Dynamic Test Facility at a line pressure which varied between 5000-6000kPa. A sketch of the test loop is shown in Figure 3. Following a straight section of around 39D, the flow was conditioned by means of a NOVA 50E flow conditioner. The orifice plate was located 30D downstream of the flow conditioner, ensuring a fully developed, symmetric velocity profile at the orifice plate. Past measurements with the NOVA 50E [11], [12] indicate that the profile is fully developed at 8D downstream of the flow conditioner with a 5D upstream mixing length. The orifice meter run was a standard Daniel orifice fitting. A thermowell was located 5.3D downstream of the orifice plate for the insertion of a RTD to measure the flow temperature.

The static pressure was measured by means of a Rosemount Smart static pressure transmitter and a Rosemount Smart temperature transmitter was used to power the RTD. The differential pressure across the orifice plate was measured by a Rosemount Smart differential pressure transmitter with a range from 0-200kPa. The static pressure transmitter was calibrated with an Ametek dead weight tester and its performance was monitored, at zero flow conditions, with another calibrated Smart transmitter located elsewhere in the loop. If the difference between the two transmitters exceeded by more than 0.1% (stated accuracy of the transmitter), the transmitters were re-calibrated.

The temperature RTD was calibrated with an Automatic Systems Laboratory (B125) dry block calibrator using a NIST traceable ERTCO-HART 850 high precision platinum RTD as a reference. Several checks performed during the course of the tests and the calibration was stable to within 0.05deg. C. The differential transmitter was calibrated at ambient conditions with an Ametek dead weight tester and was adjusted for the zero offset at line conditions. Calibration checks indicated that the drift in the slope was not more than 0.05%. The calibration curve was corrected for non-linear effects. Some typical calibration checks are presented in Table 1.

The set of orifice plates used in the present study were obtained from Daniel Industries and were manufactured to NOVA specifications, namely, a bevel angle of 37.5 degrees and a bore edge thickness of 0.06in among others. Other variations of orifice plates that were tested are tabulated in Table 2.

The flow rate from the orifice meter was compared to that from the sonic nozzle bank. Details of the uncertainty analysis and the traceability of the nozzle bank to the gravimetric facility [13], [14] indicate that the uncertainty in mass flow is around 0.2%. The maximum flow rate capacity of the facility is currently around 14kg/s.

3.0 EXPERIMENTAL RESULTS

3.1 Beveled Plates

Results of testing beveled plates (0.125in. and 0.25in. thick), manufactured to A.G.A. and NOVA specifications (bevel angle =37.5deg. and bore edge thickness = 0.06in.), in an old fitting are shown in Figures 4a,b,c,d,e,& f. The data was taken such that, for any given β-ratio, the 0.125in. and the 0.25in. plate were tested on the same day thus improving the system repeatability. The first observation from these figures is that measurements taken at two tap locations 180 deg. apart show identical trends. This indicates that the velocity profile at the orifice plate is symmetric. Further, for $\beta \leq 0.6$, the metering error is within the ±0.55% band of the R-G equation.

The statistics presented in Table 3. (for $\Delta P > 20kPa$) may imply that the 0.25in. plate over-registers in comparison to the 0.125in. plate. However, on examining the figures and the 2σ levels of the data it can be concluded that, for $\beta \geq 0.4$, there is no difference between the performance of the two plates. For $\beta = 0.2$ and 0.3, the thicker plate clearly seems to over-register in comparison to the thinner plate by about 0.3-0.4%. Using the R-G equation with the appropriate tap distances (0.9375in.) does not eliminate this difference.

In the past, the effect of plate thickness on orifice meter performance has been studied [15] in detail for a 6in. meter run. Although in their plate thickness tests the location of the taps with respect to the plate were constant (1inch) for all plates, some comparisons are made with the present results wherein the tap locations changed with plate thickness. The findings in the present study are similar to earlier findings [15]. For example, for plate thickness of 0.25in., they find that a $\beta=0.3$ over registers a 0.125in. thick plate by around 0.3%. Further, for the larger β-ratios (0.5 and 0.7) no significant differences were measured as found in the present study.

It is also clear from Figures 4a. through 4f., that a 0.25inch thick plate performs identically when used in an old fitting and a new fitting.

3.2 Non-Beveled Plates

Results of testing the non-beveled plates in an old fitting, are presented in Figures 5a,b,c,d,e &f and tabulated in Table 4. For all β-ratios, there does not appear to be a significant or systematic difference between the performance of the 0.125in. and the 0.25in,. thick plates. This is evident from the Figures as well as the statistics shown in Table 4. In the case of the non-beveled plates, previous findings [15] also indicate that there is no difference in the performance of a 0.25in. plate in comparison to the 0.125in. plate, for all β-ratios. Husain & Teyssandier [15] further state that for thickness upto 0.3in., within their system repeatability, there is no difference between the beveled and unbeveled plates. This is true in the present experiments for the 0.125in. plate as seen in Table 5a. where no definite trend seems to exist and the differences are comparable to the 2σ confidence levels. However, from Table 5b, it appears that the non-beveled plate under-registers in comparison to the beveled plates for a plate thickness of 0.25in. particularly at the lower β-ratios.

3.3 Effect of Bevel Angle and Bore Edge Thickness

This study was conducted for β-ratios of 0.2192 and 0.5952, so that two extreme, yet stable cases could be examined. Further, these tests have only been conducted with a 0.25in. thick plate because the effects are expected to become severe with increasing thickness. Specific details of the plates are provided in Table 2. Results of these tests are shown in Figures 6 & 7 and Table 6. Firstly, consider the data taken for the plates with α = 37.5deg. and e=0.06in. Results of two plates are shown for each β-ratio. The two plates were ordered and tested almost 1 month apart. The data is very repeatable with deviations not greater than 0.1%. From Figures 6 & 7 and Table 6, it could be concluded that, for both orifice fittings, there is no effect of bevel angle and bore edge thickness, within the specifications provided by the standards. This is confirmed by the experiments of Husain & Teyssandier [15], except for β=0.3 where they measured a difference of around 0.4% between α=30deg. and 45deg.

4.0 ANALYSIS AND DISCUSSION

Various theories can be postulated to explain the performance of an orifice plate. Although more information is needed, the following attempts to propose some theories explaining some of the results that have been obtained in the present study. The performance of the orifice plate, as reflected by the pressure drop measured across the plate, is influenced by the following parameters :

(a) tap location with respect to the leading edge of the orifice plate

(b) flow structure generated by the orifice plate

(c) β-ratio

Consider the performance of the 0.125in. and 0.25in. beveled plates in the old fitting. It is possible that the smaller β-ratios result in a well defined jet and hence a region of pressure (tap location) sensitivity. If the location of the vena-contracta is determined by the leading edge, then for the smaller β-ratios, if a thicker plate is used, then the vena-contracta occurs closer to the plate. If the tap location is fixed, then the thicker plate sees a higher differential pressure. Thus, at smaller β-ratios the thicker plate over-registers in comparison to the thinner plate for a fixed tap location as indicated by the measurements. On the other hand a larger β-ratio could result in a rather large wake causing an insensitivity to tap location.

Why then does the 0.25in. plate not show tap sensitivity at lower β-ratios (i.e. in the old fitting and the new fitting) ? The answer possibly lies in the fact that the flow structure is similar i.e. "*wake like*" so that the pressure downstream is not sensitive to small changes in tap location. The same can be said with the 0.25in. thick plates used in the test of bevel angle and orifice edge bore edge thickness tests.

Consider the un-bevelled plates, the results indicate that there is no sensitivity to tap location i.e. a 0.125in. plate and a 0.25in. plate behave identically in the old fitting for all β-ratios as seen in Table 4. In the absence of a bevel, the knife-edge of the orifice plate is absent and this results in a "*bluff body*" like wake which camouflages any pressure sensitivity that may be associated with varying β-ratios.

There are some exceptions that do not conform to the above theories. For example, the 0.25in. thick plate with the edge thickness of 0.16in. Should its performance be similar to that of the 0.125in. and 0.25in. unbevelled plate ? This is not the case in the present experiments.

The fact remains that more than just the tap location is responsible for the performance exhibited by an orifice plate. Although, some ideas have been proposed, there are exceptions to the hypotheses. Further, studies involving the study of the structure of the flow just downstream of an orifice plate for various geometries using flow visualization or computational techniques are warranted. These studies need to be supported with laboratory experiments where the relevant parameters involved can be artificially manipulated to isolate various effects.

In any event, comparing the performance of the plates (0.125in. and 0.25in.), using Figures 8a and 8b, one could recommend the retrofitting of existing meter runs with 0.25in. thick plates or using them in new fittings. In fact, this would not only increase the capacity but also improve the repeatability of the meter.

5.0 CONCLUSIONS

Based on the results obtained with older fittings designed for the 0.125in. plates the following can be concluded :

a) 0.25in. thick orifice plates perform identically when used in existing fittings or in new fittings. The use of 0.25in. thick orifice plates would not only increase the capacity of the meter run but also result in repeatable metering independent of β-ratio. For $0.3 \leq \beta \leq 0.6$, (i.e. for mass flow > 3kg/s), the average error is around 0.32% with a 2σ of ±0.16%.

b) in existing fittings, for β-ratios ≥ 0.4, there is no difference between the 0.25in. and the 0.125in. plates. For β-ratios < 0.4, the 0.25in. thick plates would over-register by around 0.3%.

c) bevel angle ($30° \leq \alpha \leq 45°$) and orifice bore edge thickness ($0.6\text{in.} \leq e \leq 0.16\text{in.}$), do not have a measurable effect on the metering accuracy in new or existing fittings.

d) plate thickness (0.125in. v/s 0.25in.) does not affect the performance of non-beveled plates in the existing fitting.

e) data indicates that for the 0.125in. thick plate, the difference between the beveled and non-beveled plates depends on the β-ratio and does not indicate a specific trend. In the case of the 0.25in. thick plates, the non-beveled plates tend to under-register in comparison to the beveled plates. The larger under-registration occurring at β-ratios < 0.4.

6.0 ACKNOWLEDGMENT

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7.0 REFERENCES

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Calibration of Differential Transmitter at Orifice Meter
First Calibrated on 27th September 1995.

Date	Slope	% difference
27 Sept 1995	0.123225 counts/Pa	0.000%
27 Oct 1995	0.12317 counts/Pa	-0.045%
29 Nov. 1995	0.123164 counts/Pa	-0.050%

Calibration Checks of Static Pressure Transmitter at Orifice Meter at zero flow.
Calibrated on 27th September 1995.

Date	P_{noz} kPa	P_{orf8} kPa	max. diff. %
27 Sept. 1995	6257	6259	0.03%
17 Oct. 1995	5790	5787	0.05%
31 Oct. 1995	5255	5253	0.04%
06 Nov. 1995	6166	6165	0.02%
21 Nov. 1995	6031	6029	0.03%

Calibration Checks of Temperature Transmitter at Orifice Meter with dry block.
Calibrated on 27th September 1995.

Date	T_{ref} deg.C	T_{orf8} deg.C
07 Nov. 1995	14.69	14.69
	9.18	9.19
29 Nov. 1995	14.42	14.37
	8.42	8.42

Table 1. Typical performance of pressure and temperature transmitters.

β-Ratio	bevel angle α deg.	Plate thickness inches	Bore edge thickness inches
0.2193	37.5	0.125	0.06
	37.5	0.250	0.06
	37.5	0.250	0.16
	30.0	0.250	0.06
	30.0	0.250	0.16
	45.0	0.250	0.06
	45.0	0.250	0.16
0.3132	37.5	0.125	0.06
	37.5	0.250	0.06
0.4072	37.5	0.125	0.06
	37.5	0.250	0.06
0.5012	37.5	0.125	0.06
	37.5	0.250	0.06
0.5952	37.5	0.125	0.06
	37.5	0.250	0.06
	37.5	0.250	0.16
	30.0	0.250	0.06
	30.0	0.250	0.16
	45.0	0.250	0.06
	45.0	0.250	0.16
0.7205	37.5	0.125	0.06
	37.5	0.250	0.06

Table 2. Details of orifice plates used in the present study.

	Mean Error [%] with 2σ		**Difference**	**New Fitting**
β-Ratio	**0.125inch**	**0.25inch**		**0.25inch**
0.2193	-0.29 ±0.18%	0.08±0.11%	-0.37%	0.11±0.13%
0.3132	0.09±0.07%	0.36±0.09%	-0.27%	0.36±0.13%
0.4072	0.13±0.15%	0.25±0.08%	-0.12%	0.28±0.11%
0.5012	0.17±0.08%	0.25±0.06%	-0.08%	0.23±0.16%
0.5952	0.34±0.15%	0.35±0.07%	-0.01%	0.36±0.08%
0.7205	0.69±0.28%	0.79±0.32%	-0.1%	0.60±0.02%

Table 3. Summary of results for beveled plates.

	Mean Error [%] with 2σ		**Difference**
β-Ratio	**0.125inch**	**0.25inch**	
0.2193	-0.10±0.17%	-0.18±0.15%	0.08%
0.3132	-0.045±0.09%	0.00±0.08%	-0.045%
0.4072	0.20±0.11%	0.09±0.01%	0.11%
0.5012	0.14±0.08%	0.15±0.05%	-0.01%
0.5952	0.11±0.21%	0.21±0.12%	-0.10%
0.7205	0.55±0.08%	0.57±0.05%	-0.02%

Table 4. Summary of results for non-beveled plates in old fitting

	Mean Error [%] with 2σ		Difference
β-Ratio	Beveled	Non-Beveled	Beveled minus Non Beveled
0.2193	-0.29±0.18%	-0.10±0.17%	-0.19%
0.3132	0.09±0.07%	-0.045±0.09%	0.14%
0.4072	0.13±0.15%	0.20±0.11%	-0.07%
0.5012	0.17±0.08%	0.14±0.08%	0.03%
0.5952	0.34±0.15%	0.11±0.21%	0.23%
0.7205	0.69±0.28%	0.55±0.08%	0.14%

Table 5a. Beveled v/s non-beveled for 0.125 in. thick plates.

	Mean Error [%] with 2σ		Difference
β-Ratio	Beveled	Non-Beveled	Beveled minus Non Beveled
0.2193	0.08±0.11%	-0.18±0.15%	0.26%
0.3132	0.36±0.09%	0.00±0.08%	0.36%
0.4072	0.25±0.08%	0.09±0.01%	0.16%
0.5012	0.25±0.06%	0.15±0.05%	0.10%
0.5952	0.35±0.07%	0.21±0.12%	0.14%
0.7205	0.79±0.32%	0.57±0.05%	0.22%

Table 5b. Beveled v/s non-beveled for 0.25 in. thick plates.

Bevel Angle (deg.)	orifice edge (in.)	Error±2σ (new Fitting)	Error±2σ (old Fitting)
45	0.06	0.35±0.08	0.41±0.17
37.5	0.06	0.36±0.08	0.37±0.11
30.0	0.06	0.39±0.08	0.48±0.11
		0.37%	**0.42%**
45	0.16	0.24±0.04	0.40±0.08
37.5	0.16	0.23±0.05	0.52±0.06
30.0	0.16	0.19±0.00	0.40±0.12
		0.22%	**0.44%**
0.0	0.25		0.21±0.12

Table 6a. Effect of bevel angle and orifice bore edge thickness (β-Ratio = 0.6) using a 0.25in. thick orifice plate.

Bevel Angle (deg.)	orifice edge (in.)	Error±2σ (new Fitting)	Error±2σ (old Fitting)
45	0.06	0.19±0.04	0.10±0.22
37.5	0.06	0.11±0.13	0.08±0.10
30.0	0.06	0.26±0.05	0.22±0.10
		0.20%	**0.13%**
45	0.16	0.02±0.12	0.10±0.11
37.5	0.16	0.12±0.09	0.10±0.13
30.0	0.16	-0.01±0.06	-0.02±0.09
		0.04%	**0.06%**
0.0	0.25		-0.18±0.15

Table 6b. Effect of bevel angle and orifice bore edge thickness (β-Ratio = 0.2) using a 0.25in. thick orifice plate.

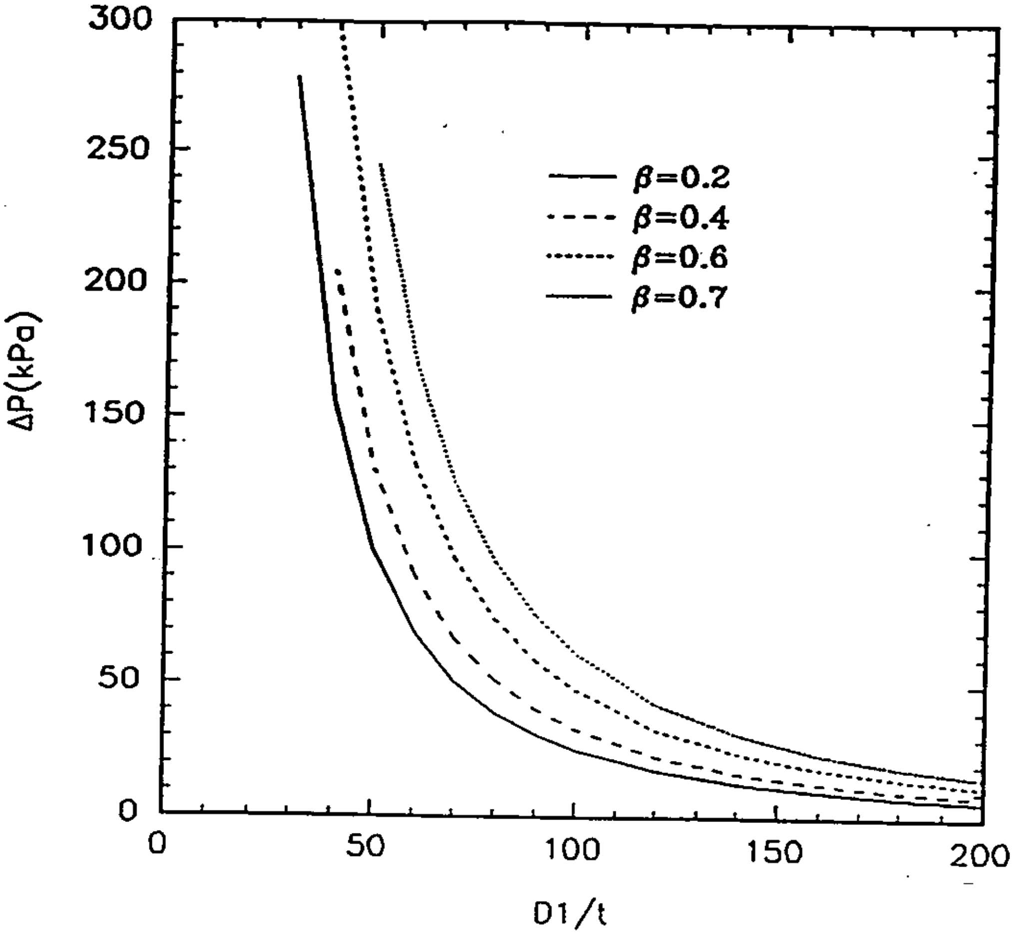
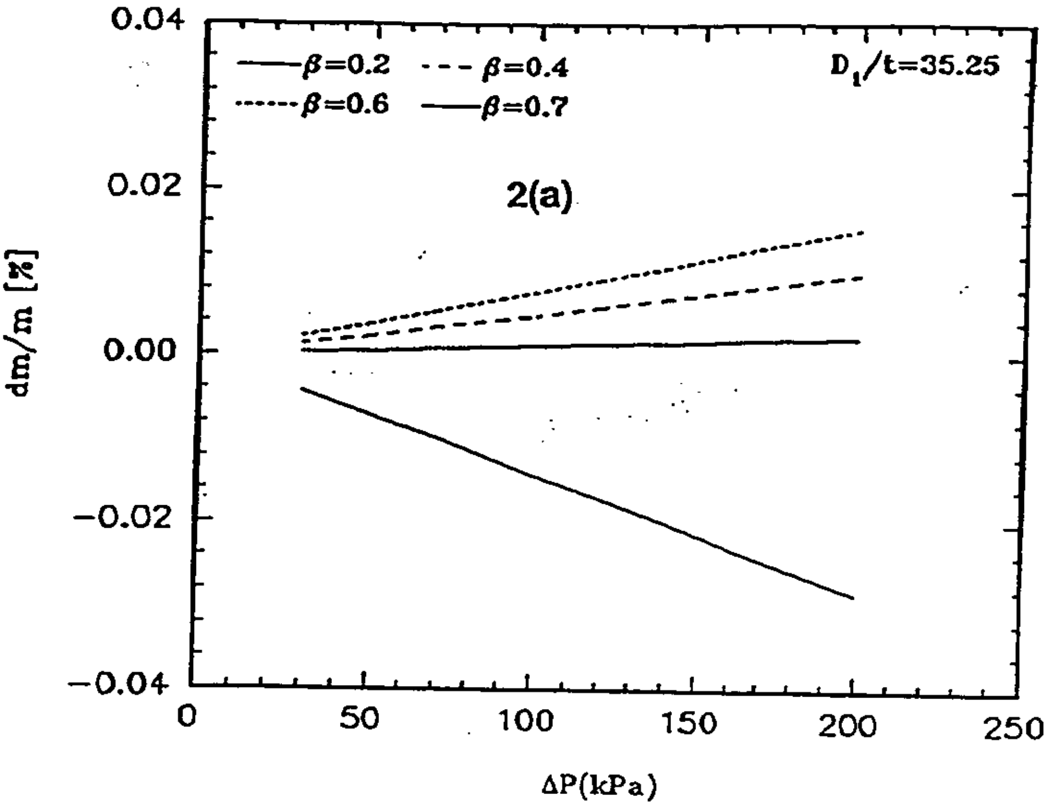
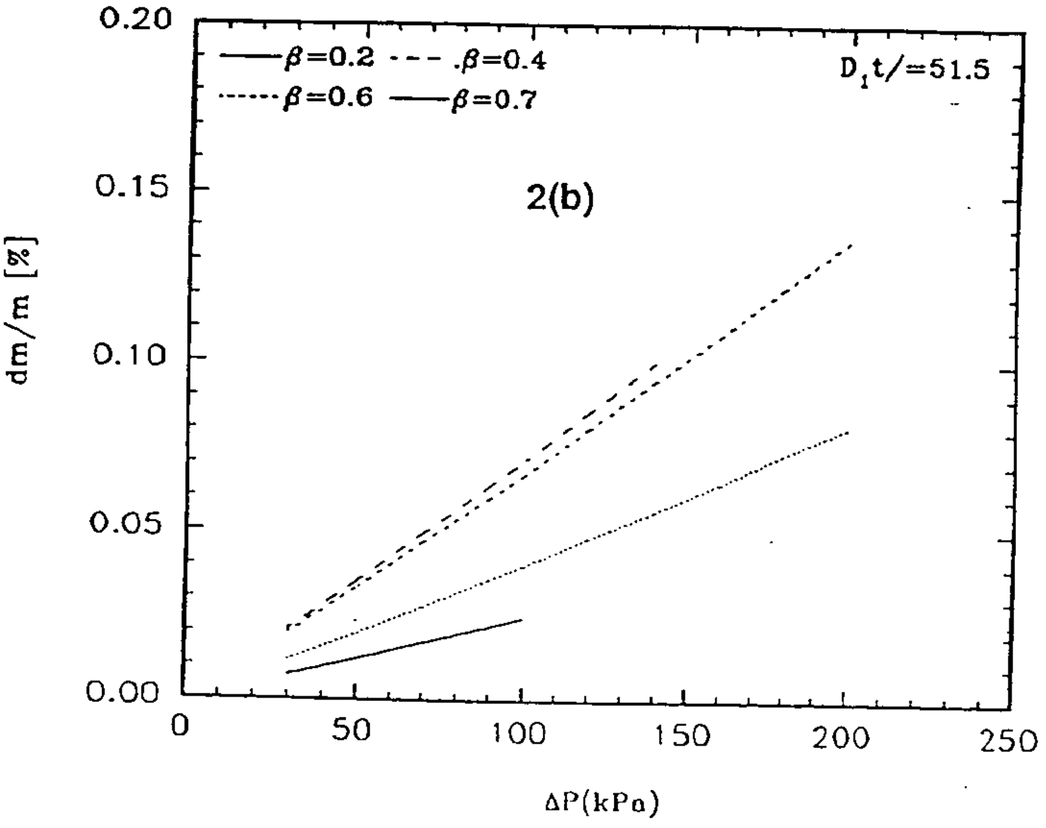


Figure 1. Allowable pressure difference across an orifice plate before yield.



β=0.2
β=0.4
β=0.6
β=0.7
D_1/t=35.25
2(a)
dm/m [%]
0.04
0.02
0.00
−0.02
−0.04
0
50
100
150
200
250
ΔP(kPa)



β=0.2
.β=0.4
β=0.6
β=0.7
D_1t/=51.5
2(b)
dm/m [%]
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
ΔP(kPa)

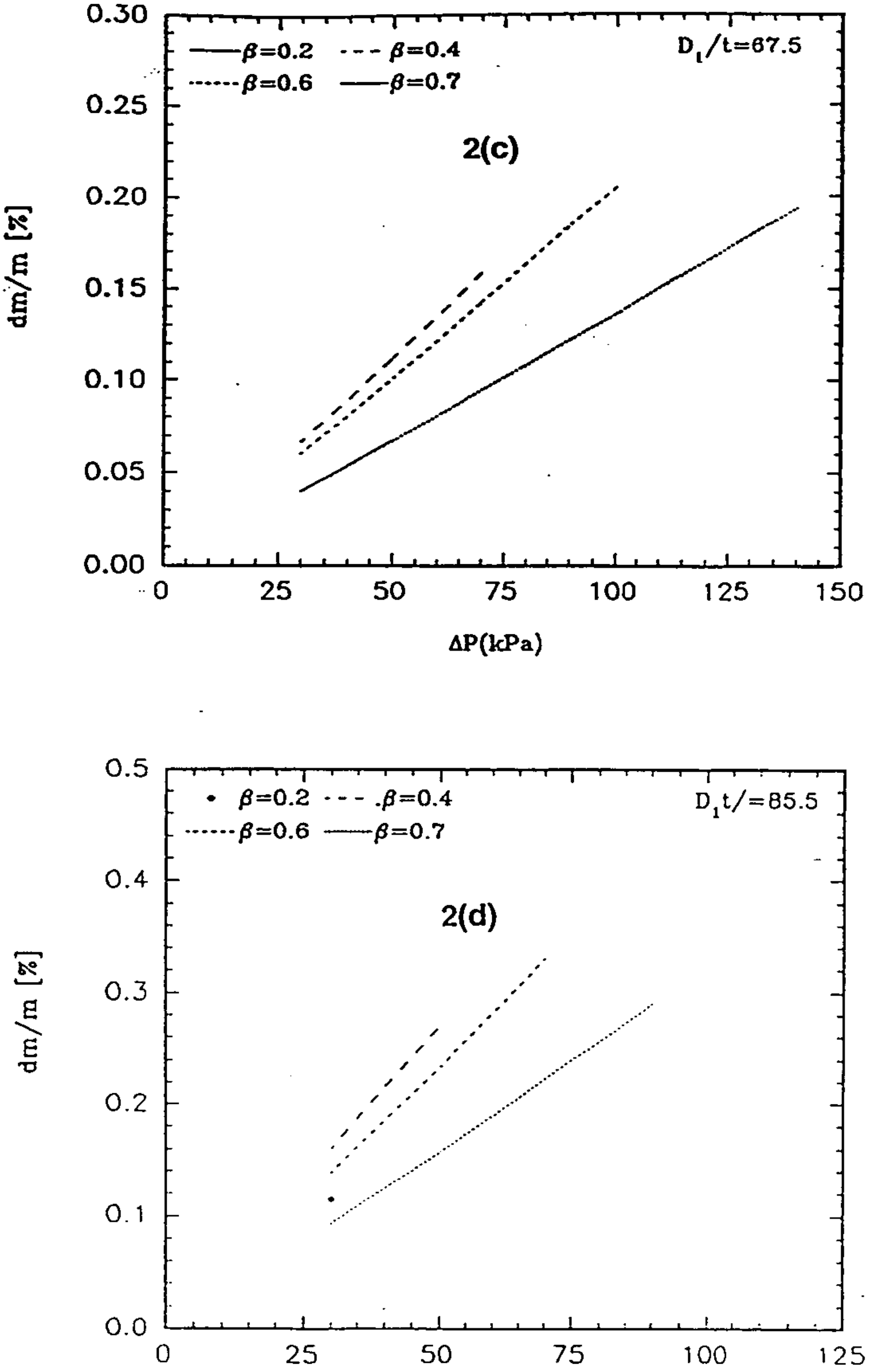
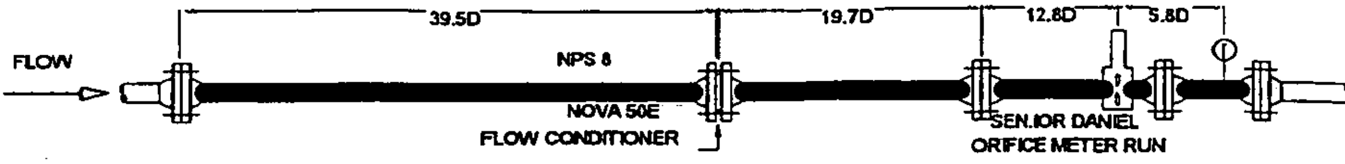


Figure 2. Total error in metering due to elastic deformation of an orifice plate .



DETAIL 'A'

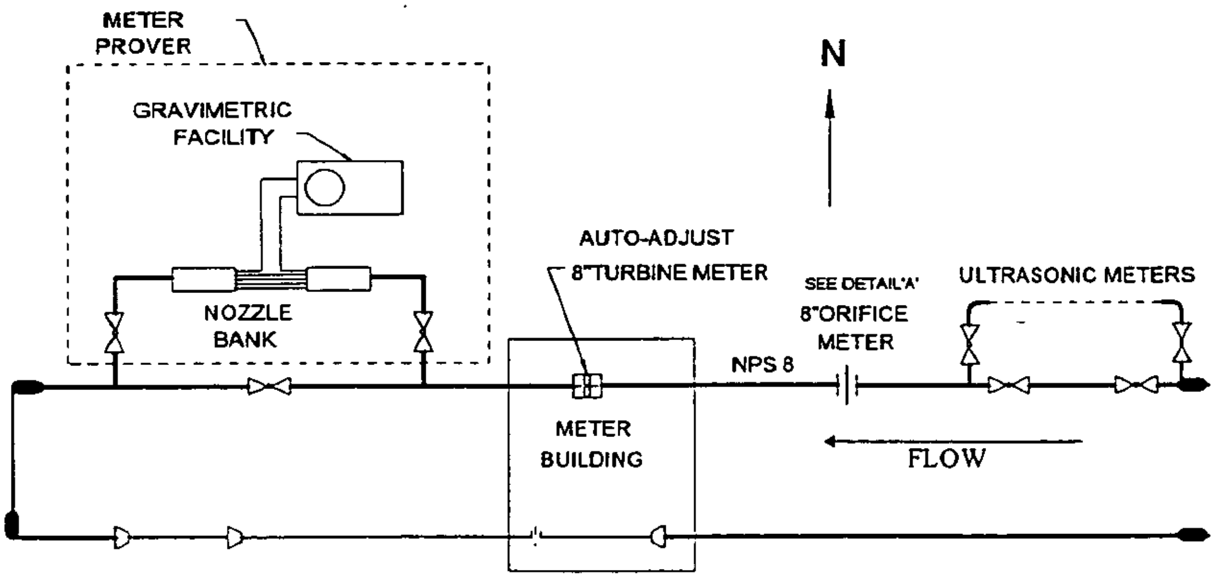


Figure 3. Schematic layout of the Test Facility

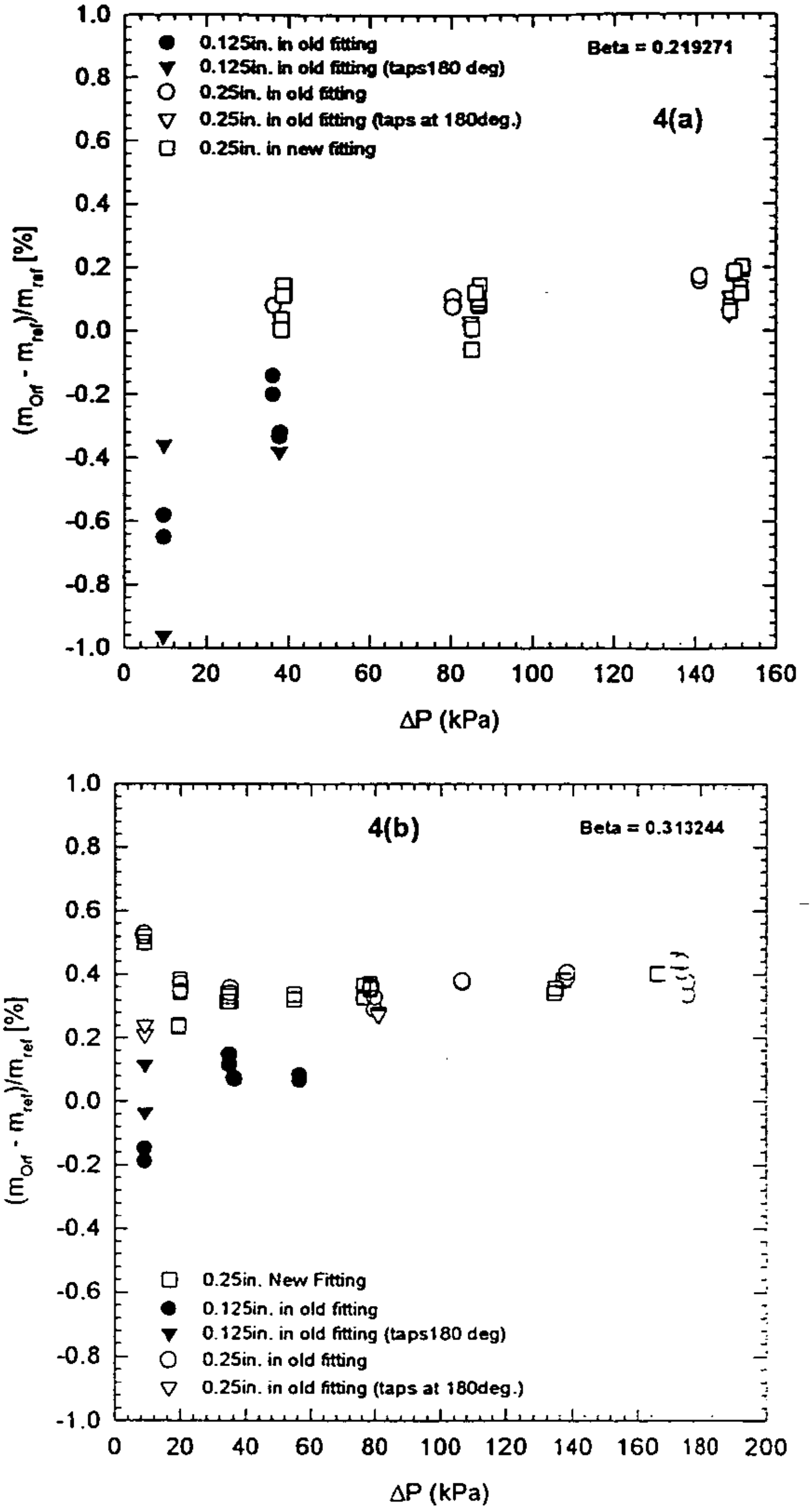


Figure 4a&b Comparison of performance of beveled orifice plates (a) β=0.2193 (b) β=0.3132.

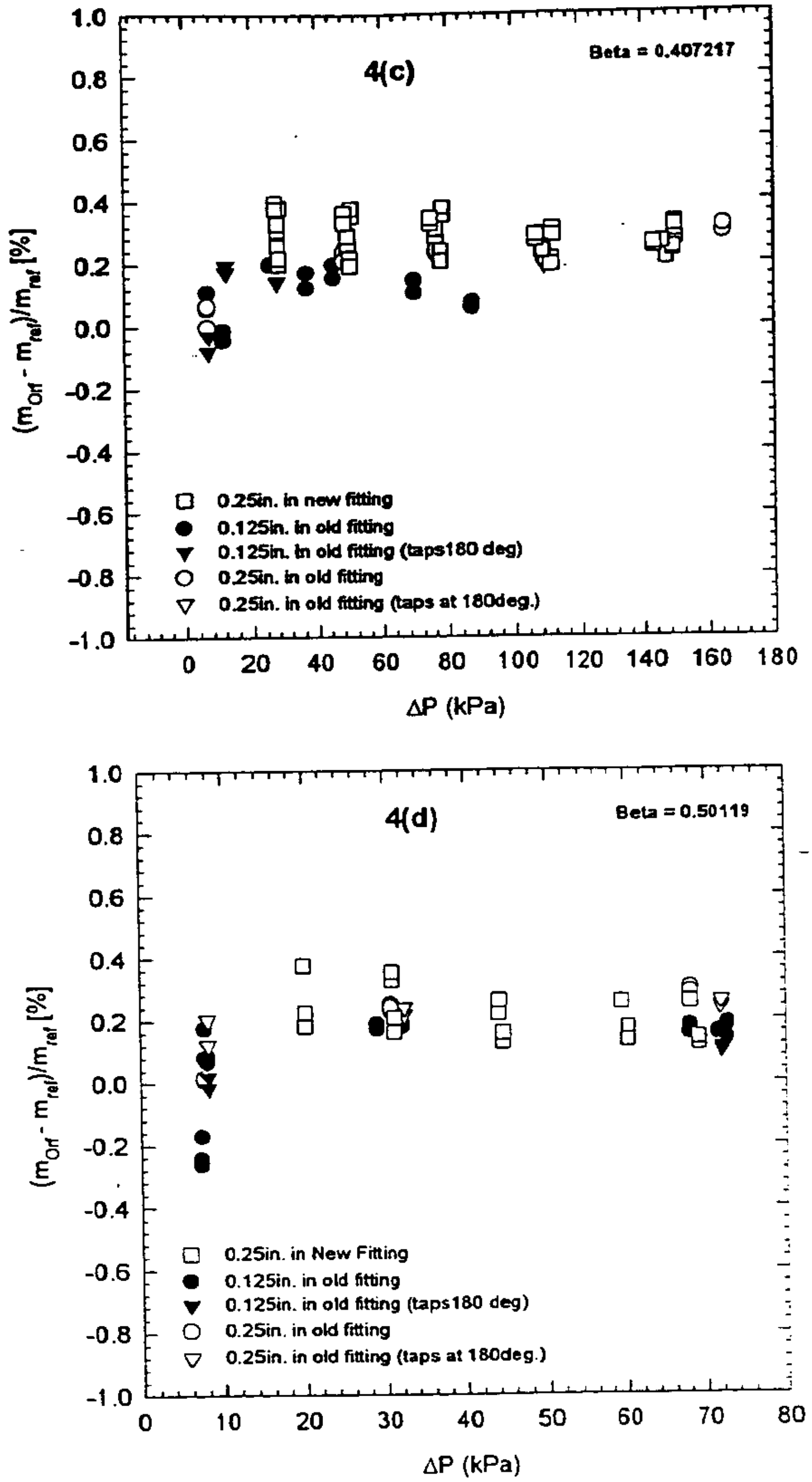


Figure 4c&d Comparison of performance of beveled orifice plates (c) β=0.4072 (d) β=0.5012.

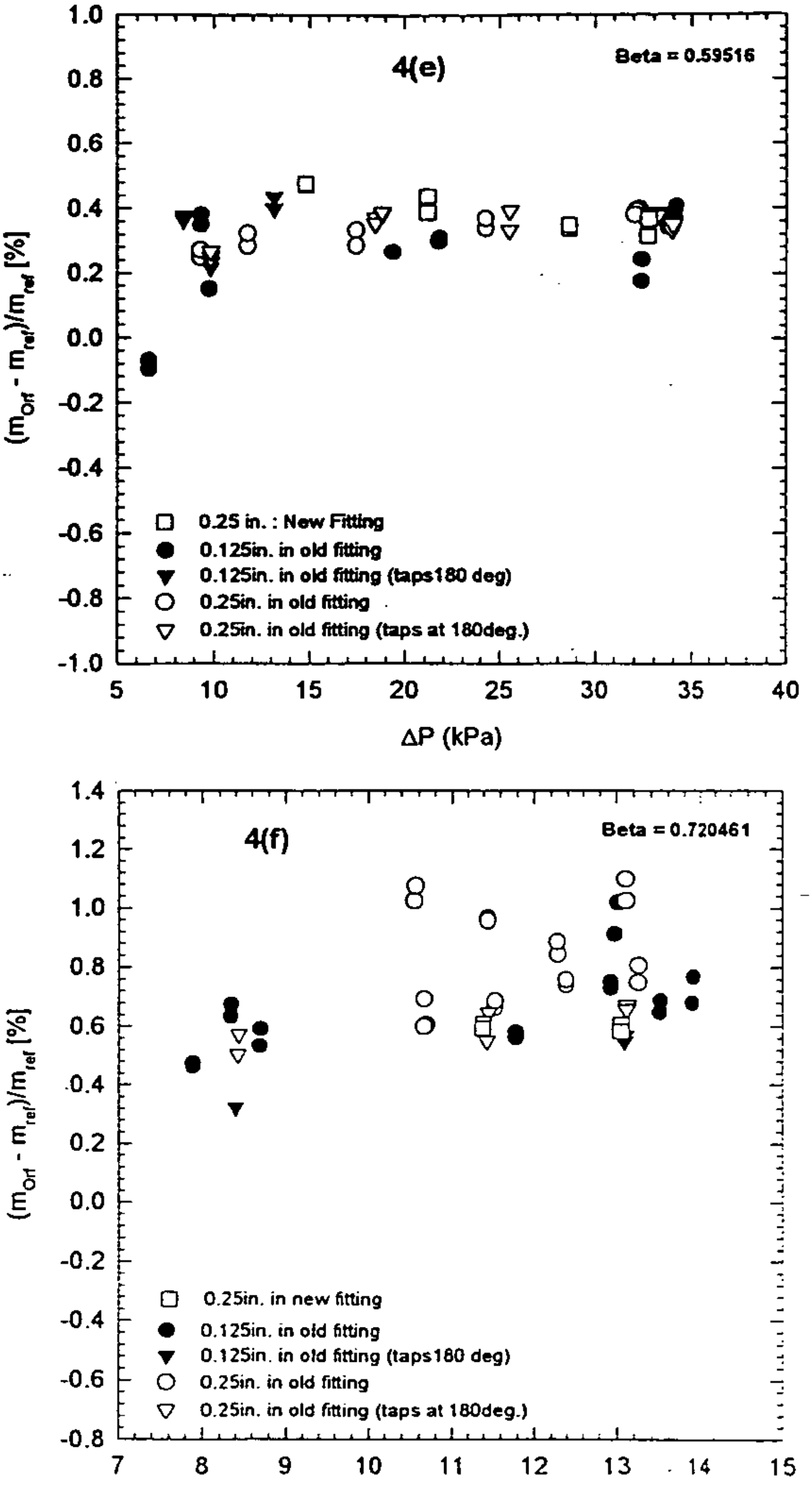


Figure 4e&f Comparison of performance of beveled orifice plates (e) $\beta=0.5952$ (f) $\beta=0.7205$.

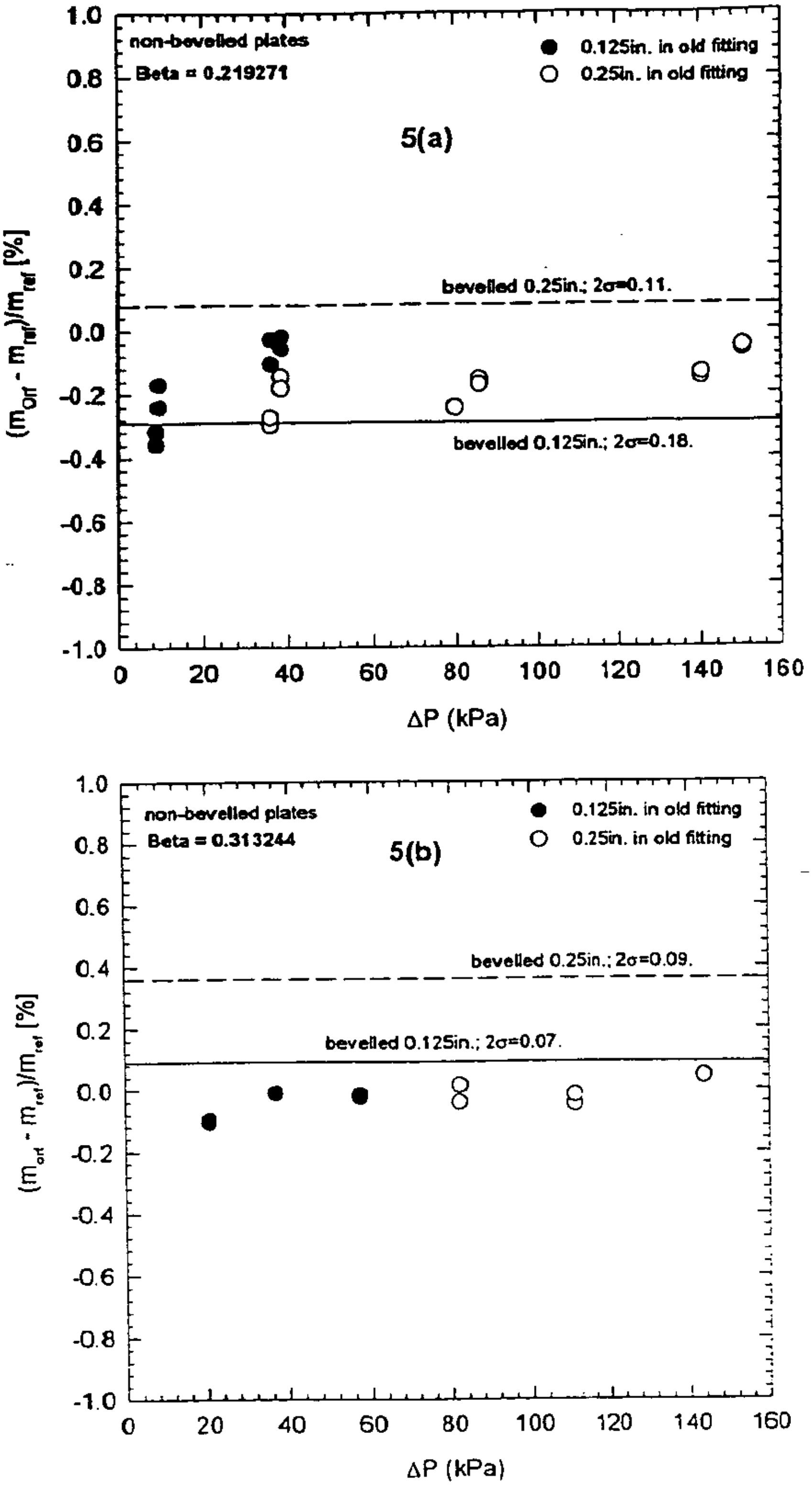


Figure 5a&b Comparison of performance of non-beveled orifice plates in old fitting (a) β=0.2193 (b) β=0.3132.

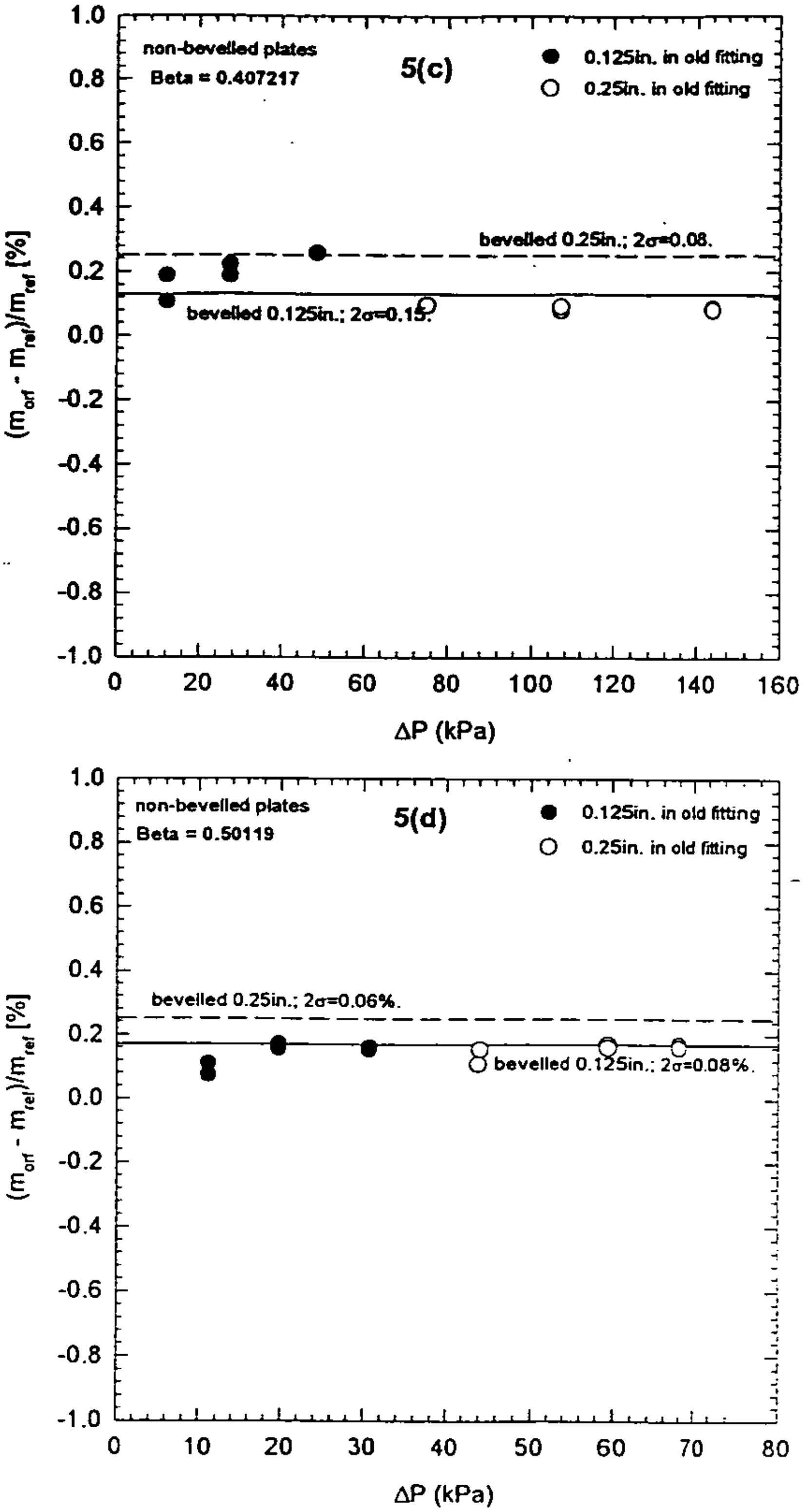


Figure 5c&d Comparison of performance of non-beveled orifice plates in old fitting (c) β=0.4072 (d) β=0.5012.

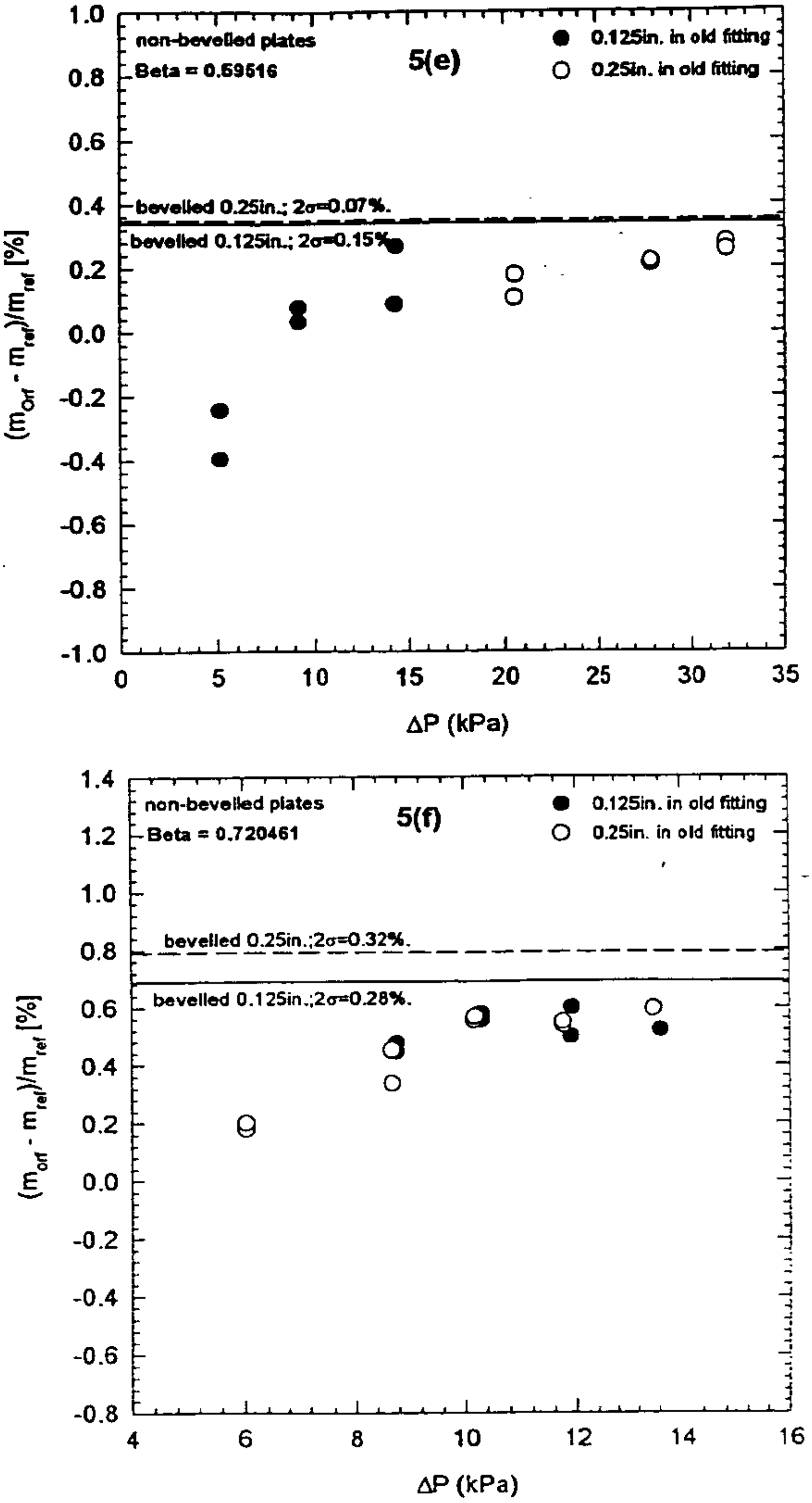


Figure 5e&f Comparison of performance of non-beveled orifice plates in old fitting (e) $\beta=0.5952$ (f) $\beta=0.7205$.

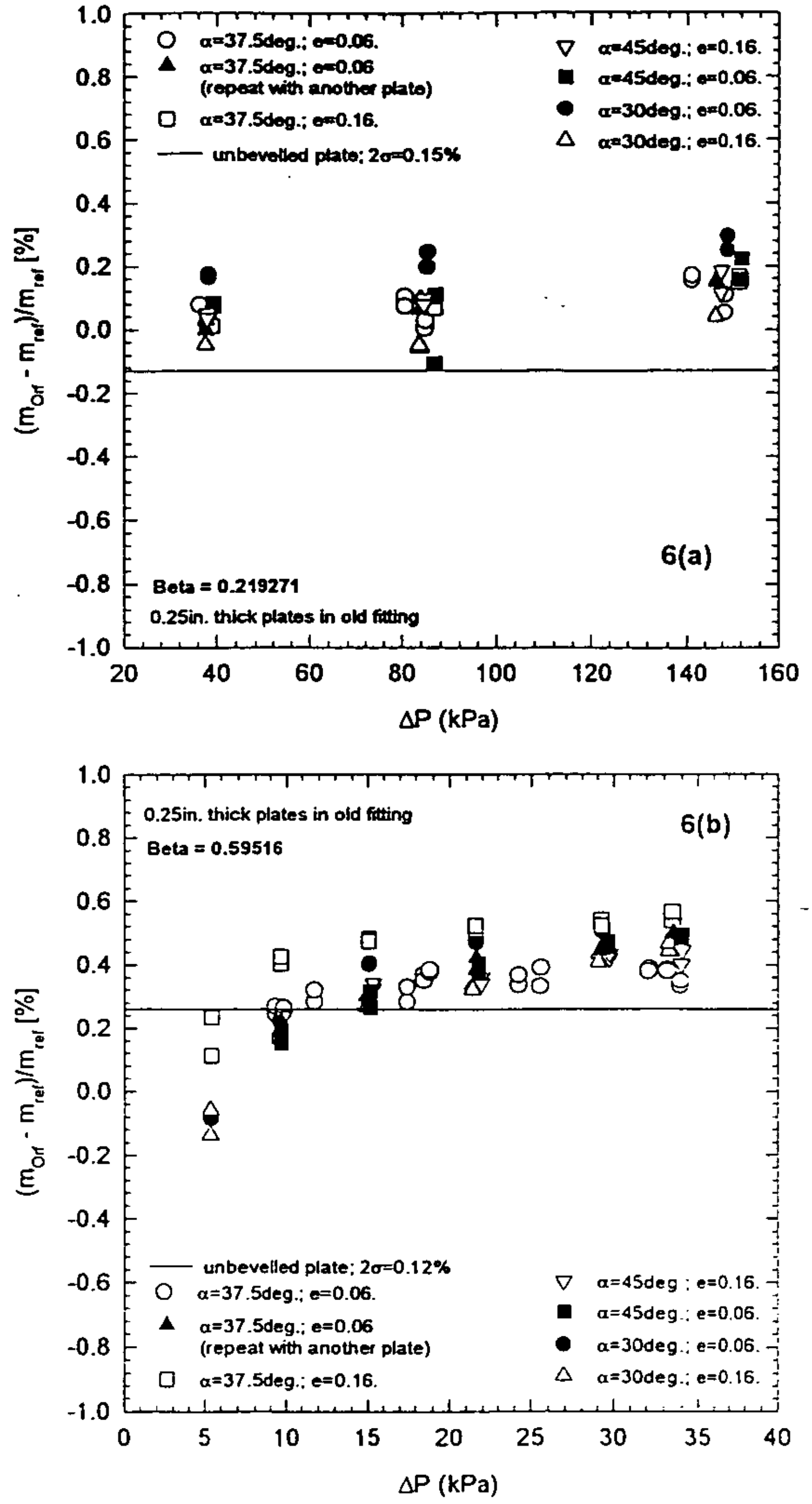


Figure 6. Effect of bevel angle and orfice bore edge thickness on meter performance; 0.25in. thick plates; (a) $\beta=0.2193$ (b) $\beta=0.5952$.

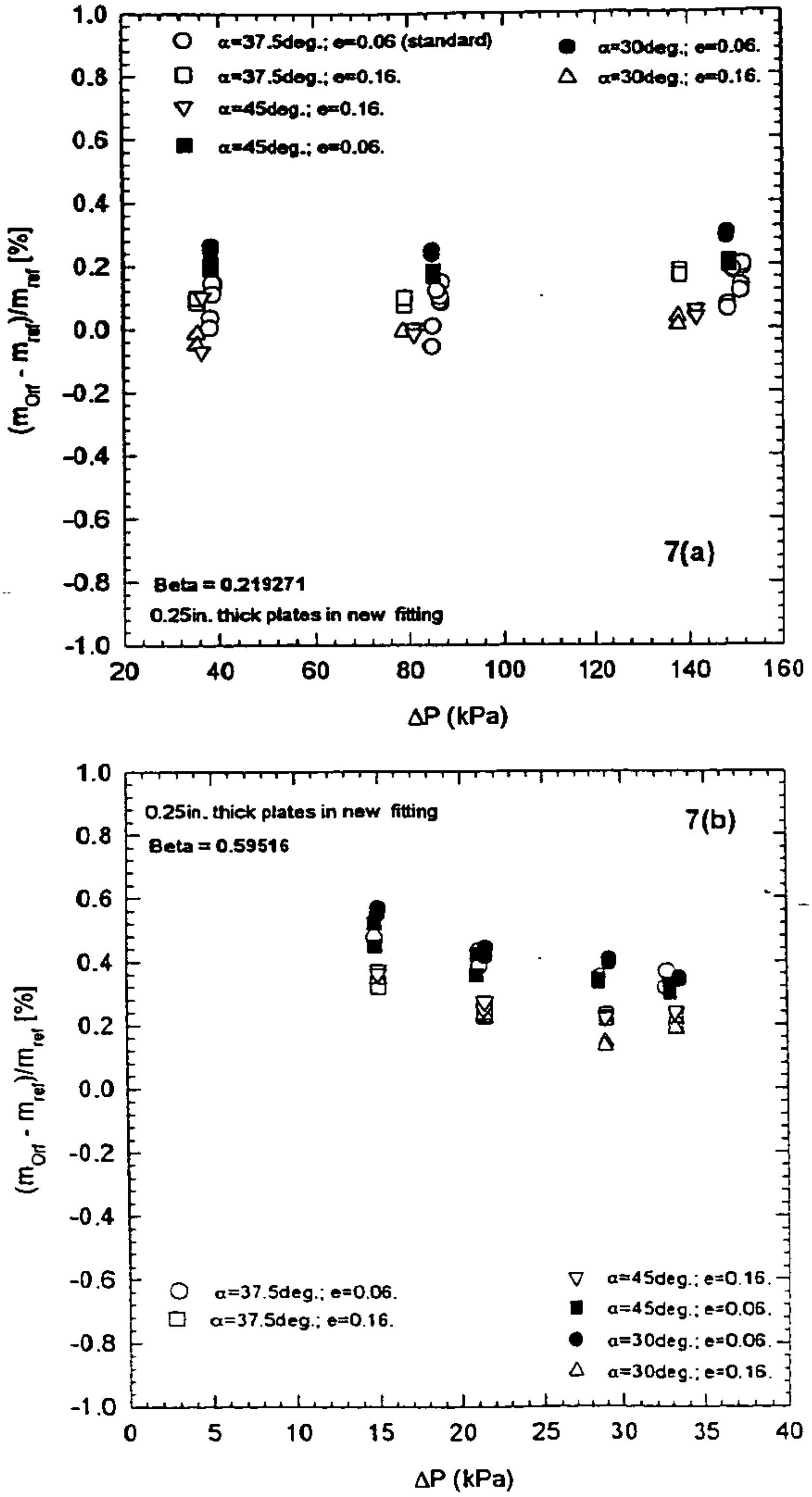


Figure 7. Effect of bevel angle and orfice bore edge thickness on new meter performance; 0.25in. thick plates; (a) β=0.2193 (b) β=0.5952.