THE GALLAGHER FLOW CONDITIONER

James E. Gallagher, P.E. - Shell USA
Paul J. LaNasa - CPL & Associates
Ronald E. Beaty, P.E. - Amoco Production

SUMMARY

This paper describes the design theory, third party research results and pending evaluations for the Gallagher Flow Conditioner (GFC).

Experimental results for the GFC indicate a maximum metering uncertainty of approximately plus or minus one-tenth of one percent (+/- 0.10%) due to upstream flow disturbances on orifice meters. The GFC has exhibited this performance irrespective of the upstream disturbance or sensing tap location.

Based on independently conducted research results, it is the authors' opinions that the GFC is a true "isolating" flow conditioner.

1. INTRODUCTION

The North American natural gas industry produces, transports, and distributes approximately 700 billion cubic meters of gas each year (25 trillion standard cubic feet). The Western European market transports and distributes 250 billion cubic meters of gas each year (9 trillion standard cubic feet). Because of the importance of gas measurement for industry operations and fiscal accountability, it is essential that metering be accurate, reliable, and cost efficient over a range of conditions.

For over sixty years, the concentric orifice meter has remained the predominant meter of choice for natural gas production, large volume gas flow and chemical metering applications. In fact, it is estimated that over 600,000 orifice meters are being used for fiscal measurement applications associated with the petroleum, chemical and gas industries in North America.

2. INSTALLATION EFFECTS

All flowmeters are subject to the effects of velocity profile, swirl and turbulence structure. The meter calibration factors or empirical discharge coefficients are valid only if geometric and dynamic similarity exists between the metering and calibration conditions or between the metering and empirical data base conditions (i.e., fully developed flow conditions). In fluid mechanics, this is commonly referred to as the Law of Similarity.

In the industrial environment, multiple piping configurations are assembled in series generating complex problems for standard writing organizations and flow metering engineers. The challenge is to minimize the difference between the actual or "real" flow conditions and the "fully developed" flow conditions in a pipe to maintain a minimum error associated with the selected metering device's performance. One of the standard error minimization methods is to install a flow conditioner in combination with straight lengths of pipe to "isolate" the meter from upstream piping disturbances.

Research programs in both Western Europe and North America have confirmed that many piping configurations and fittings generate disturbances with unknown characteristics. Even a single elbow can generate very different flow conditions from "ideal" or "fully developed" flow depending on its radius of curvature (mitred or swept). In addition, the disturbance generated by piping configurations is influenced by the conditions prior to these disturbances.

The research programs by the respective measurement communities do not fully compliment each other in their direction due to design differences between measurement standards. However, they have clearly indicated that the requirements specified in both standards are erroneous as stated by Sattary [1] -

> "The work reported here indicates that the minimum straight length specifications in the Standards are in urgent need of revision."

As a result, the current focus of today's measurement community is to lower uncertainty levels associated with "non-ideal" flow conditions. A special emphasis has been placed on retrofitting existing installations.

3. MEASUREMENT STANDARDS

Present domestic and international measurement standards provide installation specifications for pipe length requirements and flow conditioners upstream of orifice meters (American National Standards Institute's 2530[2] and International Standard Organization's 5167[3]). Unfortunately, considerable disagreement over straight length requirements exist between these highly respected documents.

With respect to installation effects and the near term flow field, the correlating parameters which impact similarity vary with flowmeter type and design. However, it is generally accepted that the concentric, square-edged, flange-tapped orifice meter exhibits a high sensitivity to time average velocity profile, turbulence structure, bulk swirl and tap location.

In North America, current design practices utilize short upstream piping lengths with a specific flow conditioner, A.G.A. tube bundles, to provide "pseudo-fully developed" flow in accordance with the applicable measurement standard (ANSI 2530/A.G.A. 3/API MPMS 14.3). Most North American installations consist of ninety degree elbows or complex header configurations upstream of the orifice meter. Tube bundles in combination with piping lengths of seventeen pipe diameters (17D) have been installed to eliminate swirl and distorted velocity profiles. Ten diameters (10D) of straight pipe is required between the upstream piping fitting and the exit of the tube bundle, and seven diameters (7D) of straight pipe is required between the exit of the tube bundle and the orifice meter (Figure 1).

In Western Europe, two design practices are currently employed to provide "pseudo-fully developed" flow in accordance with the applicable measurement standard (ISO 5167) - long upstream piping lengths with or without flow conditioners. Most Western European installations consist of complex header configurations upstream of the orifice meter. Piping lengths of one hundred pipe diameters (100D) without flow conditioners or piping lengths of forty-two pipe diameters (42D) in combination with flow conditioners have been installed to eliminate swirl and distorted velocity profiles. Three types of flow conditioners have been utilized - tube bundles, Zanker and Sprenkle designs. Twenty diameters (20D) of straight pipe is required between the upstream piping fitting and the flow conditioner, and twenty-two diameters (22D) of straight pipe is required between the flow conditioner and the orifice meter (Figure 2).

ISO 5167 allows other configurations provided that the flow quality at the primary device is within +/- 5% of u/u_{max} of fully developed flow and the swirl angle is less than two degrees. Here the notation u is used for the local velocity and u_{max} for the maximum velocity at the centerline. However, recent research by Morrow[4], Karnik[5] and Morrison[6] have indicated that the flow conditioning error is a function of time averaged velocity profile, swirl angle, tap sensing location and turbulence structure. As a result of these new findings, a significant improvement into flow conditioner performance has been achieved over other devices which were designed on velocity and swirl alone.

4. PSEUDO-FULLY DEVELOPED FLOW

The classical definition for fully developed turbulent flow is stated by Hinze[7] as follows -

> "For fully developed turbulent flow in pipe the mean-flow conditions are independent of the axial coordinate, **x** and axisymmetric, assuming a uniform wall condition."

From a practical standpoint, we generally refer to fully developed flow in terms of swirl-free, axisymmetric time average velocity profile in accordance with the Power Law or Law of the Wall prediction. However, one must not forget that fully developed turbulent flow requires equilibrium of the forces to maintain the random "cyclic" motions of turbulent flow.

Unfortunately, fully developed pipe flow is only achievable after considerable effort in a research laboratory. To bridge the gap between research and industrial applications, we will refer to the term pseudo-fully developed flow defined as -

> "a swirl-free, axisymmetric flow with time average velocity profile and turbulence structure whose values approximate those found in fully developed flow and are shown to be independent of the axial coordinate."

Stated another way, **pseudo-fully developed flow** exists when -

> "the slope of the orifice meter's discharge coefficient deviation or meter factor deviation asymptotically approaches zero (+/- 0.10%) as the axial distance from the flowmeter to the upstream flow conditioner increases"

This pragmatic definition infers that the random cyclic forces generated by the conditioner produce a self-maintenance mechanism for the time average velocity profile and turbulence structure (Figure 3).

5. OPTIMAL FLOW CONDITIONER

To truly "isolate" flowmeters, the optimal flow conditioner should achieve the following design objectives:

(1) low permanent pressure loss (low head ratio)
(2) low fouling rate
(3) rigorous mechanical design
(4) moderate cost of construction
(5) elimination of swirl
(6) independent of tap sensing location
(7) pseudo-fully developed flow for both short and long straight lengths of pipe

When the swirl angle is less than or equal to two (2) degrees as conventionally measured using pitot tube devices, swirl is regarded as substantially eliminated.

When the empirical discharge coefficient or meter calibration deviation for both short and long piping lengths is approximately plus or minus one tenth of one percent (+/- 0.10%) and shown to be independent of axial position and orifice sensing tap location, it is assumed to be at a "minimum" and pseudo-fully developed.

6. FLOW CONDITIONERS

In order to provide background information so that the present device may be completely understood and appreciated in its proper context, reference may be made to a number of flow conditioner publications over the past sixty years.

As shown in the following tabular summary, the field is crowded with attempts to "isolate" flowmeters from piping induced disturbances. Despite these efforts, the current flow conditioners are not optimal and have exhibited unsatisfactory attenuation of flow disturbances.

6.1 Classification of Flow Conditioners

All flow conditioners may be grouped into three general classes based on their mechanical design - tube bundles, vanes/screens and perforated plates.

		Head Ratio
I.	Tube Bundles	
	A.G.A.	1
	ISO	2
	Sens & Teule	10
	Bosch & Hebrard	10
	PG&E	1
II.	Vanes/Screens	
	Etoile	1
	AMCA	8
	Screens	-
III.	Perforated Plates	
	Sprenkle	15
	Bellinga	20
	Zanker	5
	Akashi et al.	2
	Kinghorn	-
	K-Lab's Mark	2
	Laws	2
	Spearman	3
	Gallagher (GFC)	2

Note:
Head ratio is the dimensionless permanent pressure loss associated with the flow conditioner.

6.1.1 Tube Bundles

A.G.A. & ISO[2,3]
The ISO and A.G.A. designs, shown in Figure 4 respectively, are intended to eliminate swirl. Both designs consist of a bundle of tubes having the same length and diameter.

For the A.G.A. design, the length of the bundle must be at least ten times the tube diameter. For 75 mm (3 inches) meter runs and larger, the bundle consists of nineteen (19) tubes arranged in a circular pattern with a bundle length of two to approximately three pipe diameters (2D to 2.7D). For smaller meter runs, the bundle consists of seven (7) tubes arranged in a circular pattern with a bundle length of three (3D) pipe diameters.

For both the ISO and A.G.A. designs, the permanent pressure loss is low, the mechanical design is rigorous, the cost of construction is low, the fouling rate is low, and swirl is eliminated.

Sens & Teule, Bosch & Hebrard[8,9]
The Sens & Teule and the Bosch & Hebrard tube bundles were designed to "isolate" piping disturbances from flow meters. Both designs consist of a bundle of tubes of different lengths and diameters arranged in a circular array. The designs are not currently used in the global measurement community (industry, fiscal, research).

For both designs the permanent pressure loss is high, the cost of construction was very high and the prototype designs were rigorous and complex. While swirl is eliminated, the fouling rate is unknown for these designs. Geometric scaling is a problem when considering a range of pipe sizes.

Pacific Gas & Electric[10] (PG&E)
The PG&E tube bundle was designed to "isolate" piping disturbances from flow meters. The prototype is similar to the Sens/Bosch approach --- a bundle of tubes of different diameters but with a constant length arranged in a circular array.

The fouling rate is unknown for these designs. Geometric scaling is a problem when considering a range of pipe sizes as well as undefined specifications for the tubes --- twist, roughness, diameter, blockage, etc.

6.1.2 Vanes/Screens

Etoile[3]
The Etoile is primarily designed to eliminate swirl in pipe. Three flat plates of equal length and width are assembled in a star-shaped pattern by means of a central hub. The length of the flat plates should be at least one pipe diameter (1D) for optimum elimination of bulk swirl. Some industrial applications currently use this design in Western Europe.

The permanent pressure loss is low, the mechanical design rigorous and the cost of construction is low. The fouling rate is low, and swirl is eliminated.

6.1.3 Perforated Plates

Sprenkle[11]
The Sprenkle was intended to "isolate" piping disturbances from flow meters for steam flow. Some fiscal applications currently use this design in Western Europe.

The Sprenkle consists of three perforated plates spaced one diameter (1D) apart and connected by rods. Each plate has a porosity of fifty percent (50%) with regularly distributed perforations in a specified hexagonal pattern. The perforations consist of holes whose diameter is five percent of the pipe diameter (0.05D).

The permanent pressure loss is very high, the mechanical design rigorous and complex and it has a high cost of construction. The fouling rate is moderate, and swirl is eliminated for all piping configurations.

Bellinga[12]
The Bellinga is a modified Sprenkle design. This invention was intended to "isolate" piping disturbances for natural gas turbine meter applications. Some fiscal turbine meter applications currently use this design in Western Europe.

The permanent pressure loss is very high, the mechanical design rigorous and complex. The cost of construction is high. The fouling rate is moderate and swirl is eliminated for all piping configurations.

Zanker[13]
The Zanker was designed to "isolate" piping disturbances for pump efficiency testing. Some fiscal applications currently use this design in Western Europe.

The Zanker consists of a perforated plate connected to a downstream grid or crate.

The perforated plate is comprised of thirty-two (32) holes with five (5) different diameters. A specified location for each hole is called for by the design.

A complex crate, similar to the AMCA design, approximately one pipe diameter (1D) in length is attached to the downstream side of the perforated plate. The crate is assembled from flat plate in a manner that does not overlap the numerous holes in the perforated plate.

The permanent pressure loss is high, the mechanical design rigorous and complex and it has a high cost of construction. The fouling rate is low, and swirl is eliminated for all piping configurations.

Akashi[14]
The Akashi, as shown in Figure 4, was designed to "isolate" piping induced disturbances for flow meters. The Akashi is sometimes referred to as the Mitsubishi. No known fiscal applications currently use this design.

The Akashi consists of a single perforated plate with thirty-five (35) holes. The hole size is thirteen percent of the pipe diameter (0.13D). The perforated plate thickness is equal to the hole diameter (0.13D). The plate has a porosity of approximately fifty-nine percent (59%). The hole distribution is dense in the middle (center of pipe) and sparse around the periphery (pipe wall). The upstream inlets of the holes are beveled.

The permanent pressure loss is low, the mechanical design rigorous and simple and it has a moderate cost of construction. The fouling rate is low to moderate, and swirl is eliminated for all piping configurations.

Kinghorn[15]
The Kinghorn flat plate was designed to "isolate" piping disturbances on flow nozzles for compressor efficiency testing. No known fiscal applications currently use this design.

The Kinghorn consists of a single perforated plate or two perforated plates in series. The hole size is four percent of the pipe diameter (0.04D). The perforated plate thickness is equal to the hole diameter. The plate has a porosity of approximately forty percent (40%). The hole distribution is dense in the middle (center of pipe) and sparse around the periphery (pipe wall). The upstream inlets of the holes are square and sharp.

The permanent pressure loss is unknown, the mechanical design rigorous and simple and it is estimated to have a moderate cost of construction. The fouling rate is moderate to high, and swirl is eliminated for all piping configurations.

K-Lab's Mark V[16]
The Mark V, a further development of the Wilcox patent, was designed to "isolate" piping induced disturbances for flow meters. No known fiscal applications currently use this design.

The Wilcox patent calls for a flow conditioner comprised of tubular passages with the area between specific tubes blocked referred to as the Mark I. Further development of the Wilcox concept has resulted in the evolution of additional models. The latest development, the Mark V, is at present considered a trade secret and, therefore, the design is unknown.

The permanent pressure loss is low, the mechanical design is rigorous and simple, the cost of construction is moderate to high and swirl is eliminated for most piping configurations.

Laws[17]

The Laws, as shown in Figure 4, was designed to "isolate" piping induced disturbances for flow meters. Some fiscal applications currently use this design in Western Europe.

The Laws design consists of a single perforated plate several holes. The perforated plate thickness is approximately twelve percent of the pipe diameter (0.12D). The plate has a porosity of approximately fifty percent (50%). The plate is perforated with a variety of holes arranged in two radially spaced circular arrays around a central hole. The upstream inlets of the holes may be beveled. Further evolution of the design has resulted in anti-swirl vanes attached to the faces of the perforated plate.

The permanent pressure loss is low, the mechanical design rigorous and simple and it has a moderate cost of construction. The fouling rate is considered to be low, and swirl is eliminated.

7. GFC DESIGN

In attempting to achieve the optimal flow conditioner objectives, the Gallagher Flow Conditioner (GFC) maintains pseudo-fully developed flow with respect to the axial position. The reason is fundamental - **the random cyclic forces generated by the conditioner produce a self-maintenance mechanism for the velocity profile and turbulence structure within a short axial distance.**

The Gallagher Flow Conditioner, as shown in Figure 5, was designed to "isolate" piping induced disturbances. The GFC consists of an anti-swirl device, settling chamber and profile device mounted sequentially in the pipe. The anti-swirl device and the flow profile device are considered to be separate devices. This approach maximizes the efficiency of both swirl elimination and profile generation.

The anti-swirl device provides an assurance of swirl elimination. A tube bundle anti-swirl device is preferred, thus eliminating geometric similarity concerns and providing for low manufacturing costs. The design generates reproducible turbulence intensities and turbulence shear stresses, regardless of the upstream piping disturbance. For some installations, the anti-swirl device may be omitted without any loss in performance.

Downstream of the settling chamber is the profile device, which generates a pseudo-fully developed flow - time average velocity profile and turbulence structure. A flat plate is preferred when considering manufacturing costs. The interaction of porosity, hole location and hole diameter are critical success factors. As a result, the profile device is based on a series of combined theoretical/empirical interactive equations.

Downstream of the profile device is the flowmeter. The dimensionless distance, X/D, between the profile device and the flowmeter is critical. The GFC provides for X as a low as three nominal pipe diameters (3D) or seven nominal pipe diameters (7D) depending on the flowmeter design. This short distance is important, especially in retrofitting short meter tubes or in fitting new meter tubes in an area where space is limited.

The flow conditioner may be preassembled into a unit or module that is then installed into a pipeline at a predetermined distance upstream of the flowmeter and beyond a predetermined distance downstream of the nearest source of flow disturbance (valve, elbow, tee, complex pipe configuration, etc.) upstream of the flowmeter. This preassembly concept is highly desirable when considering retrofitting of existing fiscal metering facilities.

The flow conditioner exhibits a low permanent pressure loss and has a rigorous, simple mechanical design. Fouling rate is anticipated to be low and swirl is eliminated. Manufacturing cost is expected to be low to moderate.

8. EXPERIMENTAL RESULTS

Research results from unbiased, highly reputable sources will be referenced for empirical performance data for several commercially available flow conditioners.

Several flow conditioners have been evaluated by the Gas Research Institute for comparison purposes[18] as part of their Installation Effects Research Program. For these tests, the same test loop or apparatus was utilized to provide consistency between experiments.

For the test loop, gas enters a stagnation bottle and flows to a straight section of pipe (Figures 6a and 6b). The gas then enters a ninety-degree elbow or tee followed by a meter tube and flowmeter. The flow conditioners tested were positioned at various upstream distances, X, from the orifice plate. To obtain dimensionless terms, the distance X was divided by the meter tube nominal pipe diameter, D.

For the experiments, the selected flowmeter was a concentric, flange tapped square-edged orifice meter with Betas of 0.67 and 0.75. The internal diameter of the meter tube, IDp, was 102.29 mm (4.027 inches) and the length of the meter tube, L1, was seventeen nominal pipe diameters (17D). For certain A.G.A. tube bundle measurements, the length of the meter tube, L1, was increased to 45D and 100D lengths. The flow disturbance was created by either a ninety degree elbow or a tee installed at the inlet to the meter tube.

By way of explanation, the designation Cd deviation (%) refers to the percent deviation of the empirical coefficient of discharge or meter calibration factor from fully developed flow to the disturbed test conditions. Desirably, this deviation should be as near to zero as possible. As explained above, a "minimal deviation" is regarded as plus or minus one-tenth of one percent (+/- 0.10%).

8.1 Analysis of Results

The results obtained for the A.G.A. design, using meter tube lengths of 17D, 45D and 100D, (Figure 7) indicate a "minimal deviation" when:

L1 = 17D; and X/D = 12 - 15
L1 = 45D; and X/D = 8 - 9
L1 = 100D; and X/D = 8 - 9 or > 45

Tests on four flow conditioners in a 17D long test pipe with a tee were funded by GRI. The Beta for the orifice meter was 0.67 and the Reynolds number was approximately 900,000.

The A.G.A. design does not produce pseudo-fully developed flow conditions for short piping configurations. This was evidenced by the instability of the coefficient performance (Figure 8). Similar results for the ISO tube bundle design are anticipated based on our current understanding of the physics.

These results are not surprising in light of our current understanding of pipe flows. The tube bundle does an excellent job in eliminating swirl. However, the fixed diameter tubes generate an unstable turbulence structure which begins to redevelop rapidly. Also, the constant and high radial porosity does not offer a method to redistribute any asymmetric flow patterns.

The Mark V conditioner does not produce pseudo-fully developed flow conditions for short piping configurations (Figure 9). This was evidenced by the instability of the coefficient performance.

The Laws conditioner is useful at distances of X/D greater than about 12 (Figure 10). The Laws performance for minimal deviation from the empirical discharge coefficient for short piping lengths is unacceptable, but completely acceptable for long piping lengths.

With respect to the Laws conditioner, it is important to note that the 100mm design tested by GRI is not similar to the 250mm design tested by NEL and funded by Amoco in 1992.

In analyzing the Laws and Mark V results, it would appear that these highly respectable devices were designed to attain the ISO 5167 time average velocity profile and swirl criteria. Unfortunately, when the criteria was adopted into ISO 5167, it was based on an understanding rather than hard experimental evidence. Research subsequent to the development of the Laws and Mark V flow conditioners have conclusively linked two additional influence quantities --- turbulence structure and sensing tap location.

The GFC produces pseudo-fully developed flow conditions for both short and long piping configurations. This is evidenced by the slope of the orifice meter's discharge coefficient deviation or meter factor deviation asymptotically approaching zero as the axial distance from the flowmeter to the upstream flow conditioner increases (Figure 11). The GFC has also demonstrated an insensitivity to tap sensing location confirming the presence of pseudo-fully developed flow.

The GFC has the benefit of being the most recent evolution in the design of flow conditioners. As such, one would expect to have significant performance improvements over existing flow conditioners (Figure 12). The design should and does exhibit this improved performance as a result of a considerable parametric study for sensitivity (profile device design, settling chamber length, etc.), as well as the added insights attained over the last four years.

9. OTHER EVALUATIONS

Several commercial and research evaluations have been completed or are currently underway to further assess the performance of the GFC on both gas and liquid fiscal metering applications.

9.1 Completed Evaluations

The first evaluation called for testing in both a 75 mm (3 inch) and 100 mm (4 inch) orifice meter runs with complex out of plane headers at variable oblique angles. The tests, funded by Amoco Production Company, were conducted at the Colorado Engineering Experiment Station Incorporated (CEESI) facility in Nunn, Colorado in the summer of 1994. The test results[19] showed the GFC eliminated piping induced disturbances and produced a maximum uncertainty due to installation effects of +/- 0.075% for a Beta of 0.67. These results are similar to the previous GRI research.

A second series of experiments called for testing the GFC in combination with a 250 mm (10 inch) helical turbine meter and straight bladed turbine meter run in series. The program, funded by Shell, was conducted at Capline's St. James, Louisiana facility. Capline is the largest imported crude oil pipeline in North America. They currently handle approximately 100 crude types with a daily throughput of 1,200,000 barrels. The GFC[20] has been successfully utilized to "isolate" any disturbances associated with the upstream piping and turbine meter, thereby eliminating a variable in the fractional factorial experimental pattern.

9.2 Planned Evaluations

An evaluation currently underway calls for the GFC to be tested as part of the GRI Orifice Meter Installation Effects Program. Current tests will assess a double elbow out of plane header configuration in conjunction with velocity profile and turbulence measurements. The experiments are limited to a 100 mm (4 inch) orifice meter run. Preliminary results[21] indicate that the GFC has exhibited a maximum error of +/- 0.10% due to installation effects for a single elbow, a single tee and double elbows out of plane.

A second evaluation underway calls for the GFC to be tested as part of the NEL Header Consortium Project. The GFC will be installed in a 250 mm (10 inch) orifice meter run in order to produce pseudo-fully developed flow regardless of the upstream piping disturbance. Separate asymmetric and bulk swirl experiments are planned for three Beta ratios. The pipe Reynolds number will be approximately 900,000 with Beta ratios of 0.40, 0.60, and 0.75.

The third evaluation currently funded calls for testing a 250 mm (10 inch) multipath ultrasonic meter (USM) in series with "best" turbine meter out of the research project stated above. The GFC will be utilized to "isolate" any disturbances associated with the upstream piping and to provide a pseudo-fully developed flow. It is believed that the GFC will improve the USM performance or ensure the manufacturer's stated performance without relying heavily on Lagrangian-Gaussian integration techniques.

A fourth evaluation calls for the GFC to be tested in a 450 mm (18 inch) straight bladed liquid turbine meter run. The research, funded by Capline, is being conducted at their Salem, Illinois facility. Problems of asymmetry associated with prover return lines located immediately upstream of the A.G.A. tube bundle indicate a possible bias.

A fifth evaluation currently funded calls for the GFC to be tested in both 250 mm (10 inch) and 150 mm (6 inch) straight bladed turbine meter runs. The project is funded by LOOP Inc. and will be conducted at their Clovelly, Louisiana facility. Asymmetry associated with prover return lines located immediately upstream of the A.G.A. tube bundle has shown to produce a bias.

10. CONCLUSION

The GFC has exhibited an ability to "isolate" flowmeters from piping-induced disturbances, thereby allowing more accurate metering of fluids flowing in pipelines. The device achieves the optimal flow conditioner objectives previously stated and maintains pseudo-fully developed flow in a pipeline with respect to the axial position.

Based on the independently conducted research results, it is the authors' opinions that the GFC is a true "isolating" flow conditioner.

REFERENCES

1. Sattary, J.A., "Progress Report No. 10 on The Effect of Installations and Straighteners on the Discharge Coefficient of Orifice Plate Flowmeters", Department of Trade and Industry, National Engineering Laboratory, East Kilbride, Scotland, March, 1991.

2. API MPMS Chapter 14 Section 3 Parts 1 - 4 (ANSI 2530, A.G.A. Report No. 3), "Concentric, Square-Edged Orifice Meters", American Petroleum Institute, Washington, D.C., USA, 1990.

3. International Standard ISO 5167-1, "Measurement of Fluid Flow by Means of Orifice Plates, Nozzles and Venturi Tubes Inserted in Circular

Cross-Section Conduits Running Full", International Standards Organization, Geneva, Switzerland, 1992.

4. Morrow, T.B., Park, J.T., McKee, R.J., "Determination of Installation Effects for a 100 mm Orifice Meter Using a Sliding Vane Technique", Flow Measurement and Instrumentation, Volume 2, Number 1, January, 1991.

5. Karnik, U., Jungowski, W.M., Botros, K.K., "Effects of Flow Characteristics Downstream of Elbow/Flow Conditioner on Orifice Meter", 9th North Sea Flow Measurement Workshop, Department of Trade and Industry, National Engineering Laboratory, East Kilbride, Scotland, 1991.

6. Morrison, G.L., DeOtte, R.E., "3-D Laser Anemometer Study of Compressible Flow Through Orifice Plates", GRI Report 91/0177, Gas Research Institute, Chicago, IL, December, 1991.

7. Hinze, J.O., "Turbulence", second edition, McGraw-Hill, New York, NY, 1975.

8. Sens, M., Teule, C., "Theoretical and Experimental Study of a New Flow Straightener", Association Technique de L'Industrie du Gaz en France, 1975.

9. Bosch, M., Hebrard, P., "Experimental and Theoretical Study of a New Flow Conditioner", Proceedings of the International Conference on the Metering of Natural Gas and Liquified Hydrocarbon Gases, February, 1984.

10. Stuart, J., "Improvements in Flow Conditioner Design for Orifice Metering", A.G.A. Operations Conference, 1993.

11. Sprenkle, R.E., Courtright, N.S., "Straightening Vanes for Flow Measurement", Mechanical Engineering, NY, NY, 1958.

12. Bellinga, H., Stronk, H.B., "The Practical Application of Flow Straighteners with Turbine Flowmeters for Gas", Paper BFL242, Presented at the IMEKO VII Congress, London, UK, May 10-14, 1976.

13. Zanker, K.J., "The Development of a Flow Straightener for Use with Orifice Flowmeters in Disturbed Flow", Paper D-2, Symposium on Flow Measurement, Scotland, 1969.

14. Akashi, K., Watanabe, H., Koga, K., "Flow Rate Measurement in Pipe Line with Many Bends", IMEKO Symposium, Flow Measurement and Control in Industry, Tokyo, Japan, 1979.

15. Kinghorn, F.C., Blake, K.A., "The Design of Flow Straightener - Nozzle Packages for Discharge Side Testing of Compressors", NEL Report, 1978.

16. Wilcox, P. L., Weberg, T., Erdal, A., "Short Gas Metering Systems Using K-Lab Flow Conditioners", 8th North Sea Flow Measurement Workshop, Department of Trade and Industry, National Engineering Laboratory, East Kilbride, Scotland, 1990.

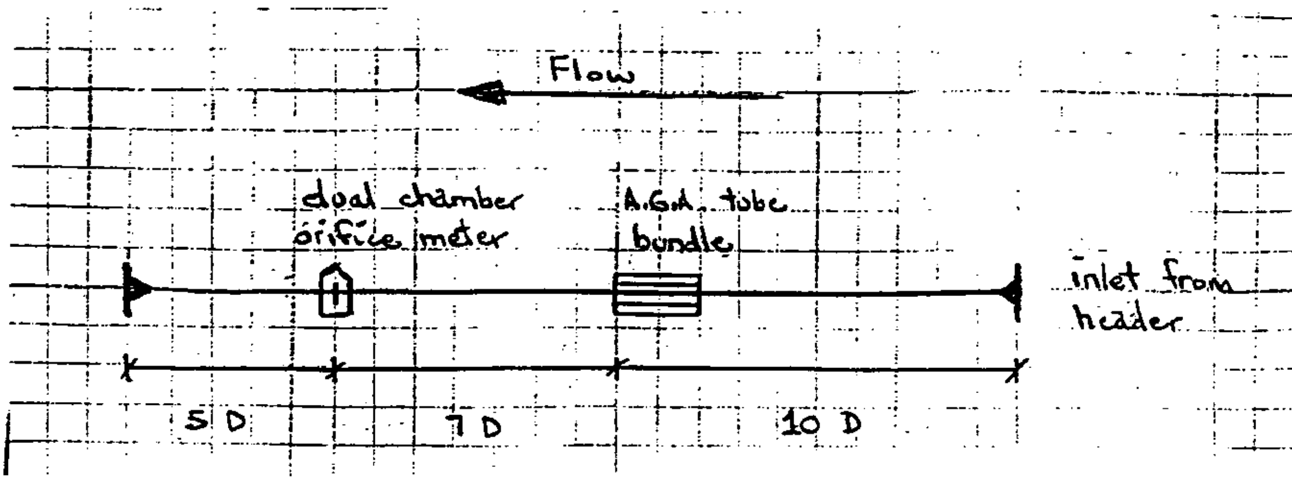
17. Laws, E.M., "Flow Conditioning - A New Development", Flow Measurement and Instrumentation, Volume 1, April, 1990.

18. GRI's Technical Advisory Committee, Summer 1994 Meeting, Southwest Research Institute, San Antonio, Texas, USA.

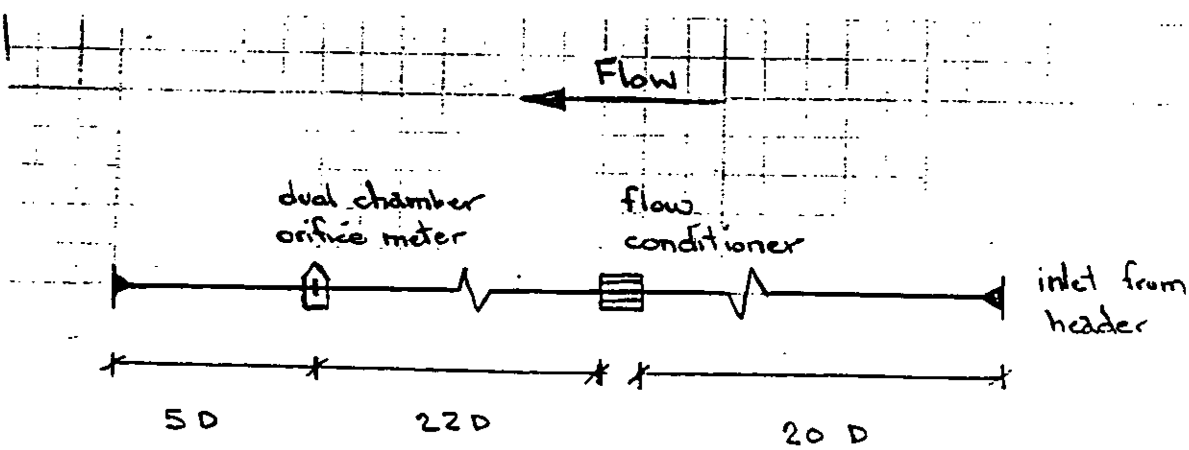
19. Private Communication with Amoco's Mr. David Simpson, July, 1994.

20. Internal Shell Research Report, September, 1994.

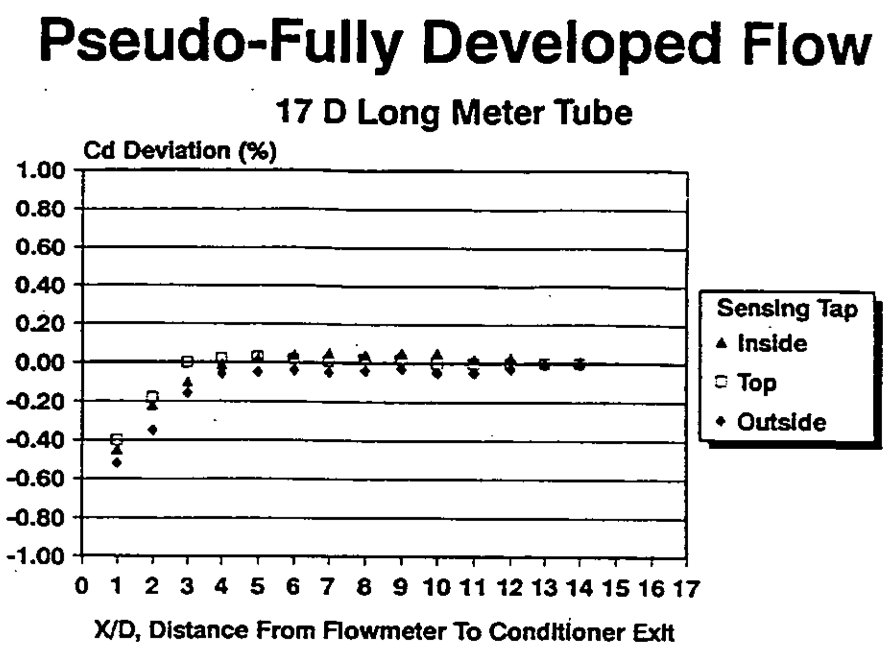
21. Private Communication with GRI's Mr. John Gregor, September, 1994.



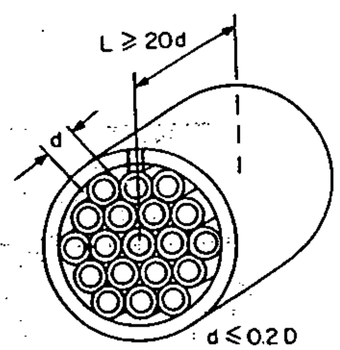
North American Practice
Figure 1



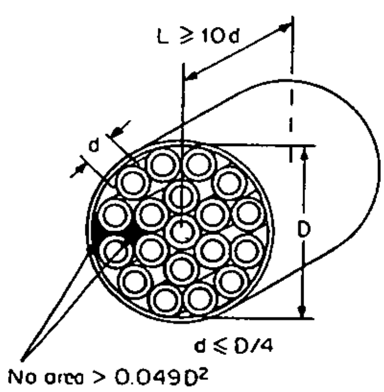
ISO 5167 Requirement
Figure 2



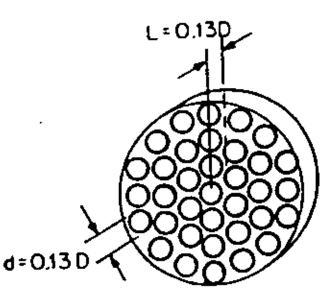
Pseudo-fully Developed Flow
Figure 3



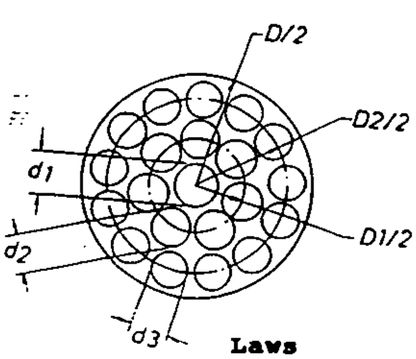
ISO



A.G.A.



Akashi



Laws

Flow Conditioners
Figure 4

[L2] + [Anti-Swirl Device] + [Lsc] + [Profile Device] + [L3]

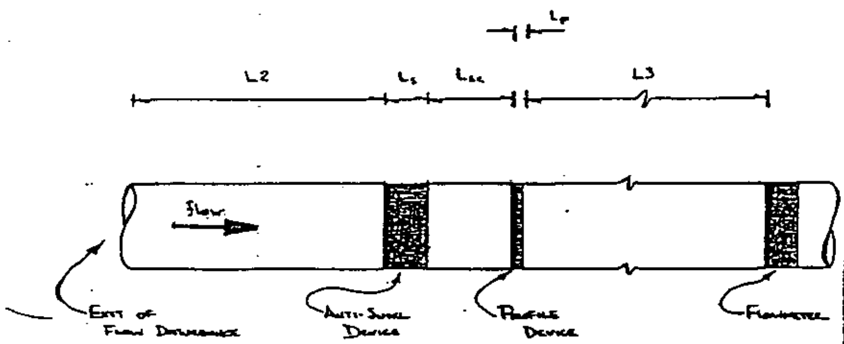
* L2 - Settling chamber, or distance from piping disturbance to inlet of "anti-swirl device".

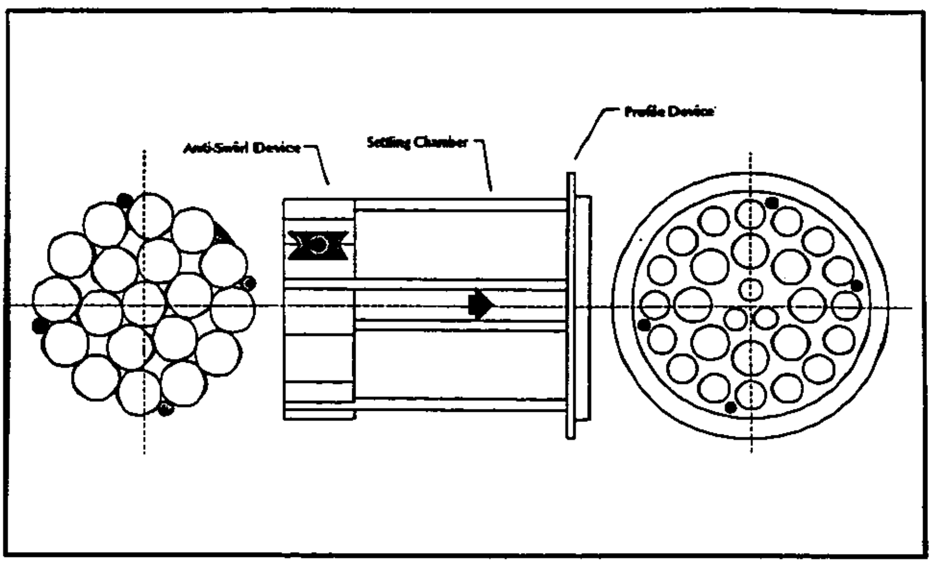
* Anti-Swirl Device
  A device designed to eliminate swirl. The most efficient designs are vanes, tubes, honeycombs or crates.

* Lsc - Settling chamber, or distance from the "anti-swirl device" to the "profile device".

* Profile Device
  A device designed to generate an axisymmetrical, "pseudo-fully developed" flow profile (in particular velocity profile and turbulence).

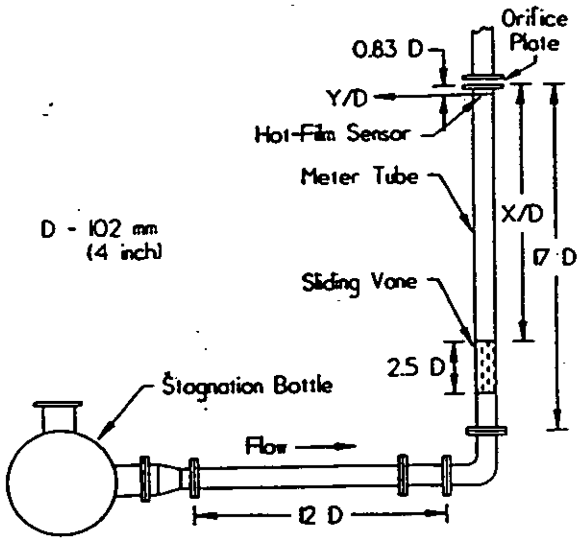
* L3 - Settling chamber, or distance from the "profile device" to the flowmeter.





Gallagher Flow Conditioner
Figure 5

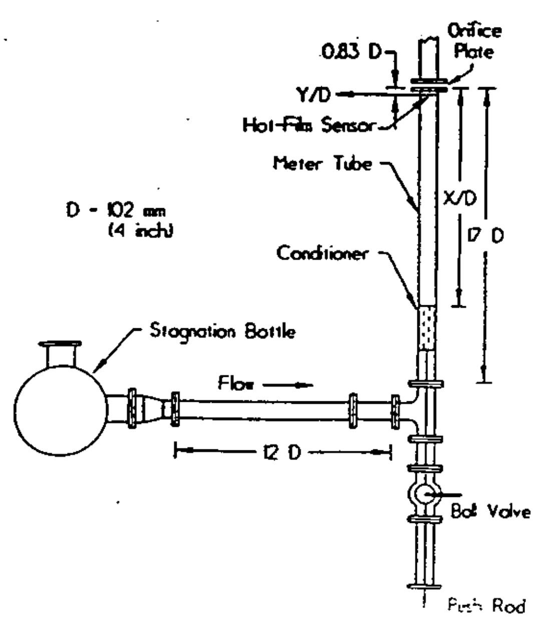
MRF UPSTREAM EFFECTS RESEARCH



MRF Orifice Meter Installation for Tube Bundle Flow Conditioner Location Tests Downstream of a 90-Degree Elbow.

Figure 6a

MRF UPSTREAM EFFECTS RESEARCH



MRF Orifice Meter Installation for New Flow Conditioner Location Tests Downstream of a Tee.

Figure 6b

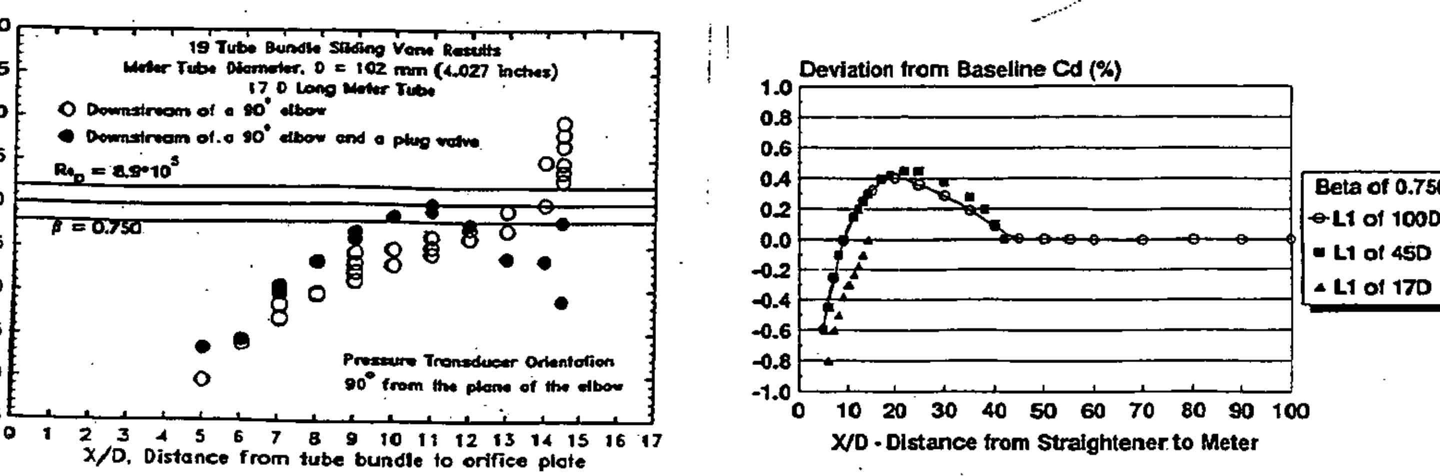


Figure 7

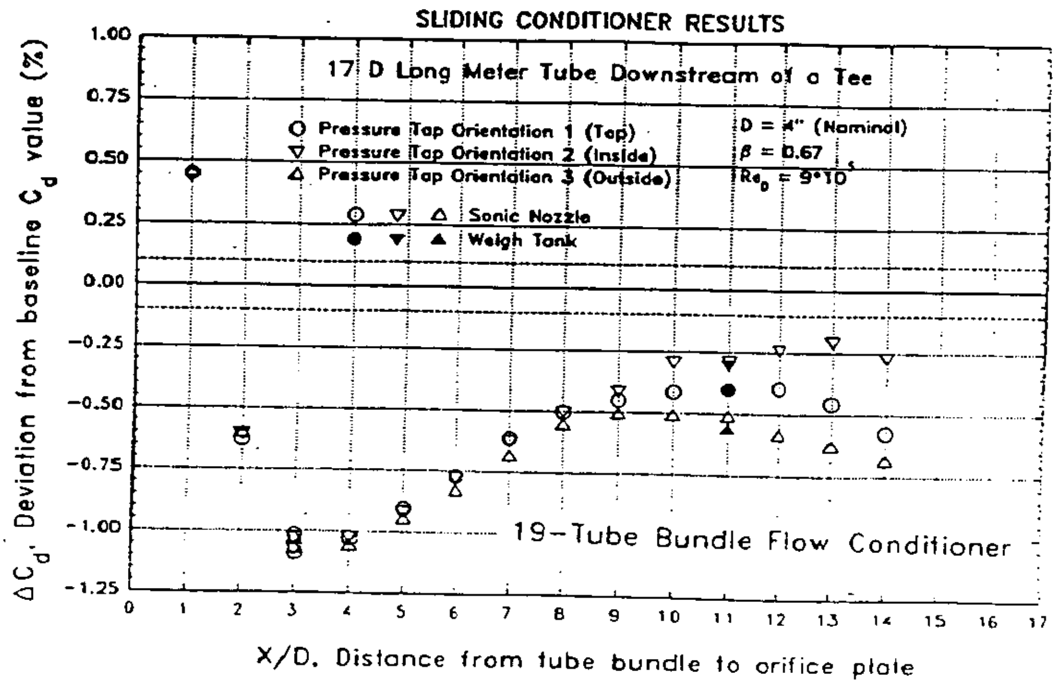


Figure 8

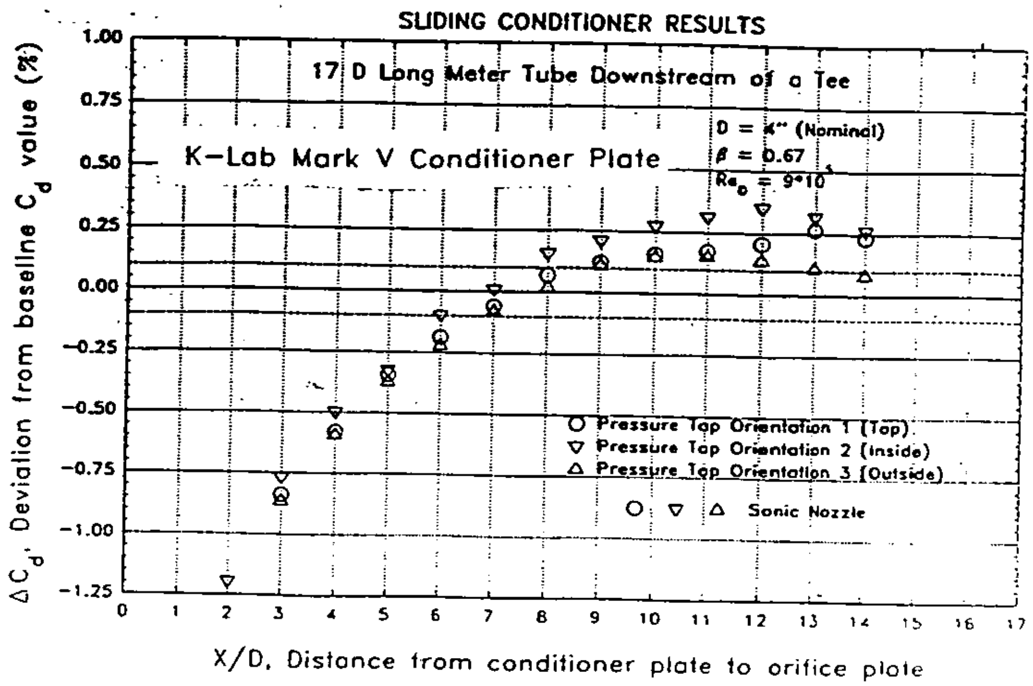


Figure 9

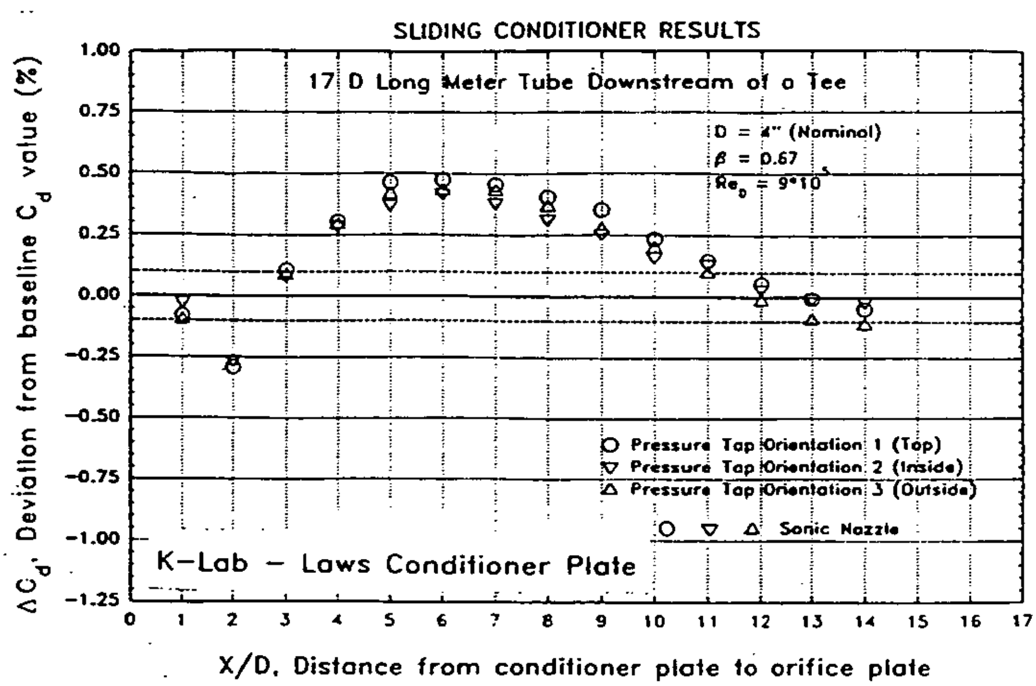


Figure 10

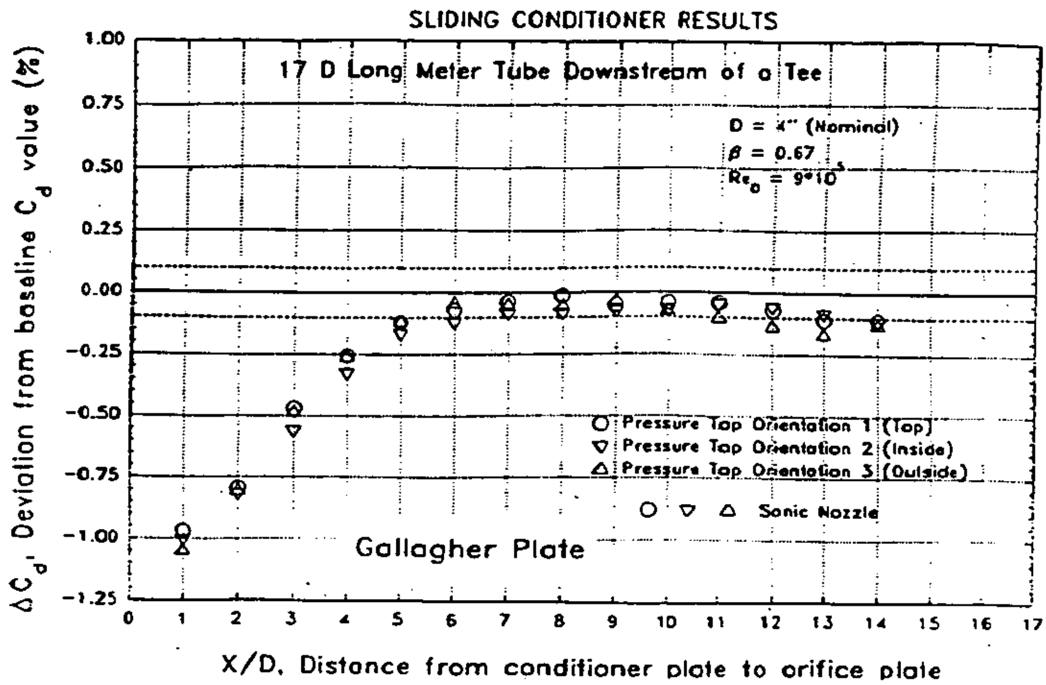


Figure 11

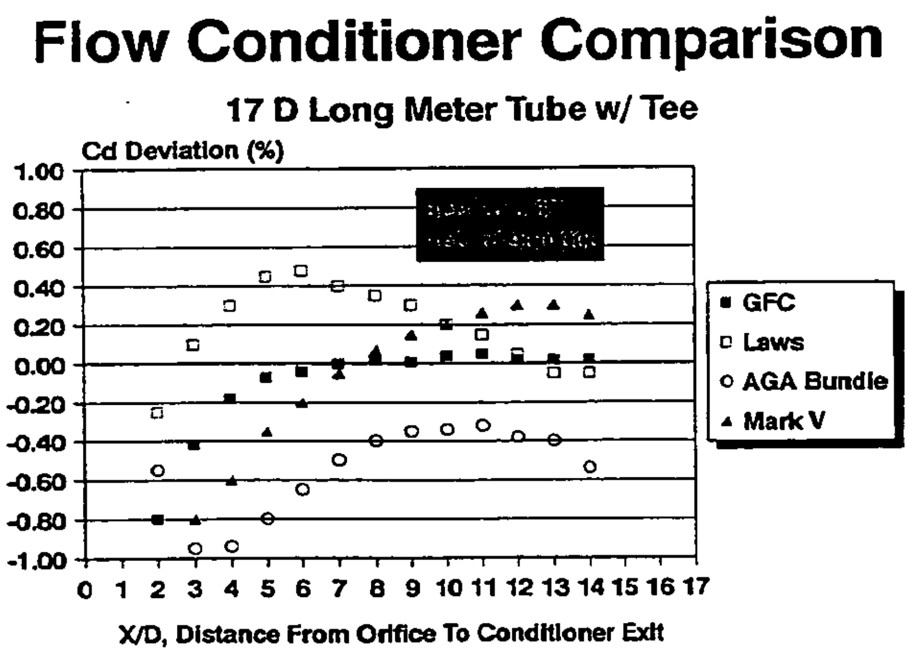


Figure 12

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.