In Situ Calibration of Large Water Meters

Report to the Water Research Commission
by
Stewart Scott Incorporated

WRC Report No 871/1/98

EXECUTIVE SUMMARY

The establishment of a flow reference standard for the cost-effective *in situ* calibration of large in-line water meters consists of the combined accuracy of point velocity measurements within pipes, a velocity-area method and a velocity-profile function.

Tests were carried out in compliance with the requirements of international and local standards relating to large water meters. Velocity profiles were measured within pipe sections of 250, 300, 400, 500, 600 and 800 mm diameter and compared to the flow measured by Eskom's Flow Laboratory. This flow laboratory has a best measurement capability of 0,1% uncertainty for the 95% confidence level as accredited by the National Laboratory Accreditation Service (NLA).

The physical dimensions of the pipes dictated at which position the turbine insertion meter should be placed within the pipe in accordance with the Log-Linear method adopted for this research. This resulted in the need to calculate the velocities near the pipe wall within pipes smaller than 700 mm dia using a first approximation of the ratio of point velocity nearest the pipe wall to the maximum (centre line) velocity. Second approximations of these velocities were derived using the actual position of mean axial velocity and revised constants for the modified Pao equation for each profile, only if the first approximation indicated a positive error.

Flow tests carried out on the 800 mm dia pipeline were used as a control because all the velocity measuring points dictated by the Log-Linear method could be reached with the turbine insertion meter. This control exercise was used to establish the meter's Calibration Factor (K) for the other tests on the 300, 400, 500 and 600 mm dia pipelines. Another turbine insertion meter was used for flow tests on the 250 mm dia pipeline and the manufacturers Calibration Factor (K) was applied.

Results of this research indicates that the method for the *in situ* calibration of large water meters can achieve accuracies that comply with relevant standards, however, practical limitations of the meters performance and the limitations of the hydraulic system in which they are installed could restrict the flow range over which they can be tested/calibrated.

The recommendation is that the flow reference standard consisting of insertion flow meter measurements, a velocity-area method and a velocity-profile function detailed in this report be adopted as an accepted test method for the *in situ* calibration of large water meters. The following specific recommendations have been made:

- The flow range over which the tests/calibrations are carried out should be from the transitional flow rate (q_t) or a mean velocity of 0,5 metres per second, whichever is greater, up to the water meter's permanent flow rate (q_p) as defined by ISO4064.
- The Organisation or Individual carrying out such site testing/calibration should be accredited by the National Laboratory Accreditation Services in a manner similar to that detailed in the UKAS NAMAS M18 manual to provide such a service.
- Future Parts of SABS 1529 applicable to water meters larger than 100 mm diameter should incorporate the recommendations of this research.

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IN SITU CALIBRATION OF LARGE FLOW METERS

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IN SITU CALIBRATION OF LARGE WATER METERS

1. Introduction

The Water Research Commission appointed Stewart Scott Inc to undertake research to establish a flow reference standard for the cost effective *in situ* calibration of large water meters required for Water Audits and other test purposes. This flow reference standard can be used to establish the accuracy of permanently installed water meters by means of regular on site comparisons to ensure that these meters remain within the limits of accuracy prescribed by local and international standards

This research established the accuracy of a flow reference standard consisting of the combined accuracy of insertion point velocity measurements, a velocity-area method and a velocity -profile function which can be effectively applied in the field through the insertion of a velocity probe into a common pipeline in which a permanent large water meter has been installed.

Flow tests were carried out in compliance with the requirements of the specifications relating to large water meters such as ISO4064[2] and possible future parts of SABS 1529[5]. Velocity profiles were measured within various pipe sections by means of a single traverse of an insertion flow meter at the depths determined by the relatively more accurate Log-Linear velocity-area method, with missing values (i.e. near the pipe wall) established with the aid of an iterative process that included the Modified Pao Equation and actual point velocity measurements.

Flows determined by means of these velocity profile measurements were compared to those established by Eskom's Flow Laboratory, which has been accredited by the National Laboratory Accreditation Service (NLA). Test sections varied in diameter from 250 mm to 800 mm in order to comply with the above-mentioned standards.

A comprehensive background to this research is provided in the paper titled "Field evaluation of large in-line flow meters[3]" a copy of which is given in Appendix A. This Research Project is essentially as the result of the Recommendations of this paper.

2. Flow Laboratory

The Eskom Flow Laboratory used for this research project has been accredited to measure flow rates in closed conduits for a flow range of 20 to 1200 ℓ/sec. The total accuracy of the installation is 0,1% of flow rate. Details of the Flow Laboratory and a copy of its Certificate of Accreditation are given in Appendix B.

3. Flow Standards and Ranges for Large Water Meters

Water meters have a flow range over which they have been designed to operate; from their minimum flow rate (q_{min}) up to their maximum or overload flow rate (q_s) .The minimum flow rate (q_{min}), is the lowest flow rate at which the meter is required to give indications within the permissible tolerance and is specified as a ratio of the permanent flow rate (q_p) for various metrological classes of water meters. The permanent flow rate (q_p), is the flow rate for which the meter is designed and at which the meter is required to give indications within the permissible tolerance under normal conditions of use. The overload flow rate (q_s), is the rate that is equal to $2q_p$ and also represents the highest flow rate at which the meter is required to operate in a satisfactory manner for a short period of time without deterioration. This short period of time is usually specified as 24 hours in the life of the meter. Between the minimum flow rate (q_{min}) and permanent flow rate (q_p), a transitional flow rate (q_t) is specified dividing the flow range into two separate accuracy zones. The transitional flow rate (q_t) is also specified as a ratio of the permanent flow rate (q_p) for various metrological classes of water meters

International Standards ISO 4064 [2] specify the flow for each nominal diameter and for each point on the flow range. The velocities for the various diameters, flow range points and metrological classes are given in Table 1.

The minimum velocity that most electronic water meters can measure is 0,1 m/sec while the minimum velocity that most mechanical meters can measure is 0,3 m/sec. However, the practical minimum velocity limit usually used by most practitioners specialising in flow metering is 0,5 m/sec. The derived velocity values in Table 1 indicate that generally most permanent in-line water meters can practically only measure velocities specified by International Standards as the transitional flow rate (q_t) for Class B meters. It is assumed that it would be very unlikely that most meters currently available could measure the minimum flow rate at the accuracies required and specified for Class A meters.

The relevance of these findings to this research is that it would only be feasible to undertake *in situ* calibration of permanent in-line flow meters over the flow range from the transitional flow rate (q_t) for Class B meters up to the overload flow rate (q_s).

4. The Log-Linear Velocity-Area Method

Velocity-area methods require that the velocity sensor should be inserted at predetermined points across the plane for the measurement of the local velocity. The mean of these local velocities is the average (or mean axial velocity) of the water flow in the pipe. Previous overseas research examined and mentioned in the paper in Appendix A, show that the greater the number of measuring points per traverse the more accurate is the flow determination for that method. It was however, found that the Log-Linear method is more efficient in its application as it requires fewer measuring points to achieve accuracies better than other velocity-area methods with a greater number of measuring points. Another important aspect of the aforementioned overseas research is that it emphasised the relative accuracy of the various velocity-area methods rather than the overall accuracy of the measurement as in this project.

Six velocity measurement positions (defined by the Log-Linear method), per traverse across the pipe diameter were selected for this project. Analysis of Salami's [4] data given in Table 2 indicates that a six velocity measurements per traverse of the diameter should achieve an accuracy of $\pm$0,4% for the 95% confidence level. (i.e. the accuracy of a six measuring point Log-Linear Method is $\pm$ 0.4%)

TABLE 1 : CLASS/VELOCITY MATRIX IN COMPLIANCE WITH ISO 4064[2]

Flow Range Points* q_{min}	**Class C** (0,006 q_p)		**Class B** (0,03 q_p)	**Class A** (0,08 q_p)			**Velocity @ permanent flow All classes**	**Velocity @ overload flow All classes**
q_t		**Class C** (0,015 q_p)			**Class B** (0,20 q_p)	**Class A** (0,3 q_p)		
q_p							q_p	
q_s								q_s
Dia (mm) **250**	0,0136	0,0340	0.068	0,1811	0,4527	0,6791	2,2635	4,5270
300	0,0141	0,0354	0,071	0,1886	0,4716	0,7074	2,3579	4,7158
400	0,0133	0,0332	0,066	0,1768	0,4421	0,6632	2,2105	4,4210
500	0,0127	0,0318	0,064	0,1698	0,4244	0,6366	2,1221	4,2442
600	0,0147	0,0368	0,0737	0,1965	0,4912	0,7368	2,4561	4,9122
800	0,0133	0,0332	0,066	0,1768	0,4421	0,6632	2,2105	4,4210
Velocity (m/s)			0,1 Minimum velocity of electronic meters	0,3 Minimum velocity of turbine insertion meter				

*Note:

- q_{min} = minimum flow rate
- q_t = transitional flow rate
- q_p = permanent flow rate
- q_s = overload flow rate

Water meter metrological classes

Class A: Value of q_{min} - 0,08 q_p Value of q_t - 0,3 q_p

Class B: Value of q_{min} - 0,03 q_p Value of q_t - 0,2 q_p

Class C: Value of q_{min} - 0,006 q_p Value of q_t - 0,015 q_p

TABLE 2: METHOD-ACCURACY COMPARISON

METHOD	LOG-LINEAR		TANGENTIAL	
Traverse points per diameter	6	10	6	10
% Error	-0,24	-0,15	+1,03	+0,56
Std Dev. (%)	±0,171	±0,107	±0,245	±0,107
Accuracy @ 95% Conf. (%)	±0,367	±0,242	±0,554	±0,242

5. Research Equipment, Methodology and Findings

5.1 *Turbine Insertion Flow Meters*

The insertion flow meters used for this project were turbine insertion meters that provide a frequency output proportional to the velocity of the flowing water. The measuring head consists of a small turbine of 32 mm diameter mounted in a cage together with a magnetic pick-up that is used to count the turbine blade's revolutions (see Appendix E). The manufacturer provided two of these meters for this project. It is important to note that this research is aimed at establishing a standard test method and not at establishing the accuracy of the meter type per se, although in order to establish the overall accuracy of the measurements the accuracy of the meters also needed to be established. The measuring head is mounted on the end of a retractable probe, which is inserted through a 45 mm dia. access tee and isolating valve into the pipeline operating under normal conditions. The exact dimensions of the meter, the access tee, valve, as well as the internal and external pipe diameters were established in order to insert the centre of the turbine to the positions prescribed by the Log-Linear Method. External measurement reference points on the meter's probe were used in conjunction with a steel measuring rule (that had a resolution of 0.5 mm), to establish the prescribed depths of penetration. In accordance with BS1042 (Section 2.2, 1983)[1] the diameter of the turbine dictates the minimum pipe diameter within which the velocity profile can be measured which, in this case is 300 mm.

A Certificate of Calibration provided by Eskom's Flow Laboratory for each flow test included the measured meter frequency for each insertion depth (See Appendix C).

The further the probe is inserted into the pipe the greater is the area of pipe blocked, causing a greater velocity of the water passing through the remaining unrestricted area. In order to establish the actual point velocity each velocity measurement was corrected by means of blockage and velocity factors that used a ratio of areas to correct these local velocities. These corrections were made during the analysis of the data as given in Appendix D.

Initial flow results as well as examination of the turbine indicated problems with 'sticking' of the turbine at the lower velocities The turbine cage was stripped and hair like fibres were found to be fouling the turbine's small bearings. In an attempt to minimise the effect of this problem on the results of this research the meter (No.30193/90) was only used for the measurements on the 250 mm dia pipeline and was not used again. A photograph of this turbine is given in Appendix E.

Meter No. 31901/96 was used for measuring flows on the 300, 400, 500, 600 and 800 mm dia pipelines. This meter was also stripped, oiled and its bearings cleaned by removing hair like fibres. As all the measuring points could be measured on the 800 mm dia pipe these flow tests were used to establish the meter's Calibration (K) Factor. (See Appendix D1).

5.2 *Methodology*

As previously mentioned the aim was to measure the six positions dictated by the Log-Linear velocity area method. Two additional point velocity measurements were taken and these were at the centre line of the pipe and at a rough approximation of the depth of the mean axial velocity as described in previous research. (See Appendix A). The reason for taking these two additional velocity measurements was that they facilitate the process of establishing revised constants for the modified Pao equation in order to establish an approximation for velocity measurements of the inaccessible measurement positions on the pipes smaller than 700 mm dia.

The access point was situated at a position between 18 and 30 diameters of straight length of pipeline downstream of any turbulence-causing devices such as 90^0 bends and tapers. These positions are indicated on the Calibration Certificates (See Appendix C).

Where possible flow test were conducted at q_t, q_p and q_s but not at q_{min} because of the extremely low velocities. In accordance with International Standards[(2)] tests were conducted within 10% of these specified flow rates.

5.3 *Research Findings*

Analysis of the results for the tests carried out on the 800 mm dia pipeline and for the velocity range of 0,4654 to 2,1455 m/sec was used to establish the meter's calibration constant of 113,2170 pulses per metre. As Eskom's Flow Laboratory has NLA Accreditation for a maximum flow of 1200 ℓ/sec the overload flow rate (q_s) for an 800 mm dia meter of 2222,2ℓ/sec could not be reached. However, two flow tests were carried out at the permanent flow rate (q_p). (See Appendix D1).

The Calibration Factor (K) was then applied to all flow tests for the 300mm, 400mm, 500mm, 600mm and 800mm diameter pipelines. The Calibration Factor originally provided with the turbine meter by the Manufacturer and used for flow tests on the 250 mm dia pipeline was adopted. However, because of the problems encountered with the turbine 'sticking' at low flows, the results from the q_{min} test was considered an outlier and omitted from further analysis. (See Appendix E)

Analysis of the data for the flow tests on the 800 mm dia pipeline included the establishment of the ratios of each point velocity to the maximum (centre line) velocity. The means of these ratios nearest the pipe wall were then used to establish a first approximation of these velocities for the pipes smaller than the 800 mm diameter pipe.

The position of mean axial velocity as well as the constants for the modified Pao equation were established for every velocity profile measured. Where necessary these derived constants were used to establish a second approximation of the velocities near the pipe wall (i.e. if the percentage error for the first approximation of flow determination was positive).

The percentage difference in the flow measured by the Flow Laboratory and that derived from the velocity profiles was established for each flow test. (See Appendices D2 to D7). A summary of these results is given in Table 3.

TABLE 3: SUMMARY OF RESULTS

			Percentage difference in measured flow to laboratory flow standard			
	Nominal Dia (mm)	**Internal Dia (mm)**	**% @ q_t**	**% @ q_p**	**% @ q_s**	**Mean Difference (%)**
	800	793.0	-3.111	-0.174	1.044	-0.7471
	600	597.8	-6.305	-0.435	1.137	-1.8677
	500	492.3	-0.336	-0.517	-5.455	-2.1027
	400	396.0	-3.496	-0.533	-3.329	-2.4527
	300	306.06	-1.168	-1.959	0.447	-0.8933
	250	257.8	-16.344	-1.333	0.494	-0.4195
Mean			-2.8833	-0.8252	-0.9436	**-1.4723**
Std Dev			2.322	0.6782	2.7686	2.1842
Student's t			2.7765	2.5706	2.5706	2.1199
Accuracy (%)			6.447	1.743	7.117	**4.630**

Examination of these results indicates that the mean percentage difference for all the tests is -1,4623%, which translates to an accuracy of ±4,630%. The best result at a particular flow rate for all the pipe sizes was that for the permanent flow rate (q_p) with an accuracy of ±1,743%.

When undertaking flow tests in the field with the pipeline operating under normal conditions the flow within the pipe will rarely be at one of the prescribed flow rates for testing. Probably the best situation for *in situ* testing would require a throttling of a valve on the pipeline to achieve the desired flow rate such that there would be minimum interference with the supply. As it probably would be very unlikely that the overload flow rate (q_s) could be achieved in the field at a predetermined time, flow tests could be practically conducted only in the region of the in-line meter's transitional (q_t) and permanent (q_p) flow rates.

It is interesting to note that SABS 1529-1:1994[5] Annex C allows for the verification of used water meters (not exceeding 100 mm dia) when tested in the installation in which they are used in trade at q_{min},q_t and q_s. The permissible tolerance given by SABS 1529-1 [5] for these tests are 8% for flow rates less than q_t and 3,5% for flow rates not less than q_t. These specifications would need modifying to be relevant for future Parts of SABS 1529 applicable to water meters larger than 100 mm dia. because of the previous observation that the larger water meters cannot generally measure the low velocities associated with the minimum flow rates (q_{min}) and the probable inability to achieve the overload flow rates (q_s) in the field.

6. Practical Application of Site Calibration and Site Testing

The practical application of the *in situ* calibration of large flow meters will require the Organisations offering this service to be accredited for site calibration and site testing by an agency such as the National Laboratory Accreditation Services (NLA) if there is to be any credibility in the field tests as well as to ensure traceability.

The United Kingdom Accreditation Service (UKAS) has published the NAMAS M18 Accreditation for Site Calibration and Site Testing -Assessment Procedures and Criteria of Competence [6]. This publication details the various site calibration/testing Categories together with their respective Criteria and Assessment Procedures. Site calibration or testing performed on site by Organisations (or individuals) that do not have a permanent calibration or testing laboratory (Category III) may perform calibration or testing according to the following methods:

- using portable calibration or testing equipment;
- in a site laboratory;
- in a mobile laboratory; or
- using equipment from a mobile or site laboratory.

Criteria of competence to be met by applicants for accreditation include aspects such as the keeping and maintaining of a quality manual; documented detailed procedures that are available for regular auditing; ensuring staff are properly trained and competent; procedures for operating, maintaining and calibration of equipment used; the holding of reference standards; having calibration/test procedures; maintenance of a record system as well as the requirements for test results and issuing of certificates.

The flow range over which the water meter can be calibrated/tested in the field is limited by practical limitations such as the maximum operating capacity of the hydraulic system at the time of testing and the ability of the system to be throttled to the lower flows without interrupting the supply.

Other types of insertion flow meters with smaller measuring heads would be able to measure at the velocity measurement positions near the pipe wall on pipes smaller than 700 mm dia and thereby possibly achieve an improvement in the accuracy of the method.

7. Conclusion and Recommendations

The *in situ* calibration of large in-line water meters with the aid of a portable insertion flow meter can achieve accuracies that comply with relevant standards. However, practical limitations of the meter's performance and the limitations of the hydraulic system in which they are installed could restrict the flow range over which they can be tested/calibrated, to between the transitional (q_t) and permanent (q_p) flow rates. The findings of this project are, that when testing at the transitional (q_t), permanent (q_p) and overload (q_s) flow rates for diameters 250, 300, 400, 500, 600 and 800 mm, accuracies of better than ±5% were achieved. Tests carried out at the permanent flow rate (q_p) for all the pipe diameters achieved accuracies of better than ±2%.

It is therefore recommended that the flow reference standard consisting of insertion flow meter measurements, a velocity-area method and a velocity profile function detailed in this report be adopted as an accepted test method for the *in situ* calibration of large water meters. The following specific aspects are also recommended:

- The flow range over which the tests/calibrations are carried out should be from the transitional flow rate (q_t) or a mean velocity of 0,5 metres per second, whichever is greater, up to the water meters permanent flow rate (q_p) as defined by ISO4064[(2)].

- The Organisation or Individual carrying out such site testing/calibration should be accredited by the National Laboratory Accreditation Services (NLA) in a manner similar to that detailed in the UKAS NAMAS M18 manual[(6)] to provide such a service.

- Future Parts of SABS 1529[(5)] applicable to water meters larger than 100 mm diameter should incorporate the recommendations of this research.

REFERENCES

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APPENDIX A

Field evaluation of large in-line flow meters

Field evaluation of large in-line flow meters#

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Abstract

The combined application of a portable insertion flow meter, a velocity-area method of flow determination together with the use of a velocity profile function provides a cost-effective method for the *in situ* evaluation of the accuracy of large in-line flow meters within the water supply and distribution network.

The calibration of large in-line flow meters in the field is required because of differing site conditions which affect a flow meter's performance, the expense of testing on off-site facilities and the practical problems associated with the removal and testing of some types of flow meters.

Research has indicated the relative accuracy of velocity-area methods for both axisymmetric and asymmetric flow profiles. The log-linear method appears to be relatively more accurate and cost-effective in its application than other velocity-area methods of flow determination.

The modified Pao equation is a function which is independent of the friction factor and which describes the velocity profile within a pipe. It is dependent, however, on the actual positions where the mean axial velocity occurs and the value of the centre-line velocity. These characteristics facilitate the practical application of the function in establishing a flow reference standard.

The position of the mean axial velocity in a pipeline varies and this position has to be determined for each situation and application.

Practical guidelines given in this paper ensure the cost-effective application of a portable insertion flow meter, the log-linear method and the modified Pao equation for providing a flow reference standard.

Research is required to establish the accuracy of this flow reference standard with respect to the national flow standard.

Introduction

As flow data collected from potable water supply and distribution systems are used for various forecasting and revenue purposes, it is important to know the degree of accuracy of the data obtained. Generally, the less the error in the data, the greater the accuracy of the forecast and possibly the reduction in lost revenue.

Flow meters can be evaluated on test facilities where the meter under test is compared against a standard. This standard could either be another flow meter of better accuracy or a technique utilising weighing methods or volumetric methods. Ideally, this standard should be traceable to an appropriate national standard.

In South Africa, the National Calibration Services (NCS) of the CSIR facilitates a national system for the calibration of instruments which then have an accuracy traceable to national measuring standards as required by law. The NCS therefore verifies a test facility's stated accuracy, the values of which have been determined by SABS, British or International Standards. The NCS specifies requirements such as which documentation should be kept, the competence of the staff undertaking the tests, the intervals with which the test facility itself should be recalibrated (i.e. reference meters), etc. On compliance with these requirements, the test facility is certified by the NCS as an approved laboratory.

The two better known NCS-approved flow laboratories are those of Eskom and the Johannesburg Municipality which can test flow meters up to 1 000 mm and 400 mm dia. respectively.

These test facilities have reference accuracies of 0.1% which is not a necessary requirement for all flow-meter calibrations.

On these types of test facilities the evaluation of in-line flow meters obviously requires their removal from site which can be expensive considering the labour, transport and testing costs.

On installation, a calibrated flow meter's performance will differ from its performance as evaluated on a test facility. This difference cannot be verified unless the meter is calibrated *in situ* (Furness, 1991).

There is, therefore, also a need to determine the flow rate to a known degree of accuracy within large pipelines by means of a portable flow meter so that those in-line meters which cannot be easily removed for testing can be evaluated or, previously calibrated flow meters can be calibrated *in situ* to take into account particular site conditions.

Guidelines for the reduction and control of unaccounted-for water give high priority to the *in situ* testing of source (production) and district meters in an unaccounted-for water investigation (Jeffcoate and Saravanapavan, 1987). These guidelines were designed for use by managers of water authorities in developing countries.

By using a portable insertion meter to measure the velocity at various points in the pipe, and the velocity-area method to determine the flow, a suitable reference standard can be established for calibrating flow meters *in situ* (Johnson, 1987).

The basic assumption in deriving most of the velocity-area methods for velocity profile integration is that the velocity curve assumed approaches the real velocity profile in the line of traverse. This is reasonable for axisymmetric flow profiles (Salami, 1971).

This paper provides a brief review of previous studies on the subject of velocity-area methods for flow determination, and suggests some practical guidelines as to the application of insertion meters to ensure that a suitable *in situ* reference standard can be established for the calibration of large in-line flow meters within a water supply and distribution network.

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Flow-meter accuracy

As the accuracy of a flow meter can be interpreted in various ways, "accuracy" has been briefly defined here to ensure conformity in its meaning and use. Accuracy is defined as the closeness of the actual reading to the true value and it includes the effect of both precision and bias error.

Precision is the ability of a measuring device to repeat the same readings for the same input. Because variations in readings are random, statistical theory can be used to calculate a precision value from the variance of the readings (Miller, 1989). Precision is calculated from the standard deviation for the data points multiplied by a correction factor derived from the student's t-distribution for the 95% confidence level. Bias error is the difference between the average and the true value, as established by a reference standard. The respective formulae are detailed in the **Appendix**.

"Uncertainty" is often used as a synonym for "accuracy". However, uncertainty is the property of a measurement rather than the instrument used to make the measurement (Hayward, 1979).

International Standard ISO 5168 (1978) defines the uncertainty of measurement as the interval within which the true value of the measured quantity can be expected to lie with a suitably high probability. This uncertainty of measurement and the confidence level associated with the uncertainty indicates the probability that the interval quoted will include the true value of the quantity being measured.

The International Organisation for Legal Metrology (Organisation Internationale de Métrologie Légale, 1971) describes accuracy as an overall quality of a measuring instrument from the point of view of errors. Accuracy is greater when the indications are closer to the true value. Therefore, an accuracy of 99% is an inaccuracy of 1%. However, inaccuracy is also sometimes referred to as "accuracy" (Miller, 1989).

Flow meters and auxiliary instruments are usually assigned a reference condition accuracy which is a laboratory-determined accuracy envelope for the range of the instrument's operation. If however, the instrument is used outside its reference range, it can be specified in terms of a limit of error.

Velocity-area method of flow determination

The determination of velocities at various points across one plane in a pipe flowing full and under pressure usually finds the maximum velocity positioned at the centre of the pipe with the velocity reducing as measurements are taken closer to the pipe wall.

The velocity-area method requires that the flow sensor should be inserted at predetermined points across the plane for the measurement of the local velocity. The mean of these local velocities is the average velocity of the water flow in the pipe.

Evaluation studies (Winternitz and Fischl, 1957; Salami, 1971) have indicated the merits of the various velocity-area methods of flow determination in pipes. The tangential method seems to be the one which is most commonly adopted while the log-linear method appears to be the most accurate.

According to Winternitz and Fischl (1957), the objective of these methods is to determine the flow rate through the pipe. This is given by:

$$Q = 2\pi \int_0^R r \, dr \, v \ldots .$$

where:

Q = flow rate
R = pipe radius
r = local radius at which point velocity is measured
v = point velocity.

Tangential method

This method consists basically of dividing the cross-section of the pipe into concentric rings of equal area, the innermost being a circle. The position at which the velocity reading is taken is at points which bisect each ring into two equal areas. The arithmetic average of these velocities is assumed to be the mean velocity of the flow through the cross-section.

The radii of these concentric rings of equal area can be determined by:

$$r = R\sqrt{\frac{2i - 1}{2N}} \qquad \text{(Salami, 1971)}$$

where:

r = local radius at which point velocity is measured
R = pipe radius
N = number of gauging points per pipe radius
i = 1, 2, 3, ... N

Log-linear method

The positions for measuring the velocities in each annulus are selected at the points where the mean velocity for a particular cross-section would occur. The proviso here is that a function must adequately describe the velocity profile and include these points.

The logarithmic functions used to describe the profile in the log-linear method can be expressed in general form as:

$$V = A^* + B^* \operatorname{Log}\left(\frac{y}{D}\right) \qquad \text{(Winternitz and Fischl, 1957)}$$

and for flow not fully developed:

$$V = A^* + B^* \operatorname{Log}\left(\frac{y}{D}\right) + C^*\left(\frac{y}{D}\right) \qquad \text{(Winternitz and Fischl, 1957)}$$

where:

A*, B* are constant with the dimension of velocity
C* = constant for a given velocity distribution and has the dimension of velocity
D = diameter
y = distance from pipe wall velocity is measured.

The **Appendix** to the article by Winternitz and Fischl (1957) provides the details of calculations and formulae for the determination of the gauging positions.

The gauging positions for both methods are indicated in Fig. 1.

Method-accuracy comparison

Salami (1971) measured ten asymmetric profiles of various shapes using four velocity-area methods of flow determination. As these profiles were asymmetric, the velocity measurements at the respective points along a number of traversing lines across the pipe are required to ensure that the true flow is determined. Salami's results concur with previous research (Winternitz and Fischl, 1957), that when measuring irregular velocity profiles, the log-linear method is more accurate for flow determination than the tangential method.

A comparison of the various integration methods for a single traverse line with volumetric measurements for 36 velocity profiles

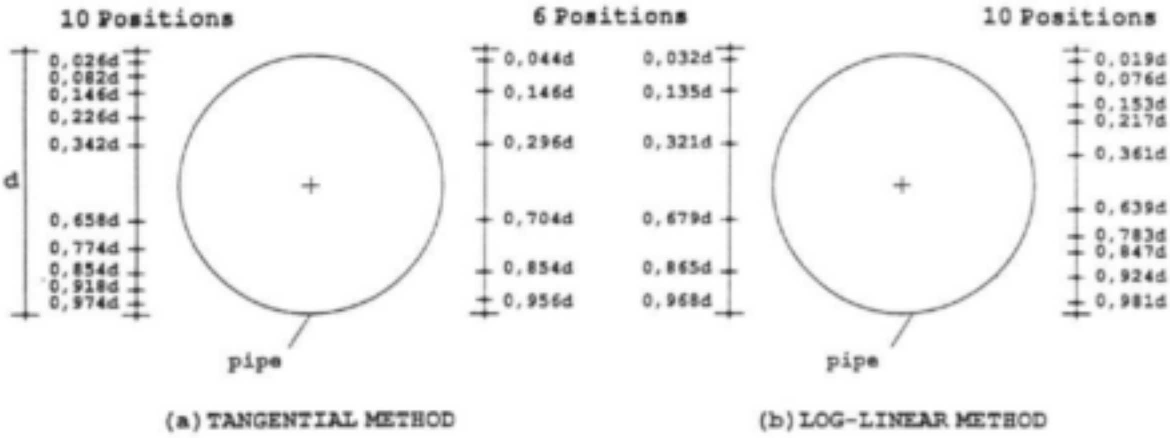

Figure 1
Gauging positions for velocity-area methods (Winternitz and Fischl, 1957)

in fully developed turbulent pipe flow, indicated that the log-linear method was relatively more accurate than the tangential method (Winternitz and Fischl, 1957).

A general observation of these results is that for any method adopted, the greater the number of measuring points per traverse the more accurate is the flow determination for that method. The log-linear method is, however, more efficient in its application as it requires fewer measuring points to achieve accuracies better than that of the tangential method with a greater number of measuring points. This method is therefore cost-effective as it reduces the time required to determine the flow.

Pitot tubes were used in both the research projects detailed above and the assumption made was that the device was error-free with emphasis on the relative accuracy of the velocity-area methods rather than the overall accuracy of the measurement.

Velocity profile function

It is not always possible to place the measuring point of an insertion meter in the position stipulated by the particular velocity-area method being used. This may be due to the fact that the measuring position is related to the particular pipe dia., and therefore, the device is unable to measure near the pipe wall in cases of small dia. pipes because of the device's physical size. Alternatively the probe's length may be insufficient to traverse the length of an isolation valve, access tee and the full dia. of the pipe in the case of large dia. pipes.

Defining a function that best describes the velocity profile being measured in the field therefore becomes important when the restrictions mentioned above prevent the actual velocity measurement of some of the prescribed positions.

Prandtl derived a formula for the velocity distribution across a pipe operating within the constraints of the smooth pipe law (Webber, 1979). This theory assumes that the turbulent flow is separated from the pipe wall by a thin layer which serves the function of transmitting frictional drag, induced by turbulent flow, to the boundary by the mechanism of viscous shear. This implies that the laminar boundary layer acts as a smooth lining preventing the flow from being influenced by any excrescences on the pipe walls and consequently no eddies are formed.

The measuring section of a pipe would generally be selected smooth enough so that excrescences would not project through the laminar boundary layer and cause a disturbance and the resultant formation of a train of eddies that is characteristic of the rough pipe law (Johnson, 1987).

The velocities nearest the pipe wall that cannot be measured by the insertion meter can be calculated by fitting a parabolic curve to those velocities that can be measured and determining these missing values by extrapolation. The velocity distribution is, however, only parabolic in the laminar zone and extrapolation of the parabolic curve outside this laminar layer can result in an inadequate approximation of the velocity distribution (Winternitz and Fischl, 1957).

The Reynolds number is a correlating parameter that combines the effect of viscosity, density and pipeline velocity. The dimensionless number is calculated with the following formula:

$$\text{Reynolds number} \quad (Re) = \frac{DV}{v}$$

where:

- D = dia. of the pipe (m)
- V = average velocity of the water (m/s)
- v = kinematic viscosity for water (m^2/s)

As the dimensionless Reynolds number and the pipe's relative roughness are useful criteria for distinguishing between laminar and turbulent flows, it can therefore be deduced that since the water mains in the network operate at a Reynolds number in the approximate region of 10^5 to 10^6 (which is well within the turbulent flow zone) and have an approximate relative roughness of 5×10^{5}, the parabola equation cannot be applied outside the laminar boundary sublayer to any great extent (Johnson, 1987).

Since the objective of measuring the velocity profile within the pipe is to determine the mean velocity and its positions, other factors influencing the velocity distribution, such as the friction factor, are not directly relevant. The function describing the measured velocity distribution should therefore be independent of the friction factor, but dependent on the actual positions at which the average velocities (Y_{ave}) occur and the value of the centre-line velocity (V_{max}).

The Pao equation which relates the friction factor to average velocity has been used to describe the velocity profile in turbulent flow (Miller, 1989) and is modified here by the author to fulfil the above stated objective.

The Pao equation expressed in the general form is:

$$\frac{V}{\overline{V}_p} = 1 + (A + B \log \frac{y}{r_p}) \sqrt{f} \qquad \text{(Miller, 1989, Eq. 5.19)}$$

where:

- V = Point velocity at distance y from pipe wall
- r_p = Radius of pipe
- y = Distance from pipe wall to point velocity (i.e. point velocity depth)
- $\overline{V}_p$ = Average velocity in the pipe
- f = Darcy-Weisbach friction factor derived from the Colebrook White formula (Webber, 1979)

$$A = \frac{1}{\sqrt{f}} \left[\frac{V_{max}}{\overline{V}_p} - 1 \right]$$

i.e. at the centre of the pipe the velocity is at a maximum and the point velocity depth is equal to the pipe radius.

$$B = \frac{-A}{\log \frac{Y_{ave}}{r_p}}$$

i.e at the depth of average velocity the point velocity equals average velocity.

therefore:

$$\frac{V}{\overline{V}_p} = 1 + \left[\left(\frac{\frac{V_{max}}{\overline{V}_p} - 1}{\sqrt{f}} \right) - \left(\frac{\frac{V_{max}}{\overline{V}_p} - 1}{\sqrt{f} \log \frac{Y_{ave}}{r_p}} \right) \log \frac{y}{r_p} \right] \sqrt{f}$$

simplifying:

$$\frac{V}{\overline{V}_p} = 1 + \left[\left(\frac{V_{max}}{\overline{V}_p} - 1 \right) - \left(\frac{\frac{V_{max}}{\overline{V}_p} - 1}{\log \frac{Y_{ave}}{r_p}} \right) \log \frac{y}{r_p} \right]$$

which shall be described as the modified Pao equation for the purposes of this paper.

The velocity profile calculated for both theories has been compared with the actual velocity profile measured within a 667 mm dia. cement mortar-lined pipeline and indicated that results from the modified Pao equation gave values closer to those measured than those determined by the smooth pipe law. The smooth pipe law is influenced by a change in temperature while the modified Pao equation is independent of temperature changes (Johnson, 1987).

Position of average velocity

Measuring the mean axial velocity within a pipe by single point measurement requires the positioning of the sensor at the position where this velocity will actually occur or within the known ratio of the insertion position to mean axial velocity depth. The latter method would appear, however, to be less accurate (Bossy et al., 1980).

A summary of 23 velocity profiles measured in pipelines ranging from 210 to 800 mm dia. has been detailed in Fig. 2 (Johnson, 1987). A portable turbine insertion meter was used to measure the point velocities at the ten positions defined by the tangential method. The position at which the mean axial velocity occurs is not constant for these profiles as indicated by standard deviations of 7.5 and 6.0% for the top and bottom positions respectively, which illustrates the degree with which these positions vary about the mean.

The slight asymmetry of the velocity profile could be ascribed to the access tee having an influence on the shape of the top portion of the profile as there is no pipe wall providing frictional drag, only a "plug" of water within the tee. The access tee could also cause a disturbance and therefore have an effect on the profile. The lower portion of the profile lies within established theories.

Profiles measured by means of Pitot tubes (Gebhardt, 1979) and electromagnetic insertion meters (Elmart Instruments, 1992) have also indicated that the location of the mean axial velocity within a pipe is not constant.

Codes, theories and research also differ as illustrated in Fig. 3 and are detailed as follows:

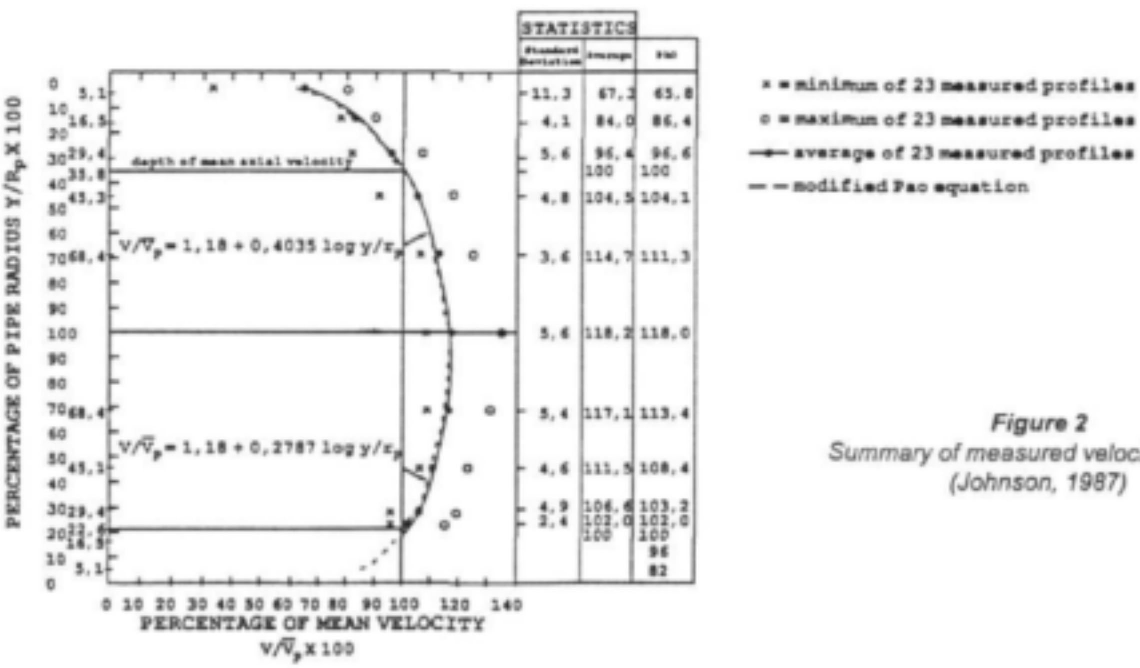

Figure 2
Summary of measured velocity profiles (Johnson, 1987)

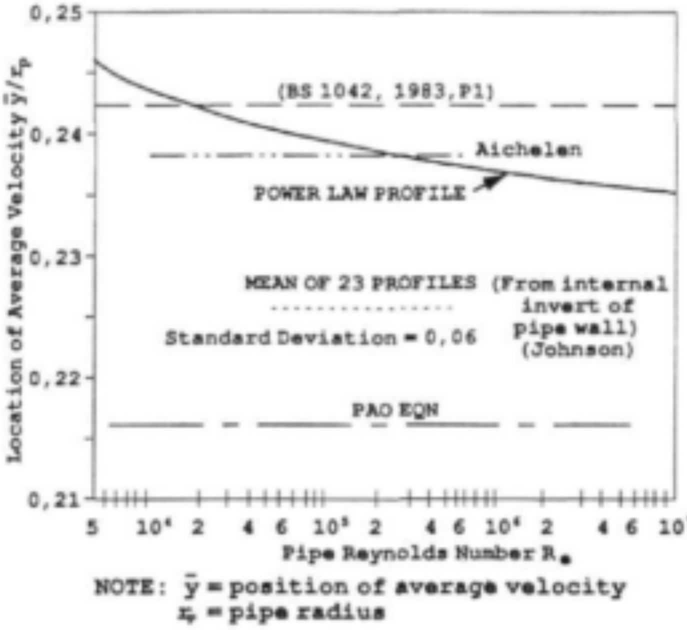

Figure 3
Location of average velocity from pipe wall (Miller, 1989)

Researcher/ Standard	Position of mean axial velocity	Reference
Aichelen	0.238 r	(Winternitz and Fischl, 1957)
Winternitz	0.224 r	(Winternitz and Fischl, 1957)
BS1042:1983	0.242 r	(BS1042 : Section 2.2 : 1983)
Pao	0.216 r	(Miller, 1989)
Johnson	0.226 r	(Johnson, 1987)

The British Standard (BS1042, Section 2.2, 1983) also provides a depth range of 0.229r to 0.255r at which the mean axial velocity can be measured in order to attain the specified flow accuracy of ± 3%. Aichelen (Bernard, 1988) found that the measured velocity at 0.238r was equal to the mean velocity within ± 0.7% for Reynolds numbers between 4×10^3 and 3×10^6.

In practice, the varying position of the mean axial velocity confirms the need to utilise a velocity profile function which is based on the actual positions for a particular installation. These positions are therefore determined each time the velocity profile is measured to allow for any change in upstream conditions.

Field application

Turbine-type current meters are accurate instruments (<0.2%) and are used for the calibration of differential pressure devices (Staubi, 1988). Although this type of insertion meter has been used by the author, other types could also be used (See **Reference Standard**).

The turbine insertion meter consists of a small diameter turbine and a magnetic pick-up on the end of a retractable probe.

The meter is inserted into the pipeline via an isolation valve (Fig. 4).

The passage of the water through the device causes the rotor to revolve at a rate proportional to the velocity of the fluid at that particular point. The magnetic pick-up at the end of the probe senses the movement of each rotor blade as it passes the pick-up. The frequency of the output pulses is directly proportional to the fluid flow rate.

In the field each point velocity is determined by measuring the frequency of the turbine's blade with the aid of the electronic instrumentation supplied with the flow meter.

This frequency is divided by the manufacturer's calibration constant for that particular flow meter. This constant has been determined by the evaluation of the flow meter's accuracy on a test facility which has a standard traceable to an appropriate national standard (local or overseas).

The measured point velocity is therefore calculated as follows:

$$\text{Measured point velocity} = \frac{\text{measured frequency}}{\text{manufacturer's calibration constant}}$$

Other factors affecting the overall accuracy of the turbine insertion

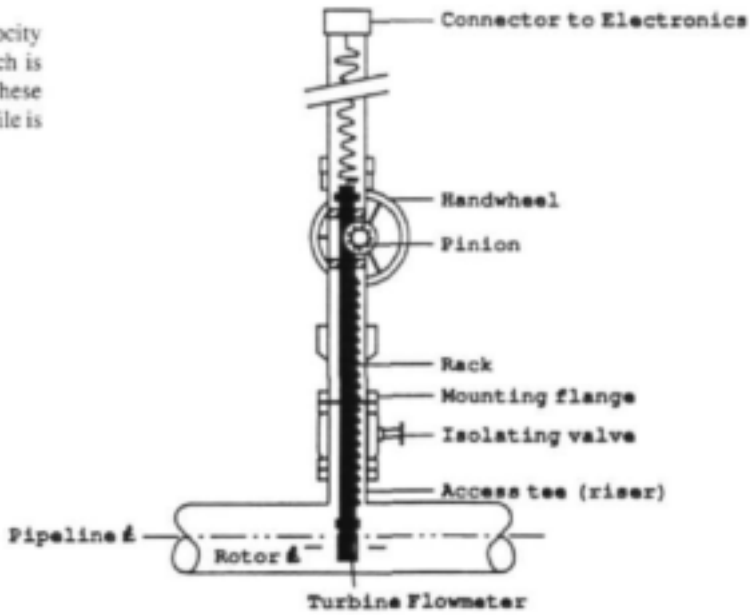

Figure 4
Insertion meter installation

meter include the blockage factor and the orientation of the insertion meter. The further the probe is inserted into the pipe the greater the area of pipeline which is blocked and, therefore, the greater the velocity of the water passing through the remaining unrestricted area. A blockage factor is determined for each insertion depth via a ratio of areas which corrects the local velocity measured.

The following relevant calculations are made:

$$\text{Blockage factor} = \frac{\text{calculated blockage} \times 100}{\text{area of pipe}}$$

$$\text{Velocity factor} = \frac{100}{100 - \text{blockage factor}}$$

$$\text{Actual point velocity} = \frac{\text{measured point velocity}}{\text{velocity factor}}$$

Application of the portable turbine insertion meter in the field requires the assistance of a hand-held computer for the determination of flow rates.

A program based on the modified Pao equation and which makes use of the log-linear method has been written for hand-held computers (Johnson, 1987).

The program developed uses empirically based constants for a first approximation of velocity measurement of the inaccessible measurement positions. The positions where the actual mean axial velocities occur are then calculated taking into account the point velocities which have been measured and new constants determined. This is an iterative process incorporating the modified Pao equation, the log-linear method and measured point velocities that determine the missing point velocities ensuring that the overall average velocity converges to within acceptable limits.

The positions of the mean axial velocity are therefore determined from actual velocity measurements during each traverse irrespective of the device's ability or inability to measure near the pipe wall and/ or over the full pipe dia. The reference accuracy would, however, generally be restricted to the accuracies of the log-linear method and those of the complete device if the whole profile could be measured.

After determination of these positions of mean axial velocity, the portable turbine insertion meter can then be set at either of these positions for the monitoring of various flow rates or for volumetric determination over a time period.

Reference standard

As it is uneconomical to calibrate a flow meter to a greater accuracy than that which is required (BS7405, 1991), it is essential when undertaking the evaluation of large "in-line" flow meters, to decide at the outset what accuracy is required from the calibration system.

From experience large in-line flow meters that are installed in the potable water supply and distribution network should have the accuracies for their respective functions as follows:

- Revenue ± 2%
- Control ± 3 to 5%
- Planning/management ± 3 to 5%

The flow rate within the large (≥300 mm dia.) pipes in the water supply and distribution network is usually restricted to an equivalent maximum velocity of 3 to 4 m/s. This smaller range ensures greater accuracy in the calibration of the reference meter itself. Extrapolation outside this range of calibration is not recommended (BS7405, 1991).

The general accepted accuracy of the reference standard for production testing is four times better than that of the meter whose accuracy is being determined. Miller (1989) considers that it should be five times better. However, the overall accuracy as determined by the root-sum-square of the reference standard plus the in-line meter complete, should be within the required accuracy limits for which the flow data are required.

Some of the various types of insertion probes that could be utilised for the measurement of velocity profiles within pressure pipes are:

- Turbine (BS7405, 1991)
- Electromagnetic (BS7405, 1991)
- Vortex Shedding (Perrin, 1977)
- Pitot static tubes (BS1042, Section 2.1, 1983)
- Ultrasonic (Spitzer, 1990)
- Target (Spitzer, 1990)

A particular insertion flow meter's suitability as part of a reference standard would be determined by the following:

- It should be portable
- It should be uncomplicated to use (easy to operate)
- The particular device's measurement of point velocities must be within the required accuracies of the reference standard
- Access by the probe into the pipe under pressure must be possible
- The probe's length should be sufficient to traverse the length of an access tee, isolation valve and full dia. of the pipe
- The probe and velocity sensor should provide minimum restriction to the flow but be rigid enough not to vibrate at full extension
- Sampling of velocities at each point of measurement defined by the method should be possible
- An external micrometer or similar device should be included in the design of the insertion meter so that the exact position of the measuring point can be determined within the pipe.

Furness (1992) considers that long lengths of pipe upstream of the meter are required before the performance is unaffected by the actual installation.

To ensure that the flow is fully developed so that the best possible velocity profile is available at the measuring cross-section, the straight length of pipe before the measuring section should, where possible, equal a hundred times the pipe dia. (Miller, 1989). The BS1042 standard considers that a straight length of pipe equal to thirty to fifty times the pipe dia. is sufficient depending on the type of turbulence-causing device upstream (BS1042, 1983). The latter standard is related to the single predetermined point measurement of the mean axial velocity and therefore is considered acceptable for the measurement of the complete velocity profile especially as subsequent flows could be measured at the derived depth of mean axial velocity.

Some of the limitations and considerations in the use of the combination of a portable turbine insertion flow meter, with log-linear method and modified Pao equation as a flow reference standard for large in-line flow meters within the potable water supply and distribution network are:

- The minimum pipe dia. within which the velocity profile can be measured is 300 mm (BS1042, Section 2.2, 1983).

- At least the top half of the velocity profile must be measured (if used in conjunction with the previously mentioned computer program), but for greater accuracies the whole profile should be measured.
- It is important to ensure that there is a fully developed turbulent velocity profile that is non-swirling and axisymmetric by allowing a straight unobstructed length of pipe at least 30 to 50 times the pipe dia. upstream of the measuring point, dependent on the type of disturbance upstream. Downstream from the measurement point, the straight length should be at least equal to five pipe dia. irrespective of the type of disturbance (BS1042, Section 2.2, 1983).
- The flow must be steady at reference conditions and in order to comply with this requirement, it must not vary by more than ±3% for linear flow meters and more than ±6% for differential pressure flow meters (Miller, 1989). A factor to consider when complying with this requirement would be to restrict the time taken to measure the velocity profile to a minimum or to sample the velocity at the derived position of mean axial velocity.
- The insertion flow meter and associated instrumentation should be calibrated by the respective approved laboratories.
- The access tee dia. should be restricted to the minimum practically feasible for the insertion of the meter probe.
- The relative roughness of the internal pipe wall should be 1.0×10^{-4} or better.

It should be noted that establishing an overall reference standard by means of a complete accuracy (uncertainty) audit including all the sources of error is not practically feasible for every application. It is therefore incumbent on the user to establish from experience or otherwise, which factors to incorporate and which factors not to incorporate into the accuracy audit for each evaluation. It is, however, still important to identify all sources of possible error even if some of the values determined are small enough to be ignored in the final audit.

The objective of establishing this reference standard is to provide a cost-effective practical method for the field evaluation of large in-line flow meters and not necessarily to attempt to duplicate the high accuracies obtained by permanent test facilities.

Conclusion

The positions at which the mean axial velocity occurs in a pipeline are not fixed. The lack of conformity about these positions in the various codes and theories confirms this finding. These positions need to be determined for each situation and application especially if the measuring device is to measure the mean axial velocity by a single point velocity measurement for various rates.

A cost-effective method for the field accuracy evaluation of large in-line flow meters is required to ensure the subsequent flow data obtained are within the required accuracy for the purpose for which it is required. The application of a portable insertion flow meter, the log-linear method and modified Pao equation can be used for this purpose, which could be considered superior to the method whereby only a single velocity measurement is taken at a predetermined position.

Previous research has generally placed emphasis on the relative accuracy of the velocity-area methods rather than the overall accuracy of the measurement as related to a national flow standard.

Recommendations

It is recommended that research is undertaken to determine the combined accuracy of insertion meter measurements and velocity-area methods as compared to the national flow standard. Knowledge as to this combined accuracy can then be used as a reference standard for the *in situ* calibration of flow meters. It is further recommended that in establishing this reference standard cognizance is taken of relevant local and overseas standards.

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Appendix

Accuracy formulae

Precision at the 95% confidence level is:

$$\sigma_p = t\sigma \qquad \text{(Miller, 1989, Eq 4.4)}$$

where:

σ_p = precision (ISO 5168 (1978) defines this as uncertainty)
t = students t-value at 95% confidence level
σ = standard deviation

Bias error (B) is the difference between the average and the true value, as established by a reference standard.

$$B = \frac{\bar{I} - I}{I} \times 100 \qquad \text{(Miller, 1989, Eq 4.5)}$$

where:

B = Bias error (directional)
$\bar{I}$ = average
I = reference standard value

However, bias-error calculations have a degree of confidence associated with the average value. When the 95% confidence level is taken into account for the determination of precision a bias error range centred on the average can be established.

$$\pm B = \sigma_p / \sqrt{n} \qquad \text{(Miller, 1989, Eq. 4.8)}$$

where:

σ_p = precision
n = number of values

With the bias error known and with each reading corrected the accuracy calculation is

$$\text{Accuracy} = \pm \sqrt{\left(1 + \frac{1}{n}\right) \sigma_p^2} \qquad \text{(Miller, 1989, Eq. 4.10)}$$

Flow meters with good precision and for a reasonable number of data values, the accuracy can be approximated from:

$$\text{Accuracy} = \pm \sigma_p \qquad \text{(Miller, 1989, Eq. 4.11)}$$

Most instruments have a reference accuracy envelope that incorporates precision, directional bias and bias-error range over a specified range of the measured variable. The limits of the envelope are expressed as a percentage of the upper range value (URV) or as a percentage of the reading. Accuracy envelopes are specified for reference conditions and apply within the stated limits.

Operating condition accuracy is used to relate other independent influence quantities by the root-sum-square method.

$$\text{Accuracy} = \pm (\text{Acc})_{ref} \pm \left(B_1^2 + B_2^2 + B_3^2 \ldots\right)^{½}$$

(Miller, 1989, Eq. 4.12)

where:

ref = reference condition accuracy
1, 2, 3 = influence quantities.

APPENDIX B

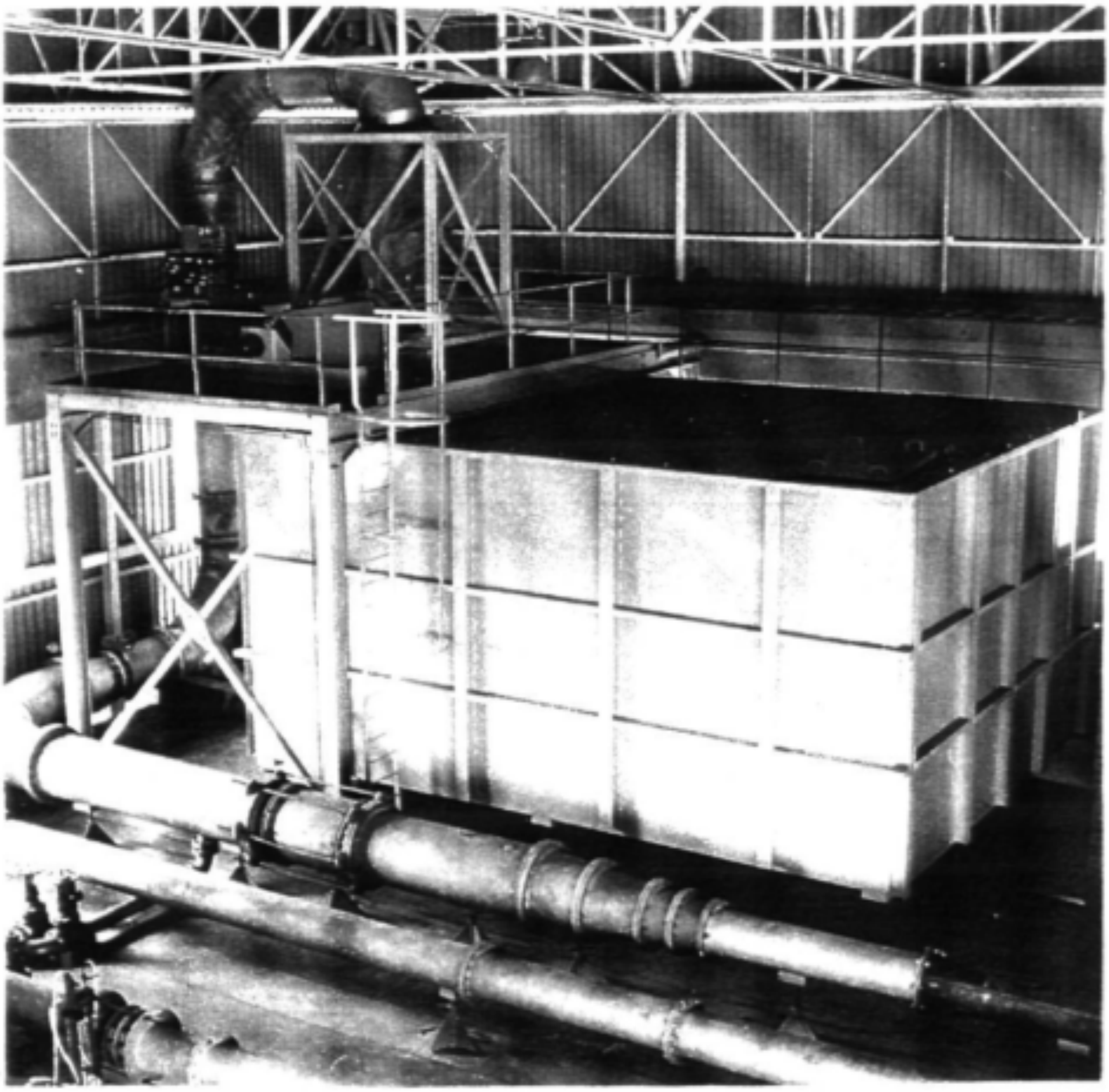
Eskom's Flow Laboratory and Certificate of Accreditation

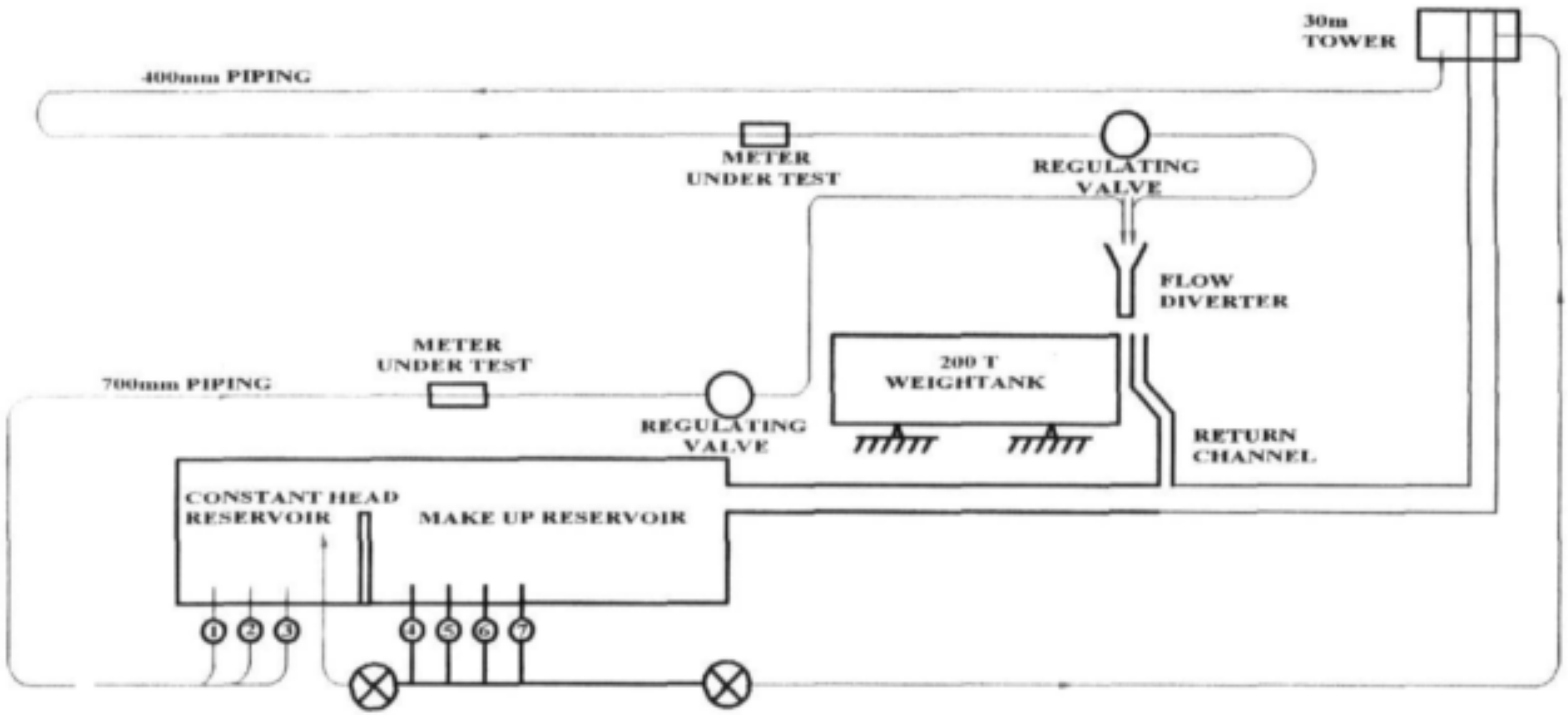
GRAVIMETRIC SYSTEM

This installation can accommodate piping from 150 - 1 000 mm diameter and flow rates of 20 - 2 000 ℓ/s. A constant water flow rate is provided either from a constant head tower (at lower flow rates) or by direct pumping from a constant head reservoir (at higher flow rates). The flow passes through the meter under test and then through a control valve and into the diverter chute. The diverter changes the flowstream into the weightank in 0,1 seconds without causing any upstream disturbance. The weightank has a 200T capacity and stands on four calibrated loadcells. When sufficient water has been diverted to the tank, the flowstream is returned to the normal direction, where it discharges into an open channel and returns to a make-up reservoir.

The quantity of water collected is obtained from the tank weight before and after the diversion period. The time period is obtained from a digital timer which is activated by sensing units attached to the diverter chute.

The total accuracy of this installation is 0,1% of flow rate.





SCHEMATIC LAYOUT OF THE LABORATORY

National Laboratory Accreditation Service

CERTIFICATE OF ACCREDITATION

This is to certify that:

ESKOM TRI

No. 901

is a National Calibration Service Accredited Laboratory for two years commencing AUGUST 1997 provided that all NLA conditions and requirements are complied with.

The types of measurement for which this certificate is valid are as follows:

WATER FLOW RATE
WATER QUANTITY

While this certificate remains valid, the Accredited Laboratory named above is authorised to issue NLA certificates.

Signed:

Chief Executive Officer, NLA

NLA

Accredited Laboratory Measuring Capabilities

NLA FLOW METROLOGY

ACCREDITATION NO: 901

PAGE 1 OF 1

DATE OF ORIGINAL ACCREDITATION: 1989

DATE OF ISSUE: AUGUST 1997

EXPIRY DATE: AUGUST 1999

LABORATORY: Eskom TRI
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Cleveland
2022

TEL: (011) 629-5245
TELEFAX: (011) 629-5542

APPROVED SIGNATORIES-

HEAD: Mr F M Liebenberg
DEPUTY: -

Mr M G Mathieson
Mr D B Walker
Mr D W F Senekal

Functions and ranges for which NLA Accreditation has been granted

ITEM	MEASURED QUANTITY OR TYPE OF GAUGE OR INSTRUMENT	RANGE OF MEASURED QUANTITY	BEST MEASUREMENT CAPABILITY EXPRESSED AS AN UNCERTAINTY (±)
1	Water flow rate in closed conduits	20 kg s^{-1} to 1200 kg s^{-1} 20 l s^{-1} to 1200 l s^{-1}	0,1 %
2	Water quantity	20 kl to 180 kl 20 000 kg to 180 000 kg (at the above flow rates)	0,1 %

The BMCs were estimated for a 95% confidence level.

Chief Executive Officer: NLA

APPENDIX C

Certificates of Calibration for this Project

C.1

NLA

ESKOM

TECHNOLOGY RESEARCH AND INVESTIGATIONS
LIQUID FLOW METROLOGY LABORATORY

NATIONAL LABORATORY ACCREDITATION SERVICE
LABORATORY No 901

CERTIFICATE OF CALIBRATION

Date of issue 21 November 1997

Certificate number 97TL133

Head of Laboratory

The accuracy of all measurements is traceable to the national measuring standards.

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care executed in handling and use of the device, and the frequency of use. Recalibration should be performed after the period so chosen to ensure that the instrument's accuracy remains within the desired limits.

This certificate is issued in accordance with the conditions of the accreditation granted by the National Laboratory Accreditation Service (NLA). It is a correct record of the measurements made. This certificate may not be reproduced other than in full except with prior written approval of the issuing laboratory.

The NLA has agreements with the European cooperation for Accreditation of Laboratories (ELA) and with the Chinese National Laboratory Accreditation (CNLA) for the mutual recognition of calibration certificates.

TECHNOLOGY RESEARCH & INVESTIGATIONS
Private Bag 40175
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NLA

ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TL133

ITEM DESCRIPTION

Calibration of a	800 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Calibration date :	21 November 1997		
Calibrated for :	Stewart Scott SA (Pty) Ltd		
Calibration range :	1111.11 l/s (4000 m3/h)		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

REFERENCE EQUIPMENT AND TRACEABILITY

Reference flow :	200 T Gravimetric system	
Temperature :	Pt 100 SENSORS	T256, T253 & T249
Analog outputs :	FLUKE LOGGER S/NO 4260001, FLUKE DMM S/NO 5465069	
Impulse Counter :	HP 5327A TIMER/COUNTER S/NO 1248A00376	
Frequency & Time :	HP 5328A TIMER/COUNTER S/NO 1804A05857	

PIPEWORK AND ENVIRONMENT

Upstream straight pipe L/D :	17.9 D	Nominal ID:	793.0 mm
Downstream straight pipe L/D :	8.6 D	Nominal ID:	793.0 mm
The control room temperature was	21.2 °C	+/- 3 °C	
The test area temperature was	22.9 °C	+/- 5 °C	

LABORATORY PROCEDURE

The calibration was performed according to procedure No 901-1001-01

UNCERTAINTY OF MEASUREMENT

The uncertainty of measurement is +/- 0.2 % of indication
(estimated for a 95% confidence level).

CALIBRATED BY : **G G CHOABI**

F M LIEBENBERG
HEAD OF LABORATORY
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NLA

ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TL133

ITEM DESCRIPTION

Calibration of a	800 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

RESULTS

TABLE 1

RUN NO.	WATER TEMP AVE. °C	WATER DENSITY kg/m3	REFERENCE FLOW AVE. l/s	METER DEPTH mm	METER FREQUENCY Hz	ACCESS TEE HEIGHT mm
1	22.1	997.75	167.420	145.8	32.15	97.3
				227.3	38.64	
				262.2	39.71	
				374.6	43.03	
				516.8	41.62	
				659.0	42.43	
				806.3	39.34	
				887.8	32.30	
2	22.1	997.75	229.862	145.8	45.24	97.3
				227.3	54.84	
				262.2	55.13	
				374.6	59.62	
				516.8	59.51	
				659.0	59.15	
				806.3	55.19	
				887.8	48.38	

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ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TL133

ITEM DESCRIPTION

Calibration of a 800 mm FLOW TRAVERSE WITH A TURBINE PROBE
Meter Make : BESTOBELL MOBREY Serial No : 31901/96
Meter Type/Model : R1B Output : PULSES
Converter Make : BESTOBELL MOBREY Serial No : 836542
Converter Type : REMOTE

RESULTS **TABLE 1 Cont.**

RUN NO.	WATER TEMP AVE. °C	WATER DENSITY kg/m3	REFERENCE FLOW AVE. l/s	METER DEPTH mm	METER FREQUENCY Hz	ACCESS TEE HEIGHT mm
3	22.2	997.74	1059.677	145.8	215.67	97.3
				227.3	249.97	
				262.2	262.48	
				374.6	277.11	
				516.8	281.61	
				659.0	276.69	
				806.3	259.63	
				887.8	225.49	
4	22.3	997.71	1058.800	145.8	206.15	97.3
				227.3	250.10	
				262.2	256.46	
				374.6	275.82	
				516.8	279.62	
				659.0	278.43	
				806.3	246.91	
				887.8	217.28	

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NLA

ESKOM

TECHNOLOGY RESEARCH AND INVESTIGATIONS
LIQUID FLOW METROLOGY LABORATORY

NATIONAL LABORATORY ACCREDITATION SERVICE
LABORATORY No 901

CERTIFICATE OF CALIBRATION

Date of issue 27 November 1997

Certificate number 97TL123A

Head of Laboratory [signature]

The accuracy of all measurements is traceable to the national measuring standards.

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care executed in handling and use of the device, and the frequency of use. Recalibration should be performed after the period so chosen to ensure that the instrument's accuracy remains within the desired limits.

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NLA

ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TL123A

ITEM DESCRIPTION

Calibration of a	600 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Calibration date :	27 November 1997		
Calibrated for :	Stewart Scott SA (Pty) Ltd		
Calibration range :	1200.00 l/s (4320 m3/h)		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836 542
Converter Type :	REMOTE		

REFERENCE EQUIPMENT AND TRACEABILITY

Reference flow :	200 T Gravimetric system	
Temperature :	Pt 100 SENSORS	T256, 253 & 249
Analog outputs :	FLUKE LOGGER S/NO 4260001, FLUKE DMM S/NO 5465069	
Impulse Counter :	HP 5327A TIMER/COUNTER S/NO 1248A00376	
Frequency & Time :	HP 5328A TIMER/COUNTER S/NO 1804A05857	

PIPEWORK AND ENVIRONMENT

Upstream straight pipe L/D :	22.8 D	Nominal ID:	597.8 mm
Downstream straight pipe L/D :	7.6 D	Nominal ID:	597.8 mm
The control room temperature was	20.9 °C	+/- 3 °C	
The test area temperature was	15.2 °C	+/- 5 °C	

LABORATORY PROCEDURE

The calibration was performed according to procedure No 901-1001-01

RE-CALIBRATION

Recommende re-calibration interval : 12 Months from date of calibration.

UNCERTAINTY OF MEASUREMENT

The uncertainty of measurement is +/- 0.2 % of indication
(estimated for a 95% confidence level).

CALIBRATED BY : **G G CHOABI**

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C.7

ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TL123A

ITEM DESCRIPTION

Calibration of a	600 mm	FLOW TRAVERSE WITH A TURBINE PROBE	
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836 542
Converter Type :	REMOTE		

RESULTS **TABLE 1**

RUN NO.	WATER TEMP AVE. °C	WATER DENSITY kg/m3	REFERENCE FLOW l/s	METER DEPTH mm	METER FREQUENCY Hz	ACCESS TEE HEIGHT mm
1	21.4	997.90	150.417	123.4	47.00	81.2
				184.8	58.84	
				211.2	61.95	
				295.9	67.98	
				403.1	68.39	
				510.3	67.17	
				621.4	55.60	
				625.0	56.02	
2	21.4	997.90	669.703	123.4	226.96	81.2
				184.8	294.09	
				211.2	288.79	
				295.9	316.76	
				403.1	309.92	
				510.3	299.89	
				621.4	275.88	
				625.0	275.76	
3	21.5	997.88	1078.514	123.4	369.35	81.2
				184.8	459.01	
				211.2	474.84	
				295.9	495.48	
				403.1	507.52	
				510.3	517.63	
				621.4	470.72	
				625.0	459.48	

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NLA

ESKOM

TECHNOLOGY RESEARCH AND INVESTIGATIONS
LIQUID FLOW METROLOGY LABORATORY

NATIONAL LABORATORY ACCREDITATION SERVICE
LABORATORY No 901

CERTIFICATE OF CALIBRATION

Date of issue 18 November 1997

Certificate number 97TL129

Head of Laboratory [signature]

The accuracy of all measurements is traceable to the national measuring standards.

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care executed in handling and use of the device, and the frequency of use. Recalibration should be performed after the period so chosen to ensure that the instrument's accuracy remains within the desired limits.

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NLA

C.9

ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TL129

ITEM DESCRIPTION

Calibration of a	500 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Calibration date :	18 November 1997		
Calibrated for :	Stewart Scott SA (Pty) Ltd		
Calibration range :	833.33 l/s (3000 m3/h)		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

REFERENCE EQUIPMENT AND TRACEABILITY

Reference flow :	200 T Gravimetric system	
Temperature :	Pt 100 SENSORS	T256, T253 & T249
Analog outputs :	FLUKE LOGGER S/NO 4260001, FLUKE DMM S/NO 5465069	
Impulse Counter :	HP 5327A TIMER/COUNTER S/NO 1248A00376	
Frequency & Time :	HP 5328A TIMER/COUNTER S/NO 1804A05857	

PIPEWORK AND ENVIRONMENT

Upstream straight pipe L/D :	27.4 D	Nominal ID:	493.5 mm
Downstream straight pipe L/D :	9.1 D	Nominal ID:	493.5 mm
The control room temperature was	22.1 °C	+/- 3 °C	
The test area temperature was	20.8 °C	+/- 5 °C	

LABORATORY PROCEDURE

The calibration was performed according to procedure No 901-1001-01

UNCERTAINTY OF MEASUREMENT

The uncertainty of measurement is +/- 0.2 % of indication
(estimated for a 95% confidence level).

CALIBRATED BY : G G CHOABI

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CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TL129

ITEM DESCRIPTION

Calibration of a	500 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

RESULTS **TABLE 1**

RUN NO.	WATER TEMP AVE. °C	WATER DENSITY kg/m3	REFERENCE FLOW AVE. l/s	METER DEPTH mm	METER FREQUENCY Hz	ACCESS TEE HEIGHT mm
1	22.3	997.70	99.302	170.1	57.32	80.7
				191.8	60.54	
				261.6	68.98	
				349.9	69.53	
				438.1	68.98	
				529.6	59.83	
2	22.3	997.70	411.006	170.1	250.49	80.7
				191.8	261.57	
				261.6	293.06	
				349.9	273.73	
				438.1	278.13	
				529.6	253.12	
3	22.6	997.63	815.783	170.1	428.02	80.7
				191.8	446.47	
				261.6	474.66	
				349.9	564.54	
				438.1	547.72	
				529.6	503.08	

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ESKOM

TECHNOLOGY RESEARCH AND INVESTIGATIONS
LIQUID FLOW METROLOGY LABORATORY

NATIONAL LABORATORY ACCREDITATION SERVICE
LABORATORY No 901

CERTIFICATE OF CALIBRATION

Date of issue 19 November 1997

Certificate number 97TC130

Head of Laboratory

The accuracy of all measurements is traceable to the national measuring standards.

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care executed in handling and use of the device, and the frequency of use. Recalibration should be performed after the period so chosen to ensure that the instrument's accuracy remains within the desired limits.

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C.12

NLA

ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TC130

ITEM DESCRIPTION

Calibration of a	400 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Calibration date :	19 November 1997		
Calibrated for :	Stewart Scott SA (Pty) Ltd		
Calibration range :	500.000 l/s (1800 m3/h)		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

REFERENCE EQUIPMENT

Reference flow :	Comparison system (Frequency)	
Temperature :	Pt 100 SENSORS	T256, T253 & T249
Analog outputs :	FLUKE LOGGER S/NO 4260001, FLUKE DMM S/NO 5465069	
Impulse Counter :	HP 5327A TIMER/COUNTER S/NO 1248A00376	
Frequency & Time :	HP 5328A TIMER/COUNTER S/NO 1804A05857	

PIPEWORK AND ENVIRONMENT

Upstream straight pipe L/D :	17.7 D	Nominal ID:	396.0 mm
Downstream straight pipe L/D :	15.1 D	Nominal ID:	396.0 mm
The control room temperature was	21.3 °C	+/- 3 °C	
The test area temperature was	18.8 °C	+/- 5 °C	

LABORATORY PROCEDURE

The calibration was performed according to procedure No 901-1001-01

RE-CALIBRATION

Recommende re-calibration interval : 12 Months from date of calibration.

UNCERTAINTY OF MEASUREMENT

The uncertainty of measurement is +/- 0.6 % of indication
(estimated for a 95% confidence level).

CALIBRATED BY : G G CHOABI

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ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TC130

ITEM DESCRIPTION

Calibration of a 400 mm FLOW TRAVERSE WITH A TURBINE PROBE
Meter Make : BESTOBELL MOBREY Serial No : 31901/96
Meter Type/Model : R1B Output : PULSES
Converter Make : BESTOBELL MOBREY Serial No : 836542
Converter Type : REMOTE

RESULTS

TABLE 1

RUN NO.	WATER TEMP AVE. °C	WATER DENSITY kg/m3	REFERENCE FLOW AVE. l/s	METER DEPTH mm	METER FREQUENCY Hz	ACCESS TEE HEIGHT mm
1	22.3	997.71	55.338	154.3	48.66	77.9
				171.8	52.15	
				227.9	58.19	
				298.9	60.67	
				369.9	55.15	
				443.5	49.21	
2	22.3	997.70	277.309	154.3	269.13	77.9
				171.8	283.54	
				227.9	302.87	
				298.9	300.05	
				369.9	279.98	
				443.5	259.74	
3	22.3	997.70	498.442	154.3	478.72	77.9
				171.8	491.58	
				227.9	519.42	
				298.9	514.57	
				369.9	498.67	
				443.5	460.81	

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TECHNOLOGY RESEARCH AND INVESTIGATIONS
LIQUID FLOW METROLOGY LABORATORY

NATIONAL LABORATORY ACCREDITATION SERVICE
LABORATORY No 901

CERTIFICATE OF CALIBRATION

Date of issue 17 November 1997

Certificate number 97TC128

Head of Laboratory

The accuracy of all measurements is traceable to the national measuring standards.

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care executed in handling and use of the device, and the frequency of use. Recalibration should be performed after the period so chosen to ensure that the instrument's accuracy remains within the desired limits.

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CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TC128

ITEM DESCRIPTION

Calibration of a	300 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Calibration date :	17 November 1997		
Calibrated for :	Stewart Scott SA (Pty) Ltd		
Calibration range :	333.333 l/s (1200 m3/h)		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

REFERENCE EQUIPMENT

Reference flow :	Comparison system (Frequency)	
Temperature :	Pt 100 SENSORS	T256, T253 & T249
Analog outputs :	FLUKE LOGGER S/NO 4260001, FLUKE DMM S/NO 5465069	
Impulse Counter :	HP 5327A TIMER/COUNTER S/NO 1248A00376	
Frequency & Time :	HP 5328A TIMER/COUNTER S/NO 1804A05857	

PIPEWORK AND ENVIRONMENT

Upstream straight pipe L/D :	23.4 D	Nominal ID:	306.1 mm
Downstream straight pipe L/D :	11.4 D	Nominal ID:	306.1 mm
The control room temperature was	21.1 °C	+/- 3 °C	
The test area temperature was	16.9 °C	+/- 5 °C	

LABORATORY PROCEDURE

The calibration was performed according to procedure No 901-1001-01

UNCERTAINTY OF MEASUREMENT

The uncertainty of measurement is +/- 0.6 % of indication
(estimated for a 95% confidence level).

CALIBRATED BY : **G G CHOABI**

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ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TC128

ITEM DESCRIPTION

Calibration of a	300 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Meter Make :	BESTOBELL MOBREY	Serial No :	31901/96
Meter Type/Model :	R1B	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

RESULTS

TABLE 1

RUN NO.	WATER TEMP AVE. °C	WATER DENSITY kg/m3	REFERENCE FLOW AVE. l/s	METER DEPTH mm	METER FREQUENCY Hz	ACCESS TEE HEIGHT mm
1	22.5	997.66	332.284	144.9	510.49	80.6
				158.4	533.66	
				201.8	610.51	
				256.6	631.65	
				311.5	603.64	
				368.4	540.38	
2	22.5	997.66	165.488	144.9	264.07	80.6
				158.4	283.10	
				201.8	310.08	
				256.6	318.66	
				311.5	312.87	
				368.4	268.96	
3	22.6	997.63	30.094	144.9	45.50	80.6
				158.4	47.18	
				201.8	52.46	
				256.6	53.83	
				311.5	54.86	
				368.4	53.19	

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TECHNOLOGY RESEARCH AND INVESTIGATIONS
LIQUID FLOW METROLOGY LABORATORY

NATIONAL LABORATORY ACCREDITATION SERVICE
LABORATORY No 901

CERTIFICATE OF CALIBRATION

Date of issue 11 November 1997

Certificate number 97TC126

Head of Laboratory

The accuracy of all measurements is traceable to the national measuring standards.

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care executed in handling and use of the device, and the frequency of use. Recalibration should be performed after the period so chosen to ensure that the instrument's accuracy remains within the desired limits.

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C.18

ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TC126

ITEM DESCRIPTION

Calibration of a	250 mm FLOW TRAVERSE WITH A TURBINE PROBE		
Calibration date :	11 November 1997		
Calibrated for :	Stewart Scott SA (Pty) Ltd		
Calibration range :	222.222 l/s (800 m3/h)		
Meter Make :	BESTOBELL MOBREY	Serial No :	30193/90
Meter Type/Model :	836542	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

REFERENCE EQUIPMENT

Reference flow :	Comparison system (Frequency)	
Temperature :	Pt 100 SENSORS	T256, 253 & 249
Analog outputs :	FLUKE LOGGER S/NO 4260001, FLUKE DMM S/NO 5465069	
Impulse Counter :	HP 5327A TIMER/COUNTER S/NO 1248A00376	
Frequency & Time :	HP 5328A TIMER/COUNTER S/NO 1804A05857	

PIPEWORK AND ENVIRONMENT

Upstream straight pipe L/D :	29.9 D	Nominal ID:	257.8 mm
Downstream straight pipe L/D :	18.5 D	Nominal ID:	257.8 mm
The control room temperature was	23.5 °C	+/- 3 °C	
The test area temperature was	18.1 °C	+/- 5 °C	

LABORATORY PROCEDURE

The calibration was performed according to procedure No 901-1001-01

UNCERTAINTY OF MEASUREMENT

The uncertainty of measurement is +/- 0.6 % of indication
(estimated for a 95% confidence level).

CALIBRATED BY : G G CHOABI

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ESKOM

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 97TC126

ITEM DESCRIPTION

Calibration of a	250 mm	FLOW TRAVERSE WITH A TURBINE PROBE	
Meter Make :	BESTOBELL MOBREY	Serial No :	30193/90
Meter Type/Model :	836542	Output :	PULSES
Converter Make :	BESTOBELL MOBREY	Serial No :	836542
Converter Type :	REMOTE		

RESULTS

TABLE 1

RUN NO.	WATER TEMP AVE. °C	WATER DENSITY kg/m3	REFERENCE FLOW AVE. l/s	METER DEPTH mm	METER FREQUENCY Hz	ACCESS TEE HEIGHT mm
1	22.4	997.68	221.725	142.6	490.72	84.8
				153.9	515.32	
				190.5	570.28	
				236.7	598.87	
				282.9	572.97	
				330.8	507.55	
2	22.4	997.68	111.188	142.6	236.77	84.8
				153.9	246.94	
				190.5	281.62	
				236.7	299.25	
				282.9	280.71	
				330.8	248.37	
3	22.4	997.68	46.487	142.6	80.03	84.8
				153.9	81.33	
				190.5	100.45	
				236.7	104.04	
				282.9	103.14	
				330.8	91.38	

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APPENDIX D

Research Results

Reference Flow(m^3/s)	Reference Mean Vel(m/s)	Pipe Dia (mm)	Depth of Meter(mm)	Distance from Top pipe Wall	Measured Frequency(Hz)	Blockage Factor	Velocity Factor	Adjusted Frequency(Hz)	Turbine Meter K Factor	Point Velocity	Position of Mean Vel.	Constant A	Constant B	Position of MeanVel:Dia	Ratio of Pt Vel:Mean	Ratio of Pt Vel:Max
0.16742	0.3390	793	145.8	25.46	32.15	0.2207	1.0022	32.0790		0.2924					0.8627	0.7873
			227.3	106.98	38.64	0.6306	1.0063	38.3963		0.3500	91.33		0.1503	0.1152	1.0326	0.9423
			262.2	141.95	39.71	0.8076	1.0081	39.3893		0.3591					1.0593	0.9667
			374.6	254.32	43.03	1.3764	1.0140	42.4377		0.3869					1.1413	1.0415
			516.8	396.50	41.62	2.0961	1.0214	40.7476		0.3715					1.0958	1.0000
			659.0	538.68	42.43	2.8158	1.0290	41.2353		0.3759					1.1090	1.0120
			806.3	686.02	39.34	3.5616	1.0369	37.9389		0.3459	98.09		0.1580	0.1237	1.0203	0.9311
			887.8	767.54	32.30	3.9742	1.0414	31.0163		0.2828					0.8341	0.7612
									109.6943	0.3390		1.0958				
0.229862	0.4654		145.8	25.46	45.24	0.2207	1.0022	45.1401		0.3994					0.8582	0.7748
			227.3	106.98	54.84	0.6306	1.0063	54.4942		0.4822	90.47		0.1678	0.1141	1.0360	0.9353
			262.2	141.95	55.13	0.8076	1.0081	54.6848		0.4839					1.0396	0.9386
			374.6	254.32	59.62	1.3764	1.0140	58.7994		0.5203					1.1179	1.0092
			516.8	396.50	59.51	2.0961	1.0214	58.2626		0.5155					1.1077	1.0000
			659.0	538.68	59.15	2.8158	1.0290	57.4845		0.5086					1.0929	0.9866
			806.3	686.02	55.19	3.5616	1.0369	53.2244		0.4709	99.45		0.1792	0.1254	1.0119	0.9135
			887.8	767.54	48.38	3.9742	1.0414	46.4573		0.4111					0.8832	0.7974
									113.0198	0.4654		1.1077				
1.059677	2.1455		145.8	25.46	215.67	0.2207	1.0022	215.1939		1.8811					0.8767	0.7805
			227.3	106.98	249.97	0.6306	1.0063	248.3938		2.1713	99.75		0.2057	0.1258	1.0120	0.9009
			262.2	141.95	262.48	0.8076	1.0081	260.3602		2.2759					1.0608	0.9443
			374.6	254.32	277.11	1.3764	1.0140	273.2959		2.3890					1.1135	0.9913
			516.8	396.50	281.61	2.0961	1.0214	275.7072		2.4100					1.1233	1.0000
			659.0	538.68	276.69	2.8158	1.0290	268.8990		2.3505					1.0955	0.9753
			806.3	686.02	259.63	3.5616	1.0369	250.3830		2.1887	95.09		0.1988	0.1199	1.0201	0.9081
			887.8	767.54	225.49	3.9742	1.0414	216.5285		1.8927					0.8822	0.7854
									114.3995	2.1455		1.1233				
1.0588	2.1438		145.8	25.46	206.15	0.2207	1.0022	205.6949		1.8328					0.8549	0.7514
			227.3	106.98	250.10	0.6306	1.0063	248.5229		2.2144	91.89		0.2171	0.1159	1.0329	0.9078
			262.2	141.95	25646	0.8076	1.0081	25438.8848		226.6639					105.7316	92.9244
			374.6	254.32	275.82	1.3764	1.0140	272.0237		2.4238					1.1306	0.9937
			516.8	396.50	279.62	2.0961	1.0214	273.7589		2.4392					1.1378	1.0000
			659.0	538.68	278.43	2.8158	1.0290	270.5900		2.4110					1.1247	0.9884
			806.3	686.02	246.91	3.5616	1.0369	238.1161		2.1216	116.23		0.2586	0.1466	0.9897	0.8698
			887.8	767.54	217.28	3.9742	1.0414	208.6448		1.8591					0.8672	0.7621
									112.2317	2.1438		1.1378				
								MEAN FACTOR :	113.2170		TOP PROF.	1.1161	0.1852	0.1177	0.8631	0.8183
								STD DEVIATION :	1.0972	3.182449	TOP PROF.	0.0183	0.0314	0.0054	0.0096	0.0097
								NUMBER OF VAL:	3			4	4	4		
											BOT PROF.		0.1987	0.1289	0.8667	0.7765
											BOT PROF.		0.0433	0.0120	0.0229	0.0178

APPENDIX D1

Referenc Flow(m^3	Referenc Mean Vel(	Pipe Dia (mm)	Depth of Meter(mm	Distance f Top pipe	Measured Frequenc	Blockage Factor	Velocity Factor	Turbine M K Factor	Point Velocity	% Error of Measured Q
0.16742	0.3390	793	145.8	25.46	32.15	0.2207	1.0022		0.2833	
			227.3	106.98	38.64	0.6306	1.0063		0.3391	
			262.2	141.95	39.71	0.8076	1.0081		0.3479	
			374.6	254.32	43.03	1.3764	1.0140		0.3748	
			516.8	396.50	41.62	2.0961	1.0214		0.3599	
			659.0	538.68	42.43	2.8158	1.0290		0.3642	
			806.3	686.02	39.34	3.5616	1.0369		0.3351	
			887.8	767.54	32.30	3.9742	1.0414		0.2740	
								113.2170	0.3284	-3.1114
0.229862	0.4654		145.8	25.46	45.24	0.2207	1.0022		0.3987	
			227.3	106.98	54.84	0.6306	1.0063		0.4813	
			262.2	141.95	55.13	0.8076	1.0081		0.4830	
			374.6	254.32	59.62	1.3764	1.0140		0.5194	
			516.8	396.50	59.51	2.0961	1.0214		0.5146	
			659.0	538.68	59.15	2.8158	1.0290		0.5077	
			806.3	686.02	55.19	3.5616	1.0369		0.4701	
			887.8	767.54	48.38	3.9742	1.0414		0.4103	
									0.4646	-0.1742
1.059677	2.1455		145.8	25.46	215.67	0.2207	1.0022		1.9007	
			227.3	106.98	249.97	0.6306	1.0063		2.1940	
			262.2	141.95	262.48	0.8076	1.0081		2.2997	
			374.6	254.32	277.11	1.3764	1.0140		2.4139	
			516.8	396.50	281.61	2.0961	1.0214		2.4352	
			659.0	538.68	276.69	2.8158	1.0290		2.3751	
			806.3	686.02	259.63	3.5616	1.0369		2.2115	
			887.8	767.54	225.49	3.9742	1.0414		1.9125	
									2.1680	1.0444
1.0588	2.1438		145.8	25.46	206.15	0.2207	1.0022		1.8168	
			227.3	106.98	250.10	0.6306	1.0063		2.1951	
			262.2	141.95	256.46	0.8076	1.0081		2.2469	
			374.6	254.32	275.82	1.3764	1.0140		2.4027	
			516.8	396.50	279.82	2.0961	1.0214		2.4180	
			659.0	538.68	278.43	2.8158	1.0290		2.3900	
			806.3	686.02	246.91	3.5616	1.0369		2.1032	
			887.8	767.54	217.28	3.9742	1.0414		1.8429	
									2.1251	-0.8703
								MEAN		-0.7779
								STDEV		1.7454

APPENDIX D2

Reference Flow(m^3/s)	Reference Mean Vel(m/s)	Pipe Dia (mm)	Depth of Meter(mm)	Distance from Top pipe Wall	Measured Frequency(Hz)	Blockage Factor	Velocity Factor	Turbine Meter K Factor	Point Velocity	Calculated Velocity	Position of Mean Vel.	Constant A	Constant B	Calculated Velocity(m/s)	% Error of Measured Q
0.150417	0.5359	597.8	123.4	19.19	47.00	0.3382	1.0034	113.2170	0.4137	0.4137					
			184.8	80.64	58.84	0.8751	1.0088		0.5152		72.74		0.2755		
			211.2	107.01	61.95	1.1099	1.0112		0.5411						
			295.9	191.71	67.98	1.8644	1.0190		0.5892						
			403.1	298.90	68.39	2.8191	1.0290		0.5870						
			510.3	406.09	67.17	3.7738	1.0392		0.5709						
			621.4	517.16	55.60	4.7632	1.0500		0.4677		117.69		0.4178		
			625.0	520.74	56.02	4.7951	1.0504		0.4711	0.4560		1.1691		0.4560	
								MeanVelocity	1st Approx.=	0.5021				0.5021	
								Calc.Flow(m3/s)	1st Approx.=	0.1409					-6.305
0.669703	2.3861		123.4	19.19	226.96	0.3382	1.0034		1.9979						
			184.8	80.64	294.09	0.8751	1.0088		2.5748		59.43		0.1707		
			211.2	107.01	288.79	1.1099	1.0112		2.5225						
			295.9	191.71	316.76	1.8644	1.0190		2.7457						
			403.1	298.90	309.92	2.8191	1.0290		2.6602						
			510.3	406.09	299.89	3.7738	1.0392		2.5488						
			621.4	517.16	275.88	4.7632	1.0500		2.3207		107.44		0.2695		
			625.0	520.74	275.76	4.7951	1.0504		2.3189	2.0665				2.0665	
								MeanVelocity	1st Approx.=	2.3757		1.1198		2.3757	
								Calc.Flow(m3/s)	1st Approx.=	0.6668					-0.435
1.078514	3.8426		123.4	19.19	369.35	0.3382	1.0034		3.2513						
			184.8	80.64	459.01	0.8751	1.0088		4.0188		69.90		0.1924		
			211.2	107.01	474.84	1.1099	1.0112		4.1475						
			295.9	191.71	495.48	1.8644	1.0190		4.2948						
			403.1	298.90	507.52	2.8191	1.0290		4.3563						
			510.3	406.09	517.63	3.7738	1.0392		4.3995						
			621.4	517.16	470.72	4.7632	1.0500		3.9596		77.84		0.2078		
			625.0	520.74	459.48	4.7951	1.0504		3.8638	3.3840		1.1214		3.3938	
								MeanVelocity	1st Approx.=	3.8847			2nd Approx.	3.8863	
								Calc.Flow(m3/s)	1st Approx.=	1.0903			2nd Approx.	1.0908	1.137
													OVERALL	MEAN error	-1.868
													STDEV		3.923

APPENDIX D3

Reference Flow(m^3/s)	Reference Mean Vel(m/s)	Pipe Dia (mm)	Depth of Meter(mm)	Distance from Top pipe Wall	Measured Frequency(Hz)	Blockage Factor	Velocity Factor	Turbine Meter K Factor	Point Velocity	Calculated Velocity	Position of Mean Vel.	Constant A	Constant B	Calculated Velocity(m/s)	% Error of Measured Q
0.099302	0.5217	492.3	0	15.80	0.0	0.4587	1.0046	113.2170	0.0000	0.4851				0.4851	
			170.1	66.41	57.32	1.1034	1.0112		0.5007		128.96		0.4996		
			191.8	88.12	60.54	1.3885	1.0141		0.5273						
			261.6	157.88	68.89	2.3047	1.0236		0.5945						
			349.9	246.15	69.53	3.4640	1.0359		0.5929						
			438.1	334.42	68.98	4.6234	1.0485		0.5811						
			529.6	425.89	59.83	5.8247	1.0618		0.4977		90.82		0.3239		
			0.0	476.50	0.0	6.4894	1.0694		0.0000	0.4605		1.1403		0.4605	
								MeanVelocity	**1st Approx =**	0.5199				0.5199	
								Calc.Flow(m3/s)	**1st Approx =**	0.0990				0.0990	-0.336
0.411006	2.1592		0	15.80	0.0	0.4587	1.0046		0.0000	1.9099				1.9099	
			170.1	66.41	250.49	1.1034	1.0112		2.1881		59.13		0.1398		
			191.8	88.12	261.57	1.3885	1.0141		2.2783						
			261.6	157.88	293.06	2.3047	1.0236		2.5288						
			349.9	246.15	273.73	3.4640	1.0359		2.3340						
			438.1	334.42	278.13	4.6234	1.0485		2.3430						
			529.6	425.89	253.12	5.8247	1.0618		2.1055		82.81		0.1829		
			0.0	476.50	0	6.4894	1.0694		0.0000	1.8130		1.0866		1.8130	
								MeanVelocity	**1st Approx =**	2.1481				2.1481	
								Calc.Flow(m3/s)	**1st Approx =**	0.4089				0.4089	-0.517
0.815783	4.2857		0	15.80	0	0.4587	1.0046		0.0000	3.9390				3.9390	
			170.1	66.41	428.02	1.1034	1.0112		3.7388		44.36		0.2526		
			191.8	88.12	446.47	1.3885	1.0141		3.8887						
			261.6	157.88	474.66	2.3047	1.0236		4.0959						
			349.9	246.15	564.54	3.4640	1.0359		4.8136						
			438.1	334.42	547.72	4.6234	1.0485		4.6141						
			529.6	425.89	503.08	5.8247	1.0618		4.1847		64.81		0.3243		
			0.0	476.50	0	6.4894	1.0694		0.0000	3.7392		1.1880		3.7392	
								MeanVelocity	**1st Approx =**	4.0519			**2nd Approx =**	4.0519	
								Calc.Flow(m3/s)	**1st Approx =**	0.7713			**2nd Approx =**	0.7713	-5.455
													OVERALL	MEAN error	-2.103
													STDEV		2.905

APPENDIX D4

Reference Flow(m^3/s)	Reference Mean Vel(m/s)	Pipe Dia (mm)	Depth of Meter(mm)	Distance from Top pipe Wall	Measured Frequency(Hz)	Blockage Factor	Velocity Factor	Turbine Meter K Factor	Point Velocity	Calculated Velocity	Position of Mean Vel.	Constant A	Constant B	Calculated Velocity(m/s)	% Error of Measured Q
0.055338	0.4493	396	0	12.71	0.00	0.6524	1.0066	113.2170	0.0000	0.4193				0.4193	
			154.3	53.42	48.66	1.4416	1.0146		0.4236		149.37		1.4858		
			171.8	70.88	52.15	1.7961	1.0183		0.4523						
			227.9	127.00	58.19	2.9351	1.0302		0.4989						
			298.9	198.00	60.67	4.3763	1.0458		0.5125						
			369.9	269.00	55.15	5.8176	1.0618		0.4588						
			443.5	342.58	49.21	7.3110	1.0789		0.4029		93.85		0.5609		
			0.0	383.29	0.00	8.1374	1.0886		0.0000	0.3981		1.1819		0.3981	
								MeanVelocity	1st Approx =	0.4336				0.4336	
								Calc.Flow(m3/s)	1st Approx =	0.0534				0.0534	-3.496
0.277309	2.2516		0	12.71	0.00	0.6524	1.0066		0.0000	2.0738				2.0738	
			154.3	53.42	269.13	1.4416	1.0146		2.3428		37.80		0.1830		
			171.8	70.88	283.54	1.7961	1.0183		2.4594						
			227.9	127.00	302.87	2.9351	1.0302		2.5966						
			298.9	198.00	300.05	4.3763	1.0458		2.5342						
			369.9	269.00	279.98	5.8176	1.0618		2.3291						
			443.5	342.58	259.74	7.3110	1.0789		2.1264		94.49		0.4096		
			0.0	383.29	0.00	8.1374	1.0886		0.0000	1.9686		1.1316		1.9686	
								MeanVelocity	1st Approx =	2.2396				2.2396	
								Calc.Flow(m3/s)	1st Approx =	0.2758				0.2758	-0.533
0.498442	4.0470		0	12.71	0.00	0.6524	1.0066		0.0000	3.5564				3.5564	
			154.3	53.42	478.72	1.4416	1.0146		4.1674		36.42		0.1508		
			171.8	70.88	491.58	1.7961	1.0183		4.2640						
			227.9	127.00	519.42	2.9351	1.0302		4.4531						
			298.9	198.00	514.57	4.3763	1.0458		4.3460						
			369.9	269.00	498.67	5.8176	1.0618		4.1483						
			443.5	342.58	460.81	7.3110	1.0789		3.7726		80.78		0.2847		
			0.0	383.29	0.00	8.1374	1.0886		0.0000	3.3760		1.1109		3.3760	
								MeanVelocity	1st Approx =	3.9123			2nd Approx =	3.9123	
								Calc.Flow(m3/s)	1st Approx =	0.4819			2nd Approx =	0.4819	-3.329
													OVERALL	MEAN error	-2.453
													STDEV		1.664

APPENDIX D5

Reference Flow(m^3/s)	Reference Mean Vel(m/s)	Pipe Dia (mm)	Depth of Meter(mm)	Distance from Top pipe Wall	Measured Frequency(Hz)	Blockage Factor	Velocity Factor	Turbine Meter K Factor	Point Velocity	Calculated Velocity	Position of Mean Vel.	Constant A	Constant B	Calculated Velocity(m/s)	% Error of Measured Q
0.030094	0.4091	306.06	0	9.82	0.00	1.0039	1.0101	113.2170	0.0000	0.3665				0.3665	
			144.9	41.29	45.50	2.0011	1.0204		0.3938		53.36		0.2359		
			158.4	54.78	47.18	2.4597	1.0252		0.4065						
			201.8	98.15	52.46	3.9334	1.0409		0.4451						
			256.6	153.03	53.83	5.7982	1.0616		0.4479						
			311.5	207.91	54.86	7.6630	1.0830		0.4475						
			368.4	264.77	53.19	9.5953	1.1061		0.4248		26.13		0.1406		
			0.0	296.24	0.00	10.6645	1.1194		0.0000	0.3479		1.1080		0.3479	
								MeanVelocity	**1st Approx.=**	0.4043				0.4043	
								Calc.Flow(m3/s)	**1st Approx.=**	0.0297				0.0297	-1.168
0.165488	2.2494		0	9.82	0.00	1.0039	1.0101		0.0000	2.1696				1.9539	
			144.9	41.29	264.07	2.0011	1.0204		2.2857		47.21		0.2918		
			158.4	54.78	283.10	2.4597	1.0252		2.4390						
			201.8	98.15	310.08	3.9334	1.0409		2.6311						
			256.6	153.03	318.66	5.7982	1.0616		2.6514						
			311.5	207.91	312.87	7.6630	1.0830		2.5517						
			368.4	264.77	268.96	9.5953	1.1061		2.1476		63.79		0.3921		
			0.0	296.24	0.00	10.6645	1.1194		0.0000	2.0596		1.1490		1.6620	
								MeanVelocity	**1st Approx.=**	2.3076				2.2053	
								Calc.Flow(m3/s)	**1st Approx.=**	0.1698				0.1622	-1.959
0.332284	4.5165		0	9.82	0.00	1.0039	1.0101		0.0000	4.3007				3.4851	
			144.9	41.29	510.49	2.0011	1.0204		4.4188		50.19		0.3273		
			158.4	54.78	533.66	2.4597	1.0252		4.5977						
			201.8	98.15	610.51	3.9334	1.0409		5.1803						
			256.6	153.03	631.65	5.7982	1.0616		5.2556						
			311.5	207.91	603.64	7.6630	1.0830		4.9232						
			368.4	264.77	540.38	9.5953	1.1061		4.3150		62.02		0.4040		
			0.0	296.24	0.00	10.6645	1.1194		0.0000	4.0826		1.1585		3.0700	
								MeanVelocity	**1st Approx.=**	4.5367			**2nd Approx =**	4.2321	
								Calc.Flow(m3/s)	**1st Approx.=**	0.3338			**2nd Approx =**	0.3114	0.447
													OVERALL	MEAN error	-0.893
													STDEV		1.226

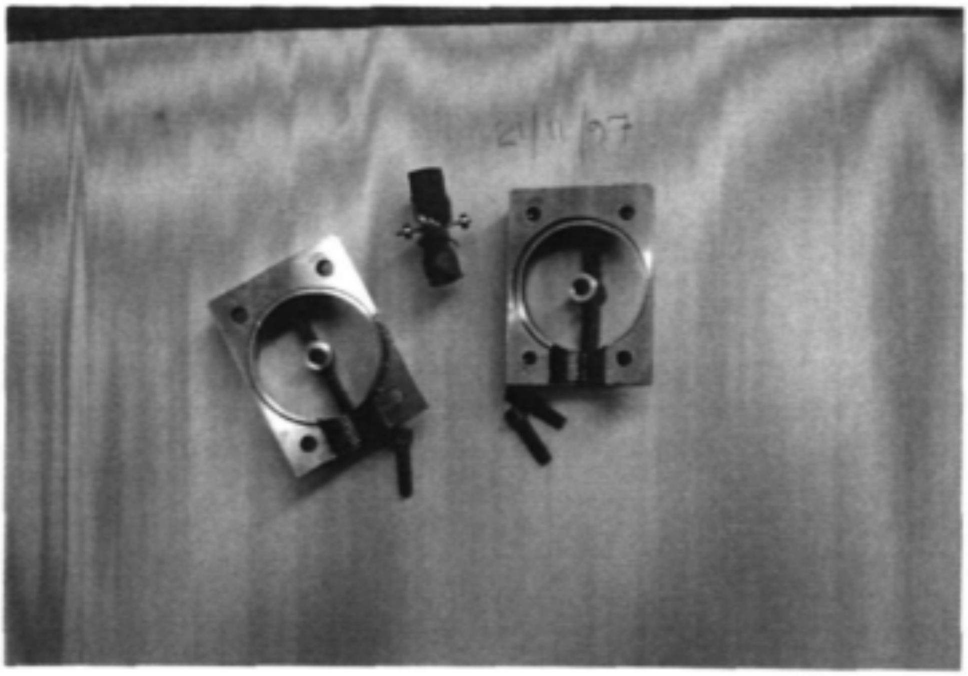
APPENDIX D6

Reference Flow(m^3/s)	Reference Mean Vel(m/s)	Pipe Dia (mm)	Depth of Meter(mm)	Distance from Top pipe Wall	Measured Frequency(Hz)	Blockage Factor	Velocity Factor	Turbine Meter K Factor	Point Velocity	Calculated Velocity	Position of Mean Vel.	Constant A	Constant B	Calculated Velocity(m/s)	% Error of Measured Q
0.046487	0.8906	257.8	0	8.28	0.00	1.3481	1.0137	112.3938	0.0000	0.7043				0.7043	
			142.6	34.78	80.03	2.5086	1.0257		0.6942		-98.15		#NUM!		
			153.9	46.15	81.33	3.0531	1.0315		0.7015						
			190.5	82.68	100.45	4.8027	1.0504		0.8508						
			236.7	128.90	104.04	7.0165	1.0755		0.8607						
			282.9	175.12	103.14	9.2304	1.1017		0.8329						
			330.8	223.02	91.38	11.5245	1.1303		0.7194		59.01		0.4575		
			0.0	249.52	0.00	12.7938	1.1467		0.0000	0.6686		1.1553		0.6686	
								MeanVelocity	**1st Approx =**	0.7450				0.7450	
								Calc.Flow(m3/s)	**1st Approx =**	0.0389				0.0389	-16.344
0.111188	2.1301		0	8.28	0.00	1.3481	1.0137		0.0000	2.0258				2.0258	
			142.6	34.78	236.77	2.5086	1.0257		2.0538		80.22		0.8638		
			153.9	46.15	246.94	3.0531	1.0315		2.1300						
			190.5	82.68	281.62	4.8027	1.0504		2.3853						
			236.7	128.90	299.25	7.0165	1.0755		2.4757						
			282.9	175.12	280.71	9.2304	1.1017		2.2670						
			330.8	223.02	248.37	11.5245	1.1303		1.9552		57.29		0.5052		
			0.0	249.52	0.00	12.7938	1.1467		0.0000	1.9231		1.1779		1.9231	
								MeanVelocity	**1st Approx =**	2.1017			**2nd Approx =**	2.1017	
								Calc.Flow(m3/s)	**1st Approx =**	0.1097			**2nd Approx =**	0.1097	-1.333
0.221725	4.2478		0	8.28	0.00	1.3481	1.0137		0.0000	4.0543				4.0543	
			142.6	34.78	490.72	2.5086	1.0257		4.2566		35.51		0.2869		
			153.9	46.15	515.32	3.0531	1.0315		4.4450						
			190.5	82.68	570.28	4.8027	1.0504		4.8303						
			236.7	128.90	598.87	7.0165	1.0755		4.9545						
			282.9	175.12	572.97	9.2304	1.1017		4.6273						
			330.8	223.02	507.55	11.5245	1.1303		3.9954		55.50		0.4390		
			0.0	249.52	0.00	12.7938	1.1467		0.0000	3.8486		1.1606		3.8486	
								MeanVelocity	**1st Approx =**	4.2687			**2nd Approx =**	4.2687	
								Calc.Flow(m3/s)	**1st Approx =**	0.2228			**2nd Approx =**	0.2228	0.494
													OVERALL	MEAN error	-5.728
													STDEV		9.239

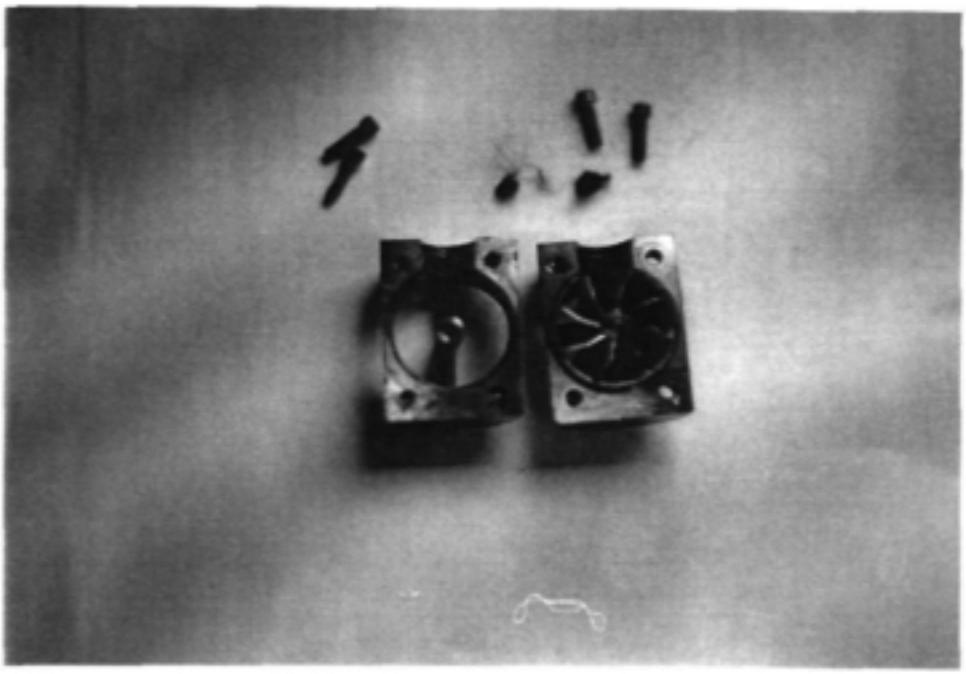
APPENDIX D7

APPENDIX E

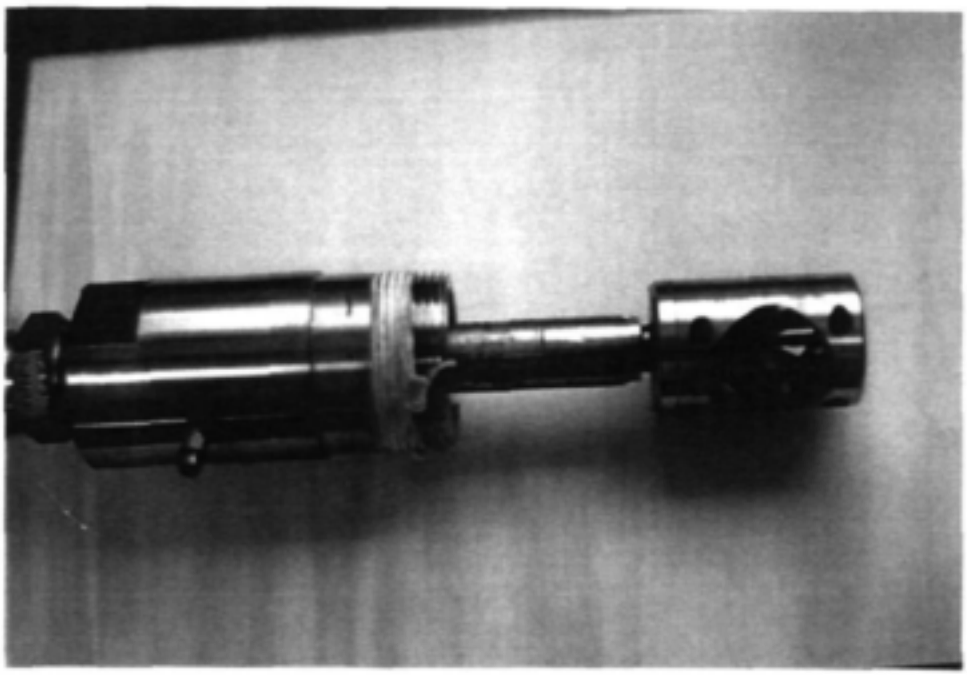
Photographs



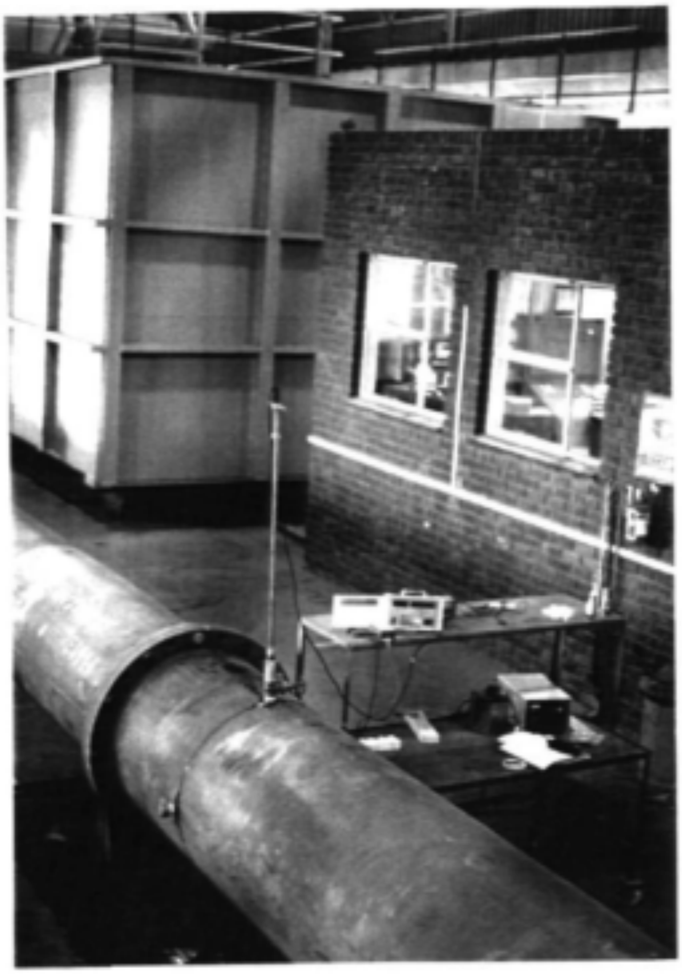
Turbine meter
No. 31901/96



Turbine meter no.
30193/90 showing
hair like fibres
removed from
bearings



Turbine insertion
meter no. 31901/96



Insertion Meter installed on 800 mm dia pipeline. Weigh tank and control room in the background.

The control room

GUIDELINES FOR THE MONITORING AND MANAGEMENT OF GROUNDWATER RESOURCES IN RURAL WATER SUPPLY SCHEMES

R Meyer

WRC Report No. 861/1/02a

Water Research Commission

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by

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CSIR
Pretoria

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